JAGUAR DRAFT RECOVERY PLAN
(*Panthera onca*)

Southwest Region
U.S. Fish and Wildlife Service
Albuquerque, New Mexico

December 20, 2016

Approved: ________DRAFT________________ Date: ________________________

Regional Director, Region 2
U.S. Fish and Wildlife Service

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(*Panthera onca*)

Prepared by:
The Technical Subgroup of the Jaguar Recovery Team in conjunction with the Implementation Subgroup of the Jaguar Recovery Team and the U.S. Fish and Wildlife Service

Prepared for:
Region 2, Southwest Region
U.S. Fish and Wildlife Service
Albuquerque, New Mexico

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DISCLAIMER

The Endangered Species Act of 1973 (ESA), as amended (16 U.S.C. 1531 et seq.), requires the development of recovery plans for listed species, unless such a plan would not promote the conservation of a particular species. In accordance with section 4(f)(1) of the ESA and to the maximum extent practicable, recovery plans delineate actions which the best available science indicates are required to recover and protect listed species. Plans are published by the U.S. Fish and Wildlife Service (USFWS), and are sometimes prepared with the assistance of recovery teams, contractors, state agencies, and others. Objectives will be attained and any necessary funds made available subject to budgetary and other constraints affecting the parties involved, as well as the need to address other priorities. Nothing in this plan should be construed as a commitment or requirement that any Federal agency obligate or pay funds in contravention of the Anti-Deficiency Act, 31 U.S.C. 1341, or any other law or regulation. Recovery plans do not necessarily represent the views or the official positions or approval of any individuals or agencies involved in the plan formulation, other than the USFWS. They represent the official position of USFWS only after they have been signed by the Regional Director. Approved recovery plans are subject to modification as dictated by new information, changes in species status, and the completion of recovery actions. Please check for updates or revisions at the website below before using.

The jaguar (*Panthera onca*) is listed throughout its range including 19 countries. The United States (U.S.) contains only a small proportion of the jaguar's range and habitat. Recovery of endangered species is the fundamental goal of the ESA. However, the USFWS has limited resources and little authority to address the major threats to the jaguar's recovery (killing and habitat destruction) outside the United States. Also, our knowledge regarding the status of the species in much of its range is very limited, and we lack the resources and authority to coordinate large scale international research and recovery for the entire species. Primary on-the-ground conservation actions to recover the jaguar will occur outside of the U.S. Therefore, it is not practicable to establish site-specific management actions, objective and measurable recovery criteria, or cost estimates throughout the species' entire range. However, we have an established relationship with Mexico to address a number of issues of mutual concern, including managing cross-border populations of rare and endangered species. Because the USFWS's limited resources are better applied to planning and on-the-ground implementation of conservation actions within the boundaries of the U.S. and in partnership with adjacent Mexico, we focused this plan on two recovery units that cover the entire species (see Figures 1 and 2). We also summarized information available in scientific literature regarding the status and threats to the jaguar throughout its range, and recommend general actions and criteria for addressing these threats and evaluating rangewide recovery that may be applied, or refined, in the future.

Literature citation of this document should read as follows:

U.S. Fish and Wildlife Service. 2016. Jaguar Draft Recovery Plan (*Panthera onca*). U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico.

Copies may be obtained online (species search, jaguar):

http://www.fws.gov/endangered

or

http://www.fws.gov/southwest/es/arizona/Jaguar.htm

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EXECUTIVE SUMMARY

Current Status of the Species

The jaguar (*Panthera onca*) is listed as endangered throughout its range under the Endangered Species Act of 1973 (ESA), as amended (16 U.S.C. 1531 et seq.). Historically, the jaguar inhabited 21 countries throughout the Americas, from the U.S. south into Argentina. Currently, jaguars are found in 19 countries: Argentina, Belize, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, French Guiana, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, United States (U.S.), and Venezuela. The species is believed to be extirpated from El Salvador and Uruguay. The jaguar is fully protected at the national level across most of its range, with hunting prohibited in Argentina, Brazil, Colombia, Costa Rica, Ecuador, French Guiana, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Suriname, U.S., Uruguay, and Venezuela (Registro Oficial No. 818 1970, Secretaría de Desarrollo Urbano y Ecología 1987, Nowell and Jackson 1996, Sistema Nacional de Áreas de Conservación 2012, Government of Guyana 2013). In Mexico, it is listed as endangered under Mexican law (NOM-059-SEMARNAT-2010) (Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT; Federal Ministry of the Environment and Natural Resource) 2010).

Recently (1996 through 2015), five, possibly six individual jaguars have been documented in the U.S. (U.S. Fish and Wildlife Service 2014). Based on the available information, all detections have been of male jaguars and have been located in southern Arizona and southwestern New Mexico. These jaguars are believed to be coming from the nearest core area and breeding population in the Northwestern Recovery Unit (see Figure 1), which is approximately 210 kilometers (km) (130 miles [mi]) south of the U.S.-Mexico border in Sonora near the towns of Huasabas, Sahuaripa (Brown and López González 2001), and Nacori Chico (Rosas-Rosas and Bender 2012). As of September 2015, one male jaguar is known to reside in southern Arizona (Culver et al. 2016).

In 2014, six critical habitat units, as defined under the ESA, were designated for the jaguar in the U.S., which encompass approximately 309,263 hectares (764,207 acres) in Pima, Santa Cruz, and Cochise Counties, Arizona, and Hidalgo County, New Mexico (USFWS 2014). There are seven primary constituent elements of critical habitat that make up the habitat features included in the physical and biological feature that meets the physiological, behavioral, and ecological needs of the species. This physical and biological feature, including these seven elements, is:

Expansive open spaces in the southwestern U.S. of at least 100 km^2 (38.6 mi^2) in size, which:

1) Provide connectivity to Mexico;
2) Contain adequate levels of native prey species, including deer and javelina, as well as medium-sized prey such as coatis, skunks, raccoons, or jackrabbits;
3) Include surface water sources available within 20 km (12.4 mi) of each other;
4) Contain from greater than 1 to 50 percent canopy cover within Madrean evergreen woodland, generally recognized by a mixture of oak (*Quercus* spp.), juniper (*Juniperus* spp.), and pine (*Pinus* spp.) trees, on the landscape, or semidesert grassland vegetation communities, usually

characterized by *Pleuraphis mutica* (tobosagrass) or *Bouteloua eriopoda* (black grama) along with other grasses;
5) Are characterized by intermediately, moderately, or highly rugged terrain;
6) Are below 2,000 meters (6,562 feet) in elevation; and
7) Are characterized by minimal to no human population density, no major roads, or no stable nighttime lighting over any 1-km^2 (0.4-mi^2) area.

As a species that is listed throughout its range (currently 19 countries, including the U.S.), the jaguar presents a significant challenge for recovery planning. Knowledge regarding the status of the species in much of its range is limited, and the USFWS and its partners lack the resources and authority to coordinate large-scale international research and recovery for the entire species. Given that the jaguar is an international species with the vast majority of its range outside of the U.S., primary actions to recover the jaguar will occur outside of the U.S. In the Northwestern Recovery Unit (NRU; Figure 1), Mexico will be the primary contributor to recovery for the jaguar because over 95 percent of the species' suitable habitat in the NRU exists within the borders of Mexico. In the Pan-American Recovery Unit (PARU; Figure 2), countries within the jaguar's range will be the principal contributors to jaguar recovery. Therefore, it is not practicable to establish site-specific management actions, objective and measurable recovery criteria, or time and cost estimates throughout the species' entire range. However, in this plan, the USFWS and Jaguar Recovery Team (JRT) have established a framework to better understand the status and conservation needs of the jaguar for recovery throughout most of its range (i.e., the PARU), while focusing more specifically on jaguar populations in the northwestern portion of its range (i.e., the NRU). Because the limited resources of the USFWS are better applied to planning and on-the-ground implementation of conservation actions within the boundaries of the U.S. and in partnership with adjacent Mexico, the USFWS and JRT have established site-specific management actions, objective and measurable recovery criteria, and time and cost estimates for the NRU that will conserve viable jaguar populations in the NRU. Priority is given to this unit because this is where the USFWS has the most jurisdiction and we have an established working relationship for issues of mutual concern with Mexico. The U.S. will continue to promote recovery throughout the range of the jaguar, as appropriate.

The jaguar was addressed in the 1990 "Listed Cats of Texas and Arizona Recovery Plan (with Emphasis on the Ocelot)," but only general information and recommendations to assess jaguar status in the U.S. and Mexico, and to protect and manage occupied and potential habitat in the U.S., were presented. No specific recovery recommendations or objectives for the jaguar were provided. Thus, the approach in this recovery plan is as follows:

- Focus exclusively on the jaguar.
- Two recovery units are included, the NRU and the PARU (Figures 1 and 2). The NRU extends from south-central Arizona and extreme southwestern New Mexico, U.S., south to Colima, Mexico (Figure 1). The PARU encompasses 18 countries from Mexico to Argentina (Figure 2). See more information on these units in section **2.1 Recovery Units**. These units are further divided into Core, Secondary, and Peripheral areas as defined in section *2.1.3 Core, Secondary, and Peripheral Areas.*
- The status of and threats to jaguars in the PARU are summarized and general actions and criteria for addressing these threats and evaluating rangewide recovery are recommended.

- Detailed criteria and actions necessary to recover jaguar populations in the NRU are provided.

We submit that the approach described above meets our statutory requirements to address recovery of the species throughout its range to the maximum extent practicable. As our knowledge of the jaguar rangewide increases and as the recovery actions described in this plan are implemented, the plan may be revised and refined.

Habitat Requirements, Threats, and Other Limiting Factors

Jaguars are known from a variety of vegetation communities (Seymour 1989). At middle latitudes, they show a high affinity for lowland wet communities, including swampy savannas or tropical rain forests (sources as cited in Seymour 1989). Swank and Teer (1989) stated that jaguars prefer a warm, tropical climate, usually associated with water, and are rarely found in extensive arid areas. However, jaguars have been documented in arid areas, including thornscrub, desertscrub, lowland desert, mesquite grassland, Madrean oak woodland, and pine-oak woodland communities of northwestern Mexico and southwestern U.S. (Boydston and López González 2005, McCain and Childs 2008, López González and Brown 2002). In the tropical dry forests in western Mexico, jaguars roam in ravines or arroyos more than in other areas (Nuñez Perez 2006), while in wetlands, jaguars move freely through water and open areas (Núñez Pérez, pers. comm. 2015a). The more open, dry habitat of the southwestern U.S. has been characterized as marginal in terms of water, cover, and prey densities (Rabinowitz 1999). Jaguars rarely occur above 2,591 m (8,500 ft) (Brown and López González 2001).

The jaguar, as a large carnivore, is more vulnerable to extinction than many other land mammals. Loss of habitat, direct killing of jaguars, and depletion of prey are the primary factors contributing to its current status, considered to have a decreasing population trend according to the International Union for Conservation of Nature (IUCN) (Caso et al. 2008). Current levels of habitat loss indicate the species is trending toward Vulnerable (IUCN category); the jaguar’s status is currently being reevaluated by the IUCN and a new analysis should be available by the end of 2016 (Quigley, pers. comm. 2016). The legal protected status in countries throughout its range does not appear to have secured jaguars in their core or corridor areas. Small and isolated jaguar populations do not appear to be highly persistent (Haag et al. 2010, Rabinowitz and Zeller 2010). Additionally, jaguars require sufficient prey, and when prey is overharvested, jaguars may turn to livestock to meet their dietary needs, resulting in retaliatory killing.

Recovery Strategy

The strategy for recovery involves the following framework for Recovery Actions:

1) Ascertain the status and conservation needs of the jaguar.
2) Assess and maintain or improve genetic fitness, demographic conditions, and the health condition of the jaguar.
3) Assess and maintain or improve the status of native prey populations.
4) Assess, protect, and restore quantity, quality, and connectivity of habitat to support viable populations of jaguars.

5) Assess, minimize, and mitigate the effects of expanding human development on jaguar survival and mortality where possible.
6) Minimize direct human-caused mortality of jaguars.
7) Ensure long-term jaguar conservation through adequate funding, public education and outreach, and partnerships.
8) Practice adaptive management in which recovery is monitored and recovery tasks are revised by the USFWS in coordination with the JRT as new information becomes available.

Recovery Goals

The goal of this revised recovery plan is to recover and delist the jaguar, with downlisting from endangered to threatened status as an intermediate goal.

Recovery Criteria

The USFWS will consider reclassifying the jaguar from endangered to threatened when <u>all</u> of the following conditions are met:

<u>A. PARU</u>

i. The status of the jaguar changes to Least Concern (LC) under the IUCN Red List criteria (as defined by the World Conservation Union, http://www.iucnredlist.org/), which would mean threats have been reduced such that the jaguar population is no longer at risk of a $\geq$ 30% decline because its area of occupancy, extent of occurrence, and/or habitat quality, as well as actual or potential levels of exploitation, have been stable for at least 15 years.

<u>B. NRU</u>

i. Maintain at least 60% occupancy (proportion of cells[a]) in each of the Core Areas over 15 years, as described in Appendix C. If baseline surveys reveal that occupancy is higher than 60%, then the higher level will be maintained over 15 years.

ii. Over 15 years, genetic distance (e.g., F_{ST} or G_{ST}) between the Sonora and Jalisco Core Areas does not significantly increase, and inbreeding coefficients (e.g., F_{IS} or G_{IS}) within each of the Sonora and Jalisco Core Areas do not significantly increase, as described in Appendix D.

iii. Over a period of 15 years, the average of at least 30% of the adult population within the Sonora and Jalisco Core Areas are female (based on data gathered through surveying, monitoring, genetic analysis, etc.).

iv. Within each Core Area (Sonora and Jalisco), a network of $\geq$ 100-km^2 blocks (the minimum area capable of supporting at least three breeding females) of high-quality

[a] Cells are sample units based on estimates of local jaguar home-range size that are used to assess occupancy in a biologically meaningful way; see Appendix C for more information.

habitat (as described in Appendix E) and habitat connections between blocks has been mapped and conditions in each block and connective area are described based on field visits.

v. Within the Sinaloa Secondary Area, one or more potential linkages between the Jalisco and Sonora Core Areas sufficient to allow natural jaguar dispersal have been mapped based on documented use by jaguars, potential barriers and impediments have been mapped and/or identified based on field visits, and strategies for mitigating these impediments in the corridor have been developed and are being implemented.

vi. Within the Borderlands Secondary Area, two or more non-overlapping potential trans-border linkages sufficient to allow natural jaguar dispersal have been mapped, potential barriers and impediments have been mapped based on field visits, and strategies for mitigating impediments in the corridor are being implemented. Additionally, half of the mapped linkages are clear of impediments and have obtained a sufficient level of protection within the corridor such that jaguar passage is attainable as measured by jaguar movement or other appropriate surrogate species, such as mountain lions.

vii. The threat of direct human killing of jaguars is decreased or maintained at sustainable levels as measured by acceptable evidence or an index as described in Appendix F.

viii. Effective Federal, State, Tribal, and/or local laws are in place or are being developed in the NRU that ensure that killing of jaguars is prohibited or regulated such that viable populations of jaguars can be maintained, and jaguars are highly unlikely to need to protection of the ESA again.

The USFWS will consider removing the jaguar from the Federal List of Endangered and Threatened Wildlife when <u>all</u> of the following conditions are met:

<u>A. PARU</u>

i. The status of the jaguar changes to Least Concern (LC) and is maintained under the IUCN Red List criteria (as defined by the World Conservation Union, http://www.iucnredlist.org) for at least 15 more years after first qualifying for LC, which would mean threats have been reduced such that the jaguar population is no longer at risk of a $\geq$ 30% decline because its area of occupancy, extent of occurrence, and/or habitat quality, as well as actual or potential levels of exploitation, have been stable for at least 30 years.

<u>B. NRU</u>

i. Maintain at least 60% occupancy (proportion of cells[b]) in each of the Core Areas over 30 years (inclusive of the 15 years required to downlist), as described in Appendix C. If

[b] Cells are sample units based on estimates of local jaguar home-range size that are used to assess occupancy in a biologically meaningful way; see Appendix C for more information.

baseline surveys reveal that occupancy is higher than 60%, then the higher level will be maintained over 30 years.

ii. Over 30 years, genetic distance (e.g., F_{ST} or G_{ST}) between the Sonora and Jalisco Core Areas does not significantly increase, and inbreeding coefficients (F_{IS} or G_{IS}) within each of the Sonora and Jalisco Core Areas do not significantly increase, as described in Appendix D.

iii. Over a period of 30 years, the average of at least 30% of the adult population within the Sonora and Jalisco Core Areas are female (based on data gathered through surveying, monitoring, genetic analysis, etc.).

iv. Agency policies and regulations (including transportation), land use regulations, and land owner agreements in Mexico are sufficient to ensure that the network of ≥ 100-km^2 blocks (the minimum area capable of supporting at least three breeding females) of high-quality habitat (as described in Appendix E) and habitat connections between blocks (as described in criterion 3.3.1.B.iv, above) within each Core Area (Sonora and Jalisco) will support genetically and demographically viable jaguar populations for the foreseeable future. Genetic and demographic viability will be demonstrated by meeting criteria i-iii, above.

v. Agency policies and regulations (including transportation), land use regulations, and land owner agreements in Mexico are sufficient to ensure that landscape permeability will be maintained for jaguars within the Sinaloa Secondary Area (as described in criterion 3.3.1.B.v, above).

vi. Agency policies and regulations (including transportation), land use regulations, and land owner agreements in the U.S. and Mexico are sufficient to ensure that landscape permeability, including at least two trans-border linkages (as described above in criterion 3.3.1.B.vi, above) will be maintained for jaguars throughout the Borderlands Secondary Area.

vii. The threat of direct human killing of jaguars is decreased or maintained at sustainable levels as measured by acceptable evidence or an index as described in Appendix F.

viii. Effective Federal, State, Tribal, and/or local laws are in place in the NRU that ensure that killing of jaguars is prohibited or regulated such that viable populations of jaguars can be maintained, and jaguars are highly unlikely to need protection of the ESA again.

Total Estimated Cost of Recovery (in U.S. dollars)

The Implementation Schedule provides the estimated costs of implementing recovery actions for the first five years after the release of the recovery plan. Continual and ongoing costs, as well as the estimated total cost, are based on the projected timeframes to recovery and delisting of the species. Annual cost estimates are as follows:

Year 1 = $2,349,000
Year 2 = $12,657,000
Year 3 = $10,301,000
Year 4 = $20,135,000
Year 5 = $10,653,000

The estimated cost to implement this plan for the first 5 years is $56,093,000. The total cost to implement this plan through the year 2066, the estimated recovery date of the jaguar, is $605,648,000.

Date of Recovery

The estimated date of recovery is 2066. This time frame was chosen because the JRT anticipates that at least 50 years are required to accomplish all of the actions and meet the recovery criteria included in this recovery plan. For example, some of the recovery criteria require changes or additions to laws and regulations protecting jaguars, their prey, and habitat, as well as ensuring a significant amount of land protection, all of which require an extensive amount of time to complete. Additionally, changing people's perceptions of and attitudes toward jaguars may take decades to accomplish. The JRT also anticipates that, while it will take a minimum of 30 years to meet the demographic and genetic criteria, additional time may be required if jaguar demographic and genetic baselines are not maintained. The JRT anticipates that projecting beyond 50 years is unrealistic, given changes in the human population, technology, and the climate.

PART 1: BACKGROUND

1.1 Introduction and Recovery Planning

The jaguar (*Panthera onca*) is currently listed as endangered throughout its range under the Endangered Species Act of 1973 (ESA) (see section **1.2 Legal Status of the Species** below for more information) and according to U.S. Fish and Wildlife Service (USFWS) policy, the jaguar has a recovery priority number of 5C. This ranking, determined in accordance with the Recovery Priority Criteria (U.S. Fish and Wildlife Service 1983), is based on a high degree of threat due to habitat loss, a low potential for recovery, a taxonomic classification as a species, and the state of conflict between jaguars and humans. Degree of threat is considered high due to continuing habitat loss, ongoing poaching, and increased isolation of populations. Potential for recovery across the species' range is considered low based on the specific needs of the species not being met in the future. These specific needs include a very large home range, a viable prey base, proximity to water, avoidance of humans and development, and connectivity to other protected wild lands, along with natural history constraints of low population densities, low reproductive rates, difficulty in controlling killing of jaguars by humans, and an increasing human population throughout the jaguar's range. Direct conflicts with humans remain, in the form of jaguar killing to prevent damage to livestock, poaching, and human encroachment into jaguar habitat through expanding resource extraction and human development. Indirect conflicts of competing for the same prey and depending on shared water sources occur, and could be exacerbated by altered prey and water availability resulting from future changes in climate.

The ESA calls for preparation of recovery plans for threatened and endangered species likely to benefit from the effort, and authorizes the Secretary of the Interior to appoint recovery teams to prepare the plans (U.S. Congress 1988). According to section 4(f)(1) of the ESA, recovery plans must, to the maximum extent practicable, describe site-specific management actions as may be necessary to achieve the plan's goals, incorporate objective and measurable delisting criteria, and estimate the time and cost required for recovery. A recovery plan is not self-implementing, but presents a set of recommendations that are endorsed by an official of the Department of Interior. Recovery plans also serve as a source of information on the overall biology, status, and threats of a species.

The jaguar was addressed in "Listed Cats of Texas and Arizona Recovery Plan (with Emphasis on the Ocelot)" (U.S. Fish and Wildlife Service 1990), but only general information and recommendations to assess jaguar status in the United States (U.S.) and Mexico, and protect and manage occupied and potential habitat in the U.S., were presented. No specific recovery recommendations or objectives for the jaguar were presented. In 2007, the USFWS made a 4(f)(1) determination that development of a formal recovery plan at this time would not promote the conservation of the jaguar. The rationale for this determination was that for the purposes of formal recovery planning, the jaguar qualifies as an exclusively foreign species (see Memorandum for details at http://www.fws.gov/southwest/es/arizona/Documents/SpeciesDocs/Jaguar/Exclusion%20from%20Recovery%20Planning.pdf). The USFWS was sued for making this determination and the court remanded the decision regarding recovery planning back to the USFWS. Subsequently, in

2010, the USFWS made a new determination that development of a recovery plan would contribute to jaguar conservation and that, therefore, the USFWS should prepare a recovery plan (http://www.fws.gov/southwest/es/arizona/Documents/SpeciesDocs/Jaguar/JaguarRPmemo1-12-10.pdf).

As a result of the 2010 determination, the USFWS convened a binational Jaguar Recovery Team (JRT or Team) to aid the USFWS in developing a Jaguar Recovery Plan and implementing recovery actions for the species. The Team is comprised of two subgroups: the Technical Subgroup and the Implementation Subgroup, both of which have about equal representation of participants from Mexico and the U.S. The Technical Subgroup is composed of nine scientists, researchers, and biologists with expertise in feline biology and ecology, landscape ecology, and conservation planning, many of whom work in governmental and nongovernmental institutions implementing recovery projects for the jaguar and its habitat. Their function is to compile and review extensive scientific information and develop recovery strategies, goals, criteria, and recommended actions for long-term jaguar conservation, according to their experience and research in the U.S. and Mexico. The Implementation Subgroup includes landowners and land and wildlife managers within the range of the jaguar in southwestern U.S. and northwestern Mexico and provides an applied management perspective to jaguar recovery planning and implementation.

As a species that is listed throughout its range (historically the species occurred in 21 countries; currently the species occurs in 19 countries, including the U.S.), the jaguar presents a significant challenge for recovery planning. Knowledge regarding the status of the species in much of its range is limited, and the USFWS and its partners lack the resources and authority to coordinate large scale international research and recovery for the entire species. Given that the jaguar is an international species with the vast majority of its range outside of the U.S., primary actions to recover the jaguar will occur outside of the U.S. In the Northwestern Recovery Unit (NRU; Figure 1), Mexico will be the primary contributor to recovery for the jaguar because over 95 percent of the species' suitable habitat in the NRU exists within the borders of Mexico. In the Pan-American Recovery Unit (PARU; Figure 2), countries within the jaguar's range will be the principal contributors to jaguar recovery. Therefore, it is not practicable to establish site-specific management actions, objective and measurable recovery criteria, and time and cost estimates throughout the species' entire range. In this plan, the USFWS and JRT have established a framework to better understand the status and conservation needs of the jaguar for recovery throughout most of its range (i.e., the PARU) because of the large, multi-jursidictional area the PARU covers and the associated impracticality of establishing site-specific management actions. Additionally, because the USFWS's limited resources are better applied to planning and on-the-ground implementation of conservation actions within the boundaries of the U.S. and in partnership with adjacent Mexico, the USFWS and JRT have established specific criteria for recovery, and actions that, if implemented, will conserve viable jaguar populations in the in the northwestern portion of their range (i.e., the NRU). Priority is given to this unit because this is where the USFWS has the most jurisdiction and we have an established working relationship for issues of mutual concern with Mexico. The U.S. will continue to promote recovery throughout the range of the jaguar, as appropriate.

Thus, the approach in this recovery plan is as follows:

- This plan focuses exclusively on the jaguar.
- Two recovery units are included, the NRU and the PARU (Figures 1 and 2). The NRU extends from south-central Arizona and extreme southwestern New Mexico, U.S. south to Colima, Mexico (Figure 1). The PARU encompasses 18 countries from Mexico to Argentina (Figure 2). See more information on these units in section **2.1 Recovery Units**. These units are further divided into Core, Secondary, and Peripheral areas as defined in section *2.1.3 Core, Secondary, and Peripheral Areas.*
- The status and threats of jaguars in the PARU are summarized and general actions and criteria for addressing these threats and evaluating rangewide recovery are recommended.
- Detailed criteria and actions necessary to recover jaguar populations in the NRU are provided.

We submit that the approach described above meets our statutory requirements to the maximum extent practicable. As our knowledge of the jaguar rangewide increases and as the recovery actions described in this plan are implemented, the plan may be revised and refined.

1.2 Legal Status of the Species

1.2.1 Rangewide

Historically, the jaguar inhabited 21 countries throughout the Americas, from the U.S. south into Argentina. Currently, jaguars are found in 19 countries: Argentina, Belize, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, French Guiana, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, U.S., and Venezuela. The species is believed to be extirpated from El Salvador and Uruguay. The jaguar is fully protected at the national level across most of its range, with hunting prohibited in Argentina, Brazil, Colombia, Costa Rica, Ecuador, French Guiana, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Suriname, U.S., Uruguay, and Venezuela (Registro Oficial No. 818 1970, Secretaría de Desarrollo Urbano y Ecología 1987, Nowell and Jackson 1996, Sistema Nacional de Áreas de Conservación 2012, Government of Guyana 2013). According to Nowell and Jackson (1996), hunting is restricted to "problem animals" in Brazil, Costa Rica, Guatemala, Mexico, and Peru, and trophy hunting is permitted in Bolivia; because regulations change, this information may change for some or all countries. In Mexico, jaguars are killed mainly due to livestock predation, although occasionally out of fear or as a trophy (Núñez Pérez, pers. comm. 2015a). See Appendix A for a summary of the legal status, threats, and conservation efforts for jaguars in each of the historical range countries.

On July 1, 1975, the jaguar was included in Appendix I of Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and, in 2011, the species' status was reassessed rangewide, the conclusion being to maintain it in Appendix I (AC25 Doc. 15.2.3, CITES 2011). The jaguar is classified as "Near Threatened" on the Red List of the IUCN due to a number of factors, including habitat loss and fragmentation of populations across portions of the range (Caso et al. 2008). Current levels of habitat loss indicate the species is trending toward Vulnerable (IUCN category); the jaguar's status is currently being reevaluated by the IUCN and a new analysis should be available by the end of 2016 (Quigley, pers. comm. 2016).

1.2.2 Mexico

The jaguar is listed as endangered under Mexican law (NOM-059-SEMARNAT-2010) in Mexico (Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT; Federal Ministry of the Environment and Natural Resource) 2010) and as endangered throughout its range under authority of the ESA. Illegal hunting may be punished with a fine of up to about $500,000 (U.S.) or three years in prison, but this has never been enforced (Núñez Pérez, pers. comm. 2011).

1.2.3 United States

Prior to the USFWS's rule clarifying its listing status in the U.S. (U.S. Fish and Wildlife Service 1997), the jaguar was listed as endangered from the U.S. and Mexico international border southward to include Mexico and Central and South America (U.S. Fish and Wildlife Service 1972; 50 Code of Federal Regulations 17.11, August 20, 1994). The species was originally listed as endangered under the Endangered Species Conservation Act of 1969 (ESCA). Under the ESCA, two separate lists of endangered wildlife were maintained, one for foreign species and one for the U.S. The jaguar appeared only on the "List of Endangered Foreign Wildlife." In 1973, the ESA replaced the ESCA. The foreign and native lists were replaced by a single "List of Endangered and Threatened Wildlife," which was first published in the Federal Register on September 26, 1975 (U.S. Fish and Wildlife Service 1975). On July 25, 1979, the USFWS published a notice stating that, although the jaguar was originally listed as endangered in accordance with the ESCA, when the ESA superseded the ESCA, through an oversight the jaguar (and six other endangered species) remained listed on the List of Endangered Foreign Wildlife, but populations in the U.S. were not protected by the ESA (U.S. Fish and Wildlife Service 1979). The notice asserted that it was always the intent of the USFWS that all populations of jaguars warranted listing as endangered, whether they occurred in the U.S. or in foreign countries. The jaguar's endangered status in the U.S. was therefore clarified on July 22, 1997 (U.S. Fish and Wildlife Service 1997).

On April 18, 2012, the USFWS published the Jaguar Recovery Outline, to provide interim guidance on recovery until this formal recovery plan was developed. On March 4, 2014, the USFWS designated critical habitat (as defined under the ESA) in the U.S. for the jaguar (U.S. Fish and Wildlife Service 2014). In total, approximately 309,263 hectares (ha) (764,207 acres (ac)) in Pima, Santa Cruz, and Cochise Counties, Arizona, and Hidalgo County, New Mexico, fall within six critical habitat units. See section **1.7 Critical Habitat** for more information about this designation.

1.3 Evolutionary History, Description, and Taxonomy

The jaguar is the largest felid in the New World (Seymour 1989). Recently-discovered fossil evidence suggests jaguars (and all pantherines) originated in Asia more than two million years ago, with the species arriving in North America approximately one million years ago after crossing the Beringia land bridge connecting Eurasia and North America (Rabinowitz 2014). Rangewide, jaguars measure about 1.5-2.4 meters (m) (5-8 feet (ft)) from nose to tip of tail and weigh from 36-158 kilograms (kg) (80-348 pounds (lb)), although the 36- and 158-kg (80- and 348-lb) weights are exceptional (Seymour 1989, Nowak 1999). Males are typically larger than females, with reports of males being 10-20% larger than females (Seymour 1989). Leopold (1959) listed a weight range in Mexico of 63-113 kg (140-250 lb) for males and 45-82 kg (100-180 lb) for females. Jaguars have a relatively robust head, compact but muscular body, short limbs and tail, and powerfully built chest and forelegs (Leopold 1959, Nowak 1999, Seymour 1989, Tewes and Schmidly 1987). They have the strongest teeth and jaws of any American cat, and their skulls are more massive than those of pumas (Brown and López González 2001). Their canines are well developed (Seymour 1989) and effectively deployed. The overall coat of a jaguar is typically pale yellow, tan, or reddish yellow above, and generally whitish on the throat, belly, insides of the limbs, and underside of the tail, with prominent dark rosettes or blotches throughout (Seymour 1989). Melanistic jaguars (or "black" jaguars) occur primarily in parts of South America, and are virtually unknown in wild populations residing in the subtropical and temperate regions of North America; they have never been documented north of Mexico's Isthmus of Tehuantepec (Brown and López González 2001).

The jaguar was divided into a number of subspecies based on physical characteristics, like skull morphology (Mearns 1901, Nelson and Goldman 1933, Hall 1981, Seymour 1989, Wozencraft 2005). Pocock (1939) as cited by Larson (1997), described eight subspecies of jaguars, including five North American subspecies (Brown and López González 2001): *Panthera onca arizonensis*, ranging from Arizona southward to southern Sonora; *P. o. hernandesii*, ranging from southern Sonoran southward to the state of Guerrero, Mexico; *P. o. centralis*, ranging from south of the Isthmus of Tehuantepec down through Central America and into Colombia; *P. o. goldmani*, ranging from the Yucatan Peninsula; and *P. o. veraecrucis*, ranging from southern Texas and eastern Tamaulipas southward to Tabasco. Yet, Larson's (1997) analysis of 11 skull characters (used historically to define subspecies) of jaguar specimens did not indicate distinct taxonomic groups, and found more variation within the previously-recognized subspecies than between them. More recently, molecular genetic analyses have revealed that subspecies recognition may not be warranted in jaguars (Eizirik et al. 2001, Culver and Ochoa Hein 2013). Ruiz-Garcia et al. (2006) reported that the genetic heterogeneity between the two subspecies previously recognized by Pocock (1939) in Colombia (*P. o. centralis* and *P. o. onca*) and considered in their DNA microsatellite analysis was small, and therefore casts some doubt on the morphologically proposed subspecies separation. Johnson et al. (2002) found that mitochondrial DNA (mtDNA) analysis weakly supported two phylogeographic groups of jaguars, one north and one south of the Amazon River, South America, although there was evidence of continued gene flow between the two groups. Similarly, Eizirik et al. (2001) reported that the Amazon River may represent a historical barrier to gene flow predominantly in females, though it appears to have been less of an impediment for male dispersal as inferred from microsatellite data.

Larson's (1997) and Eizirik et al.'s (2001) studies had relatively small sample sizes, particularly in the northwestern-most portion of their range. Larson (1997) examined 170 skulls, but confined his study to data from 115 complete skulls; of these, four were from the *P. o. arizonensis* group. Eizirik et al.'s (2001) study included 44 jaguar samples, of which 42 were typed only for microsatellites and 37 for mtDNA. Of the 44 samples, none were from Sonora, Chihuahua, or the U.S.; one was from Sinaloa; and two were from Jalisco. Furthermore, it is unclear where specifically the Sinaloan sample and two of the Mexican zoos samples were from.

Ruiz-García et al. (2012) assessed the microsatellite and mtDNA marker diversity in 248 wild jaguars from seven countries (156 from Colombia, 38 from Peru, 30 from Bolivia, 12 from Brazil, 8 from Guatemala, 2 from Costa Rica, and 2 from Paraguay). They found no genetic differences among the previously recognized South American subspecies *centralis*, *onca*, and *paraguensis*. Although microsatellite patterns of the animals from Guatemala (classified as *goldmani*) were distinct from and had different microsattelite loci from the other pututaive subspecies, those differences could be the product of more recent differentiation caused by gene drift by recent fragmentation and isolation of this population and detected by rapid evolutionary nuclear markers as microsatellites. Ruiz-Garcia et al. (2012) did not observe concordant changes in slower evolutionary markers such as mtDNA, which are required to designate distinct subspecies (Avise 2000, as cited by Ruiz-García et al. 2012). Their results also indicate the Amazon River was not a geographical barrier for the jaguar, disagreeing with the claims of Eizirik et al. (2001).

Because of limited samples from the northern portion of the jaguar's range in Eizirik et al.'s (2001) study (none from Sonora), Culver and Ochoa Hein (2013) evaluated the genetic diversity and taxonomy of jaguars in the northern part of the NRU (Figure 1) using 24 samples (hides, scats, blood, hair, and saliva) from Arizona and Sonora, as well as 1 sample from Sinaloa (which possibly may be from Jalisco) and 2 from Jalisco. They used mitochondrial DNA and microsatellites as genetic markers because both have high levels of genetic variation. They compared their results with two other data sets collected previously by Eizirik et al. (2001): one containing samples from the Amazon River north to the State of San Luis Potosí, Mexico (Northern), and the other from the Amazon River south to the Chaco region of Paraguay (Southern). Their results showed that mtDNA haplotypes from Sonora/Arizona are unique to this region and separated from the haplotypes in each of the other two data sets (Northern and Southern), suggesting a recent colonization event (in evolutionary time; likely within the last approximately 300,000 years based on the control region mutation rate estimated in Lopez et al. 1997 (Culver, pers. comm. 2015)) in Sonora and Arizona, as well as a tendency for females not to disperse long distances.

Culver and Ochoa Hein (2013) also found a lack of genetic structure in microsatellites among Sonora/Arizona, Northern, and Southern populations, which is consistent with the findings of Eizirik et al. (2001). The samples from Sinaloa and Jalisco were more closely related to samples from Eizirik et al.'s (2001) Northern population than those from the Sonora/Arizona population; however, such differences may be attributed to the small sample size (three) from Sinaloa and Jalisco.

Culver and Ochoa Hein (2013) determined that the levels of mitochondrial and nuclear genetic diversity found in the Sonora/Arizona samples were reduced relative to Eizirik et al.'s (2001) Northern and Southern populations, reflecting a general pattern for peripheral populations with a small effective size. Culver and Ochoa Hein (2013) recommended international cooperation to promote connectivity among jaguar populations. The NRU populations are of conservation interest because of unique genetic diversity and because peripheral populations (such as those within the NRU) have a greater likelihood of suffering a local extinction in the short-run. Additionally, peripheral populations often harbour rare genetic diversity, which might be adaptive (Culver and Ochoa Hein 2013) and, therefore, potentially beneficial for the species in light of climate change. The addition of 20 or more samples from Sinaloa and Jalisco would clarify the genetic relationships within the NRU and between the NRU and other jaguar populations.

1.4 Distribution, Connectivity, Abundance, and Population Trends

1.4.1 Rangewide

Jaguars historically ranged from southern U.S. to central Argentina (Swank and Teer 1989, Caso et al. 2008). Currently, they range from the southwestern U.S. to northern Argentina, and are found in all countries except for El Salvador and Uruguay (Zeller 2007). According to the IUCN red list species assessment, the population trend of jaguars is decreasing (Caso et al. 2008), although the rate of decline is unknown and likely highly variable throughout the jaguar range. Although no rangewide population estimates exist, estimates have been made for various countries and regions; see Appendix A for these estimates and below for estimates specific to Mexico. Work is underway to provide a valid rangewide population estimate in the near future (Quigley, pers. comm. 2016). Density estimates at different study sites throughout the jaguar's range can be found in Table 2 in section *1.5.7 Density*. To better understand abundance and population trends, research, inventories, and monitoring programs are being implemented in some parts of the jaguar range (Chávez et al. 2007, Caso et al. 2008, Panthera 2011). Tobler et al. (2013) estimate that more than 80% of the currently occupied range lies in the Amazon. Sanderson et al. (2002) found that the jaguar is thought to be extant (based on expert opinion) in about 8.75 million square kilometers (km^2) (3.4 million square miles [mi^2]), which represents 46% of its historical global range. Jaguars are thought to be extirpated in 37% of their historical range, and their status in another 18% is unknown (Sanderson et al. 2002). The probability of long-term survival of the jaguar is considered high in 70% of the currently occupied range (over 6 million km^2 [2.3 million mi^2]) (Sanderson et al. 2002).

Zeller (2007) updated Sanderson et al.'s (2002) work and found that the jaguar is thought to be extant (based on expert opinion) in about 11,700,000 km^2 (4,517,395 mi^2), which represents 61% of its historical range, likely reflecting improved knowledge rather than range expansion. Within the currently occupied range, 90 Jaguar Conservation Units (JCUs) were identified representing a total area of 1,900,000 km^2 (733,594 mi^2) (Zeller 2007). The JCUs were defined either as: 1) areas with a stable prey community, currently known or believed to contain a population of resident jaguars large enough (at least 50 breeding individuals) to be potentially self-sustaining over the next 100 years, or 2) areas containing fewer jaguars but with adequate habitat and a stable, diverse prey base, such that jaguar populations in the area could increase if threats were alleviated (Sanderson et al. 2002, Zeller 2007) (see further discussion of JCUs in section 1.10 Conservation Efforts, below).

Rabinowitz and Zeller (2010) identified least-cost corridors connecting the 90 JCUs across the jaguar's range. Cost was assessed based on the species' response to land cover types and risk of negative interactions with humans (Rabinowitz and Zeller 2010). The total area of all 90 JCUs is 1,900,000 km^2 (730,000 mi^2) (Zeller 2007), while the total area of the corridors connecting these JCUs is 2,562,378 km^2 (989,340 mi^2). They identified 182 potential corridors between populations, ranging from 3 to 1,607 km (2 to 998.5 mi) in length; 44 of these corridors are characterized as being of immediate concern due to their limited width (less than 10 km (6.2 mi) at any point along their length), and thus their high potential for being severed. Rodríguez-Soto et al. (2013) considered corridors more than 10 km (6.2 mi) wide to be useful for jaguars, and considered those < 10 km (6.2 mi) wide at any point to be potential corridors.

1.4.2 Mexico

In Mexico, the estimate is 4,100 jaguars within the country, of which 1,800 are located in the Yucatan Peninsula, 550 in the North Pacific (Sinaloa and Sonora), 420 in the Central Pacific (Nayarit, Jalisco, Colima, and Michoacán), 670 in the South Pacific (Guerrero, Oaxaca, and Chiapas), and 620 in the northeastern-central part of the country (Nuevo Leon, Tamaulipas, San Luis Potosí, Querétaro, and Hidalgo) (Zarza et al. 2010). Rodríguez-Soto et al. (2011) used an ensemble model to estimate the potential distribution of jaguars in Mexico and identify the priority areas for conservation. In their model, jaguars avoided arid vegetation, higher elevations, and grasslands. Their model indicates that 16% of Mexico (312,000 km^2 (120,000 mi^2)) is suitable for jaguars and that 13% of the suitable areas are included in existing protected areas and 14% of suitable areas are included in the JCUs defined by Sanderson et al. (2002).

Rodríguez-Soto et al. (2013) also modeled jaguar corridors within Mexico, identifying a total of 13 corridors (seven viable and six potential) between all Jaguar Conservation Management Areas (JCMAs), one of which was within the NRU in the state of Nayarit. Currently, the corridors described through this modeling effort have not been validated through field studies. Núñez Pérez (pers. comm. 2015a) modeled a jaguar corridor for western Mexico, which connects all the Biosphere Reserves in western Mexico where jaguars have been detected.

<u>Mexico Portion of the NRU</u>

In northwestern and western Mexico, jaguars occur from the border of Colima and Jalisco north through Nayarit, Sinaloa, southwestern Chihuahua, and Sonora to the border with the U.S. Until recently, Colima had not had any verified jaguar sightings for more than 50 years (López González, pers. comm. 2011a), although credible jaguar reports from the state have been reported in the last decade, mainly near the border with Jalisco (Núñez Pérez, pers. comm. 2011), including a jaguar that was killed in 2015 (Núñez Pérez, pers. comm. 2015b). Breeding populations currently occur in Jalisco, Nayarit, Sinaloa, and Sonora. The most northern recently-documented breeding population of jaguars occurs in Sonora near the towns of Huasabas and Sahuaripa, about 210 km (130 mi) south of the U.S.-Mexico international border (Valdez et al. 2002, Brown and López González 2001). Since 2009, two jaguars have been documented at Rancho El Aribabi, Sonora, about 48 km (30 mi) southeast of Nogales, and one jaguar has been documented in the Sierra Los Ajos within the Reserva Forestal Nacional y Refugio de Fauna Silvestre Ajos-Bavispe, about 48 km (30 miles) south of the U.S. border near Naco, Mexico. This individual was photographed in 2009 and 2013. In August 2012, in Papigochic, Sonora, about 60 km (37 mi) south of the U.S. border near the town of Cananea, a jaguar track was seen on a private cattle ranch. In 2013, one jaguar male was photographed within the Janos Biosphere Reserve between Chihuahua and Sonora about 70 km (45 mi) south of the U.S.-Mexico border (López González, pers. comm. 2014a).

As stated above, population estimates in the Sonora and Jalisco JCUs were 50-100 and > 500, respectively (Zeller 2007). The Mexican National Jaguar Census (Manríquez Martínez, pers. comm. 2011) estimated there are 271 jaguars in Sonora, 211 in Sinaloa, 92 in Nayarit, and 176 in Jalisco.

Sanderson et al. (2002) identified two JCUs in the NRU. These two most northwestern JCUs (both considered highest priority JCUs in Mexico) occur in the Sierra Madre Occidental of Sonora/Chihuahua and southern Sinaloa/Nayarit/Jalisco (Figure 1(c) in Sanderson et al. 2002). Of the 13,613-km^2 (5,256-mi^2) Sonora JCU and the 29,409-km^2 (11,355-mi^2) southern Sinaloa/Nayarit/Jalisco JCU, 100% and 61%, respectively, were identified as areas where probability of long-term survival is high (Zeller 2007). Both Sanderson et al. (2002) and Zeller (2007) characterized the Sonora JCU as having low connectivity to other JCUs, medium habitat quality, much hunting of jaguars and prey, and stable jaguar population status. They characterized the Jalisco JCU as having high connectivity to other JCUs, high habitat quality, some hunting of jaguars, much hunting of prey, and decreasing jaguar population. The two most northeastern JCUs occur in the Sierra Madre Oriental and Tamaulipas (Sanderson et al. 2002, Zeller 2007, Rabinowitz and Zeller 2010).

Rodríguez-Soto et al. (2011) identified new JCMAs (complementary to previously identified JCUs) within the NRU that were not previously recognized in Sanderson et al. (2002), as follows:

JCMA-1. North Pacific coast: from the center of Sonora to the north of Nayarit (86,326 km^2 (33,331 mi^2)). It represents the northernmost distribution of the jaguar in Mexico and is limited by the Sierra Madre Occidental towards the east and agricultural areas along the Pacific coast to the west.

JCMA-2. Central Pacific coast: from the center of Nayarit to Colima, including the northeastern part of the Trans-Mexican Volcanic Belt (18,157 km^2 (7,010 mi^2)). It is limited by the high mountain ranges to the east and by the high human-population densities to the west.

Rodríguez-Soto et al. (2011) identified Jalisco as the biggest and likely most important area of potential jaguar habitat in Mexico, and recommended studies on the status of jaguar populations in other areas, such as Nayarit and Sinaloa, that have high habitat suitability but have yet to be studied in detail.

Rabinowitz and Zeller (2010) identified two potential corridors in the northernmost portion of the jaguar range, one between the southern Sinaloa/Nayarit/Jalisco JCU and the Sonora JCU and another connecting the Sierra Madre Occidental with the Sierra Madre Oriental (the northernmost corridors in Figure 2). It seems unlikely, however, that jaguars would use the latter corridor, as it passes through one of the most arid regions of the Mexican plateau dominated by Chihuahuan desert and there are several four-lane highways between the two sierras (Rosas-Rosas, pers. comm. 2011). Furthermore, there are no jaguar records in the corridor or in Coahuila at the eastern terminus of the corridor. Additionally, this 670-km (416-mi) long corridor has very low jaguar habitat suitability (extremely hot and arid, very low estimated prey populations, nine federal roads) in the model of Rodríguez-Soto et al. (2013). Rosas-Rosas (pers. comm. 2011) recommended studies to identify potential corridors between the jaguar populations in the Sierra Madre Occidental and Oriental.

Rodríguez-Soto et al. (2013) mapped one corridor in the NRU, specifically a north to south corridor parallel to the Pacific Coast of Nayarit. This corridor is likely to be functional due to the large percentage of suitable jaguar habitat within the corridor and its relatively short length and large width. Núñez Pérez (pers. comm. 2015a) and collaborators also modeled a corridor that includes Jalisco and Nayarit. They state jaguar populations are still connected through this corridor, but the location of the corridor may change due to global climate change, making climate change an important factor to consider (Núñez Pérez, pers. comm. 2015a).

1.4.3 United States

Jaguars historically occurred in California, Arizona, New Mexico, Texas, and possibly Louisiana (U.S. Fish and Wildlife Service 1997). The last jaguar sightings in California, Texas, and Louisiana were documented in the late 1800s into the early 1900s, with the last confirmed jaguar killed in Texas in 1948 (Nowak 1975). While jaguars have been documented as far north as the Grand Canyon, Arizona, occurrences in the U.S. since 1963 have been limited to south-central Arizona and extreme southwestern New Mexico. Three records of females with cubs have been documented in the U.S. (all in Arizona), the last in 1910 (Lange 1960, Nowak 1975, Brown 1989), and no females have been confirmed in the U.S. since 1963 (Brown and López González 2001, Johnson et al. 2011; note the validity of the 1963 record (a female jaguar killed in the White Mountains of Arizona) has been disputed—see Johnson et al. 2011 for further information). As a result, jaguars in the U.S. are thought to be part of a population, or populations, that occur largely in Mexico.

Recently (1996 through 2015), five, possibly six, individual jaguars have been documented in the U.S. (U.S. Fish and Wildlife Service 2014). One adult male was observed and photographed on March 7, 1996, in the Peloncillo Mountains in New Mexico near the Arizona border (Glenn 1996, Brown and López González 2001, U.S. Fish and Wildlife Service 2014). The Peloncillo Mountains run north-south to the Mexican border, where they join the foothills of the Sierra San Luis and other mountain ranges connecting to the Sierra Madre Occidental. A second adult male (later referred to as "Macho B") was observed and photographed on August 31, 1996, in the Baboquivari Mountains of southern Arizona (Childs 1998, Brown and López González 2001, U.S. Fish and Wildlife Service 2014). In February 2006, a third adult male jaguar was observed and photographed in the northern part of the San Luis Mountains in Hidalgo County, New Mexico (U.S. Fish and Wildlife Service 2014). From 2001 to 2009, a fourth adult male jaguar (referred to as "Macho A") and the jaguar observed and photographed in 1996 in the Baboquivari Mountains (referred to as "Macho B") were photographed (one repeatedly) by camera traps in south-central Arizona, near the Mexico border (U.S. Fish and Wildlife Service 2014). More specifically, these two jaguars were documented in three different mountain range complexes in southeastern Arizona, over an area extending 66 km (47 mi) north from the U.S.-Mexico international border and 63 km (39 mi) east to west (McCain and Childs 2008). Furthermore, they were found using areas from rugged mountains at 1,577 m (5,174 ft) to flat lowland desert floor at 877 m (2,877 ft) (McCain and Childs 2008). A fifth jaguar (adult male) was observed and photographed in November 2011 in the Whetstone Mountains (U.S. Fish and

Wildlife Service 2014). This jaguar has been repeatedly (2012 to 2015) photographed using remote cameras in the Santa Rita Mountains (https://www.flickr.com/photos/usfws_southwest/sets/72157632294203147/). A possible sixth jaguar was photographed in 2004; however, it could not be determined if the animal was a unique individual or was "Macho A" (the photo was of the animal's right side and only photos of "Macho A's" left side were available for comparison) (U.S. Fish and Wildlife Service 2014).

There are differences of opinion regarding the characteristics and significance of jaguars in the U.S. For example, Rabinowitz (1999, supported by Rabinowitz 2014) argues that although the jaguar cannot simply be considered an accidental wanderer into the U.S., the southwestern U.S. is marginal habitat at the extreme northern limit of the jaguar's range because: 1) the small number of confirmed or credible jaguar sightings indicates a small, short-lived jaguar populations north of the Mexican border over the last century; 2) the fact that 74% of the animals identified by their sex were male suggests most are dispersers from south of the border; 3) there have been only three instances of females with young, all from the early 1900s; this is not indicative of a long term resident population; and 4) the lack of substantial anecdotal evidence, mythology, religious beliefs, or folklore about jaguars in old books, by hunters, or recorded among Native American groups north of the Mexican border strongly suggests a lack of permanent presence even by relatively small numbers of jaguars within the last several hundred years. He further concludes that there is no indication that habitat in the southwestern U.S. is critical for survival of the species. In contrast, McCain and Childs (2008) and Grigione et al. (2007) argue that female jaguars with young are proof that there was once a breeding population in Arizona. Brown (1983) plotted numbers of jaguars killed in Arizona and New Mexico at 10-year intervals from 1900 to 1980 and argued that the decline is characteristic of a resident population that was hunted to extinction. If the jaguars killed during this period were dispersers from Mexico, the numbers would have fluctuated erratically, not in a declining pattern (Brown 1983).

The value of peripheral populations, such as jaguars in the northernmost portion of their range, has been discussed by a number of authors as summarized by Johnson et al. (2011). Miller et al. (1996) established the value of peripheral populations in recovery of the black-footed ferret, as did Schaller (1993) for the giant panda. Ehrlich and Ehrlich (1992) and Garcia-Ramos and Kirkpatrick (1997) affirmed the conservation value of populations at the fringe of the range in a more general sense. Channell and Lomolino (2000), studying dynamic biogeography and conservation of endangered species, also assessed importance of populations at the edge of a species' range. They suggested populations undergoing dramatic range reductions persist longest at the extremes of their range; accordingly, they postulated such populations might deserve even greater conservation focus than "core" populations. Peterson (2001) discounted the conservation value of peripheral populations, asserting they often are sink populations, i.e., populations that would become extinct without immigration from other populations (Pulliam 1988). Nielsen et al. (2001) contested Peterson's argument, claiming peripheral populations are "vitally important to a species' past, present, and future existence."

1.5 Life History and Ecology

1.5.1 Reproduction and Lifespan

Jaguars may breed year-round rangewide, but tend to breed seasonally at the southern and northern ends of their range (Seymour 1989). On average, gestation is 101 days with cubs being born in a sheltered place (Seymour 1989). Litters range from one to four but usually consist of two cubs (Seymour 1989). Cubs remain with their mother for 1.5 to 2 years (Seymour 1989). Sexual maturity ranges from 2 to just over 3 years for females and 3 to 4 years for males (Seymour 1989). According to Seymour (1989), in Belize, Rabinowitz (1986) found few wild jaguars over 11 years of age. Jaguar populations of northern Mexico have a high individual turnover rate (Rosas-Rosas and Bender 2012) with a maximum permanency of 8 years in the area for a female and 5 years for a male (Gutiérrez-González et al. 2015). A wild male jaguar in Arizona was documented to be at least 15 years of age (Johnson et al. 2011). In Jalisco, two wild females were documented to be at least 12 and 13 (Núñez-Pérez, pers. comm. 2011). Therefore, the lifespan of the jaguar in the wild is estimated to be approximately 10-15 years.

1.5.2 Diel Activity Patterns

In Belize, Rabinowitz and Nottingham (1986) report that jaguars are primarily nocturnal. Similarly, in Jalisco, Núñez Pérez (2014) also reports that jaguars are mainly nocturnal. In Brazil, Crawshaw and Quigley (1991) report more crepuscular activity patterns of jaguars, with three distinct peaks at dawn, noon, and the highest at dusk. Hernández-SaintMartín et al.'s (2013) recent study in San Luis Potosi, northeastern Mexico, shows that jaguars are cathemeral (irregularly active at any time of night or day, according to prevailing circumstances), although tending toward nocturnal activity. New data indicate that daylight activities are more normal than previously thought (López González, pers. comm. 2014b).

Núñez-Perez's (2014) study indicates that activity patterns of jaguars in Jalisco, Mexico, are not determined by prey species, and that other factors, such as temperature and human activity, may contribute to defining jaguar's activity patterns. Jaguars showed a strong negative correlation with human activity. Hernández-SaintMartín et al. (2013) found that jaguar activity was negatively correlated with the activity of their main prey, suggesting that jaguars hunt when prey are not active and are likely more vulnerable, such as during night hours.

1.5.2 Diet

Cats are specialized ambush hunters with the stalk being the most important and least variable part of the prey capture sequence (Kitchener 1991, as cited by Cavalcanti 2008). Like other large cats, jaguars rely on a combination of cover, surprise, acceleration, and body weight to capture their prey (Schaller 1972 and Hopcraft et al. 2005, as cited by Cavalcanti 2008). Jaguars usually catch and kill their prey by stalking or ambush and biting through the nape as do most Felidae; however, sometimes they bite through the skull or occasionally through the neck vertebrae of large prey (Seymour 1989). The list of prey taken by jaguars rangewide includes more than 85 species (Seymour 1989). Known prey include, but are not limited to, peccaries (Tayassuidae), capybaras (*Hydrochoerus* spp.), pacas (*Cuniculus paca*), agoutis (*Dasyprocta* spp.), deer (*Odocoileus* and *Mazama* spp., *Blastocerus dichotomus*), opossum (*Didelphis* spp.), rabbits (Leporidae), armadillos (*Dasypus* spp.), caimans (*Caiman* spp.), turtles (*Podocnemis* spp.), livestock, and various other reptiles, birds, and fish (Seymour 1989, Núñez et al. 2000, Rosas-Rosas 2006, Rosas-Rosas et al. 2008, Figueroa 2013, Hernández-SaintMartín et al. 2015). Jaguars are considered opportunistic feeders, especially in rainforests, and their diet varies according to prey density and ease of prey capture (Seymour 1989). Jaguars use medium- and large-size prey, with a trend toward use of larger prey as distance increases from the equator (López González and Miller 2002).

In Brazil, jaguars preferably feed on medium to large sized prey, but can adapt to the fauna in different biomes (Astete et al. 2008). In coastal Jalisco, Núñez et al. (2000) found that jaguars killed eight prey species, including white-tailed deer (*O. virginianus*; 54% of biomass consumed), collared peccary (*Pecari tajacu*; 15%), white-nosed coatimundi (*Nasua narica*; 15%), and nine-banded armadillo (*D. novemcinctus*; 13%). Combined, these four species contributed 89% of occurrence and 98% of the biomass consumed by jaguars. Other prey items included black iguana (*Ctenosaura similis*), birds, opossum, and rabbit (Núñez et al. 2000). In the northern most breeding population of jaguars (northeastern Sonora), Rosas-Rosas (2006) found that large prey (> 10 kg (22 lb)) accounted for > 80% of the total biomass consumed, led by cattle (*Bos taurus*; 57% of biomass), white-tailed deer (23%), and collared peccary (5%). Medium sized prey (1–10 kg (2.2–22 lbs)), including lagomorphs (rabbits and hares) and coatis, accounted for < 20% of biomass. Small prey (< 1 kg (2.2 lbs) body weight) were not found in scats. Jaguar consumption of carrion in Sonora has also been documented (Lopez Gonzalez and Lorenzana Piña 2002). In other areas, different prey items become important in their diet such as reptiles (e.g., caimans and turtles) or large rodents (e.g., paca and capybara) (Da Silveira et al. 2010). In wetlands of Nayarit, medium-sized mammals like raccoon (*Procyon lotor*) and slider turtles (*Pseudemys scripta*) are and important food items (Núñez Pérez, pers. comm. 2015a). In the U.S.-Mexico borderlands, it is thought that collared peccary and deer are mainstays in the diet of jaguars, though other available prey, including livestock and coatis, are likely taken as well (U.S. Fish and Wildlife Service 1997).

Jaguars and pumas coexist in much of their ranges. Scognamillo et al. (2003) hypothesized that adequate availability of appropriate medium-sized prey and habitat heterogeneity may be factors that facilitate the coexistence of jaguars and pumas in the llanos of west-central Venezuela. Núñez et al. (2000) found that jaguars and pumas fed mainly on mammals, with white-tailed deer dominating the biomass of the diet of each species (54% and 66% respectively). They also found there was a high degree of overlap between jaguar and puma diets, but pumas had a broader food niche than jaguars, and their ability to exploit smaller prey may give them an advantage over jaguars when faced with human-induced habitat changes. Cascelli de Azevedo (2008) found that jaguars consumed a less diverse diet and larger prey than pumas in Iguaçu National Park in southern Brazil, suggesting this allowed them to coexist in that location. In San Luis Potosí, northeastern Mexico, Hernández-SaintMartín et al. (2013) found that temporal segregation among jaguars and pumas allowed them to coexist within small natural protected areas with high densities of prey, which permitted flexibility in the carnivore community.

1.5.3 Genetic Fitness

In addition to studies of genetic structure of jaguars across the species geographic range (section **1.3 Evolutionary History, Description, and Taxonomy**), several studies have examined genetics of regional or local jaguar populations (e.g., Eizirik et al. 2008, Haag et al. 2010, Soto 2014, Ruiz-García et al. 2012, Culver and Ochoa Hein 2013). Eizirik et al. (2008) surveyed the molecular diversity of two adjacent wild jaguar populations in the Brazilian Pantanal region. Their results indicate that moderate to high levels of variability are present in wild jaguar populations in the surveyed areas. Given that jaguars are believed to be more abundant in the southern Pantanal region than in many other parts of their distribution, Eizirik et al.'s (2008) preliminary data from this biome may serve as a baseline when assessing genetic diversity in small, fragmented jaguar populations.

Haag et al. (2010) investigated the genetic structure of four remnant jaguar populations in a recently fragmented Atlantic Forest region of South America. They suggest that recent large-scale habitat fragmentation disrupted original patterns of gene flow and lead to drift-induced differentiation among local populations. Top predators, such as the jaguar, may be particularly susceptible to this effect, given their low population densities, leading to small effective sizes in local fragments. Although the jaguar's high dispersal capabilities and relatively long generation time might counteract this process, slowing the effect of drift on local populations, Haag et al. (2010) conclude that jaguars cannot disperse across that region's human-dominated landscapes. They recommend restoring connectivity and gene flow among the fragments to avoid the negative demographic and genetic consequences of small population size and ensure the long-term viability of the metapopulation.

Ruiz-García et al. (2012) reported high diversity of microsatellite and mtDNA markers in 248 wild jaguars from seven countries (156 from Colombia, 38 from Peru, 30 from Bolivia, 12 from Brazil, 8 from Guatemala, 2 from Costa Rica, and 2 from Paraguay). The western Amazon region in Colombia, Peru, and Bolivia was found to have the highest genetic diversity, plus the species, overall, displayed high genetic diversity.

Recent genetic analysis of scat samples from 38 jaguars in Costa Rica indicate the overall genetic variation of jaguars across the country is moderate (Soto 2014). Additionally, the Tortuguero population of jaguars (in northern Costa Rica) is becoming isolated from other populations in Costa Rica. The increasing agricultural and hunting pressure along the borders of Tortuguero National Park, in addition to availability of prey along the coastline, may be causing population isolation and divergence (Soto 2014).

Boydston and López González (2005) suggest that range expansion to the north of eastern Sonora could help prevent genetic isolation and extinction of these northern jaguars and also increase chances for long-term survival of this species in the face of global anthropogenic changes. Citing Young and Clarke (2000), Grigione et al. (2009) suggest that conservation of peripheral populations, such as the jaguar in the northernmost portion of its range, plays a role in maintaining the total genetic heterozygosity of the species. Culver and Ochoa Hein (2013) suggest that long-distance male dispersal is sufficient to avoid loss of genetic diversity rangewide for the species.

1.5.4 Disease and Epizootics

Furtado and Filoni (2008) report the most common virus in jaguars is canine distemper virus, which is known to cause high mortality in wild felids (e.g., 30% mortality in Serengeti lions) and has also caused epizootics in captive felids. Canine distemper virus is usually associated with the presence of domestic dogs. Feline leukemia virus, feline coronavirus, and feline immunodeficiency virus, have also been detected in jaguars, all of which commonly affect domestic cats (Furtado and Filoni 2008). Feline immunodeficiency virus may cause, although infrequently, feline infectious peritonitis, which results in systemic failure and, ultimately, death. Additionally, feline parvovirus has been detected in jaguars (Furtado and Filoni 2008), and, specifically, in Mexico, feline parvovirus antibodies were detected in Quintana Roo (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO; National Commission for Knowledge and Use of Biodiversity) 2011) and Jalisco (Núñez Pérez, pers. comm. 2015a). Its presence can be asymptomatic or with specific symptoms, and in severe cases leads to gastroenteritis and a decrease in blood cells, which can be fatal. There are also reports of jaguars with feline herpesvirus (Furtado and Filoni 2008). The bacteria most frequently detected in jaguars are *Leptospira* sp., which does not cause major problems for jaguars; *Brucella* sp., commonly found in cattle; and *Bartonella henselae*, of which jaguars are reservoirs and potential transmitters to humans (Furtado and Filoni 2008). Some jaguars have also been shown seropositive to the anthrax bacterium (*Bacillus anthracis*) (Furtado and Filoni 2008). Infection by the fungus *Pythium insidiosum* has also been reported in jaguars (Furtado and Filoni 2008). Toxoplasmosis (*Toxoplasma gondii*) has been found in wild and captive jaguars; however, jaguars with toxoplasmosis have not been found to exhibit any clinical symptoms (Demar et al. 2008, Furtado and Filoni 2008). *Tungia penetrans* was found in a wild jaguar captured in Brazil; however, the presence of the disease did not appear to affect the animal's movements and behavior (Widmer and Azevedo 2012).

A wide variety of endoparasites has been found in wild jaguars, particularly the nematode *Dirofilaria immitis* (Furtado and Filoni 2008, CONABIO 2011). Other parasites found in captive and wild jaguars are: *Spirometra mansonoides, Molineus* spp., *Toxascaris leonina, Toxocara cati* and *Strongyloides* spp. (Aranda et al. 2013). Ectoparasite information is scarce and little information exists on the micro-parasites for which they are vectors (Furtado and Filoni 2008). Non-infectious diseases that have been reported include dental, gastrointestinal, musculoskeletal, and integumentary diseases as being the most common causes of morbidity (Furtado and Filoni 2008). Neoplasia, degenerative spinal disorders, and impairment of hearing have also been detected in captive jaguars (Furtado and Filoni 2008). The first report of cutaneous adenocarcinoma was reported during 2014 in a captive jaguar in India (Majie et al. 2014). Dental fractures (particularly of the canines) have been reported in wild jaguars (Furtado and Filoni 2008; Van Pelt, pers. comm. 2011). The first record of mercury in wild jaguars was reported by Racero-Casarrubia et al. (2012) in Colombia. The levels of mercury were not higher than the maximum permissible for wildlife, but the authors discuss the importance of monitoring jaguar populations, especially in areas near mining operations.

In their northernmost range, jaguars have been reported to feed on domestic animals, including cattle and dogs, which could represent a threat to jaguars due to the potential for disease transmission (Rosas-Rosas, pers. comm. 2011). This may particularly be a problem in the Sierra Madre Oriental, where jaguars are known to feed on dogs (Rosas-Rosas, pers. comm. 2011), as well as in Nayarit, where jaguars frequently prey on dogs (Núñez Pérez, pers. comm. 2015a). Furtado and Filoni (2008) explain that information on jaguar health is limited because animals in captivity are rarely subjected to clinical examinations. Furthermore they state that information on infectious and noninfectious diseases in jaguars is limited throughout its range, fragmented, based on small samples, and collected without an established methodology that allows comparisons among the case studies. They recommend that long-term studies in wild and captive jaguars are needed to understand the role and effect of diseases within populations.

1.5.5 Home Range

Like most large carnivores, jaguars have relatively large home ranges. According to Brown and López González (2001), their home ranges are highly variable and depend on topography, available prey, and population dynamics. However, little information is available on this subject outside of tropical America, where a number of studies of jaguar ecology have been conducted.

Jaguar home range size can be documented using a variety of techniques (global positioning system (GPS) telemetry, very high frequency (VHF) radio-telemetry, trail cameras) and estimated using various methods (minimum convex polygon, kernel, and other methods). Jaguar home range sizes estimated by telemetry have been documented from 10 km^2 (3.9 mi^2) (Rabinowitz and Nottingham 1986) in Belize to 959 km^2 (370 mi^2) in Paraguay (Hernandez-Santin 2007) (Table 1). Home range sizes vary between seasons (wet vs. dry) and between sexes (see, for example, Figueroa 2013).

A small number of home range studies have been conducted in the NRU. In the tropical deciduous forest of Jalisco, Mexico, mean home range size for two males was 100.3 ± 15.0 km^2 (38.7 ± 5.8 mi^2) and four females was 42.5 ± 16 km^2 (16.4 ± 6.2 mi^2) (Nuñez Perez 2006). Only one limited home range study using standard radio-telemetry techniques has been conducted for jaguars in northwestern Mexico. One adult female was tracked for four months during the dry season in the municipality of Sahuaripa, Sonora, had a home range size of 100 km^2 (39 mi^2) (López González, pers. comm. 2011b). In the municipality of Sahuaripa, Sonora, camera trap data indicated that one male had a home range of 84 km^2 (32 mi^2) (López González, pers. comm. 2011b), and another male had a home range of 163.7 km^2 (63.2 mi^2) (Gutiérrez-González et al. 2015). Also using camera traps, in Nacori Chico, Sonora, Rosas-Rosas and Bender (2012) estimated the home range for one adult male jaguar encompasses about 200 km^2 (77 mi^2). McCain and Childs (2008), based on the use of camera-traps, report one jaguar in southeastern Arizona as having a minimum observed “range” of 1,359 km^2 (525 mi^2). It is difficult to say whether this might be a “typical” home range size for jaguars in this area due to the small number of locations for the animal and the potential influence of female jaguar scat at some camera traps at various times throughout their research.

Although the jaguar is considered a territorial species, male home ranges can overlap. There is typically more than one female within one male’s home range (Rabinowitz and Nottingham 1986).

1.5.6 Movement and Dispersal Distances

Jaguars move regularly throughout their home ranges, with mean daily movements ranging from 1.8 ± 2.5 km (1.1 ± 1.6 mi) to 8.17 ± 7.26 km (5.08 ± 4.51 mi) using a variety of methods. The mean one-day movement of radio-collared jaguars in the Pantanal region of southwestern Brazil was 2.4 ± 2.3 km (1.5 ± 1.4 mi), with males moving significantly larger distances (3.3 ± 1.8 km (2.0 ± 1.1 mi)) than females (1.8 ± 2.5 km (1.1 ± 1.6 mi)) (Crawshaw and Quigley 1991). Additionally, the mean distance travelled by all animals during one-day intervals in the dry season (2.7 ± 2.5 km (1.7 ± 1.5 mi)) was significantly greater than the mean one-day movement for all other months combined (1.6 ± 2.1 km (1.0 ± 1.3 mi)) (Crawshaw and Quigley 1991). In the forests of Jalisco, jaguars can move up to 20 km (12 mi) in a single night, frequently finishing very close to where they started (Nuñez Perez 2006). Hernandez-Santin (2007) found the mean daily movement of female jaguars in Paraguay ranged from 2.68 ± 2.20 to 3.82 ± 3.14 km (1.67 ± 1.37 to 2.37 ± 1.95 mi) and of males from 3.37 ± 2.69 to 8.17 ± 7.26 km (2.09 ± 1.67 to 5.08 ± 4.51 mi). Hernandez-Santin (2007) states the maximum distance traveled in one day by a male jaguar was 39 km (24 mi) and 30 km (19 mi) by a female. According to Rabinotwiz and Zeller (2010), de Almeida (1990) cites jaguars moving 15 km or more in a single night on hunting patrols in the Brazilian Pantanal. In Nacori Chico, Sonora, female jaguars returned to a given location approximately every 20 days and males every 30 days (Rosas-Rosas and Bender 2012). Figueroa (2013) found, on average, jaguars moved 2.56 km (0.99 mi) per day in Belize, with the mean daily distance traveled during the dry season significantly larger than the distance traveled during the wet season or the average distance traveled

Table 1. Home range sizes in different study areas throughout the jaguar's range. GPS = global positioning system. SECR = spatially explicit capture-recapture. VHF = very high frequency.

Country	Location	Method	Habitat type	# Ind	Home range		Reference
United States	Arizona	Camera trapping	Madrean evergreen woodland Semidesert scrub Grassland	1 M	1,359 km^2	524.7 mi^2	McCain and Childs (2008)
Mexico	Jalisco	Radio collars	Tropical deciduous forest	2M	100.3 ± 15.0 km^2	38.7 ± 5.8 mi^2	Nuñez Perez (2006)
				4F	42.5 ± 16 km^2	16.4 ± 6.2 mi^2	
Mexico	Sahuaripa, Sonora	Radio collars	Tropical deciduous forest	1 F	100 km^2	39 mi^2	López González (pers. comm. 2011)
Mexico	Sahuaripa, Sonora	Camera trapping-closed models	Tropical deciduous forest	1 M	84 km^2	32 mi^2	Gutiérrez-González and López González (2011)
Mexico	Sahuaripa, Sonora	Camera trapping-open models	Tropical deciduous forest	1 M	163.7 km^2	63.2 mi^2	Gutiérrez-González et al. (2015)
Mexico	Nacori Chico, Sonora	Camera trapping	Tropical deciduous forest	1 M	200 km^2	77 mi^2	Rosas-Rosas and Bender (2012)
Mexico	Calakmul, Campeche	Track search	Tropical rainforest	8 F	20 - 26 km^2	7.7 - 10.0 mi^2	Aranda (1998)
				6 M	79 km^2	30.5 mi^2	
Mexico	Calakmul, Campeche	Radio collars	Tropical rainforest	3 F 5 M	41 km^2	15.8 mi^2	Ceballos et al. (2002)
Mexico	Yucatan Peninsula	Radio collars	Tropical rainforest	7 F	204 km^2	78.8 mi^2	Chávez (2010)
				1 M	558 km^2	215.5 mi^2	
Belize	Cockscomb	Radio collars	Tropical forest	1 F	10 km^2	3.9 mi^2	Rabinowitz and Nottingham (1986)
				5 M	28 - 40 km^2	10.8-15.4 mi^2	
Belize	Central Belize	GPS collars	Tropical forest	1 F	111 - 169 km^2	42.9 - 62.3 mi^2	Figueroa (2013)
				6 M	257 - 264 km^2	99.2 - 102 mi^2	
Costa Rica	Osa Peninsula	Camera trapping-closed models	Tropical rainforest	2 M	6.57 - 25.64 km^2	2.5 - 9.9 mi^2	Salom-Pérez et al. (2007)

Country	Location	Method	Habitat type	# Ind	Home range		Reference
Costa Rica	Talamanca	Camera trapping-closed models	Tropical forest	1 M	7.87 km^2	3.0 mi^2	González-Maya et al. (2008)
Panama	Darien National Park	Camera trapping-closed models	Tropical rainforest	1 M	159 km^2	61.4 mi^2	Moreno Ruis (2006)
				1 F	121 km^2	46.7 mi^2	
Panama	Alto Chagres	Camera trapping-closed models	Secondary forest	1 M	37 km^2	14.3 mi^2	Moreno et al. (2008)
Venezuela	Llanos	Radio collars	Grassland Flooded vegetation	3 F dry season	80 km^2	30.9 mi^2	Scognamillo et al. (2003)
				Wet season	51 - 53 km^2	19.7 - 20.5 mi^2	
				2 M dry season	100 km^2	38.6 mi^2	
Brazil	Pantanal	Radio collars	Floodplain	2 F dry season	38 km^2	14.7 mi^2	Schaller and Crawshaw (1980)
Brazil	Pantanal	Radio collars	Swamp	4 F dry season	12.8 km^2	4.9 mi^2	Crawshaw and Quigley (1991)
				1 M dry season	54.3 km^2	21.0 mi^2	
Brazil	Pantanal	Radio collars	Flooded plains	7	142 km^2	54.83 mi^2	Quigley and Crawshaw (1992)
Brazil	Emas National Park	Radio collars	Cerrado savanna	3 M	932 km^2	359.85 mi^2	Silveria (2004)
				1 F	295 km^2	113.9 mi^2	
Brazil	Morro do Diablo State Park	GPS and VHF collars	Atlantic Forest	5 F	60 km^2	23.17 m^2	Cullen (2006)
				2 M	162 km^2	62.55 mi^2	
	Ivinhema State Park		Marsh	1 M	147 km^2	56.76 mi^2	
				2 F	130 km^2	50.19 mi^2	
Brazil	Pantanal	GPS collars	Marginally-flooded semi-deciduous forest	2 F dry season	52 - 65.1 km^2	20.1 - 25.1 mi^2	Soisalo and Cavalcanti (2006)
				4 M dry season	116.5 km^2	45.0 mi^2	
		Camera trapping-closed models		11 M	9.5 km^2	3.7 mi^2	
				4 F	5.6 km^2	2.2 mi^2	

Country	Location	Method	Habitat type	# Ind	Home range		Reference
Brazil	Pantanal	Radio collars	Cerrado, Chaco Amazon forest	4 F wet season	57.1 km^2	22.1 mi^2	Cavalcanti and Gese (2009)
				4 F Dry season	69.1 km^2	26.7 mi^2	
				6 M wet season	152 km^2	58.69 mi^2	
				6 M Dry season	170.8 km^2	65.95 mi^2	
Peru	Madre de Dios	Camera trapping-SECR model	Amazonian moist forest	21 F	130 km^2	50.19 mi^2	Tobler et al. (2013)
				40 M	283 km^2	109.27 mi^2	
Bolivia	Tucavaca	Camera trapping-closed models	Chaqueño forest	2 F	16 - 18 km^2	6.18 - 6.95 mi^2	Maffei et al. (2002)
				1 M	65 km^2	25.1 mi^2	
Bolivia	Tucavaca	Camera trapping-closed models	Dry forest	2 F	24 - 29 km^2	9.27 - 11.2 mi^2	Maffei et al. (2004)
				1 M	65 km^2	25.1 mi^2	
	Cerro Cortado			2 M	20 - 23 km^2	7.72 - 8.88 mi^2	
	Ravelo			1 F	10 km^2	3.86 mi^2	
				1 M	44 km^2	16.99 mi^2	
Bolivia	Gran Chaco National Park	Camera trapping-closed models	Dry forest	2 M	84 - 190 km^2	32.43 - 73.36 mi^2	Romero-Muñoz et al. (2007)
				1 F	22 km^2	8.49 mi^2	
Paraguay	Dry Chaco	GPS collars	Tropical dry forest	2 F	958.81 km^2	370.2 mi^2	Hernandez-Santin (2007)
				3 M			
	Pantanal		Flooded grassland	1 F	87.63 km^2	33.83 mi^2	
				1 M			

for the duration of the study. The maximum daily distance traveled by jaguars during the study was 9.19 ± 3.78 km (3.55 ± 1.46 mi).

In Guatemala, the Mean Maximum Distance Moved (the average maximum distance between detections of each individual) by jaguars was 9.87 km (6.13 mi) in the Mayan Reserve (Moreira et al. 2011). In Honduras, the average Mean Maximum Distance Moved by jaguars was 2.87 km (radius; 1.78 mi) between cameras (Portillo-Reyes and Hernández 2011). In Oaxaca, Figel et al. (2011) reported the maximum distance moved of a jaguar was 12.6 km (7.83 mi) (obtained with camera trapping).

Jaguars can disperse long distances from their natal home range, and males disperse farther than females, but little data exist on jaguar dispersal, including dispersal distance and duration. In coastal Jalisco, one juvenile male dispersed about 70 km (43.5 mi) to the north (Núñez et al. 2002). Crawshaw and Quigley (1991) documented dispersal of two subadult males in Brazil, one of which was killed before establishing a home range, the other other of which dispersed in a series of movements over time, the longest of which was 64 km (39.8 mi) from his presumed natal area. Rabinowitz and Zeller (2010) note that Leopold (1959) speculated that a jaguar killed in California in the 1950s had traveled more than 800 km (497 mi) from its point of origin.

1.5.7 Density

Jaguar density estimates vary throughout the jaguar's range, and are calculated using either camera trap or telemetry-based methods (Table 2). Camera trapping efforts have yielded jaguar population density estimates from 0.11-1.74 adult jaguars per 100 km^2 (39 mi^2) in the tropical rain forest of the Upper Paraná in Argentina (Paviolo et al. 2008) to 11.7 jaguars (possibly including one cub) per 100 km^2 (39 mi^2) in the semi deciduous forest of the Pantanal in Brazil (Soisalo and Cavalcanti 2006) (see Table 2 in Núñez-Pérez 2011). Telemetry-based studies have estimated densities ranging from 1.56 resident adult jaguars per 100 km^2 (39 mi^2) in the Brazilian Pantanal (Quigley and Crawshaw 1992) to 6.6 adult jaguars per 100 km^2 (39 mi^2) in the Calakmul Biosphere Reserve in Mexico (Ceballos et al. 2002) and the Brazilian Pantanal (possibly including one cub; Soisalo and Cavalcanti 2006). Soisalo and Cavalcanti (2006) report that estimates using camera trapping techniques can over-estimate cat density (camera techniques yielded densities of 10.3 to 11.7 instead of 6.6 jaguars per 100 km^2 (39 mi^2)), likely due to the larger linear distances detected using telemetry, which were almost twice as long as the maximum distances detected by cameras. This produces considerably larger effectively sampled areas and, consequently, lower density estimates when compared to smaller areas and higher densities derived from camera techniques.

<u>Camera-trapping Studies in the NRU</u>

In the NRU, several studies have estimated jaguar density using camera trapping techniques. A population density estimate of 5.4 jaguars (possibly including one sub-adult) per 100 km^2 (39 mi^2) was reported in the tropical dry forest of the Chamela-Cuixmala Biosphere Reserve in coastal Jalisco (Núñez-Pérez 2011). During the dry season of 2010, in the tropical deciduous and oak

Table 2. Jaguar density estimates at different study sites throughout the jaguar's range. See original citations to determine if density estimates are the number of adults, or number of adults plus sub-adults and cubs. MMDM = mean maximum distance moved. #ind = number of individuals. Mh CAPTURE = heterogeneous model using program CAPTURE. Mo CAPTURE = null model using program CAPTURE. MEA = modelo del encuentro aleatorio (random encounter model). SECR = spatially explicit capture-recapture. SCR = spatial capture-recapture. Mb CAPTURE = behavioral model using program CAPTURE.

Country	Study area	Method	Density (#ind per 100 km^2 (39 mi^2)) ± SE	Effective sampling area		Sampling period	Model used	Habitat	Reference
Mexico	Sahuaripa, Sonora	MMDM	1.05 ± 0.4	684.6 km^2	264.3 mi^2	16 months	Open population	Tropical deciduous forest	Gutiérrez-González et al. (2012)
Mexico	Sahuaripa, Sonora	MMDM	0.89 ± 0.16	798 km^2	308 mi^2	13 years	Open population	Tropical deciduous forest	Gutiérrez-González et al. 2015
Mexico	Nacori Chico, Sonora	1/2 MMDM	1.1	360 km^2	139 mi^2	60 days		Tropical deciduous forest	Rosas-Rosas and Bender (2012)
Mexico	Marismas Nacionales North, Nayarit	MMDM	1.9 - 2.5	153 km^2	59.1 mi^2	43 days	Mh CAPTURE	Mangrove	CONANP (2011)
	Marismas Nacionales South, Nayarit	MMDM	4.8 - 5.9	83 km^2	32 mi^2				
Mexico	Sierra de Vallejo, Nayarit	1/2 MMDM	5.6	89 km^2	34 mi^2	45 days	Mh CAPTURE	Tropical subdeciduous forest	Núñez Pérez (pers. comm. 2015a)
Mexico	San Luis Potosi	MMDM	1.55 ± 1.93	320.85 km^2	123.88 mi^2	30 days	Mo CAPTURE	Tropical deciduous forest	Ávila (2009)
		1/2 MMDM	3.2 ± 1.93	155.7 km^2	60.12 mi^2				
Mexico	Potrero de mulas, Jalisco	1/2 MMDM	4.2			35-60 days			Núñez (2010)
	Santa Cruz del Tuito, Jalisco	1/2 MMDM	2.8						

Country	Study area	Method	Density (#ind per 100 km^2 (39 mi^2)) ± SE	Effective sampling area		Sampling period	Model used	Habitat	Reference
	Chamela-Cuixmala Biosphere Reserve, Jalisco	1/2 MMDM	5.5						
	Sierra de Manantlan Biosphere Reserve, Jalisco	1/2 MMDM	2.6						
Mexico	Chamela-Cuixmala Biosphere Reserve, Jalisco	1/2 MMDM	5.38	200 km^2	77.2 mi^2	35 days	Mh CAPTURE	Tropical dry forest	Núñez-Pérez (2011)
Mexico	Santa Cruz del Tuito, Jalisco	1/2 MMDM	2.27	176 km^2	68.0 mi^2		Mo CAPTURE	Tropical dry forest	Nuñez (2014)
		1/2 MMDM	2.84				Mh CAPTURE		
		Telemetry	2.06	194 km^2	74.9 mi^2		Mo CAPTURE		
		Telemetry	2.58				Mh CAPTURE		
Mexico	Sierra de Manantlan Bisphere Reserve, Jalisco	1/2 MMDM	0.98 and 1.47	204 km^2	78.8 mi^2	30 days	Mh and Mo CAPTURE	Pine-oak forest	Núñez Pérez (pers. comm. 2015a)
Mexico	Costa Michoacan	Radius (Nuñez 2011)	1.8	154 km^2	59.5 mi^2	35 days		Tropical dry and subdeciduous forest	Núñez Pérez (pers. comm. 2015a)
Mexico	Sierra Gorda, Queretaro	1/2 MMDM	0.75			30 days			Coronel and López (2009)
Mexico	Montes Azules	MMDM	1.7 ± 0.7	223 km^2	86.1 mi^2	60 days	Mh	Tropical	de la Torre and

Country	Study area	Method	Density (#ind per 100 km^2 (39 mi^2)) ± SE	Effective sampling area		Sampling period	Model used	Habitat	Reference
	dry season	1/2 MMDM	2.6 ± 1.0				CAPTURE	rainforest	Medellín (2011)
	Montes Azules wet season	MMDM	3.0 ± 1.2	148.5 km^2	57.34 mi^2				
		1/2 MMDM	4.6 ± 1.6						
Mexico	Yaxchilán, Chiapas	MMDM	0.63 ± 1.8	317 km^2	122 mi^2	30 days	Mh CAPTURE	Tropical rainforest	Tierra Verde Naturaleza y Cultura A. C. (2012)
		1/2 MMDM	1.2 ± 1.9	189 km^2	73.0 mi^2				
Mexico	Bonampak, Chiapas	Track search	2.85 - 4.34	70 km^2	27 mi^2			Tropical rainforest	Aranda (1996)
	Pijijiapan, Chiapas	Track search	5 - 7.69	40 km^2	15 mi^2				
Mexico	Calakmul, Campeche	Telemetry	6.66					Tropical rainforest	Ceballos et al. (2002)
Mexico	Calakmul, Campeche	Track search	3.7	380 km^2	147 mi^2			Tropical rainforest	Aranda (1998)
Mexico	Yucatán Peninsula	Telemetry	1.1 (females only)			7 years			Chávez (2010)
		Telemetry	3.3			10 years			
		Cameras	6.6			30 days			
Belize	Chiquibul dry season	1/2 MMDM	7.48 ± 2.74					Deciduous forest	Noss et al. (2006)
			5.17 ± 3.22						
			2.31 ± 1.28					Pine forest	
	Chiquibul wet season	1/2 MMDM	3.21 ± 1.67					Deciduous forest	
Belize	Cockscomb Basin	1/2 MMDM	8.8 ± 2.25	159 km^2	61.4 mi^2	59 days	Mh CAPTURE	Tropical moist rainforest	Silver et al. (2004)
	Chiquibul Forest Reserve	1/2 MMDM	7.48 ± 2.74	107 km^2	41.3 mi^2	54 days			

<table>
<tr><th>Country</th><th>Study area</th><th>Method</th><th>Density (#ind per 100 km^2 (39 mi^2)) ± SE</th><th colspan="2">Effective sampling area</th><th>Sampling period</th><th>Model used</th><th>Habitat</th><th>Reference</th></tr>
<tr><td rowspan="2">Guatemala</td><td rowspan="2">Mirador-Rio Azul National Park</td><td>MMDM</td><td>0.90 ± 0.48</td><td>90.6 km^2</td><td>35.0 mi^2</td><td rowspan="2">47 days</td><td rowspan="2">Mo CAPTURE</td><td rowspan="2">Tropical forest</td><td rowspan="2">Moreira et al. (2011)</td></tr>
<tr><td>1/2 MMDM</td><td>1.99 ± 1.57</td><td></td><td></td></tr>
<tr><td>Honduras</td><td>Mosquitia</td><td>MMDM</td><td>4.2</td><td>96 km^2</td><td>37 mi^2</td><td>60 days</td><td>Mo CAPTURE</td><td>Tropical rainforest</td><td>Portillo-Reyes and Hernández (2011)</td></tr>
<tr><td>Costa Rica</td><td>Peninsula de Osa</td><td>1/2 MMDM</td><td>2</td><td>218 km^2</td><td>84.2 mi^2</td><td>35 days</td><td>Mh CAPTURE</td><td>Tropical rain forest</td><td>Bustamante (2008)</td></tr>
<tr><td>Costa Rica</td><td>Talamanca</td><td>MMDM</td><td>5.41 ± 2.3</td><td>92.96 km^2</td><td>35.89 mi^2</td><td>2 months</td><td>Mh CAPTURE</td><td>Tropical forest</td><td>González-Maya et al. (2008)</td></tr>
<tr><td>Costa Rica</td><td>Osa Peninsula</td><td>MMDM</td><td>6.98 ± 2.36</td><td>86.02 km^2</td><td>33.21 mi^2</td><td>3 months</td><td>CAPTURE</td><td>Tropical rainforest</td><td>Salom-Pérez et al. (2007)</td></tr>
<tr><td>Costa Rica</td><td>Corcovado National Park</td><td>MMDM</td><td>2 ± 1.49</td><td>218 km^2</td><td>84.2 mi^2</td><td></td><td></td><td></td><td>Bustamante and Moreno (2008)</td></tr>
<tr><td>Panama</td><td>Alto Chagres</td><td>MMDM</td><td>3</td><td></td><td></td><td></td><td>CAPTURE</td><td>Secondary forest</td><td>Moreno et al. (2008)</td></tr>
<tr><td rowspan="4">Panama</td><td rowspan="2">Darien National Park 2005</td><td>MMDM</td><td>0.71</td><td>246 km^2</td><td>95.0 mi^2</td><td rowspan="2">35 days</td><td rowspan="4">Mh CAPTURE</td><td rowspan="4">Tropical rain forest</td><td rowspan="4">Moreno Ruiz (2006)</td></tr>
<tr><td>1/2 MMDM</td><td>1.63</td><td>274 km^2</td><td>106 mi^2</td></tr>
<tr><td rowspan="2">Darien National Park 2006</td><td>MMDM</td><td>2.69</td><td>561 km^2</td><td>217 mi^2</td><td rowspan="2">50 days</td></tr>
<tr><td>1/2 MMDM</td><td>5.55</td><td>216 km^2</td><td>83.4 mi^2</td></tr>
<tr><td rowspan="8">Guyana</td><td rowspan="2">Counami</td><td>MMDM</td><td>1.5</td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8">Amazonian forest</td><td rowspan="8">Kwata Association (2013)</td></tr>
<tr><td>1/2 MMDM</td><td>3.3</td></tr>
<tr><td rowspan="2">Montagne de Fer</td><td>MMDM</td><td>2.5</td></tr>
<tr><td>1/2 MMDM</td><td>4.9</td></tr>
<tr><td rowspan="2">Montagne de Kaw</td><td>MMDM</td><td>1.4</td></tr>
<tr><td>1/2 MMDM</td><td>2.9</td></tr>
<tr><td rowspan="2">Nouragues</td><td>MMDM</td><td>2</td></tr>
<tr><td>1/2 MMDM</td><td>4.7</td></tr>
<tr><td>French Guiana</td><td>Amazonian Basin</td><td>MMDM</td><td>3.3 - 4.9</td><td></td><td></td><td></td><td></td><td>Amazonian moist forest</td><td>de Thoisy & Poirier (2009)</td></tr>
</table>

Country	Study area	Method	Density (#ind per 100 km^2 (39 mi^2)) ± SE	Effective sampling area		Sampling period	Model used	Habitat	Reference
Ecuador	Coast	1/2 MMDM	2.63 ± 196			29-39 days	MEA	Tropical Rain forest	Zapata-Ríos and Araguillin (2013)
Brazil	Pantanal	Telemetry	4	227 km^2	87.6 mi^2	17 months		Floodplain	Schaller and Crawshaw (1980)
Brazil	Amazon	MMDM	1.33	301 km^2	116 mi^2	80 days	Mo CAPTURE	Tropical semideciduous forest	Negroes et al. (2012)
		1/2 MMDM	3.35						
Brazil	Emas National Park	SECR	0.29 ± 0.1	2,004 km^2	773.7 mi^2	85 days	SECR	cerrado savanna	Sollmann et al. (2011)
		MMDM	0.62 ± 0.18	1,498 km^2	578.4 mi^2	85 days	Closed models in MARK		
Brazil	Serra da Capivara National Park	Genetic methods	2.03 ± 0.77	506 km^2	195 mi^2		SCR	Caatinga	Sollmann et al. (2013)
		SECR	1.45 ± 0.46	205 km^2	79.2 mi^2	92 days			
Brazil	Caatinga	MMDM	0.3			60 days		Caatinga	de Paula et al. (2012)
Brazil	Emas National Park	MMDM	2	500 km^2	193 mi^2		Mo CAPTURE	cerrado savanna	Silveria (2004)
Brazil	Morro do Diablo	1/2 MMDM	2.47 ± 0.46	526.17 km^2	203.16 mi^2	8 months	Mh CAPTURE	Atlantic Forest	Cullen (2006)
		Telemetry	2.2	1,137 km^2	439.0 mi^2				
Brazil	Pantanal	Telemetry	1.56					Flooded	Quigley and Crawshaw (1992)
Brazil	Pantanal 2003	MMDM	5.7 ± 0.84	653 km^2	252 mi^2		Mb CAPTURE	Marginally-flooded semi-deciduous forest	Soisalo and Cavalcanti (2006)
		1/2 MMDM	10.3 ± 1.53	360 km^2	139 mi^2				
		Telemetry	6.6 ± 0.99						
	Pantanal 2004	MMDM	5.8 ± 0.97	554 km^2	214 mi^2		Mh CAPTURE		
		1/2 MMDM	11.7 ± 1.94	247 km^2	95.4 mi^2				
		Telemetry	6.7 ± 1.13						

Country	Study area	Method	Density (#ind per 100 km^2 (39 mi^2)) ± SE	Effective sampling area		Sampling period	Model used	Habitat	Reference
Argentina and Brazil	Urugua-í	½ of radius of mean adult home range estimates (n=3) from Crawshaw (1995)	0.33	299.01 km^2	115.45 mi^2	96 days	Minimum number present	Upper Paraná Atlantic Forest	Paviolo et al. (2008)
		½ MMDM	0.17	367.69 km^2	141.97 mi^2				
		MMDM	0.12	823.63 km^2	318.01 mi^2				
	Iguazú, 2004	½ of radius of mean adult home range estimates (n=3) from Crawshaw (1995)	1.07 ± 0.33	467.65 km^2	180.56 mi^2		Mh CAPTURE		
		½ MMDM	0.87 ± 0.3	576.61 km^2	222.63 mi^2				
		MMDM	0.49 ± 0.16	1,023.78 km^2	395.284 mi^2				
	Iguazú, 2006	½ of radius of mean adult home range estimates (n=3) from Crawshaw (1995)	1.74 ± 0.34	804.88 km^2	310.77 mi^2		Mh CAPTURE		
		½ MMDM	1.46 ± 0.34	958.16 km^2	369.95 mi^2				
		MMDM	0.93 ± 0.2	1,499.52 km^2	578.968 mi^2				

Country	Study area	Method	Density (#ind per 100 km^2 (39 mi^2)) ± SE	Effective sampling area		Sampling period	Model used	Habitat	Reference
	Yabotí	½ of radius of mean adult home range estimates (n=3) from Crawshaw (1995)	0.25	807.94 km^2	311.95 mi^2		Minimum number present		
		½ MMDM	0.2	1,000.67 km^2	386.361 mi^2				
		MMDM	0.11	1,762.62 km^2	680.551 mi^2				
Peru	Los Amigos 2005	SECR	12.2 ± 3	56 km^2	22 mi^2	3 months	SECR	Amazonian moist forest	Tobler et al. (2013)
	Los Amigos 2006		3.3 ± 1.7						
	Los Amigos 2007		3.9 ± 1.5						
	Tampopata 2007		12 ± 4.3	52 km^2	20 mi^2				
	Espinoza 2009		3.7 ± 0.7	250 km^2	96.5 mi^2	5 months			
	CM2 2010		4.3 ± 1.7	196 km^2	75.7 mi^2	9 months			
Bolivia	Tucavaca, Gran Chaco	1/2 MMDM	3.93 ± 1.3	272 km^2	105 mi^2	60 days	Mh CAPTURE	Tropical dry forest	Silver et al. (2004)
	Cerro Cortado, Gran Chaco	1/2 MMDM	5.11 ± 2.1	137 km^2	52.9 mi^2	60 days		Xeric Chacoan Forest	
	Madidi National Park	1/2 MMDM	2.48 ± 1.78	458 km^2	177 mi^2	56 days		Amazonian moist forest	
Bolivia	Cerro Cortado, Gran Chaco	MMDM	5.11 ± 2.1	137 km^2	52.9 mi^2	3 months	Mh CAPTURE	Dry forest	Maffei et al. (2004)
			5.37 ± 1.79	149 km^2	57.5 mi^2				
	Tucavaca,		2.57 ± 0.77	272 km^2	105 mi^2				

Country	Study area	Method	Density (#ind per 100 km^2 (39 mi^2)) ± SE	Effective sampling area		Sampling period	Model used	Habitat	Reference
	Gran Chaco		3.1 ± 0.97	128 km^2	49.4 mi^2				
	Ravelo, Gran Chaco		2.22 ± 0.89	309 km^2	119 mi^2				
Bolivia	Tuichi Valley	1/2 MMDM	1.68 ±0.78	169.8 km^2	65.56 mi^2	30 days	CAPTURE	Plain forest	Wallace et al. (2003)
Bolivia	Tucavaca	1/2 MMDM	3.93	178 km^2	68.7 mi^2	60 days	Mh CAPTURE		Maffei et al. (2002)
Bolivia	Guanacos	1/2 MMDM	2.05 ± 0.21			60 days		Chaco	Noss et al. (2006)
	Cerro wet season		5.38 ± 1.79						
	Cerro dry season		5.11 ± 2.1						
	Ravelo wet season		2.27 ± 0.89					Chaco transitional	
	Ravelo dry season		1.57 ± 1.16						
	Tucavaca wet season		2.57 ± 0.77					Cerrado	
	Tucavaca dry season		3.1 ± 0.97						
	Tucavaca wet-dry season		4.8 ± 2.17						
	San Miguelito		14.8 ± 4.68					Chiquitano forest	

forests of Cabo Corrientes, Jalisco, a density was estimated of 2.84 jaguars per 100 km^2 (39 mi^2) with an equal proportion of males to females (Núñez-Pérez 2014). In 2010 in the tropical deciduous and semi-evergreen forests Sierra de Vallejo, Nayarit, densities were estimated at 4.6 (null model) and 5.6 (heterogeneous model) jaguars per 100 km^2 (39 mi^2) with an equal proportion of males to females (Núñez-Pérez et al. 2010). In 2009 in the mangroves of Marismas Nacionales, Nayarit, a density was estimated of 6 jaguars per 100 km^2 (39 mi^2) with an equal proportion of males to females (Núñez-Pérez et al. 2010) and in 2011, the density estimate was of 4.2 jaguars per 100 km^2 (39 mi^2) for the same reserve (CONANP 2011). Additionally, the presence of cubs was documented at all four of the aforementioned sites in Jalisco and Nayarit (Núñez-Pérez et al. 2010). In the Sinaloan thornscrub of Sonora, calculated density estimates include 0.94 ± 0.28 (Gutiérrez-González et al. 2012), 1.1 (Rosas-Rosas and Bender 2012), 1.4 (Gutiérrez-González and López González 2011), and 0.89 ± 0.16 jaguars per 100 km^2 (39 mi^2) (Gutiérrez-González et al. 2015) have been reported. In the state of San Luis Potosí in the Sierra Madre Oriental, a density was estimated of 4 jaguars per 100 km2 (39 mi2) (Ávila et al. in review as cited by Rosas-Rosas, pers. comm. 2011).

Radio-telemetry Studies in the NRU

One study calculating jaguar densities using radio-telemetry techniques has been conducted in the NRU. In the tropical dry forest of the Chamela-Cuixmala Biosphere Reserve in coastal Jalisco, telemetry-based calculations produced a population density estimate of 5 jaguars/100km^2 (39 mi^2), which was similar to that produced by camera techniques (5.4 jaguars per 100 km^2) for the same population (Núñez-Pérez 2011).

1.6 Habitat Characteristics and Use

Vegetative Communities

Jaguars are known from a variety of vegetation communities (Seymour 1989). At middle latitudes, they show a high affinity for lowland wet communities, including swampy savannas or tropical rain forests (sources as cited in Seymour 1989). Swank and Teer (1989) stated that jaguars prefer a warm, tropical climate, usually associated with water, and are rarely found in extensive arid areas. However, jaguars have been documented in arid areas, including thornscrub, desertscrub, lowland desert, mesquite grassland, Madrean oak woodland, and pine-oak woodland communities of northwestern Mexico and southwestern U.S. (Boydston and López González 2005, McCain and Childs 2008, López González and Brown 2002). In the tropical dry forests in western Mexico, jaguars roam in ravines or arroyos more than in other areas (Nuñez Perez 2006), while in wetlands, jaguars move freely through water and open areas (Núñez Pérez, pers. comm. 2015a). The more open, dry habitat of the southwestern U.S. has been characterized as marginal in terms of water, cover, and prey densities (Rabinowitz 1999). Jaguars rarely occur above 2,591 m (8,500 ft) (Brown and López González 2001).

In the Pantanal region of southwestern Brazil, Crashaw and Quigley (1991) found that the mean percentage composition of the four most common habitat types for all jaguars in their study was 44% open forest (35-57%), 29% grassland, 19% gallery forest, and 7% forest patches. Jaguars used habitat in different proportions than available in their home ranges (3rd order habitat selection as described by Johnson 1980); gallery forest and forest patches were used more often than expected on the basis of their availability and open forest and grassland were used less than expected (Crawshaw and Quigley 1991). Additionally, the mean distance radio-collared jaguars were located from permanent water sources (0.5 km or 0.3 mi) was significantly smaller than the distance from water of randomly generated points within jaguar home ranges (1.7 km or 1.1 mi) (Crawshaw and Quigley 1991). In Venezuela, Polisar et al. (2003) reported that jaguars were located significantly more often within the interior of large (> 300 ha/ > 741 acres) forest patches than pumas, which were located significantly more often within the first 500 m (1,640 ft) of such patches. Cavalcanti (2008) examined 2nd and 3rd order habitat selection (see Johnson 1980) of jaguars in the southern Pantanal in west-central Brazil. She found that, in general, jaguars used habitats disproportionately to their availability in the study area (2nd order selection) in the wet and dry seasons. Forests and shrublands were selected by jaguars, while open field, open field with sparse trees, wetland vegetation, open water, and bare soil/agricultural land habitats were generally avoided by jaguars. However, herbaceous field and drainage vegetation habitats were only avoided during the wet season, but used according to their availability during the dry season.

Distance to Water

Additionally, the mean distance radio-collared jaguars were located from permanent sources of water was significantly smaller than the distance from water of randomly generated points within the study area (Cavalcanti 2008). Jaguars differed in the use of different habitat types available within their individual home ranges (3rd order selection) (Cavalcanti 2008). In Belize, Figueroa (2013) compared habitat use from the 95% fixed kernel home ranges of jaguars with habitat availability in the total study area (2nd order selection) and confirmed that jaguars did not establish home ranges at random. For annual, dry season, and wet season home ranges, shrub and broadleaf habitats were the top two communities used. The same preference of these habitats was also found based on the proportional distribution of GPS locations within the minimum convex polygons (3rd order selection) for annual, dry, and wet season home ranges (Figueroa 2013).

Male vs. Female Habitat Selection

Conde et al. (2010) found significant differences in habitat use between male and female jaguars in the Mayan Forest of the Yucatan Peninsula by modeling occupancy as a function of land cover type, distance to roads, and sex. Although both male and female jaguars preferred tall forest, short forest was used by females but avoided by males. Whereas females significantly avoided roads, males did not and ventured into low-intensity cattle ranching and agriculture. Females' preference for intact forests and against roads led to a less extensive, more fragmented habitat distribution for females than for males. Conde et al. (2010) suggest that specifying sex differences increases the power of habitat models to predict landscape occupancy by large carnivores, and so greater attention should be paid to these differences in their modeling and conservation.

Distance to Human Activities

Other studies have also shown that jaguars selectively use large areas of relatively intact habitat away from certain forms of human influence. Zarza et al. (2007) report that towns and roads had an impact on the spatial distribution of jaguars (jaguars used more frequently than expected by chance areas located more than 6.5 km (4 mi) from human settlements and 4.5 km (2.8 mi) from roads) in the Yucatan peninsula. In the state of Mexico, Monroy-Vichis et al. (2007) report that one male jaguar occurred with greater frequency in areas relatively distant from roads and human populations. In some areas of western Mexico, however, jaguars (both sexes) have frequently been recorded near human settlements and roads (Núñez-Pérez, pers. comm. 2011). In Marismas Nacionales, Nayarit, a jaguar den was recently located very close to an agricultural field, apparently 1 km (0.6 mi) from a small town (Núñez-Pérez, pers. comm. 2011). Jaguar presence is affected in different ways by various human activities; however, direct persecution likely has the most significant impact.

Habitats and Corridors in the Northwestern Recovery Unit (NRU)

No formal habitat use studies have been conducted (with the exception of Núñez et al.'s (2002) examination of arroyo use) in the NRU. However, results of a study in the municipality of Nácori Chico, Sonora, showed that jaguar kill sites of wild prey (i.e., white-tailed deer and peccary) (Rosas-Rosas, pers. comm. 2011) and cattle were positively associated with oak forest and semi-tropical thornscrub vegetation types, whereas they were negatively associated with upland mesquite (Rosas-Rosas et al. 2010). Sites of cattle kills were also positively associated with proximity to permanent water sources and roads (Rosas-Rosas et al. 2010). General jaguar habitat associations have been described in this region by various authors. In western Mexico, including Nayarit and Jalisco, jaguars primarily occur in tropical deciduous forest, although other formerly important habitats are the mangrove forests and swamps of the Agua Brava and Marismas Nacionales straddling the borders of Nayarit and Sinaloa (Brown and López González 2001). In Jalisco, oak and pine forest are used by jaguars, some of them located between 2,700 and 2,800 m (8,858 ft and 9,186 ft) in elevation (Núñez-Pérez, pers. comm. 2011). Although jaguars are not primarily associated with these vegetation communities, it is important to consider oak woodlands and pine forests as potential jaguar corridors (Núñez-Pérez, pers. comm. 2011).

In the tropical dry forest of coastal Jalisco, jaguars use arroyos in greater proportion to their availability (Núñez et al. 2002). Jaguars also occur in tropical deciduous forest in southern Sonora and Sinaloa (Brown and López González 2001, Navarro-Serment et al. 2005). Through interviews, Navarro-Serment et al. (2005) obtained 57 Class I records of jaguars in Sinaloa; records were most abundant in the southern half of the state (Class I records include those records with physical evidence for verification, and are considered "verified" or "highly probable" as evidence for a jaguar occurrence; see Tewes and Everett (1986)). Most occurrences were from the tropical deciduous forest, which originally grew across most of the lowlands in Sinaloa and still covers much of the Sierra (Navarro-Serment et al. 2005). According to Brown and López González (2001), the most important biotic community for jaguars in the southwestern borderlands (Arizona, New Mexico, Sonora, Chihuahua) is Sinaloan thornscrub, which inhabits the lower bajadas and basins between 457 and 945 m (1,500 and 3,100 ft) in elevation. Based on records obtained through interviews, they report that nearly 80% of the jaguars killed in state of Sonora were documented in Sinaloan thornscrub. Madrean evergreen woodland is also important for borderlands jaguars; nearly 30% of jaguars killed in the borderlands region were documented in this biotic community (Brown and López González 2001).

Collective Habitat Features for Jaguars of the Northwestern Recovery Unit (NRU)

To better understand habitat characteristics of jaguars in the northwestern portion of their range, the USFWS sent a questionnaire in 2011 to scientists with experience or expertise in jaguar ecology (primarily in the northwestern most portion of the jaguar range) or large cat ecology. The respondents included nine members of the Technical Subgroup of the JRT and two other jaguar experts. Among other questions, the survey asked "what features constitute high-quality habitat for jaguars in the northwestern portion (i.e., southwestern U.S. and northwestern Mexico) of their range?" High-quality habitat was defined as habitat that can support a self-sustaining population of jaguars (i.e., breeding with population growth (a λ of 1.0 or greater) and a minimal risk of extinction). The respondents' compiled answers indicated the following features constitute high-quality habitat for jaguars in the northwestern portion of their range:

- High abundance of native prey, particularly large prey, like deer and peccary, and adequate numbers of medium sized prey;
- Water available within 10 km (6.2 mi) year round;
- Dense vegetative cover (to stalk and ambush prey and for denning and resting), particularly including Sinaloan thornscrub;
- Rugged topography, including canyons and ridges, and some rocky hills good for denning and resting;
- Connectivity to allow normal demographic processes to occur and maintain genetic diversity;
- Expansive areas of adequate habitat (i.e., area large enough to support 50 to 100 jaguars) with low human density;
- Low human activity, development, and infrastructure, including high speed roads, mines, agriculture; and
- No to low jaguar persecution/poaching by humans.

These characteristics were further refined and used in a habitat modeling exercise for the NRU (see Sanderson and Fisher (2011 and 2013) in section *1.6.1 Habitat Modeling* below for more information on this modeling).

1.6.1 Habitat Modeling

Rangewide

Rangwide jaguar habitat modeling was conducted by Rabinowitz and Zeller (2010) who identified least-cost corridors connecting the 90 JCUs across the jaguar's range. Cost was assessed based on habitat structure and the species' response to the landscape in an effort to quantify the ease of movement by jaguars through the landscape matrix with the least chance of negative interactions with humans (Rabinowitz and Zeller 2010). The total area of all 90 JCUs is 1.9 million km^2 (733,594 mi^2) (Zeller 2007), while the total area of the corridors connecting these JCUs is 2,562,378 km^2 (989,340 mi^2). They identified 182 potential corridors between populations, ranging from 3 to 1,607 km (2 to 998.5 mi) in length; 44 of these corridors are characterized as being of immediate concern due to their limited width (less than 10 km (6.2 mi) at any point along their length), and thus their high potential for being severed. See section *1.4.1 Rangewide* for more information on Rabinowitz and Zeller (2010).

As discussed in section *1.4.2 Mexico*, Rodríguez-Soto et al. (2011) used an ensemble model to estimate the potential distribution of jaguars in Mexico and identify the priority areas for conservation. Their results indicate that 16% of Mexico (312,000 km^2; 120,464 mi^2) can be considered suitable for the presence of jaguars and that, furthermore, 13% of the suitable areas are included in existing protected areas and 14% are included in JCUs as defined by Sanderson et al. (2002). Their results show that although the jaguar in Mexico actively selects particular habitat types, it retains a relatively high ecological flexibility. In particular, the presence of the species is mainly associated with tropical rain forests, high prey-species richness, and regularly flooded vegetation, with a clear avoidance for arid vegetation, higher elevations, and grasslands.

To better understand the habitat and other variables associated with livestock predation risk by jaguars in Mexico, Zarco-González et al. (2013) used ecological niche modeling to generate a risk model of livestock predation by puma and jaguar based on environmental and livestock management variables, which allows identification of zones of risk to define mitigation strategies at a national level. The variables most positively related with predation risk by jaguars were vegetative cover percentage, percentage of free-grazing animals, and altitude, whereas arid vegetation had a negative influence on predation risk. In particular, tree cover influenced the success probability of attack by a jaguar, which is a stalk-and-ambush predator; on the contrary, scarce cover, a characteristic of arid vegetation, explained the negative relation with the risk. The zones with highest predation risk by jaguar were those with a tree cover percentage over 70%. They noted that modeling provides an accurate approach to delineating the zones of predation risk by felids; however, at a regional scale the environmental characteristics that favor predation may be different. They recommend that studies be conducted for each biogeographic region to identify specific patterns and mitigation strategies most suitable for each region.

<u>NRU</u>

Several mapping and modeling efforts have been conducted to provide a better understanding of habitats and habitat linkages that have been or might be used by jaguars in the NRU, including studies by Hatten et al. (2002 and 2005), Menke and Hayes (2003), Boydston and López González (2005), Robinson et al. (2006), Grigione et al. (2009), Valera-Aguilar (2010), Sanderson and Fisher (2011 and 2013), and Stoner et al. (2015). These are summarized below.

Hatten et al. (2005) used a Geographic Information System (GIS) model to characterize potential jaguar habitat in Arizona by overlaying 25 historical jaguar sightings on landscape and habitat features believed important (e.g., vegetation biomes and series, elevation, terrain ruggedness, proximity to perennial or intermittent water sources, human density). The amount of Arizona land area identified as potential jaguar habitat ranged from 21 to 30%, depending on the input variables. In their analysis they only used jaguar records (25) with physical evidence of jaguars (body, skin, or photographs) or first-hand accounts of jaguar sightings that were obtained and accepted by a reliable source (game warden or scientist) and had an acceptable positional accuracy (< 8 km or 5 mi). Because jaguars tend to avoid highly disturbed areas, Hatten et al. (2005) removed areas from analysis within city boundaries, higher density rural areas, and agricultural areas. All of the jaguar records (100%) were observed in four biomes. Of these, 56% were observed in scrub grasslands of southeastern Arizona, 20% in Madrean evergreen forest, 12% in Rocky Mountain montane conifer forest, and 12% in Great Basin conifer woodland. At the vegetation series level, jaguars were observed 4.7 times more often in mixed grass-scrub than any other community. All (100%) of the jaguar records were within 10 km (6.2 mi) of water (spring, river, or creek). A total of 60% of the jaguars were observed between 1,220 and 1,829 m (4,003 and 6,001 ft) in elevation, largely in the scrub grassland biome of southeastern Arizona. The remaining jaguar sightings were between 1,036 and 2,743 m (3,399 and 8,999 ft). A total of 92% of jaguar sightings occurred in intermediately rugged to extremely rugged terrain, with the remainder (8%) in nearly level terrain. Hatten et al. (2005) report that apparent preference of jaguars for scrub grasslands might reflect the use of travel corridors from the Sierra Madre Occidental of Mexico into southeastern Arizona rather than a preferred vegetation type, or perhaps jaguars were more visible in open grasslands. They suggest that river valleys might provide travel corridors for jaguars, along with higher prey densities, cooler air, and denser vegetation than surrounding habitats. Furthermore, they suggest that perhaps the most important factor explaining jaguars' apparent preference for rugged terrain is the abundance of water in mountainous areas of southeastern Arizona. They identified a great deal of potential jaguar habitat along the Mogollon Plateau, but hypothesize that land use practices are limiting jaguar movement into central Arizona. They report that jaguar distribution patterns in the last 40 years suggest that southeastern Arizona is the most likely area for future jaguar occurrence in the U.S. and conservation efforts should focus on protecting potential jaguar habitat in Santa Cruz, Pima, Cochise, Pinal, and Graham counties.

Menke and Hayes (2003) conducted a spatial analysis of potential habitat for the jaguar in New Mexico. Because only seven jaguar reports and records from 1900 to 1996 have occurred in New Mexico, Menke and Hayes identified positive and negative potential habitat features for jaguars based on literature sources and evaluations from the Jaguar Habitat Subcommittee and Jaguar Scientific Advisory Group of the Arizona Game and Fish Department (AGFD)- and New Mexico Department of Game and Fish (NMDGF)-led Jaguar Conservation Team. A GIS model was used to combine data layers for landscape features influencing suitability for jaguar habitat, and create a composite potential habitat map. Potential habitat variables modeled were human density, vegetation community, distance to water, prey abundance, and terrain ruggedness. Their final model predicted two areas with the highest probability of containing habitat variables that could support jaguars in New Mexico, including the Peloncillo and Animas mountains in far southwestern New Mexico, and the river canyon and adjacent areas of the Gila and San Francisco River drainages along the New Mexico-Arizona border and to the east. Although their relative suitability map for potential jaguar habitat in New Mexico does not predict the probability of jaguars occurring in any specific area, it can be used to evaluate potential corridors and routes of travel for jaguars in the U.S. They recommend that a complete evaluation of the prospects for long-term persistence of the jaguar in the U.S. must encompass information regarding not only the availability of potential habitat, but must also consider the potential linkages to habitats that currently sustain breeding populations of jaguars. Furthermore, they suggest that additional jaguar habitat-use data from the northern end of the jaguar's range is needed to test and improve the existing habitat models.

Robinson et al. (2006) conducted another analysis of potential habitat for jaguars in New Mexico. They mapped suitable habitat based on the Jaguar Habitat Subcommittee's criteria used to identify jaguar habitat in the U.S., which included:

1) The area considered must be within 80 km (50 mi) of a documented jaguar occurrence. This would include an entire mountain range, if a portion of that range is within 80 km (50 mi) of the occurrence.
2) Based on Brown and Lowe (1994) habitat associations, the area must be in the Semi-desert Grassland, Plains and Great Basin Grassland, Subalpine Grassland, Interior Montane Conifer Forest, Petran Subalpine Conifer Forest, Chihuahuan Desertscrub, Arizona Upland Sonoran Desertscrub, or Great Basin Desertscrub. Areas in the Lower Colorado River Sonoran Desertscrub, Mojave Desertscrub, and Alpine Tundra are not considered jaguar habitat.
3) The area must be within 16 km (10 mi) of surface water, at least seasonally.
4) Areas with continuous row crop agriculture over an area greater than one square mile and any agricultural crop areas immediately adjacent to those areas are not considered adequate habitat. Areas with human residential development in excess of 1 house per 4 ha (10 ac) are not considered jaguar habitat. Areas developed for industrial purposes or a combination of industrial and residential development that create a footprint equal to or greater than 1 house per 4 ha (10 ac) are not suitable jaguar habitat.

To conduct their mapping exercise, Robinson et al. (2006) used 18 sightings (including three Class I sightings and 15 Class II sightings) from New Mexico and added 6 occurrences within 50 miles of New Mexico that are mapped in Hatten et al. (2005). Robinson et al.'s (2006) effort indicates that approximately one half of New Mexico is considered suitable habitat, and suggests the greatest threat to the integrity of jaguar habitat in the U.S. today is likely to be heavily-traveled, multiple-lane highways, such as interstates 25, 10, and 40 in New Mexico.

Boydston and López González (2005) estimated the potential geographic distribution of jaguars in the southwestern U.S. and northwestern Mexico by modeling the jaguar ecological niche from occurrence records (100 male records from Arizona [42], New Mexico [6], Chihuahua [8], and Sonora [39] and 42 female records from Arizona [6] and Sonora [36]). They assumed that records of occurrence for jaguar males would include dispersing or non-territorial males in search of areas without male competitors, while records for females were more likely to be from animals with established home ranges in areas with adequate food and shelter resources for reproduction. They therefore predicted that males would show a broader ecological niche than females, and females would have a more restricted niche, as their distribution should be more closely tied to the distribution of resources. After modeling male and female distributions together and separately, their results indicated that the total area of the predicted distribution for jaguars was 367,000 km^2 (141,699 mi^2), with an area of 391,000 km^2 (150,966 mi^2) predicted based on males only and 145,000 km^2 (55,985 mi^2) based only on females. The amount of area where the male and female geographic distributions overlapped was 132,000 km^2 (50,965 mi^2). This amount was 91% of the predicted female distribution but was only 34% of the range predicted for males. Thus, very little area was uniquely predicted for females compared to males. They report that eastern Sonora appeared capable of supporting male and female jaguars with potential range expansion into southeastern Arizona, while New Mexico and Chihuahua contained environmental characteristics primarily limited to the male niche and thus may be areas into which males occasionally disperse. They found significant differences between land cover within the female distribution and the available landscape. The predicted distribution of female jaguars was mainly across areas of shrubland, deciduous broadleaf forest, and grassland, but deciduous broadleaf forest and mixed forest composed more of the female distribution than expected by chance when compared to the available land cover for the study area. Shrubland was a smaller proportion of the female distribution than expected, and grassland and needleleaf forest were present in proportion to their availability. Boydston and López González's (2005) results indicated that the availability of areas meeting females' environmental requirements may be an important factor limiting the distribution of northern jaguars.

Grigione et al. (2009) conducted a study to construct a blueprint of priority conservation areas for jaguars, ocelots, and jaguarundis in the U.S.-Mexico border region. This was done by: 1) compiling reliable (i.e., Class I) sightings for each species from the early 1900s to 2003, 2) conducting field surveys to ascertain species presence, and 3) conducting a GIS-based habitat mapping workshop in which 29 scientists and conservationists provided information on the distribution and status of each species. Participants were asked to delineate and describe specific areas in the border region where historical and recent sightings of the three cats have occurred, resulting in a compilation of 84 Class I jaguar sightings from Arizona (20), New Mexico (8), and Sonora (56). They were then asked to identify important habitat areas, dispersal corridors, required or existing underpasses, and to characterize habitat areas and corridors. Finally, each participant was also asked to delineate Cat Conservation Units (units) and Cat Conservation Corridors (corridors) for their area of knowledge onto maps. Units were defined as habitat areas important to the long-term survival of a species, often where populations are currently located or areas likely to support relocated populations. Corridors were defined as strips of habitat connecting otherwise isolated units that had documented Class I sightings. Units were ranked by: 1) connectivity between the unit and other habitat areas, 2) habitat quality, 3) size, 4) hunting of felids, 5) hunting of prey, 6) population status, 7) threats from roads, 8) effectiveness of protection, and 9) human density in and around the unit. Corridors were ranked by: 1) continuity of connectivity, 2) habitat quality, 3) width, 4) length, 5) hunting of felids, 6) hunting of prey, 7) gaps/barriers, 8) threats from roads, 9) effectiveness of protection, and 10) human density in and around the corridor. Each participant was asked to rank these factors by importance from 1 (most important) to 9 (least important) for each species. All resulting units and corridors were ranked into prioritization categories of very high, high, and moderate conservation importance. If there was only one unit or corridor in a bioregion it was given a priority of very high.

For the jaguar in the western bioregion of the study area (including Arizona, New Mexico, Sonora, Chihuahua, and Sinaloa), four units were identified (two very high priority, one high priority, and one low priority), including two in the U.S. and two in Mexico (totaling 102,530 km^2 (39,587mi^2)). Within these four units, currently 19.8% of the area has any form of protection (Grigione et al. 2009). A very high priority corridor was identified between the two Mexican units; otherwise the connections between the units are poorly understood and consequently two corridors needing further study were identified. Two underpasses were identified as being needed in northern Sonora, where jaguars are believed to be crossing roads as they disperse north. The authors conclude that the region to the south of Arizona and New Mexico is especially critical for the recovery of the jaguar in the southwestern U.S. because the source population is likely in central Sonora. Citing Brown and López González (2001) and List (2007), Grigione et al. (2009) explain that to reach the U.S., jaguars need to travel through Sonora and Chihuahua, where there are many challenges to jaguar survival and movement, including the U.S.-Mexico border fence.

As part of the work of the JRT, Sanderson and Fisher (2011 and 2013) created a jaguar habitat model for the NRU using the methodology described in Hatten et al. (2005), but with some modifications, and using a larger number of jaguar observations. A total of 13 habitat models were run, with each iteration modified based on feedback from the Technical Subgroup of the JRT. This habitat model helped to define the boundaries of the NRU (Figure 1) and estimate the carrying capacity of jaguars that was used in the population viability analysis (see Miller 2013 and 2014 in section 1.8 Population Model for more information on this analysis). The first models are described in Sanderson and Fisher (2011), while more recent versions, including the final habitat model, version 13, are described in Sanderson and Fisher (2013). A summary of version 13 is provided below.

Sanderson and Fisher (2013) used a GIS to characterize potential jaguar habitat in the NRU by overlaying 453 jaguar observations (not 452 as indicated in Table 1.3 of Sanderson and Fisher 2013) on landscape and habitat features believed important (i.e., percentage of tree cover, ruggedness, human influence (as measured by the Human Influence Index, or HII), ecoregion, elevation, and distance from water). Unlike Hatten et al. (2005), model 13 used all jaguar observations throughout the NRU for which the location was known within 10 km (6.2 mi), and for which a date to the nearest century was available. These included Class I (observations with physical evidence for verification, such as a skin, skull, or photo), II (observations with detailed information but no physical evidence, such as a first-hand report from a qualified individual), and III (all other observations, such as second- or third-hand report of a jaguar) sightings, but excluded any sightings recorded as cat, spotted cat, or large quadruped (four-footed animal), as well as locations that were described too generally to accurately locate on a map (e.g., southern Arizona). They also considered a broad north-south ecological divide between HII and the amount of tree cover used by jaguars in the Jalisco Core Area compared to these same features used by jaguars in the northern three Areas (Borderlands Secondary Area, Sonora Core Area, and Sinaloa Secondary Area), as these two habitat features varied greatly from north to south.

Sanderson and Fisher (2013) found that jaguars in the Jalisco Core Area appeared to use areas of higher human influence (HII < 30) and higher tree cover (> 1 and ≤ 100%) compared to jaguars in the northern three Areas (HII < 20; tree cover > 1 and ≤ 50%). However, throughout the entire NRU jaguars used areas of similar ruggedness (intermediately, moderately, and highly rugged), elevation (< 2,000 m or < 6,562 ft), and distance from water (≤ 10 km or ≤ 6.2 mi). Using these habitat features, they determined the amount jaguar habitat available in each of the Areas within the NRU, as shown in Table 4 in the *2.1.1 Northwestern Recovery Unit* section. Additionally, they weighted the amount of available habitat by ecoregion, and, using 12 jaguar density estimates from throughout the NRU, suggest a potential carrying capacity of 3,414 jaguars over the total area of over 226,826 km^2 (87,578 mi^2) (Figure 3). They further broke this capacity down into the smaller Areas of the NRU, which, from south to north, they suggest may have the potential to contain: ~1,318 jaguars in the Jalisco Core Area, ~929 jaguars in the Sinaloa Secondary Area, ~1,124 jaguars in the Sonora Core Area, and ~42 jaguars in the Borderlands Secondary Area (37 in the Mexico portion and 6 in the U.S.) portion.

The boundaries of the NRU were mapped by the Technical Subgroup of the Jaguar Recovery Team using the definition of core and secondary areas (see section *2.1.3 Core, Secondary, and Peripheral Areas* for these definitions) and their expert knowledge on the distribution of jaguars and jaguar habitat in the NRU, in conjunction with Sanderson and Fisher, using their 2013 jaguar habitat mapping exercise. The map of Jaguar Carrying Capacity Model 13 (Sanderson and Fisher 2013) depicts how the NRU bounds jaguar habitat and occurrences in the southwestern United States and northwestern and western Mexico.

Corridors in the NRU

To model corridors and linkages for jaguars in northwestern Mexico, Valera-Aguilar (2010) simulated jaguar dispersal for the three known populations in Sonora and Chihuahua (Sahuaripa, Bacatete, and Quirego, all within the Sonora Core Area of the NRU) and identified potential linkages that promote connectivity between these populations. Using the Spatial Analysis and Modeling Tool software package applying an Individual-Based Movement Model, virtual jaguars dispersed in a suitability landscape that included variables of elevation, land use types, cattle density, and human impact. Virtual females dispersed for a mean time of 503.7 days and males 1,084 days. The mean straight-line distance from start point to end point was 62.31 km (38.72 mi) for females and 106.04 km (65.89 mi) for males. Females and males from the southern and midwestern populations (Quirego, Bacatete) moved to the north and northeast respectively, likely due to habitat loss from agricultural activities in western Sonora. Individuals from the mideastern population moved randomly due to the availability of habitat around the population. Linkages identified had the following characteristics: 1) an average elevation of 483.4 ± 306.6 m (1,586 ± 1,006 ft), 2) 96% of the area with adequate habitat classified as woodlands with an herbaceous layer, and evergreen or deciduous trees that are taller than 5 m (16 ft) and provide 40 to 60% cover, 3) a cattle density of 11.7 ± 4.2 head/km^2 (30.4 ± 10.9 head/mi^2), and 4) with very low human impact (8.4 ± 6.5 on a scale of 100). The linkages that connected the three populations were located in the region of Yecora in eastern Sonora. Linkages for females covered 5,106 km^2 (1,971 mi^2) and for males covered 8,174 km^2 (3,156 mi^2). The area of linkage overlap for females and males was about 2,116 km^2 (817 mi^2).

In the NRU, Stoner et al. (2015) used Circuitscape (citing version 4.0; Shah and McRae 2008) to predict jaguar corridors and locations where jaguar movement may be obstructed by transportation infrastructure. Much of the Mexico portion of the Borderlands had many redundant pathways available to dispersing cats; therefore, it was difficult to predict which path a jaguar would use. However, two distinct potential corridors extended from the northern part of the Sonora Core Area through the Mexico portion of the Borderlands Secondary Area, which split into three corridors near the U.S.-Mexico border (Figure 4). Specifically, in the Borderlands Secondary Area, the western potential corridor diverged around Mexican Federal Highway 15 in northern Mexico and crossed the border at the Pajarito, Patagonia, and Huachuca Mountains in southern Arizona. The eastern potential corridor was quite narrow and crossed the U.S.-Mexico border at the Peloncillo Mountains in Arizona and New Mexico.

Connectivity appears to be quite diffuse in the central part of the Sonora Core Area, but narrows to a more obvious potential corridor in the southern part of the Area (Figure 5). Connectivity is likewise dispersed across the landscape in the Sinaloa Secondary Area; however, a potential corridor running from north to south is still apparent in the central part of the Area (Figure 6). In the Jalisco Core Area, connectivity is concentrated near the center of the northern portion of this Area, with potential corridors running primarily north to south (Figure 7). In the southern portion of the Jalisco Core Area, connectivity is concentrated along several north-south potential corridors (Figure 8).

Stoner et al.'s (2015) results suggest 10 candidate sites where highway mitigation measures may help maintain jaguar connectivity in the NRU: six in the Borderlands Secondary Area (three in the U.S. and three in Mexico) and four in the Jalisco Core Area (Figures 4-8). These 10 sites are general areas where additional on-the-ground, localized evaluations are needed to assess the feasibility of installing over- and under-passes and fences to accommodate jaguar dispersal. These assessments, complemented by empirical field studies of jaguar movement in each region (e.g., using GPS and remotely-triggered cameras to validate the connectivity model results), would help identify the specific sites where passages are most likely to be used by jaguars (see Polisar et al. 2014a for a review of monitoring techniques).

1.7 Critical Habitat

Critical habitat (as defined under the ESA) for the jaguar is designated in the U.S. for approximately 309,263 ha (764,207 ac) in Pima, Santa Cruz, and Cochise counties, Arizona, and Hidalgo County, New Mexico, in six critical habitat units (U.S. Fish and Wildlife Service 2014; Figure 9):

1) Unit 1, Baboquivari Unit, approximately 25,549 ha (63,134 ac) in the Baboquivari Mountains, Arizona;
2) Unit 2, Atascosa Unit, approximately 58,624 ha (144,865 ac) in the Tumacacori, Atascosa, and Pajarito Mountains, Arizona;
3) Unit 3, Patagonia Unit, approximately 147,248 ha (351,501 ac) in the Santa Rita, Patagonia, and Huachuca Mountains and Canelo Hills, Arizona;
4) Unit 4, Whetstone Unit, approximately 38,149 ha (94,269 ac) in the Whetstone Mountains, including connections to the Santa Rita and Huachuca Mountains, Arizona;
5) Unit 5, Peloncillo Unit, approximately 41,571 ha (102,724 ac) in the Peloncillo Mountains, Arizona and New Mexico; and
6) Unit 6, San Luis Unit, approximately 3,122 ha (7,714 ac) in the San Luis Mountains, New Mexico.

There are seven primary constituent elements of critical habitat, which include those habitat features required for the following physical and biological feature that provides for the physiological, behavioral, and ecological needs of the species. The physical and biological feature including these seven elements is:

Expansive open spaces in the southwestern U.S. of at least 100 km^2 (38.6 mi^2) in size which:

1) Provide connectivity to Mexico;
2) Contain adequate levels of native prey species, including deer and javelina, as well as medium-sized prey such as coatis, skunks, raccoons, or jackrabbits;
3) Include surface water sources available within 20 km (12.4 mi) of each other;
4) Contain from greater than 1 to 50 percent canopy cover within Madrean evergreen woodland, generally recognized by a mixture of oak (*Quercus* spp.), juniper (*Juniperus* spp.), and pine

(*Pinus* spp.) trees on the landscape, or semidesert grassland vegetation communities, usually characterized by *Pleuraphis mutica* (tobosagrass) or *Bouteloua eriopoda* (black grama) along with other grasses;

5) Are characterized by intermediately, moderately, or highly rugged terrain;
6) Are below 2,000 m (6,562 feet) in elevation; and
7) Are characterized by minimal to no human population density, no major roads, or no stable nighttime lighting over any 1-km^2 (0.4-mi^2) area.

Note that designated critical habitat carries with it consultative requirements in the U.S. under section 7(a)(2) of the ESA with regard to adverse modification.

1.8 Population Modeling

To conserve the jaguar, it is critical to understand its population dynamics and the sensitivities of vital rates to human influences on those vital rates. To examine these, population viability analyses (PVAs) are performed. A PVA is the estimation of extinction probabilities incorporating identifiable threats to population survival into models of the extinction process; however, this kind of analysis traditionally does not include different density-dependent survival probabilities, nor does it include interactions between genes that can affect the population or model breeding in the population as a random process. These models do not quantify differences in dispersal patterns depending on age or sex, which could be important for jaguars (Lacy 1993). Most important for PVAs is the quality of the data incorporated into the modeling effort (Lacy 1993, Lindenmayer et al. 1993). A number of PVAs have been conducted in various parts of the jaguar's range (Carillo et al. 2007, Sollmann et al. 2008, Desbiez et al. 2012, Miller 2013 and 2014, Zanin et al. 2014), and are summarized below.

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A model created from a population habitat viability analysis for jaguars in Mexico indicated that poaching mortality significantly reduces population growth and increases the risk of extinction of small populations (Carrillo et al. 2007). This effect is stronger in females, as when take is over 3% of the female population, the population becomes non-viable over a period of 100 years (Carrillo et al. 2007). According to the model, population sizes of < 100 individuals are not viable (Carrillo et al. 2007). Five regional models were also created, two of which (Sonora and Jalisco/Nayarit) are discussed below in the NRU section.

The PVA conducted by Sollmann et al. (2008) in Brazil assessed the potential long term survival of jaguars in protected areas for five Brazilian biomes. Baseline data used were generated by Eizirik et al. (2002), and some demographic parameters were adjusted based on additional empirical data. They highlight the importance of connectivity between protected areas to ensure viable population numbers.

Another jaguar PVA was conducted for Brazil during the Jaguar National Action Plan workshop in spring 2012 using *VORTEX* software (Desbiez et al. 2012). The participants developed a general model for the Brazilian biomes. This model represented the biological potential of jaguars in a scenario without jaguar harvest, with no mortality due to road kills and diseases, and no natural catastrophes. This general base model was made to identify the gaps in demographic knowledge for jaguars in the region. The focus of this work was to examine concepts of jaguar population dynamics, stimulate discussions on jaguar life history parameters, and evaluate different threats and their potential impact, while introducing participants to concepts of population viability analysis. The results for one model showed that data on the sex of animals hunted had a significant impact on the final outcome of the model, while the age class of jaguars hunted (adults or sub-adults) had less impact.

Zanin et al. (2014) analyzed data from 28 jaguar populations cited by other authors (from Brazil, Mexico, Costa Rica, Belize, Guatemala, Nicaragua, Honduras, Colombia, and Bolivia) and analyzed the synergistic and isolated effects of habitat loss and fragmentation to understand how landscape patterning affects the long-term persistence of species with a PVA. They used real landscapes where the species is present, as well as simulations using hypothetical landscapes, to investigate how the landscape configuration could determine jaguar persistence probability. Their results showed that the landscapes composed of habitat aggregated into one single patch had a larger proportion of suitable habitat than landscapes with two or more patches. When populations had a density greater than 4.13 jaguars per 100 km^2 (39 mi^2), jaguar population viability suffered an abrupt and consistent change following a small reduction of habitat. Based on that, the critical threshold for jaguar habitat varied from 3,000 to 7,000 km^2 (1,158 to 2,703 mi^2). The real landscapes evaluated were able to support a jaguar population only in 2 out of the 28 sites investigated, based on 95% persistence probability after 200 years. Both of these viable populations are located in Guatemala and exhibit high jaguar density and a landscape with almost 100% native vegetation. Many other high-density populations were nonviable; these landscapes frequently had a total area that was larger than the habitat loss critical threshold, but the area was divided into a number of patches that were also larger than the fragmentation critical threshold, which resulted in nonviable populations. They therefore conclude that fragmentation is more detrimental than habitat loss to jaguar populations.

NRU

As mentioned above, Carillo et al. (2007) created a PVA model for jaguars throughout Mexico, as well as for five regions within the country, including Sonora and Jalisco/Nayarit. The model created specifically for jaguars in the Sonora region indicates that without anthropogenic influences, the jaguar population will be reduced to less than 50% of its original size in 100 years (or about 65 individuals) and that with anthropogenic influences (illegal killing of jaguars, estimated at 3.35% of the population annually, was the only anthropogenic influence included in this model), jaguars will be reduced to about 20 individuals in 100 years (Carrillo et al. 2007). The model created for jaguars in the Jalisco/Nayarit regions indicates that without anthropogenic influences, the jaguar population will remain viable but be reduced from 140 to 110 individuals, and that with illegal killing (estimated at 10% of the population annually), jaguars will be extirpated from that area in 80 years (Carrillo et al. 2007).

Because no PVA had been done specifically for jaguars in the NRU, the Technical Subgroup of the JRT worked with Conservation Breeding Specialist Group to conduct multiple PVAs (Miller 2013 and 2014) to inform jaguar recovery planning efforts in the NRU. *Vortex*, a simulation software package written for PVA, was used as a vehicle to study the interaction of a number of jaguar life history and population parameters, and to test the effects of selected management scenarios. Miller (2013) considered four subpopulations: the Jalisco Core Area, Sinaloa Secondary Area, Sonora Core Area, and the U.S.-Mexico Borderlands Secondary Area. These models considered a probability of movement between subpopulations to be different by gender (90% of dispersing animals are assumed to be male, making them nine times more likely to disperse in any given year). Furthermore, it was assumed that the dispersing cohort was composed only of individuals aged two to three years, i.e., those animals dispersing out of their natal range to seek out new territories. As dispersal information is not available for the NRU, they assumed dispersal was not density-dependent and, with no dispersal cost (e.g., increase in mortality risk). Additional assumptions included a lack of physical barriers to jaguar movement and one litter per breeding cycle (i.e., one litter every other year, or 50% of adult females expected to reproduce each year). Demographic parameters included onset of reproduction at three years of age, and maximum age of reproduction at 13 years old (Miller 2013).

The model, intended to describe the current Sonora population, included the effects of human poaching in age-specific mortality rates (Miller 2013). Natural catastrophes, such as drought, were not modelled; however, the authors suggested that future research should include the frequency and severity of catastrophic events, which would improve existing jaguar PVA efforts. Specifically, long-term drought could be a significant factor that reduces jaguar prey population abundance and, by extension, jaguar demographic stability. Long-term changes in climate may also impact jaguar populations, perhaps by increasing prey population densities and thereby having a beneficial effect on jaguar demography. A modified climate may also introduce negative impacts such as increased risk of disease introduction and transmission, reducing jaguar demographic viability. Future research on better estimating frequency and severity of proposed catastrophic events could bring valuable improvements to existing jaguar PVA efforts.

The results of the 2013 PVA suggested that jaguar populations in both the Jalisco and Sonora Core Areas are sufficiently large (both in terms of current abundance and estimated long-term habitat carrying capacity) to serve as effective source populations within the larger NRU metapopulation and remain demographically viable as long as some level of dispersal occurs to reduce the potentially deleterious effects that inbreeding depression may bring to a small and relatively isolated population. This viability is critically dependent on at least minimal opportunities for population growth of these subpopulations in the absence of dispersal so that these areas can act as demographic source populations of dispersing individuals. The strength with which a source population can supply individuals for neighboring regions is critically dependent on its intrinsic capability for growth, itself a function of the threats imposed on it by local human activities (Miller 2013). Changes in mortality of either cubs or adults could significantly reduce the growth potential of the Core Areas (Miller 2013 and 2014). This could, in turn, reduce the dispersal rate of individuals from these Core Areas to the neighboring secondary areas, thereby potentially comprising long-term viability of the metapopulation. According to Miller (2013), the Sinaloa Secondary Area, which is thought to support a smaller population that may suffer the ill effects of inbreeding depression, demonstrates less vigorous growth potential, especially when dispersal amongst nearest neighbors is rare.

Miller (2013) reports that establishment of a jaguar population in the Mexico and U.S. portions of Borderlands Secondary Area depends on three basic aspects: 1) a demographically robust core source population in Sonora, 2) suitable habitat in northern Sonora to maintain jaguars in the long-term and provide key dispersal corridors to the international border, and 3) a permeable border between the Mexico and U.S. portions of the Borderlands Secondary Area. The Mexico portion of the Borderlands Secondary Area, being closer to the Sonora Core Area, has a relatively high probability of housing a resident jaguar population if that Core Area is able to maintain its own demographic stability and if the local habitat distribution facilitates northward dispersal (Miller 2013). Situated even farther to the north, the U.S. portion of the Borderlands Secondary Area has a much lower probability of population establishment through dispersal from the small population that may occupy the Mexico portion of the Borderlands Secondary Area. This analysis suggests that conditions are not currently favorable for establishing a long-term viable population of jaguars in the northernmost portion of the NRU, most likely due to low abundance of jaguars in the Mexico portion of the Borderlands Secondary Area, relatively low levels of dispersal across the U.S.-Mexico border, and habitat-mediated limitations to long-term robust population growth in the U.S. portion of the NRU. If there is a specific desire to facilitate such a process of establishment, directed attention to improving any or all of these limiting factors is an essential step to achieving the long-term goal (Miller 2013).

Miller (2013) reports that based on a large-scale view of the analyses, it is likely that existing jaguar populations within the NRU as a whole are currently and can remain viable in the future, given the absence of deleterious impacts of significant threats to individual survival. Poaching of jaguars can significantly increase mortality in the Core Areas, which could in turn reduce the number of dispersing individuals received by smaller population units like those in the Borderlands Secondary Area. Dedicated efforts by the jaguar research and management community in estimating the magnitude of poaching-based mortality are an important component of ongoing metapopulation management within the NRU (Miller 2013). Populations within the northern reaches of the NRU may be able to expand and become important contributors to metapopulation viability if suitable habitat remains available in sufficient quantity to support a breeding population of adults over time (Miller 2013).

To better understand the importance of the Sinaloa Secondary Area as a connection between the two Core Areas to maintain long-term demographic stability, an addendum (Miller 2014) to Miller (2013) was conducted to explore the conditions under which the two jaguar populations currently occupying the Core Areas (Sonora and Jalisco) can survive on their own—in other words, assuming demographic isolation from neighboring subpopulations. Results from Miller (2014) showed that an isolated core population of approximately 120 individuals (corresponding to an adult abundance of about 70-75 animals given the underlying demographic profile) in the Jalisco Core Area appears to be the smallest population that can persist with a sufficiently high probability of survival, defined in this analysis as a 10% probability of population extinction over a 100-year timeframe. Because this abundance is defined in the context of the minimal conditions for long-term population growth, this could be considered minimum viable population abundance, but relatively small changes in survival among both cubs and adults, especially females, can dramatically increase the risk of extinction of jaguars within this modelled population. The Sonora population analysis was not explicit in the addendum of August 2014; this was because of the close similarity in both initial population size and carrying capacity between the Jalisco and Sonora Core Areas, meaning the results obtained for the Jalisco Core Area were applicable to the Sonora Core Area, as well.

According to Miller (2014), experts in jaguar population dynamics in Mexico suggest that both Jalisco and Sonora Core Area populations may already be impacted by a combination of threatening factors that limit their growth to a considerable extent. In this case, it may be reasonable to conclude that these populations may be at considerable risk of future population declines if additional mortality occurs through hunting, etc., and dispersal of jaguars into these habitats through demographic connectivity is not possible. The additional loss of as few as 10 adult females annually from one of these core populations may tip the demographic balance. Maintenance of metapopulation dynamics among these core populations and neighboring corridor habitats may therefore be a vitally important component of a successful management strategy for jaguars in the northern part of the species' range. The success of such a strategy must also depend, of course, on the responsible management of threats to survival and reproduction of jaguars in the presence of humans (Miller 2014).

As with all applications of simulation models of wildlife demography featuring parameter uncertainty, the models discussed here should not be interpreted as accurate predictions of the future, but rather as a critical analysis of the available information on the species and its ecology through a set of simulations. Future PVAs for the NRU and PARU will be needed as additional information is obtained on jaguar vital rates and population dynamics.

1.9 Reasons for Listing/Threats Assessment

Section 4(a)(1) of the ESA outlines five factors to consider when a species is a candidate for listing as threatened or endangered. The following analysis considers these factors in contributing to the endangered status of the jaguar. The 1997 final rule to extend endangered status for the jaguar in the U.S. (U.S. Fish and Wildlife Service 1997) provided an analysis of the five factors; however, because the rule only applied to the U.S., the analysis generally only addressed threats to the species in the U.S. The 1972 final listing rule (U.S. Fish and Wildlife Service 1972) did not include a five factor analysis. Below, we address threats based on the five listing factors throughout the species range but focus on the NRU.

1.9.1 Factor A. The present or threatened destruction, modification, or curtailment of its habitat or range

Range wide, habitat destruction, modification, and fragmentation form one of the two most significant threats to the jaguar (Nowell and Jackson 1996, Medellín et al. 2002, Núñez et al. 2002, Chávez and Ceballos 2006, Medellín 2009, Rodríguez-Soto et al. 2013, Petracca et al. 2014b). To recover jaguars, addressing this threat of habitat loss requires immediate response. The jaguar is classified as "Near Threatened" on the Red List of the IUCN due to a number of factors, including habitat loss and fragmentation of populations across portions of the range (Caso et al. 2008). Current levels of habitat loss indicate the species is trending toward Vulnerable (IUCN category); the jaguar's status is currently being reevaluated by the IUCN and a new analysis should be available by the end of 2016 (Quigley, pers. comm. 2016). Various factors, particularly habitat loss, have caused a considerable reduction in the historical range of the jaguar (Sanderson et al. 2002, Zeller 2007, Rabinowitz and Zeller 2010). Most loss of occupied range has occurred in the southern U.S., northeastern Mexico, northern Brazil, and southern Argentina (Sanderson et al. 2002). Deforestation rates are high in Latin America (e.g., Figure 10) and fragmentation of forest habitat isolates jaguar populations so that jaguars are more vulnerable to human persecution (Nowell and Jackson 1996). Medellín et al. (2002) report that loss, fragmentation, and modification of jaguar habitat have contributed to population declines throughout much of the species' range, including northern Mexico. The main threats for jaguars in habitat corridors in Mexico are habitat fragmentation, roads and highways, and possible human-wildlife conflicts (livestock predation) (Rodríguez-Soto et al. 2013). Faller Menéndez (2009) reported that, in addition to habitat loss, fires are causing abnormal concentrations of wildlife in the remaining available habitat in southern Mexico, which provides a possible explanation for the relatively high densities reported in southern Mexico.

Chávez and Ceballos (2006) reported that deforestation was one of the two most important threats to jaguars in Mexico; 60% of the jaguar's historical range in Mexico has been lost; the nationwide population was fewer than 5,000 individuals; and a variety of threats suggested that, absent effective conservation efforts, jaguar imperilment in Mexico would only worsen. Rosas-Rosas and Valdez (2010) reported that jaguar habitats were degraded and conflicts between jaguars and human interests were common in Sonora. Furthermore, they reported that habitat fragmentation and illegal hunting of jaguars and their potential prey species are probably the main threats to long-term conservation of jaguars in their northernmost western range. Increased illegal activities and responsive law enforcement actions, including construction and maintenance of the border fence along the U.S.-Mexico international border, may be limiting jaguar movement across the border, but it is uncertain if and how much this is affecting that movement.

Human population growth has both direct and indirect impacts on jaguar survival and mortality. For example, human growth and development tend to fragment habitat and isolate populations of jaguars and other wildlife. For carnivores in general, the impacts of high road density have been well documented and thoroughly reviewed (e.g., Noss et al. 1996, Carroll et al. 2001, as cited by Menke and Hayes 2003). Carnivores are particularly vulnerable to extinction in fragmented landscapes, owing to intrinsic biological traits, such as large body sizes, large area requirements, low densities, and slow population growth rates, as well as external anthropogenic threats, including hunting and other forms of direct mortality (sources as cited in Matthews et al. 2014). Roads may have direct impacts to carnivores and carnivore habitats, including mortality caused by vehicles (see Factor E), disturbance, habitat loss and fragmentation, changes in prey numbers or distribution, and provision of increased access for legal or illegal harvest (Menke and Hayes 2003, Colchero et al. 2010, Matthews et al. 2014). Roads are among the most widespread and impose some of the most lasting impacts on ecosystems of all human-made linear infrastructures (sources as cited in Matthews et al. 2014). In the U.S. alone, roads and roadsides cover over 1% of the land, equivalent in area to the state of South Carolina, and influence the ecology of at least one-fifth of the land area of the entire country (Forman 2000, Cerulean 2002, as cited by Matthews et al. 2014). Núñez Pérez (2007) considered habitat fragmentation a risk to the long-term conservation of jaguars in western Mexico. In some areas, like Colima, connectivity is being lost due to four-lane road construction and forest destruction (Núñez Pérez 2014). In the Mayan forest, Conde et al. (2010) found that jaguar male movements were not influenced by road presence, but that females showed strong road avoidance. Males also used agricultural and livestock areas more often than females. Núñez Pérez (pers. comm. 2015a) found that if jaguars are tolerated by people, they can get very close to human settlements if not disturbed.

Overall, the threat of human encroachment cannot be eliminated, but through conservation planning and implementation efforts, it can be reduced. Conservation of key habitat areas is critical to the recovery of jaguars and, as discussed below in section **1.10 Conservation Efforts**, various efforts have been made to protect jaguar habitat. There are many opportunities and methods (e.g., creation of new reserves, incentive programs) to continue to conserve jaguar habitat; however, they will require significant international, national, and local cooperation, as well as financial support.

1.9.2 Factor B. Overutilization for commercial, recreational, scientific, or educational purposes

The USFWS and JRT are not aware of current overutilization of jaguars for legal commercial, recreational, scientific, or educational purposes throughout its range. See Factor E below for more information on illegal killing of jaguars.

1.9.3 Factor C. Disease or predation

The 1997 listing rule stated that the USFWS is unaware of any known diseases or predators that threaten the jaguar. Nonetheless, diseases are an increasing threat to wild felids due to habitat restriction and fragmentation and encroachment from domestic animals (Brousset and Aguirre 2007, Furtado and Filoni 2008). The potential role of diseases in wild felid and other carnivore populations, however, is still poorly understood, especially for the jaguar (Brousset and Aguirre 2007, Furtado and Filoni 2008) (see section *1.5.4 Disease and Epizootics* above for information on specific diseases affecting jaguars). Diseases should always be considered as an important factor in conservation biology, and surveillance and monitoring programs are required for an adequate understanding of disease dynamics in wild jaguars (Furtado and Filoni 2008). Brousset and Aguirre (2007) proposed to implement a standard protocol for the health evaluation of wild jaguar populations in Mexico to: 1) allow a comparison of results from different areas over time, 2) expand knowledge of the role of infectious diseases and other pathogens on the population dynamics of the species, 3) identify diseases that may represent a direct or indirect threat to jaguar conservation, and 4) develop strategic recommendations to strengthen the understanding of the eco-epidemiology and conservation of jaguars in Mexico.

In summary, currently diseases are not known to significantly impact jaguar populations; however, diseases can devastate wild carnivore populations, and their effects to jaguars should be carefully monitored. If diseases are found to affect jaguar populations, steps should be taken to address this threat.

1.9.4 Factor D. The inadequacy of existing regulatory mechanisms

The jaguar and its habitat and prey are generally protected by numerous laws throughout its range. However, many of these laws are not properly enforced (often due to lack of funding and personnel), and in some cases laws are not adequate to prevent illegal killing of jaguars, overharvest of their prey, and habitat loss and fragmentation. Therefore, while regulatory mechanisms to protect jaguars are in place, they may not be adequate and thus the USFWS considers this Factor a threat. A summary of existing laws that protect jaguars from killing is provided below.

On July 1, 1975, the jaguar was included in Appendix I of CITES; in 2011, a reassessment of the species maintained the same category (CITES 2011). CITES is a treaty established to prevent international trade that may be detrimental to the survival of plants and animals. Generally, both import and export permits are required from the importing and exporting countries before an Appendix I species may be shipped, and Appendix I species may not be exported for primarily commercial purposes. CITES permits may not be issued if the export will be detrimental to the survival of the species or if the specimens were not legally acquired.

The jaguar is fully protected at the national level across most of its range, with hunting prohibited in Argentina, Brazil, Colombia, Costa Rica, Ecuador, French Guiana, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Suriname, U.S., Uruguay, and Venezuela (Registro Oficial No. 818 1970, Secretaría de Desarrollo Urbano y Ecología 1987, Nowell and Jackson 1996, Sistema Nacional de Áreas de Conservación 2012, Government of Guyana 2013). According to Nowell and Jackson (1996), hunting is restricted to "problem animals" in Brazil, Costa Rica, Guatemala, Mexico, and Peru, and trophy hunting is permitted in Bolivia; because regulations change, this information may change for some or all countries.

Laws Protecting Jaguars in Mexico

In Mexico, there are a number of laws and regulations that directly or indirectly protect jaguars. Some of these are discussed below.

The Norma Oficial Mexicana NOM-059-SEMARNAT-2010, Protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo (NOM-059-SEMARNAT-2010), is a list of endangered species in Mexico. This law has no direct restriction regarding the protection of the listed species, but it includes the criteria for including, excluding, or changing the risk category for species or populations on the list, and it is related with other instruments of environmental protection. It has 4 categories: Probably extinct in the wild (E—"Probablemente extinta en el medio Silvestre"), Endangered (P—"En Peligro de extinción"), Threatened (A—"Amenazadas"), and Subject to special protection (Pr—"Sujetas a protección especial"). The jaguar is listed as Endangered on this list.

In Mexico, although jaguars are protected by federal law, poaching continues and legal action is rarely taken against hunters (Núñez-Pérez, pers. comm. 2011). Illegal hunting may be punished with a fine of up to about $500,000 (U.S.) or three years in prison, but this has never been enforced (Núñez, pers. comm. 2011).

In 2000, environmental authorities in Mexico (SEMARNAT, Procuraduría Federal de Proteccion del Ambiente (PROFEPA; Federal agency of environmental protection), CONANP) created the "Comites de Vigilancia Ambiental Participativa" (Environmental Surveillance Committees), which are rural community groups responsible for observation and participatory defense of the natural heritage within their communities. These committees are organized, supported, and supervised by Mexican environmental governmental institutions and are qualified to patrol the area. If illegal activity is detected, they must report it to the local, state, or federal authorities (PROFEPA 2002). Since 2005, a number of "special" surveillance committees were created in those areas with jaguar presence in order to protect jaguar populations, prey, and their habitat (Ramírez-Flores and Oropeza-Hernández 2007). Additionally, the Mexican government created 50 groups comprised of local people to protect the jaguar in their communities (CONABIO 2011). During 2012, there were Jaguar Surveillance Committees in all Mexican states with jaguar presence, most of them in Chiapas and Sinaloa (13 and 11 committees, respectively). The NRU states of Sonora, Nayarit, and Jalisco have 8, 3, and 8 committees, respectively (SEMARNAT-PROFEPA 2013).

In July 2014, the ACUERDO por el que se da a conocer la lista de especies y poblaciones prioritarias para la conservación (Priority Species List) of Mexico was published. It is not necessarily a list of species at risk, but rather a list of important species developed to promote efforts to maximize resources in conservation. Species may be considered important because, for example, they require large amounts of intact habitat, are charismatic, or are important to the public. Conservation of these species will enable conservation of many other associated species and biological communities. One of the priority species on this list is the jaguar. The list was created in accordance with the Ley General de Vida Silvestre (LGVS; General Wildlife Law—see below) to promote the development of projects for the conservation and recovery of priority species.

The LGVS (SEMARNAT 2000) has several restrictions that only apply to species at risk (i.e., species listed in the NOM-059-SEMARNAT-2010), depending on their risk status. For example, it has strict provisions on the collection and capture of threatened and endangered species. It also contains general provisions on the sustainable use of wildlife; incentives for land owners; cooperation among federal, state, and municipal governments and private individuals; wildlife diseases; ethical use of wildlife; restrictions on exotic species, wildlife research, and rehabilitation centers; wildlife use by indigenous people; environmental education; species at risk and their critical habitat; reintroduction and translocation protocols; scientific collection permits; control of nuisance species; and law enforcement investigations and citations (Valdez et al. 2006). Additionally, under the LGVS, critical habitat for species at risk can be established. Critical habitat is habitat that requires special management and protection due to its importance to the survival of species at risk.

In addition, Código Penal Federal (Federal Penal Law) includes Artículo 420, which, among other things, assigns a fine and/or prison for illegally trafficking, capturing, transporting, or exporting species at risk (those listed in the NOM-059-SEMARNAT-2010) or species considered in international treaties signed by Mexico (e.g., CITES). Penalties increase in cases involving illegal activities in natural protected areas (e.g., Reserva de la Biosfera El Pinacate).

The Ley General Del Equilibrio Ecológico y Protección al Ambiente (LGEEPA; General Act for Ecological Balance and Protection of the Environment) can protect habitat for jaguars through ecological land zoning, environmental impact assessments, and establishment of natural protected areas. Exploration, extraction, and mining of minerals are among the activities requiring an environmental impact assessment (Szekely et al. 2005). Natural protected areas can be one of eight types: biosphere reserves, national parks, natural monuments, areas for the protection of natural resources, areas for the protection of flora and fauna, sanctuaries, state parks and reserves, and ecological preservation zones in population areas.

A recent federal law, the Ley Federal de Responsabilidad Ambiental (Environmental Responsibility Law), recognizes damages to the environment and charges responsible parties for reparations and compensation of said damages. Its function is to protect, preserve, and restore the environment and ecological equilibrium, and to guarantee human rights to a healthy environment for the development and well-being of people.

Some states in Mexico, like Sonora, also have a law that provides general protection for wildlife, such as the Ley del equilibrio ecológico del estado de Sonora (Law of the Ecological Balance Of the State Of Sonora), which aims to encourage sustainable development and provides some protection of wildlife and habitat.

Laws Protecting Jaguars in the U.S.

In addition to being protected under the ESA (listed as endangered throughout its range), jaguars are also protected by state law in Arizona and New Mexico. As described in Johnson et al. (2011), the Arizona Game and Fish Commission protected the jaguar in 1969, prohibiting take by licensed hunters. Jaguars are now listed as nongame mammals under AGFD Commission Order 14, with no open season for legal take by hunting. Violation of this order is a Class 2 misdemeanor. On May 7, 1998, state legislation (Senate Bill 1106) was signed into law that provides, when the jaguar is delisted federally, for imposing a $2,500 criminal penalty (Class 2 Misdemeanor) and up to $72,500 in civil penalties for unlawful take of a jaguar. The civil fine is commensurate with the current federal fine under the ESA but the criminal penalty is considerably lower than the companion federal fine. The legislature's intent was to ensure that state penalties would not be additive to current federal penalties and could serve as an inducement to federal delisting. Also as described in Johnson et al. (2011), the State of New Mexico classifies the jaguar as a Restricted species (19.33.6.9 NMAC) because of its status as a CITES Appendix 1 species. In 1999, Senate Bill 252 was signed into law, establishing new regulations and penalties for illegally killing a jaguar. The penalties would take effect only if the jaguar was removed from the federal endangered species list. Although this law provided state penalties as high as those for any animal protected by New Mexico, the penalties are not as high as those under the ESA. In the 2006 New Mexico legislative session, House Bill 536 ("Unlawful Trophy Animal Disposition") was passed and signed into law. It allows the New Mexico Game Commission to establish regulations authorizing higher civil damages than previously allowable for wildlife designated as trophy animals and establishes a minimum $2,000 in civil penalties (without requiring removal from ESA listing to take effect). Thus, higher penalties for illegal jaguar killing may be established through Commission action. As of December 2010, no such action had been initiated.

Summary of Factor D

Despite the aforementioned protections, as described below under Factor E, illegal killing of jaguars continues to be a major threat to jaguars south of the U.S.-Mexico border. The U.S. has little authority to implement actions needed to recover species outside its borders, especially when recovery requires the employment of laws and regulations. As described above, in many of the foreign countries in the range of the jaguar, key threats include the killing of jaguars and their prey and destruction of their habitat. The powers that the USFWS can employ in this regard are limited to prohibiting unauthorized importation of listed species into the U.S.; prohibiting persons subject to U.S. jurisdiction from engaging in commercial transportation or sale of listed species in foreign commerce; and assisting foreign entities with education, outreach, and other aspects of conservation through authorities in section 8 of the ESA. The "take" prohibitions of section 9 of the ESA only apply within the U.S., within the territorial seas of the U.S., and on the high seas. They do not apply in the foreign countries where the majority of jaguars are actually found. Section 7 of the ESA, which provides for all Federal agencies to utilize their authorities to carry out programs for the conservation of the species, and to ensure that any action authorized, funded, or carried out by the agency is not likely to jeopardize the continued existence of listed species or adversely modify its critical habitat, is the primary tool within the ESA to address conflict with development or construction. The USFWS has no section 7 authority outside the boundaries of the U.S. Within the U.S., section 7 authority has been waived in specific instances regarding threats to the jaguar and construction of the border fence and roads pursuant to the REAL ID Act (P.L. 109-13; for more details see below in Factor E). Under section 7 of the ESA, incidental take of jaguars has been authorized and no jeopardy opinions have been issued.

1.9.5 Factor E. Other natural or manmade factors affecting its continued existence

Illegal Killing of Jaguars

Illegal killing of jaguars is the other of the two most significant threats to the jaguar (Nowell and Jackson 1996, Medellín et al. 2002, Núñez et al. 2002, Chávez and Ceballos 2006, Medellín 2009) and, to recover jaguars, likely requires the most immediate response. Commercial hunting and trapping of jaguars for their pelts has declined drastically since the mid-1970s, when anti-fur campaigns and CITES controls progressively shut down international markets (Nowell and Jackson 1996). However, although hunting (for pelts) has decreased, there is still demand for jaguar paws, teeth, and other products (Nowell and Jackson 1996, CITES trade database 2014). Additionally, illegal killing of jaguars due to conflicts with humans is a major threat to jaguars. Jaguars are known to kill cattle and are killed by ranchers as pest species (Nowell and Jackson 1996). People compete with jaguars for prey and jaguars are frequently shot on sight, despite protective legislation (Nowell and Jackson 1996). Continuing deforestation in Latin America and fragmentation of forest habitat isolates jaguar populations so that they are more vulnerable to human persecution (Nowell and Jackson 1996). Experts from throughout the jaguar range agree that one of the most severe causes of mortality is the direct hunting of jaguars, either because jaguars have caused some conflict by killing livestock or to sell the jaguar as a trophy or its skin or teeth (Medellín 2009). This illegal and indiscriminate killing eliminates hundreds or even thousands of jaguars each year in Latin America and must be controlled to reduce the risk of extinction (Medellín 2009).

In western Mexico, illegal killing is considered the main threat to jaguars (Núñez-Pérez, pers. comm. 2011). In northwestern Mexico, Rosas-Rosas and Valdez (2010) reported that illegal hunting of jaguars and their potential prey species and habitat fragmentation are probably the main threats to long-term conservation of jaguars in their northernmost western range. According to the 1997 listing rule (U.S. Fish and Wildlife Service 1997), the primary threat to jaguars in the U.S. is illegal shooting (see listing rule for a detailed discussion). This, however, is no longer accurate and the most recent known shooting of a jaguar in Arizona was in 1986 (Brown and Lopez-González 2001).

As described in Carillo et al. (2007), illegal killing increases the risk of extinction of small populations, such as those in Sonora and Jalisco/Nayarit. See section **1.8 Population Modeling** for more details.

Many studies and actions are being taken across the jaguar's range to understand and reduce illegal killing of jaguars (both retaliatory killing due to livestock depredation and killing for trade of jaguar parts). For example, Zimmermann et al. (2005) examined ranchers' attitudes towards jaguars and conservation in the northern Pantanal, Brazil, to identify ways of resolving jaguar-rancher conflict. Their results suggest that most respondents supported the conservation of the Pantanal but that attitudes towards jaguars were mixed and difficult to predict on the basis of socio-economic factors. Attitudes towards jaguars were more closely related to respondents' age (a weak relationship indicated those > 60 years old held more negative views of jaguars than younger respondents) and relative wealth (as represented by a weakly significant negative relationship with cattle density) than to jaguar-related benefits through tourism or costs through cattle predation. They suggest that while efforts to reduce cattle losses are needed, it may be equally as important for conservation initiatives to focus on the inherent appreciation of the natural value of the Pantanal within this ranching community.

In Jalisco, Mexico, Núñez-Perez (2014) conducted interviews to understand the perceptions and attitudes of ranchers towards jaguars. Questions were asked about conflict with jaguars due to depredation, the status of jaguars and their prey, hunting, and attitudes towards jaguar conservation. The majority of those interviewed considered that few cases of livestock depredation by jaguars existed, even though the jaguar was identified as the predator most responsible for attacks. Additionally, ranchers did not consider the jaguar dangerous to humans and agreed with its protection. That said, a strong tradition of persecuting jaguars over other predators exists, but more for cultural reasons (such as the perception of the jaguar as a possible trophy highlighting a person's courage) than due to conflicts with livestock. To promote the jaguar as a charismatic keystone species in the conservation of ecosystems, in 2009, CONANP published the Programa de Acción para la Conservación de Especies (PACE; Species Conservation Action Program) for the jaguar (see *1.10.2 Mexico*, below, for more information). Chapter 5 of this document is related to Culture, including two subsections entitled Environmental Education and Communication and Information specifically highlighting activities needed to address these cultural changes and achieve awareness for the general public.

In the U.S., the University of Arizona, under an Intra-Agency Agreement between USFWS and U.S. Geological Survey, surveyed ranchers in southern Arizona and southwestern New Mexico about their opinions on jaguar issues, wildlife management activities they conduct, and expectations of the impact the designation of critical habitat for the jaguar would have on their ranching operations (University of Arizona 2015). Despite the formal designation of critical habitat by USFWS, 85% of ranchers did not think there is jaguar habitat in Arizona and New Mexico, and, in a reflection of their opinions about critical habitat, most ranchers did not support management of public and private lands for jaguars because they did not believe there is habitat in the region. Overall, ranchers were also more concerned about livestock depredation by pumas than by jaguars, which is likely because many ranchers deal regularly with depredation from pumas, while depredation by jaguars is extremely rare in the U.S. As the most common management practice used to combat livestock depredation is puma hunting, ranchers expressed concern that the critical habitat designation could result in restrictions on puma hunting, and therefore may result in an increase in livestock depredation.

In Mexico, officials have been working to assess and address retaliatory killing of jaguars by ranchers instigated by jaguar predation on livestock. In 2007, a study was conducted to develop a "National Strategy for the Diagnosis and Resolution of Conflicts with Big Cats due to Livestock Predation," which is sponsored by CONANP through the Directorate of Priority Species, and implemented by civil society organizations, researchers, and government institutions. In 2007, an assessment of retaliatory killing in priority areas for jaguar conservation revealed that individual communities were killing up to five jaguars per year (Manríquez Martínez, pers. comm. 2011). It is estimated that 20 jaguars are killed each year in the state of Quintana Roo and at least 15 in Tamaulipas (Azuara et al. 2008). From 2011 to 2013, at least four jaguars were killed by firearms in Quintana Roo, Chiapas, and Nuevo León (Morelos 2012, Aristegui Noticias 2013, Romero 2014); one female died because of a dog pack attack in Sinaloa (Gómez, pers. comm. 2013, as cited by Gutiérrez-González, pers. comm. 2014); one female was poisoned in Sonora (Noticias MVS 2014); and another female was run over by a vehicle in Quintana Roo (López 2014, Mentado 2014). Attempts to sell two more individuals were thwarted by Mexican authorities, who confiscated the jaguars (Excélsior 2013, Proceso.com.mx 2014).

As part of a national compensation program for livestock depredation, from July 2009 to March 2014, ranchers throughout Mexico were compensated through the Livestock Insurance Fund for 1,101 head of cattle attacked by jaguars and pumas. Of these, 493 corresponded to jaguar and 608 to puma attacks (Confederación Nacional de Organizaciones Ganaderas 2013). The number of reported attacks to livestock was greater than those actually compensated.

It is unlikely that this threat will ever be completely eliminated; however, through education, outreach, financial incentive programs, and improved law enforcement, it can be reduced. Significantly reducing this threat is imperative to the recovery of jaguars.

Road Mortality

Roads and associated traffic can detrimentally affect wildlife populations, including increased mortality due to collisions with vehicles (sources as cited in Matthews et al. 2014). Population persistence can be compromised if higher birth rates do not compensate for increased mortality (Fuller 1989, Ferreras et al. 1992, van der Zee et al. 1992, as cited by Matthews et al. 2014). In Jalisco, there is evidence that jaguars have been killed by vehicle collisions (Núñez Pérez, pers. comm. 2015a); in general, more information about this potential threat to jaguars is needed.

Illegal and Legal Overharvesting of Jaguar Prey

The jaguar is classified as "Near Threatened" on the Red List of the IUCN in part due to poaching of prey (Caso et al. 2008). According to experts across the jaguar range, hunting of the most important prey, such as peccaries and deer, is one of the primary factors negatively affecting the jaguar (Medellín 2009). An estimated 27% of jaguar range has a depleted wild prey base (WCS 2008 as cited by Caso et al. 2008). Illegal hunting of potential jaguar prey species is one of the main threats to long-term conservation of jaguars in northwestern Mexico (Rosas-Rosas 2006). Human population growth can put pressure on game populations that are used for human consumption. These same game populations are often prey for jaguars. Furthermore, overhunting of natural prey may cause an increase in jaguar predation on livestock and consequently increase human-jaguar conflicts, including continued negative attitudes toward jaguars and illegal killing of jaguars.

It is unlikely that this threat will ever be completely eliminated; however, through education, outreach, improved law enforcement, and other programs, it can be reduced. Reducing this threat is imperative to the recovery of jaguars.

Border Issues

A number of activities along the U.S.-Mexico border may affect jaguar conservation. Continuing threats from construction and maintenance of border infrastructure (e.g., pedestrian and vehicle fences, towers, roads), as well as illegal activities and resultant law enforcement response (e.g., increased human presence, vehicles, lighting) may limit movement of jaguars at the U.S.-Mexico border (U.S. Fish and Wildlife Service 2007 and 2008).

In 2006, Congress passed the Secure Fence Act (Public Law 109–367), mandating that 700 miles of physical fencing be installed along the U.S.-Mexico border by the end of 2008. The Real ID Act of 2005 also gave the Secretary of the Department of Homeland Security the ability to waive any law or treaty to erect the fence, including environmental laws such as the National Environmental Policy Act, Clean Water and Clean Air Acts, Refuge Improvement Act, Migratory Bird Treaty Act, and ESA. On April 1, 2008, Department of Homeland Security Secretary Michael Chertoff invoked his ability to waive these laws and continued construction without compliance.

The border from the Tohono O'odham Nation, Arizona, to southwestern New Mexico has a mix of pedestrian fence (not permeable to jaguars), vehicle fence (fence designed to prevent vehicle but not pedestrian entry; it is generally permeable enough to allow for the passage of jaguars), legacy (older) pedestrian and vehicle fence, and unfenced segments. Nearly the entire southern border of the Tohono O'odham Nation has vehicle fence. To the east, nearly the entire southern border of the Buenos Aires National Wildlife Refuge has pedestrian fence. From the Buenos

Aires National Wildlife Refuge to Nogales, only a portion of the Coronado National Forest has vehicle fence, the rest is unfenced. Pedestrian fence exists from Nogales east to the boundary of the Coronado National Forest and from Douglas west through the Coronado National Memorial. Most of the Coronado National Forest, which lies between Nogales and Naco, is bordered by vehicle fence, but the steepest areas are unfenced. The San Rafael Valley is bordered by vehicle fence. Vehicle fence also exists from two miles west of the Arizona/New Mexico border west to the terminus of the pedestrian fence on the east side of Douglas. In southwestern New Mexico, the border fence is entirely vehicle fence.

Fences designed to prevent the passage of humans across the border also prevent passage of jaguars. Because jaguars in Arizona and New Mexico are believed to be part of a population centered in northern Mexico, impeding jaguar movement from the Mexico to the U.S. would likely adversely affect the presence and persistence of jaguars in the U.S. Additionally, fences may cause an increase in illegal traffic and subsequent law enforcement activities in areas where no fence exists. This activity may limit jaguar movement across the border and result in general disturbance to jaguars and degradation of their habitat.

Predator Control Programs

Wildlife damage management programs may impact jaguars where these programs are implemented in the jaguar range. In the U.S., the U.S. Department of Agriculture Animal and Plant Health Inspection – Wildlife Services implements a nationwide animal damage control program that may impact jaguars in the southwestern U.S. Although jaguars are not a target of the program, according to the USFWS (1999), jaguars may be incidentally impacted by certain animal damage control methods used in the program (e.g., use of toxic chemicals, leghold traps, snares, dogs). However, incidental take of jaguars resulting from this program is authorized under section 7 of the ESA, and Wildlife Services implements reasonable and prudent measures to minimize any such take (U.S. Fish and Wildlife Service 1999). To date, no incidental take has been documented resulting from Wildlife Service's program. In Mexico, when authorized by SEMARNAT, under certain circumstances, "problem" jaguars may be controlled through translocation or capture and confinement in a zoo (Azuara et al. 2010). Additionally, such an effort would be conducted under the advice of a wildcat expert. Therefore, we do not consider government-authorized predator control programs to be a threat to jaguar recovery in the NRU at this time.

Loss of Genetic Diversity

Little is known about the genetic health of jaguars. However, it has been documented that large-scale habitat removal and fragmentation of once contiguous habitat have caused the reduction of genetic diversity in local jaguar populations, as well as drift-induced differentiation among local fragments. Citing a number of sources, Rabinowitz and Zeller (2010) explain that reduction or loss of genetic exchange leads to smaller effective population sizes, increased levels of genetic drift and inbreeding, and potential deleterious effects on sperm production, mating ability, female fecundity, and juvenile survival. Furthermore, they state that such effects eventually compromise adaptive potential, reduce fitness, and contribute to extinction risk for a population and, ultimately, for the species. Haag et al. (2010) investigating the genetic structure of jaguars in a recently fragmented

Atlantic Forest region to test whether loss of diversity and differentiation among local populations were detectable, and whether they could be attributed to the recent effect of drift. Their results indicated that jaguars' ability to effectively disperse across the human-dominated landscapes that separate the fragments was very limited, and that each fragment contained a small, isolated population that was already suffering from the effects of genetic drift. To ensure genetic health and long-term viability of jaguars rangewide, it is critical to maintain gene flow among populations through maintaining and restoring connectivity (Haag et al. 2010, Rabinowitz and Zeller 2010). Corridors can provide one of the most basic requirements for species persistence-genetic exchange (Rabinowitz and Zeller 2010).

Climate Change

Based on the evidence of warming of the earth's climate from observations of increases in average global air and ocean temperatures, widespread melting of glaciers and polar ice caps, and rising sea levels recorded in the Intergovernmental Panel on Climate Change Report (Intergovernmental Panel on Climate Change (IPCC) 2007, 2014), climate change is now a consideration for Federal agency analysis (Government Accountability Office 2007). Average Northern Hemisphere temperatures from 1983 to 2012 likely represent the warmest 30-year period of the last 1,400 years in this hemisphere, where such assessment is possible (IPCC 2014). The globally averaged combined land and ocean surface temperature data show a warming of 0.85 °C (1.5 ºF) between 1880 and 2012 (IPCC 2014). The earth's surface has warmed by an average of 0.74 ºC (1.3 ºF) during the 20th century and, over the past 50 years, cold days, cold nights, and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent (IPCC 2007).

Changes in the global climate system during the 21st century are predicted to be larger than those observed during the 20th century (IPCC 2007). The IPCC projects heat waves will occur more often and last longer, and extreme precipitation events will become more intense and frequent in many regions (IPCC 2014). For the next two decades, a warming in the range 0.3 °C to 0.7 °C (0.5 °F to 1.26 °F) is projected, with future temperature projections increasingly dependent on specific emission scenarios (IPCC 2014). Various emission scenarios suggest that by the end of the 21st century, average global temperatures are expected to increase 0.3 °C to 4.8 °C (0.5 °F to 8.6 °F) with the greatest warming expected over land (IPCC 2014). Localized projections suggest the southwestern U.S. may experience the greatest temperature increase of any area in the lower 48 states (IPCC 2007). There is also high confidence that many semi-arid areas like the western U.S. will suffer a decrease in water resources due to climate change (IPCC 2007). Currently, southeastern Arizona is experiencing abnormally dry to moderate drought conditions in both the short- and long-term (Arizona Department of Water Resources 2015).

Many species of plants and animals have already shifted their ranges in response to climate change. Although patterns of range shifts vary greatly among species, the dominant direction of movement has been poleward (Parmesan 2006), including northward shifts of several species in the Sky Islands ecoregion of Arizona and New Mexico (Brown and Davis 1994). Although it is too early to tell if the northern edge of jaguar range is expanding poleward, maintaining and enhancing the opportunity for range expansion of jaguars may be a prudent precaution. Apart from monitoring and conserving the opportunity for range expansion, addressing the threat of climate change is generally beyond the scope of jaguar recovery planning and implementation.

We do not know whether the changes that have already occurred have affected jaguar populations or distribution, nor can we predict how the species will adapt to or be affected by the type and degree of climate changes forecast by a range of models. But, ongoing and future changes in climate have the potential to adversely affect the jaguar within the next 50 to 100 years. Stochastic events driven by climate, such as drought and wildfires in jaguar habitat, may affect this species. Monitoring of habitat and populations will be needed to address the potential threat of climate change.

1.10 Conservation Efforts

Throughout its range, the jaguar has a very active conservation constituency and many conservation planning efforts and actions have been taken in numerous countries across its range to address the species' recovery needs. Below is a summary of just some of these efforts.

1.10.1 Rangewide

In March 1999, during a Wildlife Conservation Society sponsored, priority-setting and planning exercise for the jaguar across its range, from northern Mexico to northern Argentina, scientists determined the most important areas for jaguar conservation in each regional habitat type, based on factors important for long-term survival of jaguars (compiled within Sanderson et al. 2002). The authors determined that saving a species means, at least, saving populations of the species in all the significantly different ecological settings in which they occur to capture the array of ecological differences throughout the species' distributional range. They report, for example, that the ecology of jaguars in tropical moist lowland forest is significantly different from that in xeric deserts because of differences in factors such as prey base and habitat use. Similarly, because of regional differences in species composition and geographic factors, the role of jaguars in the tropical moist lowland forests of Central America is substantively different from their role in the tropical moist lowland forests of the southeast Amazon.

As a result of this meeting, ecological differences were represented geographically through Jaguar Geographic Regions (JGRs) or geographic units defined by potential habitat and bioregion across the jaguar's historical range to provide a convenient, ecologically based unit for planning. Codes were assigned to JGRs or divisions of JGRs to reflect the status of jaguars in the areas as: "status unknown"; "no jaguars"; and for areas that were known and currently occupied by jaguars, one of the following three classes was assigned: 1) high, 2) medium, or 3) low probability of long-term survival. As described above in section **1.4 Distribution, Connectivity, Abundance, and Population Trends**, JCUs were defined either as 1) areas with a stable prey community, currently known or believed to contain a population of resident jaguars large enough (at least 50 breeding individuals) to be potentially self-sustaining over the next 100 years, or 2) areas containing fewer jaguars but with adequate habitat and a stable, diverse prey base, such that jaguar populations in the area could increase if threats were alleviated. Based on present jaguar population size, prey base, and habitat quality in specific areas, 51 areas were identified as being important to the long-term survival of jaguars. By definition, each JCU represents a core population of jaguars on which conservation might be based. In 2006, Sanderson et al.'s (2002) work was updated by Zeller (2007) to include 90 Jaguar Conservation Units.

In November 2009, another workshop titled "The Jaguar in the XXI Century: The Continental Perspective" was conducted to discuss the conservation status of the jaguar rangewide. The most urgent conservation strategies were defined. Experts concluded that the jaguar's extinction can be avoided only with the commitment of all the governments of the countries and regions where the species exists. They called on the entire population of Latin America to join efforts to conserve the jaguar through reporting and preventing the indiscriminate killing of jaguars and their prey and promoting the message of the importance of jaguars as a keystone species and symbol of strength, pride, and power of all the peoples of America (Medellín 2009).

Panthera, an organization with a mission to "ensure the future of wild cats through scientific leadership and global conservation action," has launched a Jaguar Corridor Initiative (http://www.panthera.org/node/27). It plans to use a rangewide approach and a targeted set of activities, in partnership with local communities, governments, and other conservation organizations, to conserve jaguar populations and allow their safe passage from Mexico to Argentina.

The Wildlife Conservation Society, with financial support from the U.S. Agency for International Development, joined in 1990 with the governments and conservationists of Central America to establish an initiative called Paseo Pantera, or Path of the Panther (http://www.wcs.org/saving-wildlife/big-cats/jaguar.aspx). The proposal called for the designation of biological corridors to connect the relatively small jaguar protection areas. The concept was adopted by all seven countries of Central America.

During 2009, the International Jaguar Symposium was part of the WILD Foundation's 9th World Wilderness Congress. In this meeting, all American countries that participated agreed that it is a priority to diminish illegal jaguar hunting for the species to persist (Castaño-Uribe et al. 2013). In the same year, Mexico, Guatemala, and Belize met in a reunion of the "Trilateral Initiative for Jaguar Without Frontiers." The purpose of the meeting was to implement strategies for: 1) the management of natural protected areas that includes the prevention of wildfires, illegal logging, and illegal wildlife trade; 2) planning zoning for future building and investigating the restoration of habitat connectivity; 3) biological research of the jaguar and its habitat; and 4) jaguar-livestock conflict attention (SEMARNAT 2010).

Paraguay, Brazil, and Argentina share the Atlantic Forest Biodiversity Vision. This objective of this strategy is to protect wildlife in areas without human influence to preserve the biodiversity of the region. The jaguar is one of the focal species included in this conservation vision (Di Bitetti et al. 2003).

The USFWS's Wildlife Without Borders Latin American and the Carribean program funds jaguar conservation projects throughout Central America and the Carribean. From 2010 through 2014, 10 jaguar-related projects were funded in Belize, Columbia, Costa Rica, Guatemala, Honduras, and Paraguay for a total of 434,628 U.S. dollars (project summaries listed at http://www.fws.gov/international/wildlife-without-borders/latin-america-and-the-caribbean/).

For a summary of some conservation efforts in countries throughout the PARU, please see Appendix A.

1.10.2 Mexico

Mexico considers the jaguar an endangered species (SEMARNAT 2010) and a national priority species for conservation (Ramírez-Flores and Oropeza-Huerta 2007) and, as a result, has carried out many planning and conservation-related actions for jaguars on a national level.
Within the NRU in Mexico, there are at least 17 federally-recognized protected areas that provide for the conservation of the jaguar (CONANP 2014), including: Área de Protección de Flora y Fauna Tutuaca, Área de Protección de Flora y Fauna Papigochic, and Reserva de la Biosfera Janos in Chihuahua; Área de Protección de Flora y Fauna Campo Verde in Sonora and Chihuahua; Reserva Forestal Nacional y Refugio de Fauna Silvestre Ajos-Bavispe and Área de Protección de Flora y Fauna Sierra de Alamos-Rio Cuchujaqui in Sonora; Área de Protección de Flora y Fauna Meseta de Cacaxtla, Santuario Playa Ceuta, and Santuario Playa el Verde Camacho in Sinaloa; Reserva de la Biosfera Marismas Nacionales and Cuenca Alimentadora del Distrito de Riego 043 in Nayarit; Reserva de la Biosfera Chamela-Cuixmala, Santuario Playa Teopa, Santuario Playa Cuitzmala, Santuario Playa Tecuan, and Santuario Playa Mismalaya in Jalisco; and Reserva de la Biosfera Sierra de Manantlán in Jalisco and Colima. The Reserva Forestal Nacional y Refugio de Fauna Silvestre Ajos-Bavispe occurs within the Borderlands Secondary Area in Mexico.

There are also several state natural protected areas: Mesa del Campanero, El Vaso de la Presa, Arivechi-Las Conchas, and Ciénega de Sarachi in Sonora; La Chara Pinta in Sinaloa; and Reserva Ecológica Sierra de San Juan and Sierra de Vallejo in Nayarit. Additionally, there are two municipally-protected areas in Jalisco, including Estero El Salado and Parque Municipal Petrificado Malpais. The Northern Jaguar Reserve, Rancho el Aribabi, and Sierra San Bernardino are private protected areas that also contribute to jaguar conservation in Sonora (López González, pers. comm. 2014b).

There is a proposal for the creation of three new federally protected areas in the NRU. The proposal is under public review before it can be established as a reserve: Área Natural Protegida "Monte Mojino" in Sinaloa (Guido-Sánchez et al. 2010), Área de Protección de Recursos Naturales "Sierra de Vallejo-Río Ameca" in Jalisco and Nayarit, and Área de Protección de Flora y Fauna Sierra Huérfana in Sonora (CONANP 2012a and 2012b).

In 2005, Chinantec communities in Oaxaca decided to protect their communal lands (at least 80% of their territory) as conservation areas with the objective to forbid the hunting of red brocket deer (*Mazama americana*), as well as other jaguar prey species, unless they become pests in agricultural areas. The statutes also ban the killing of jaguars but do not specifically prohibit retaliatory killings for livestock depredation (Durán et al. 2010).

In 1999, SEMARNAT (previously the Secretaría de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP; Ministry of the Environment, Natural Resources, and Fish)) created a technical jaguar conservation group, similar to a technical group of a recovery team in the U.S., comprised of the experiences wildcat researchers in Mexico. The group recognized that conserving the jaguar throughout Mexico would require a sustained and large-scale effort of diverse governmental and non-governmental groups in Mexico.

In 2005, the Instituto de Ecología de la Universidad Nacional Autónoma de México (Ecology Institute of the National Autonomous University of Mexico), with the support of the CONANP, sponsored its first national symposium on jaguar conservation, El Jaguar Mexicano en el Siglo XXI: Situación Actual y Manejo (Chávez and Ceballos 2006). The current status of the jaguar in Mexico was assessed and threats to jaguar existence and priority conservation actions at the local, regional, and national scale were determined. Subcommittees were established to work at the local level, including one for the northern jaguar population in Chihuahua and Sonora. At least eight high-priority (priority I) regions for the conservation of jaguar exist in Mexico; the three most northwestern of these regions are northeastern Sonora, Vallejo Mountains (Sierra de Vallejo) in Nayarit (in the 2009 PACE—see below for definition)), this priority I area was renamed to the Corredor Region Occidente (Nayarit, Michoacan, Jalisco)), and the Chamela-Cuixmala Biosphere Reserve (Reserva de la Biosfera Chamela-Cuixmala) in Jalisco (Chávez and Ceballos 2006). All regions, with the exception of two (the ones in Nayarit and Jalisco) are generally large enough to maintain populations of 100 or more animals. Ten priority II areas were documented; the three most northwestern of these regions are Sinaloa, coastal Nayarit, and the Cabo Corrientes region of Jalisco (in the PACE, eight priority II areas were included; the three most northwestern areas, however, remained the same). Some of the priority II areas, like Sinaloa, are large enough to maintain to maintain populations of 100 or more animals. Various priority III areas were also identified (none were named in the northwestern/western Mexico). The need to conduct a population and habitat viability analysis for jaguars in Mexico at a national scale was recognized (Carrillo et al. 2007).

In 2006, a second national symposium was held, the Jaguar Mexicano en el Siglo XXI: Taller de Análisis de la Viabilidad de Poblaciones y del Hábitat (Population and Habitat Viability Workshop). The primary objective of the workshop was to develop an action plan that determines conservation strategies for the jaguar in Mexico (Carrillo et al. 2007). Extinction risk assessments were developed for the life history, population dynamics, ecology, and history of different jaguar populations (the outcome of the assessment for jaguars is described under Listing Factor B above). A third national symposium took place in Cuernavaca, Morelos, in November 2007 (Manríquez Martínez, pers. comm. 2011). Priority sites and the methodology used for the National Jaguar Census were selected. Preliminary results were presented on five pilot projects focused on livestock-jaguar conflicts. National symposia have been conducted on annual basis with varying themes in Mexico, producing various publications (Chávez and Ceballos 2006, Ceballos et al. 2007). For example, in 2010, results from the National Jaguar Census were presented.

In 2006, CONANP's National Technical Consultants Subcommittee for Conservation and Management of the Jaguar published a Proyectos de Recuperación de Especies Prioritarias (PREP; Recovery Projects for Priority Species) for jaguars in Mexico that outlines general conservation guidelines for the jaguar and its habitat (Ramírez-Flores and Oropeza-Huerta 2007). In 2009, CONANP published a PACE for the jaguar (CONANP 2009). PACEs are planning documents that establish the strategies, tools, and actions (i.e., protection, management, research, monitoring, evaluation, etc.) necessary to meet the conservation objectives of each priority species (Ramírez-Flores and Oropeza-Huerta 2007; see Appendix B for an English translation of Mexico's jaguar PACE). Many recovery actions have been accomplished and are currently being implemented under the PACE. Additionally, state-specific jaguar conservation strategies have been completed for Oaxaca, Michoacán, Chiapas, and San Luis Potosí (Ramírez-Flores and Oropeza-Huerta 2007) and drafted, though not finished, for Jalisco and Nayarit (Núñez-Pérez, pers. comm. 2011). None have been completed for Sonora, Chihuahua, or Sinaloa.

A Censo Nacional del Jaguar (CENJAGUAR; National Jaguar Census) in Mexico was started in 2008. The objective of the CENJAGUAR is to estimate the population status of the jaguar (abundance is estimated using camera traps) and its prey in priority conservation areas in Mexico (Chavez et al. 2007). The results serve to determine priority areas for jaguar conservation at the local, regional, and national level (Chavez et al. 2007). The initial study was conducted in 11 regions of high priority for the species over a period of three years, yielding an estimate of about 4,000 jaguars in Mexico, with tropical forest ecosystems being the most densely populated (Hernández et al. 2014).

In 2009, the Group of Experts on Conservation and Sustainable Management of Jaguar and other wild cats proposed jaguar priority conservation areas in 10 states (Campeche, Chiapas, Jalisco, Michoacan, Nayarit, Quintana Roo, Sinaloa, Sonora, Tamaulipas, and Yucatan), thereby increasing areas of eligibility under the Payment for Environmental Services program of PROARBOL (a plan to to combat poverty, restore forest cover, and increase productivity of forests of Mexico), led the Comisión Nacional Forestal (CONAFOR; National Forestry Commission) (Hernández et al. 2014). One such program that has been operating since then provides payments for livestock (sheep, cattle, and goats) that have been attacked by predators, including the jaguar (other predators include the puma, coyote, and Mexican gray wolf). In 2014, a total of 676,325.10 Mexican pesos (~41,255 in U.S. dollars as of this writing) was paid to compensate farmers affected by jaguar depredation on their livestock.

In 2013, CONANP brought together this same group of experts to support the efforts of jaguar photoidentification. These experts elected subregions and areas for a pilot project to monitor jaguars in 2014 (Phase A). Based on the results of this pilot project, a systematic monitoring method will be developed to establish a nationwide baseline during 2015 (Phase B) and 2016 (Phase C), which will provide a platform for integrating information and images (Hernández et al. 2014).

In 2014, a jaguar corridor project for western Mexico was initiated with support from CONANP, initiating actions to identify and promote a jaguar corridor in the states of Nayarit, Jalisco, Colima, and Michaocan (Núñez Pérez 2014).

Many other federally-supported conservation efforts for jaguars in Mexico have been made in the areas of public outreach. 2005 was nationally declared the "Year of the Jaguar." Habitat conservation has grown through the creation of new reserves, as well as incentive programs to conserve jaguar habitat within reserves. Protection has improved through increased vigilance and law enforcement efforts. In Jalisco, Nayarit, Sonora, and Sinaloa, PROFEPA and CONANP, together with a local non-governmental organization, have formed groups of Community Jaguar Rangers with the goal of protecting jaguars and their prey from illegal activities.

International agreements have been developed. Mexico, Belize, and Guatemala signed the "Jaguars without Borders" initiative in 2006. As part of this initiative, a series of trilateral meetings and workshops have been conducted to review progress of direct and indirect conservation actions for the species, including research, environmental education, and habitat conservation in the three countries. As a result of these meetings, authorities now have a better understanding of the challenges to jaguar conservation in the region and a strategy has been developed to conserve jaguars and their habitat in the region. This initiative has been made possible through funding from CONANP and the Inter-American Development Bank, as well as the participation of non-governmental organizations (NGOs); academia; federal, state and municipal governments; and representatives of communities located in the Mayan region of the three countries.

In 2007, the Dirección de Especies Prioritarias (Department of Priority Species) of CONANP created the Programa de Conservación de Especies en Riesgo (PROCER; Conservation Program for Species at Risk), which helps to accomplish PACE objectives. It has four main objectives: 1) species and ecosystem improvement without affecting the welfare of society; 2) to develop alternatives for the production and improvement of regions with a high degree of marginalization (social and economic); 3) conservation of the environment, which must be beneficial to society; and 4) conservation of genetic diversity as a basis for preserving the genetic and food heritage of Mexico. One important aspect for the PROCER project is that it is not limited to natural protected areas. The number of projects and the budget allocated to each one differs by year and region; for example, in 2014, the CONANP funded 18 new jaguar projects for a total budget of more than 11 million Mexican pesos (~855,000 U.S. dollars at the time of writing). Most of the projects have an emphasis on jaguar monitoring, density and abundance estimation, attention to jaguar-livestock conflicts, and workshops with local communities (CONANP 2014).

Local conservation efforts are also being undertaken. Mexican NGO, Naturalia, and U.S. NGO, Northern Jaguar Project (NJP), have worked together for years to conserve jaguars in Sonora. In 2004, Naturalia and the NJP purchased a 4,047-ha (10,000-ac) ranch, Rancho Los Pavos, in northern Sonora for the conservation of jaguars and other species. In 2008, they purchased Rancho Zetasora, a 14,164-ha (35,000-ac) ranch located adjacent to Rancho Los Pavos for the purpose of jaguar conservation. In 2011, a third purchase of two ranches took place, Rancho Las Tesotas and Rancho El Carricito of 2,535-ha (6,264-ac). These four ranches are now collectively referred to as the Northern Jaguar Reserve (NJR) and support part of the northernmost breeding population of jaguars. In 2007, Naturalia started a working group with diverse governmental and non-governmental partners, to address conservation concerns of carnivores, particularly felids, in Sonora. Naturalia and NJP developed and implement the Feline Photo Project. Under this project, when a rural landowner participating in the project produces a photograph of a jaguar on his ranch, the landowner will be paid a cash value equal to the long-standing bounty offered locally for dead jaguars. Ten ranch owners near the NJR are enrolled in the project and have signed agreements not to harm wildlife. Their land encompasses a total of 16,592 ha (41,000 ac), effectively increasing the protected area for jaguars.

During field surveys in 1999, scientists of the Wildlife Sciences Department at New Mexico State University found a resident jaguar population in the municipality of Nacori Chico in northeastern Sonora. Cattle ranchers in this area considered jaguars and pumas a threat to livestock and often killed them. However, through meetings with authorities and stakeholders in the area, a plan to conserve jaguars that also met the needs of cattle ranchers was developed. As a result, in January 2003, a 55,000 ha (135,908 ac) Unidad para la Conservación, Manejo y Aprovechamiento Sustentable de la Vida Silvestre (UMA; Wildlife Conservation, Management, and Sustainable Utilization Unit) encompassing 12 cattle ranches was created to compensate and mitigate for occasional jaguar predation on livestock and promote tolerance and conservation of the jaguar. The UMA's collective conservation efforts are designated as the "Programa de Conservacion del Jaguar en la Sierra Alta de Sonora" (Jaguar Conservation Program in the High Sierra of Sonora). The UMA raises compensation and other funds used to further jaguar conservation through managed white-tailed deer trophy hunts designated as "conservation hunts" (Rosas-Rosas and Valdez 2010).

In 2011, Rancho El Aribabi, a ranch owned by the Robles family, was declared a Natural Protected Area, under the category of Voluntary Land Conservation, by CONANP. This ranch, about 48 km (30 mi) southeast of Nogales, Arizona, supports jaguars as well as a host of other endangered and sensitive species. In southern Nayarit, another group, Alianza Jaguar (Jaguar Alliance), has been working to establish the Sierra de Vallejo reserve primarily for jaguar conservation.

The USFWS's Wildlife Without Borders Mexico Program has funded several jaguar conservation projects, including a jaguar camera survey contest along the U.S.-Mexico border designed to conserve jaguars by engaging landowners and ranchers in 2006 (37,371 U.S. dollars) and an environmental education and training project for jaguar conservation in Yucatan that established a field station for jaguar monitoring, trained local people, produced a jaguar recovery/management plan, and created educational material in 2005 (35,000 U.S. dollars). Most recently, a program to strengthen the local capacities of residents of rural and urban areas of the Yucatan Peninsula to conserve the jaguar and its habitat was awarded in 2014 (25,000 U.S. dollars).

<u>Primary Agencies Responsible For Jaguar and Habitat Conservation and Management in Mexico</u>

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT; Federal Ministry of the Environment and Natural Resources)
SEMARNAT is responsible for promoting the protection, restoration, and conservation of ecosystems, natural resources, and environmental goods and services in Mexico. To fulfill this mandate, SEMARNAT and its undersecretaries and decentralized agencies work in four priority areas, including the conservation and sustainable use of ecosystems and their biodiversity. Among other duties, SEMARNAT's various agencies conduct wildlife law enforcement, management, and natural area protection. SEMARNAT was created from the federal Secretaría

de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP; Ministry of the Environment, Natural Resources, and Fish) in 2001.

Dirección General de Vida Silvestre (DGVS; Federal Office of Wildlife)
DGVS, the Federal Office of Wildlife, an agency under SEMARNAT, is responsible for, among other things, approving hunting permits submitted by UMAs; determining extraction quotas; and regulating harvest of wildlife throughout the country. Wildlife regulation and administration was decentralized in the northern Mexican States, including Sonora, meaning that the states now have authority for certain wildlife regulation such as approving some hunting permits submitted by UMAs. DGVS also has responsibility for issuing documents, agreements, permissions, or authorizations for conducting research on wildlife species when it involves managing or manipulating individuals. It also authorizes repopulation, relocation, and reintroduction of wildlife species, as well as permits for endangered species (NOM-059-SEMARNAT-2010).

Procuraduría Federal de Proteccion del Ambiente (PROFEPA; Federal Agency of Environmental Protection)
Wildlife and environmental law enforcement is under the jurisdiction of PROFEPA, which is within SEMARNAT (Valdez et al. 2006). The principal function of PROFEPA, since its creation over 20 years ago, is to oversee the execution of all the legal dispositions, among them the LGVS, protecting the interest of the Nation in regards to the environment, and issuing sanctions to those who violate said legal precepts.

Comisión Nacional de Areas Naturales Protegidas (CONANP; National Commission of Natural Protected Areas)
CONANP is within SEMARNAT and is responsible for the protection, restoration, and sustainable use of natural resources, principally fauna and flora, within Areas Naturales Protegidas (ANPs; Natural Protected Areas) (Valdez et al. 2006). CONANP runs hundreds of conservation areas (176 federal protected areas) totaling more than 24,282,239 ha (60 million ac), or 12% of the country's land (Ring et al. 2012).

Branches of CONANP include, among others:

Especies Prioritarias Para La Conservacion (Priority Species for Conservation) manages the PROCER, which develops and implements recovery programs called PACEs for the 30 at-risk species. The jaguar is a priority species in this program with the PACE: Jaguar.

Areas Naturales Protegidas manages natural areas that are protected, including at least 17 within the NRU (see above).

Secretaría de Agricultura, Ganaderia, Desarrollo Rural, Pesca, y Alimentación (SAGARPA; Federal Ministry of Livestock, Agriculture, Rural Development, Fisheries, and Foods)
SAGARPA is responsible for agricultural, livestock, and fish management throughout the country, including depredation of livestock by wildlife (including the jaguar). SAGARPA is also in charge of zoosanitary and phytosanitary law enforcement and regulation for international movements of wildlife (animal and plants).

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO; National Commission for Knowledge and Use of Biodiversity)
Created in 1992, CONABIO is a permanent, interdepartmental commission. The mission of CONABIO is to promote, coordinate, support, and carry out activities aimed at increasing awareness of biodiversity and its conservation and sustainable use for the benefit of society. This includes educating the public about wildlife, including the jaguar. CONABIO was conceived as an applied research organization, sponsoring basic research that generates and compiles information regarding biodiversity, developing capacity in the area of biodiversity informatics, and to act as a publicly accessible source of information and knowledge.

1.10.3 United States

Federal endangered status was extended to jaguars in the U.S. in 1997. The same year, AGFD and NMDGF entered into the Jaguar Conservation Agreement with other State, local, and Federal cooperators, with voluntary participation by many private individuals, and thereby formed the Jaguar Conservation Team, to contribute to conserving the jaguar in Arizona and New Mexico and to encourage parallel efforts in Mexico. The Jaguar Conservation Agreement provides opportunities and incentives for interested parties to become involved with conservation activities including: collection of biological information (to provide a sound scientific basis for decisions); consideration of relevant cultural, economic, and political factors; design and implementation of a comprehensive approach to conservation (including public education); and monitoring, evaluation, and feedback.

In addition to an over-arching Memorandum of Agreement among the signatories, the Conservation Agreement included a Conservation Assessment. The Conservation Assessment described the status of the jaguar in the U.S. and identified threats to the jaguar in Arizona and New Mexico, and a offered a Conservation Strategy, which focused on reducing or eliminating threats in Arizona and New Mexico that might prevent expansion of the current range and distribution of the jaguar, and thus contribute to recovery of the species (Van Pelt 2006). In 2007, the Memorandum of Agreement was replaced with an updated conservation framework (finalized July 2007) and Memorandum of Understanding (signed on March 22, 2007). The AGFD, NMDGF, and USFWS are the lead agency signatories on these documents, while other Federal and County governmental agencies in Arizona and New Mexico are Cooperator signatories. Additionally, the original Conservation Assessment and Strategy was replaced with a revised Jaguar Conservation Assessment for Jaguars in Arizona, New Mexico, and northwestern Mexico (finalized in January 2011).

The Jaguar Conservation Team has made several conservation-related accomplishments, including: 1) collaboration with Mexico on jaguar conservation; 2) a jaguar-based educational curriculum (in Spanish and English) that meets State and National standards and is in use in area schools; 3) enhanced public awareness of jaguar presence and conservation needs; 4) increased penalties under state law for unlawful killing of jaguars (in Arizona these increased penalties apply only if the jaguar is delisted federally); 5) a jaguar detection project (using still and video "camera traps"); 6) a system for evaluating and archiving sighting reports; 7) GIS-based evaluations of areas and habitats of historical and recent jaguar occurrence in Arizona and New Mexico for delineation of primary emphasis areas in both states for this conservation effort; 8) delineation of research recommendations intended to guide studies and provide the Jaguar Conservation Team with information requisite to science-based conservation efforts; 9) a rural outreach program (see Rinkevich and Bashum 2002 and Warshall and Bless 2003 as cited by Johnson et al. 2011); and 10) regular public forums in Arizona and New Mexico for discussion of jaguar-related issues (Johnson et al. 2011). The Jaguar Conservation Team remains a viable approach to borderlands conservation. Although activity has virtually ceased since February 2009, due to legal and other proceedings revolving around the death of a jaguar (Macho B, captured by an AGFD contractor and subsequently euthanized) in south-central Arizona, the AGFD intends to reconvene the Jaguar Conservation Team in the near future.

In 2010, the USFWS convened the binational JRT to develop a Jaguar Recovery Plan and to guide and implement jaguar recovery (see section **1.1 Introduction and Recovery Planning** for background on the JRT and recovery planning). The JRT has been instrumental in the development of this plan and in implementing jaguar recovery actions, including the projects discussed below and in Table 3.

Several formal consultations (pursuant to section 7 of the ESA) have been completed by the USFWS that analyzed the effects of various actions on jaguars. As a result of these consultations, a number of conservation measures have been identified, including support and funding of jaguar survey, monitoring, and recovery efforts; and closure and restoration of an unauthorized road in jaguar habitat. To implement one of these conservation measures, in 2011, U.S. Customs and Border Protection provided funding to the USFWS to implement jaguar monitoring and recovery efforts in the U.S. to help offset effects of border security activities on the jaguar. A summary of the U.S. Customs and Border Protection-funded projects and their conservation benefit to jaguars is provided in Table 3. Final reports of these projects can be found at https://www.fws.gov/southwest/es/arizona/Jaguar.htm.

In the U.S., regulatory mechanisms, in particular section 7, have been and will continue to be important in maintaining recovery options for jaguars in the U.S. Section 7 allows the USFWS to work with Federal agencies to 1) ensure that their actions do not jeopardize the continued existence of jaguars and 2) incorporate measures into projects that help minimize impacts to jaguars and contribute to their recovery. Because such a small portion of the jaguar's range occurs in the U.S., it is anticipated that recovery of the species will rely primarily on actions that occur outside of the U.S. Activities that may adversely or beneficially affect jaguars in the U.S. are less likely to affect recovery than activities in core areas of their range.

Table 3. Summary of U.S. Customs and Border Protection-funded projects and their conservation benefit to jaguars. NRU = Northwestern Recovery Unit for the jaguar. USFWS = U.S. Fish and Wildlife Service. Final reports of these projects can be found at https://www.fws.gov/southwest/es/arizona/Jaguar.htm.

Project	Final Deliverable(s)	Purpose/Conservation Benefit
Genetics	*Jaguar taxonomy and genetic diversity for southern Arizona, U.S., and Sonora, Mexico*	Investigates unique genetic diversity of jaguars at the northern edge of the range and answers taxonomic question of whether or not northern jaguars are a distinct subspecies

Project	Final Deliverable(s)	Purpose/Conservation Benefit
PVAs	*Population Viability Analysis for the Jaguar (Panthera onca) in the Northwestern Range*	Describes demographic viability of the jaguar metapopulation defined as the NRU
PVAs (cont.)	*Addendum: Population Viability Analysis for the Jaguar (Panthera onca) in the Northwestern Range*	Describes the structure, implementation, and interpretation of a new set of demographic simulations of jaguar population viability in Core Areas of the NRU
Habitat Modeling	*Digital Mapping in Support of Recovery Planning for the Northern Jaguar*	Assisted USFWS in digital mapping aspects of recovery planning for the northern jaguar (habitat models used in population viability analyses, above, and Recovery Outline for the Jaguar)
	Jaguar Habitat Modeling and Database Update	Updates jaguar database with additional observations, conducts analyses of different selections of jaguar observations, produces five revised versions of the habitat model (habitat models used in population viability analyses, above, as well as this Recovery Plan)
	jaguardata.info	Converts jaguar observations database to web-based platform allowing stakeholders, general public, and scientific community to search and access jaguar data; provides an interface for administrators to add, edit, and delete jaguar observations in the NRU
Jaguar Survey and Monitoring (U.S. portion of NRU)	*Jaguar Surveying and Monitoring in the United States: Final Report*	Provides results and analyses of the two-year investigation of jaguars, prey base, and habitat in the U.S. portion of the NRU to inform recovery planning; multiple photos of one jaguar (and three ocelots) provided to USFWS and posted on USFWS Flickr site
Jaguar Survey and Monitoring (Tohono O'odham Nation; TON)	*Jaguar Surveying and Monitoring on the Tohono O'odham Nation*	Provides results and analyses of surveys for jaguars and ocelots on the TON to inform recovery planning
Citizen Science, Education, Outreach, and Grant Writing	*Citizen Science Teams*	Developed and implementing a citizen science program to survey and monitor for jaguars within the U.S. portion of the NRU

Project	**Final Deliverable(s)**	**Purpose/Conservation Benefit**
	K-12 Jaguar Educational Curricula	Developed and implementing formal educational curricula on jaguar and ocelot conservation for different educational levels to promote an understanding of feline conservation
Citizen Science, Education, Outreach, and Grant Writing (cont.)	*Jaguar Conservation Outreach*	Developed and presented a PowerPoint presentation on jaguar and ocelot biology and conservation for the general public to promote an understanding of feline conservation
	Education and Outreach Materials	Developed posters, stickers, etc. to promote jaguar conservation within the NRU
	Grant Writing	Applied for funding opportunities to continue aspects of jaguar survey and monitoring effort currently being conducted, to continue and/or expand the volunteer citizen science program, and to continue and/or expand public outreach and school education programs
Rancher Incentive Program	*Complete Project Overview*	See http://udallcenter.arizona.edu/jaguarproject/ for project summary, additional information, and reports
	Assessment of Rancher Knowledge	Pilot assessment of nine ranch owner/manager's knowledge of jaguar conservation issues
	Ranch Owner/Manager Survey Questionnaire	Survey of ranch owner/manager knowledge about and attitudes toward jaguar conservation issues
	Results of Ranch Owner/Manager Survey Questionnaire	Summary of survey results included in Results of Rancher Workshops report (below); comprehensive analysis of data still to be published
	Report on PES sources	Conducted research policy analysis of payment for ecosystem services (PES) program and analysis of jaguar-friendly ranch management options for distribution; available at http://extension.arizona.edu/pubs/payments-ecosystem-services-southern-arizona-ranchers
	Rancher Workshops	Developed workshops to enhance rancher knowledge of jaguar conservation, jaguar friendly ranch management practices, and conservation incentive programs; as well as receive feedback from ranchers regarding incentive programs that may generate participation

Project	Final Deliverable(s)	Purpose/Conservation Benefit
	Brochures	Provides a simple program of actions for landowners to implement for promoting jaguar conservation on their lands
Survey of Residents' Attitudes on Jaguar Conservation	*Results of Survey of Residents' Attitudes on Jaguar Conservation*	Provides insights into attitudes, mores, and level of knowledge of stakeholders in the U.S. portion of the NRU regarding jaguars to understand what is needed from a social perspective to create an environment that is conducive to jaguar conservation
Jaguar Survey and Monitoring Protocol	*Review of Jaguar Survey and Monitoring Techniques and Methodologies* (English and Spanish)	Provides a review of literature on jaguar and, as appropriate, other large felid survey and monitoring techniques and methodologies
	Jaguar Survey and Monitoring Protocol (English and Spanish)	Provides a jaguar survey and monitoring protocol applicable in measuring occupancy recovery criteria (3.3.1.B.i. and 3.3.2.B.i.) in the NRU, as well as other areas rangewide
Review and Develop Recommendations for Road Crossing Designs	*Review of Road Passage Designs for Jaguars*	Conducts a review of enhancements (e.g., underpasses, overpasses, guiding fences, etc.) that allow for passage of large carnivores, particularly jaguars, across road corridors
	Road Passage Design Recommendations (English and Spanish)	Develops recommendations for enhancements (e.g., underpasses, overpasses, guiding fences, etc.) that allow for passage of jaguars across road corridors that would be effective in a variety of different habitat types in the NRU
	Road Passage Location Recommendations (English and Spanish)	Identifies potential areas in the NRU where enhancements (e.g., underpasses, overpasses, guiding fences, etc.) would improve the passage of jaguars across different types of road corridors that would be effective in a variety of different habitat types

1.11 Biological Constraints and Needs

In addition to the numerous anthropogenic threats affecting jaguars, the species has a number of intrinsic biological factors that limit its recovery, including being a K-selected species (a species with delayed maturity, large body size, high investment in individual maintenance at the cost of a low reproductive effort, low fecundity with a large investment in each offspring, and longer life span; Reznick et al. 2002) and having large spatial requirements.

Small and isolated jaguar populations do not appear to be highly persistent (Haag et al. 2010, Rabinowitz and Zeller 2010). However, persistence of relatively small populations appears to increase with connectivity to other populations and reduction of threats within a corridor (Rabinowitz and Zeller 2010). The prospects for the jaguar being self-sustaining in the wild are favorable; however, conservation of key jaguar habitats and populations, and connectivity between them, is critical to this sustainability.

Jaguars require sufficient prey and when prey is overharvested, jaguars may turn to livestock to meet their dietary needs. Therefore, ensuring a sufficient prey base through proper prey management is necessary to sustain jaguars and decrease jaguar livestock depredation that can lead to retaliatory killing of jaguars.

The jaguar, as a large carnivore, is more vulnerable to extinction than many other land mammals. Loss of habitat, direct killing of jaguars, and depletion of prey are the primary factors contributing to its current status, considered to be trending toward Vulnerable (IUCN category) (Quigley, pers. comm. 2016). The legal protected status in range countries does not appear to have secured jaguars in their core or corridor areas, although it likely has aided in increased awareness and reduced direct killing in some areas. For instance, in Costa Rica and Columbia not only has it become socially unacceptable to kill jaguars, it has even been proposed in Costa Rica that jaguars become part of the government payment for environmental services (Quigley, pers. comm. 2016). In terms of habitat protection, the enforcement of habitat protection laws in some countries, such as Belize and Brazil, have had additional positive impacts, as opposed to Uruguay and El Salvador, where most habitat has been eliminated and jaguars are now extirpated (Quigley, pers. comm. 2016). Ultimately, the long-term recovery needs for the jaguar throughout its range focus on the stabilization of core area populations, the expansion of the core areas, and the maintenance of secondary areas that provide connectivity between core areas and that could allow for range expansion and genetic exchange. Conservation of jaguars might be enhanced through natural expansion into previously occupied areas, given the negative effects of habitat fragmentation and the unknown effects of climate change.

1.12 Jaguar As an Umbrella Species

According to Mexico’s jaguar PACE, jaguars are the biggest predators in the Neotropics, and therefore play a major ecological role in affecting the population densities of its prey (Medellín et al. 2002, Tewes and Schmidly 1987, as cited in the PACE). The jaguar is an important element in the ecosystem because it is a keystone, flagship, and umbrella species (Miller et al. 1999). This species is considered the cornerstone for conservation planning at regional and country levels because it is a charismatic top carnivore, has a wide distribution, requires extensive areas for survival, and inhabits a huge variety of ecosystems (Miller et al. 1999, Ceballos et al. 2002, Medellín et al. 2002).

Also according to the PACE, one of the most important, yet often ignored factors for the loss of jaguar populations is the lack of recognition of the ecological role that this species meets in the ecosystem and hence the social benefit that can be generated through its role as a flagship and umbrella species (Miller and Rabinowitz 2002). Unfortunately in many places it is still considered simply as a dangerous animal. As outlined in the PACE, strategies that promote social participation as one of the key strategies aimed at the conservation and protection of the populations of the jaguar as an umbrella species are important. Conservation of large landscapes and corridors that connect them is critical to conservation of umbrella species, including the jaguar. Conservation plans designed to sustain viable populations of jaguars by considering the species as an umbrella species promote the biodiversity within large regions of the jaguar's range. An example of this is the Biodiversity Vision for the Upper Paraná Atlantic Forest of Brazil and Paraguay (De Angelo et al. 2013).

PART 2: RECOVERY STRATEGY

The recovery goal, as detailed below, is to ultimately delist the jaguar. To achieve that goal, viable jaguar populations should be secured throughout their range by removing, reducing, and mitigating the primary threats to the jaguar (habitat loss and fragmentation, illegal killing, and unsustainable depletion of jaguar prey resources). This will require protecting jaguar habitat quantity, quality, and connectivity; providing incentives to protect jaguars and their habitat; reducing human-caused mortality of jaguars, particularly retaliatory killing due to livestock depredation; improving, enacting, and/or enforcing effective laws that regulate illegal killing of jaguars, jaguar prey, and habitat loss; securing adequate funding to implement recovery actions; and maintaining and developing partnerships in the Americas, particularly in Mexico. These protections are needed and must remain in place after delisting to ensure the long-term viability of the species. Due to past habitat loss, it is unlikely that jaguars will be fully self-sustaining throughout their historical range; however, conservation of key jaguar habitat (including core and secondary areas) and populations will be critical to the recovery of jaguars. Successful recovery may include restoration of some historical habitats, which could facilitate expansion of the current jaguar range; however, a substantial increase in the number of jaguar populations is not anticipated.

Our criteria embrace the USFWS Recovery Planning Guidance (National Marine Fisheries Service 2010) (sections 5.1-16) that indicates criteria should provide *representation* (conserving the breadth of genetic makeup and adaptive capability), *resiliency* (each population large enough to withstand stochastic events), and *redundancy* (enough populations to ensure a margin of safety). Following Redford et al. (2011) we believe recovery will have occurred for the species if there are "multiple populations across the range of the species in representative ecological settings, with replicate populations in each setting. These populations should be self-sustaining demographically and ecologically, healthy, and genetically robust—and therefore resilient to climate and other environmental changes." Following Sanderson et al. (2000) and Zeller et al. (2007), we accept that, because jaguars still have such a large geographic range, "across the range" can exclude some portions of their historical range from which jaguars have been extirpated. However, resilience to climate change means that populations, especially peripheral populations like those in the NRU, should have the potential for range shift.

While the recovery plan and strategy consider the jaguar throughout its range, the USFWS and JRT focus the details of this recovery plan on the NRU. We recognize the conservation needs and challenges facing the jaguar elsewhere in its range (i.e., throughout the PARU), but there are compelling circumstances that dictate this focus. The USFWS has little authority to implement actions needed to recover species outside the U.S. borders. The management and recovery of listed species outside of U.S. borders, including the jaguar, are primarily the responsibility of the countries in which the species occur, with the help, as appropriate, of available technical and monetary assistance from the U.S. Thus, it is appropriate to focus our efforts and resources on conservation of the jaguar in the northwestern part of its range (NRU) as our contribution toward an international effort to conserve and recover the jaguar rangewide. The USFWS and JRT acknowledge the significant contribution Mexico has made to the conservation of jaguars, and because a major portion of the NRU is within Mexico, we will work with Mexico to ensure coordination in jaguar recovery.

Therefore, this Jaguar Recovery Plan aims to:

1) Incorporate the important biodiversity principles of representation, resiliency and redundancy (Shaffer and Stein 2000) as summarized below:
    a. species representation, by conserving the breadth of ecological settings in which jaguar populations occur;
    b. redundancy, by retaining a sufficient number of populations to provide a margin of safety to withstand catastrophic events; and
    c. resiliency, by maintaining sufficient numbers of animals in subpopulations to withstand fluctuations due to randomly occurring events.

2) Summarize what is known about the status of the jaguar throughout its range, and identify primary information gaps and broad actions necessary to address conservation of the species outside of the U.S. and northwestern/western Mexico (i.e., within the PARU).

3) To address in significant detail the actions necessary to conserve jaguars in the northwestern portion of their range (i.e., within the NRU).

2.1 Recovery Units

In recognition of the international distribution of the jaguar, and the unique challenges and opportunities this presents, two recovery units have been designated that encompass the range of the species. These units are defined and described below.

Recovery units are subunits of the listed species that are geographically or otherwise identifiable and essential to the recovery of the species. Recovery units are individually necessary to conserve genetic robustness, demographic robustness, important life history stages, or some other feature necessary for long-term sustainability of the species. Each designated recovery unit is critical to recovering the jaguar throughout its entire current range. Establishing recovery units is a useful tool for species occurring across wide ranges with multiple populations, varying ecological pressures, or different threats in different parts of their range. Recovery units are primarily delineated on a biological basis; however, boundaries may be modified to reflect differing management regimes. Recovery units are not necessarily self-sustaining viable units on their own, but instead need to be collectively recovered to ensure recovery of the entire listed entity.

2.1.1 Northwestern Recovery Unit

The NRU extends from south-central Arizona and extreme southwestern New Mexico, U.S., south to Colima, Mexico, (Figure 1) and is approximately 226,826 km^2 (87,578 mi^2); with 29,021 km^2 (11,205 mi^2) in the U.S. and 197,805 km^2 (76,373 mi^2) in Mexico (Table 4). The estimated area of jaguar habitat within the NRU is 170,854 km^2 (65,967 mi^2; Table 4) (see section 1.6.1 Habitat Modeling above for further explanation about how the NRU boundaries and jaguar habitat within them were mapped). The NRU is a logical recovery unit because: 1) it includes two core areas (see definition above) and two of the highest priority Jaguar Conservation Units (Rabinowitz and Zeller 2010); 2) it has distinct ecological conditions (e.g., xeric habitat) that occur nowhere else in the species' range (Sanderson et al. 2002) and thus provides species representation across the breadth of ecological settings in which jaguar populations occur; 3) peripheral populations such as these are important genetic resources (Culver and Ochoa Hein 2013); and 4) peripheral populations may be beneficial to the protection of evolutionary processes and the environmental systems that are likely to generate future evolutionary diversity (Lesica and Allendorf 1995). This may be particularly important considering the potential threats of global climate change.

Table 4. Northwestern Recovery Unit Area size and estimate of jaguar habitat within each Area.

NRU Area	**Area Size**		**Estimate of Jaguar Habitat within Area**	
	km^2	**mi^2**	**km^2**	**mi^2**
Jalisco Core Area	54,949	21,216	44,460	17,166
Sinaloa Secondary Area	31,191	12,043	28,723	11,090
Sonora Core Area	77,710	30,004	67,931	26,228
Borderlands Secondary Area – Mexico portion	33,955	13,110	22,901	8,842
Borderlands Secondary Area – U.S. portion	29,021	11,205	6,839	2,641
Total	226,826	87,578	170,854	65,967

As described in section **1.4 Distribution, Connectivity, Abundance, and Population Trends** above, in the NRU, jaguars currently occur from the border of Colima and Jalisco north through Nayarit, Sinaloa, southwestern Chihuahua, Sonora, and southeastern Arizona. There are breeding populations in Sonora, Sinaloa, Nayarit, and Jalisco. Just south of the southern boundary of the NRU, jaguars may occur in very low densities. Colima has not had any verified jaguar sightings for more than 50 years (López González, pers. comm. 2011a), although credible jaguar reports from the state have been reported in the last decade, mainly near the border with Jalisco (Núñez, pers. comm. 2011), including a jaguar that was killed in 2015 (Núñez, pers. comm. 2015b). No jaguars have been documented in the northern part of the state of Michoacán for more than 50 years; however, jaguars have been confirmed in the last couple of years along the central coast of Michoacán (Charre-Medellín 2013). Although historically jaguars were present in the region, current habitat conditions (such as extensive agricultural development and a highway) in the Jalisco/Colima border area are likely not suitable to support a jaguar population, but may provide connectivity between the NRU and small extant populations in Guerrero, Oaxaca, and Chiapas. This may allow limited passage of individual jaguars between the NRU and remaining jaguar populations along the Pacific coast of Mexico into Central America. In reference to the eastern boundary of the NRU, there is no verified connectivity between the Sierra Madre Occidental and the Sierra Madre Oriental. Rabinowitz and Zeller (2010) hypothesized a potential corridor between these mountain ranges, but it seems unlikely that jaguars would use this corridor as it passes through one of the most arid regions of the Mexican plateau dominated by Chihuahuan desert (see section *1.4.2 Mexico*).

In the U.S. portion of the NRU, including southeastern Arizona and extreme southwestern New Mexico, only male jaguars have been documented since 1950; the last female documented in this area was in 1949 (Brown and López González 2001). No jaguars have been documented north of the NRU in the U.S. since 1963 (Brown and López González 2001, Johnson et al. 2011; note the validity of the 1963 record (a female jaguar killed in the White Mountains of Arizona) has been disputed—see Johnson et al. 2011 for further information). Hatten et al. (2005) hypothesize that current land uses, notably urban expansion around Phoenix and Tucson, mining, and Interstate 10, are limiting jaguar movement into central Arizona. While recent survey and monitoring efforts in south-central and southeastern Arizona and extreme southwestern New Mexico have provided important data, as more information is gathered on the distribution and status of jaguars within the NRU and adjacent areas, the boundaries of the NRU may need to be expanded or reconfigured.

Land Ownership of NRU

Within the U.S., jaguar habitat in the NRU primarily occurs on tribal (Tohono O'odham Nation) lands and federally and state owned lands, including those managed by the U.S. Forest Service (Coronado National Forest), Bureau of Land Management, National Park Service, USFWS, and Arizona State Land Department. The remaining non-state or federal land within the NRU is privately owned.

Within Mexico, jaguar habitat within the NRU primarily occurs on privately-owned, ejido (communal), and indigenous community (e.g., Yaqui) lands. Although there are ANPs designated by CONANP within the NRU, they overlap privately-owned and communal lands. These lands may have multiple uses within them, such as livestock production, agriculture, and human residences. The protected status of these ANPs does not change the land ownership status but instead imposes use restrictions on the lands. At this time, within the NRU in Mexico, there are at least 17 federally-recognized protected areas that provide for the conservation of the jaguar (CONANP 2014) (see subsection *1.10.2 Mexico* for more detailed information on protected areas).

2.1.2 Pan American Recovery Unit

The PARU encompasses 18 countries from Mexico to Argentina and 82 of 84 core areas (modified from Zeller 2007), as well as all potential corridors connecting these areas and the PARU with the NRU (modified from Rabinowitz and Zeller 2010) (Figure 2). The jaguar is thought to be extant (based on expert opinion) in about 11,700,000 km^2 (4,517,395 mi^2), an area encompassing both the PARU and NRU (Zeller 2007). The total area of the 82 JCUs in the PARU is 4,624,885 km^2 (1,785,678 mi^2). The total area of the corridors connecting these JCUs and the PARU to the NRU is 2,120,964 km^2 (818,909 mi^2). Therefore, the estimated size of the PARU (82 JCUs plus the corridors) is 6,745,849 km^2 (2,604,587 mi^2).

Land Ownership of PARU

It is difficult to characterize the land tenure for the entire PARU. However, some general statements do apply. Within this part of the jaguar's range, jaguars occur on all the potential land tenure classes, including state- and federally-managed lands and privately-owned lands. Government-managed lands can vary in the level of protection they provide, providing high levels of protection in some areas; and, at times, and in other locations, providing little protection for jaguar habitat or jaguar prey. Private lands can also vary in their level of protection and value for jaguar conservation; however, in general, and in the long-term, government lands are considered a higher potential for jaguar conservation. This is tempered in some areas where very large tracts of privately-owned land are hospitable to jaguars; here, the regional and local conservation potential is enhanced by these private lands and their management.

2.1.3 Core, Secondary, and Peripheral Areas

Based on examination of historical and recent evidence, and using a format applied in other recovery documents, jaguar habitat and occurrence was categorized as: 1) core areas, 2) secondary areas, and 3) peripheral areas. These areas are categorized within larger units defined as "recovery units." Recovery units are subunits of the listed species that are geographically or otherwise identifiable and essential to the recovery of the species (National Marine Fisheries Service 2010).

Within recovery units, the areas with the strongest long-term evidence of jaguar population persistence are defined as "core areas." Core areas have both persistent verified records of jaguar occurrence over time and recent evidence of reproduction. Two core areas occur within the NRU (see Figure 1 and description below); these areas have been identified by the JRT and are also supported by literature (i.e., Sanderson et al. 2002, Zeller 2007, Rabinowitz and Zeller 2010). Eighty-eight core areas occur in the PARU (see Figure 2 and Sanderson et al. 2002, Rabinowitz and Zeller 2010, and Zeller and Rabinowitz 2011). Successful jaguar conservation efforts in these core areas and corridors will help ensure the continued persistence of jaguars by addressing fundamental principles of conservation biology, such as:

1) species representation, by conserving the breadth of ecological settings in which jaguar populations occur;
2) redundancy, by retaining a sufficient number of populations to provide a margin of safety to withstand catastrophic events; and
3) resiliency, by maintaining sufficient numbers of animals in subpopulations to withstand fluctuations due to randomly occurring events.

Areas classified as "secondary areas" are those that contain jaguar habitat with historical and/or recent records of jaguar presence with no recent record or very few records of reproduction. These secondary areas are of particular interest when they occur between core areas and can be used as transit areas through which dispersing individuals can move, reach adjacent core areas, and potentially breed. Dispersing individuals may also periodically establish residency in secondary areas and become breeders. Jaguars may occur in lower densities in secondary areas because of past control efforts and the area has not been recolonized by jaguars. If future surveys document reproduction in a secondary area, the area could be considered for elevation to core, particularly if the area of reproduction is contiguous with a core area (e.g., one isolated reproductive event in the middle of a secondary area would not necessarily elevate that area to a core); likewise, new information could reduce a secondary area to peripheral status. We hypothesize that secondary areas may contribute to jaguar persistence by providing habitat to support jaguars during dispersal movements, by providing small patches of habitat (perhaps in some cases with a few resident jaguars), and as areas for cyclic expansion and contraction of the core areas. Should the jaguar exhibit poleward expansion in response to changing climate conditions, the role of the U.S. in functioning as a secondary area to accommodate northward dispersing jaguars may become more significant. In "peripheral areas" most historical jaguar records are sporadic and there is no or minimal evidence of long-term presence or reproduction that might indicate colonization or sustained use of these areas by jaguars.

I. Core Area Criteria—By JRT guidelines, a core area for jaguars is an area meeting the following conditions:

- Has reliable evidence of long-term historical and current presence of jaguar populations; jaguar occurrence within a core area has been persistent over time;
- Has recent (within the past 10 years) evidence of reproduction (although reproduction or recruitment into the population may not occur every year); and
- Contains habitat (e.g., suitable vegetation types, adequate prey and water availability) of the quality (e.g., low human density) and quantity (e.g., large tracts of contiguous habitat with connectivity to others areas of contiguous habitat) (see Sanderson and Fisher 2011 and 2013 as described in section *1.6.1. Habitat Modeling*) that are known to support jaguar populations, and of sufficient size to contain at least 50 adult jaguars.

NRU Core Areas (Figure 1):

1) Sonora Core Area (central Sonora, southwestern Chihuahua, and northeastern Sinaloa); and

2) Jalisco Core Area (central Sinaloa, Nayarit, and the coast and coastal mountains of Jalisco).

PARU Core Areas (Figure 2):

The JRT considers the areas known as JCUs (modified from Figure 2 in Rabinowitz and Zeller 2010), excluding those in Sonora and Nayarit/Jalisco, as Core Areas in the PARU.

II. Secondary Area Criteria—By JRT guidelines, a secondary area for jaguars is an area meeting the following conditions:

• Compared to core areas, secondary areas are generally smaller, likely contain fewer jaguars, maintain jaguars at lower densities, and exhibit more sporadic current and historical records of jaguars; some of the secondary areas may not have not been surveyed through the use of defined survey protocols, thus resulting in the unknown current status of jaguars in some secondary areas;
• There is no or little evidence of recent reproduction (within 10 years); and
• Quality and quantity of jaguar habitat is lower compared to core areas. Jaguar habitat is likely less optimal due to one or more or a combination of these variables important for jaguar presence, including increased human impact, smaller amount of contiguous habitat, different vegetation types, lower prey populations.

NRU Secondary Areas (Figure 1):

1) Borderlands Secondary Area (south-central and southeastern Arizona and southwestern New Mexico, U.S., and Northern Sonora; and
2) Sinaloa Secondary Area (northeastern to central-eastern Sinaloa).

PARU Secondary Areas (Figure 2):

In the PARU, distribution of Secondary Areas is extensive. Although an accurate map of Secondary Areas may be available or possible to develop in small regions in the jaguar's range, it is not possible to provide such detail throughout the PARU. For the purposes of this recovery plan, Secondary Areas are the corridor areas of jaguar permeability as modified from Figure 2 of Rabinowitz and Zeller (2010).

III. Peripheral Area Criteria—By JRT guidelines, a peripheral area for jaguars is an area meeting the following conditions:
• Areas that contain few verified historical or recent records of jaguar and records are sporadic;
• Quality and quantity of habitat are marginal for supporting adequate jaguar populations. Habitat may occur in small patches and is not well-connected to larger patches of high-quality habitat; and
• May sustain short-term survival of dispersing jaguars and temporary residents.

Peripheral Areas outside but in the vicinity of the NRU:

In the U.S., generally, California, Arizona (outside of the secondary areas listed above), New Mexico (outside of the secondary areas listed above), Texas, and possibly Louisiana. In Mexico, generally, parts of Chihuahua, Durango, Jalisco, and Zacatecas.

Peripheral Areas within or adjacent to the PARU:

Jaguar peripheral areas within or adjacent to the PARU are those areas included in general range maps, but that are inhospitable to jaguars, rarely having jaguar presence, and almost never supporting resident jaguars in recent times (last 100 years). Examples would be areas of extreme and consistent flooding, extremely dry climates, and high-elevations. Some high mountain passes in the Andes, for instance, may have historical records of jaguars, and dispersers may pass through the low passes periodically, but the presence of jaguars is very rare, and resident jaguars are non-existent. The same would be true of coastal areas of Ecuador and central and northern Argentina.

PART 3: RECOVERY GOAL, OBJECTIVES, AND CRITERIA

3.1. Recovery Goal

The goal for this plan is to conserve and protect the jaguar and its habitat so that its long-term survival is secured and it can be considered for removal from the list of threatened and endangered species (delisted). The JRT estimates that meeting this goal will require 50 years—see explanation in **PART 5: IMPLEMENTATION SCHEDULE**. As a species that is listed throughout its range in 19 countries, the jaguar presents a significant challenge for recovery planning. Knowledge regarding the status of the species in much of its range is limited, and the USFWS and its partners lack the resources and authority to coordinate large scale international research and recovery for the entire species. However, USFWS and JRT can establish the framework to better understand the status and conservation needs of the jaguar for recovery throughout its range. The JRT, supported by Mexico and the USFWS, has established specific criteria for recovery, and actions that, if implemented, will conserve viable jaguar populations in the northwestern portion of their range (i.e., from Arizona and New Mexico south to Colima—see description of the NRU above). The USFWS and JRT will cooperate with partners in the northwestern and western states of Mexico (Sonora, Chihuahua, Durango, Sinaloa, Nayarit, Jalisco, and Colima) to focus efforts within respective jurisdictions to conserve and recover jaguar populations in the northwestern limits of the species' range.

3.2. Recovery Objectives

Recovery objectives collectively describe the specific conditions under which the goals for recovery of the jaguar will be met. These objectives apply to the recovery of the jaguar throughout its range and the five listing factors (see "Reasons for Listing/Threats" for a description of the five Listing Factors):

1) Ascertain the status and conservation needs of the jaguar (Listing Factors A, C, D, E).
2) Assess and maintain or improve genetic fitness, demographic conditions, and the health condition of the jaguar (Listing Factors C, E).
3) Assess and maintain or improve the status of native prey populations (Listing Factors D, E).
4) Assess, protect, and restore quantity, quality, and connectivity of habitat to support viable populations of jaguars (Listing Factors A, D, E).
5) Assess, minimize, and mitigate the effects of expanding human development on jaguar survival and mortality where possible (Listing Factors A, D, E).
6) Minimize direct human-caused mortality of jaguars (Listing Factors D, E).
7) Ensure long-term jaguar conservation through adequate funding, public education and outreach, and partnerships (Listing Factors A, C, D, E).
8) Practice adaptive management in which recovery is monitored and recovery tasks are revised by the USFWS in coordination with the JRT as new information becomes available (Listing Factors A, C, D, E).

3.3. Recovery Criteria

Recovery criteria are the objective, measurable criteria that if met, provide a basis for determining whether a species can be considered for reclassification (downlisting to threatened status, or removing it from the list of threatened and endangered species (delisted)). Because the same five statutory factors must be considered in delisting as in listing, 16 U.S.C. § 1533 (a), (b), (c), the USFWS, in designing objective, measurable criteria, must address each of the five statutory delisting factors and measure whether threats to the jaguar have been ameliorated (see Fund for Animals v. Babbitt, 903 F. Supp. 96 [D.D.C. 1995]).

The recovery criteria in this plan are not binding, and it is important to note that meeting the recovery criteria provided below does not automatically result in downlisting or delisting the species. Downlisting and delisting decisions are under the authority of the USFWS Director and must undergo the rulemaking process and analyses. Both anthropogenic and non-anthropogenic threats to the jaguar must be acceptable in a five-factor analysis and adequate regulatory mechanisms must be in place to ensure that the species will persist into the foreseeable future. The management recommendations in this plan are believed to be necessary and advisable to achieve this goal, but the best scientific information derived from research, management experiments, and monitoring conducted at the appropriate scale and intensity should be used to test this assumption. Even if these criteria are achieved, continued management of the jaguars may be necessary to control the threats that may promote a need for relisting.

As stated in the "Threats Assessment" Section above, Factors A-E, the ESA outlines five factors to consider when a species is a candidate for listing as threatened or endangered. These five factors include the following:

- Factor A. The present or threatened destruction, modification, or curtailment of its habitat or range;
- Factor B. Overutilization for commercial, recreational, scientific, or educational purposes;
- Factor C. Disease or predation;
- Factor D. The inadequacy of existing regulatory mechanisms; and
- Factor E. Other natural or manmade factors affecting its continued existence.

In the criteria below, we address factors A, C, D, and E. We do not address factor B because we are not aware of any current overutilization for commercial, recreational, scientific, or educational purposes.

3.3.1 Downlisting Criteria

The jaguar should be considered for downlisting to threatened when the following criteria are met:

A. PARU

i. The status of the jaguar changes to Least Concern (LC) under the IUCN Red List criteria (as defined by the World Conservation Union, http://www.iucnredlist.org/), which would mean threats have been reduced such that the jaguar population is no longer at risk of a ≥ 30% decline because its area of occupancy, extent of occurrence, and/or habitat quality, as well as actual or potential levels of exploitation, have been stable for at least 15 years (3 generations). (Factors A, C, D, E)

B. NRU

i. Maintain at least 60% occupancy (proportion of cells) in each of the Core Areas over 15 years (3 generations), as described in Appendix C. If baseline surveys reveal that occupancy is higher than 60%, then the higher level will be maintained over 15 years. (Factors A, C, D, E)

ii. Over 15 years (3 generations), genetic distance (e.g., F_{ST} or G_{ST}) between the Sonora and Jalisco Core Areas does not significantly increase, and inbreeding coefficients (e.g., F_{IS} or G_{IS}) within each of the Sonora and Jalisco Core Areas do not significantly increase, as described in Appendix D. (Factors A, D, E)

iii. Over a period of 15 years (3 generations), the average of at least 30% of the adult population within the Sonora and Jalisco Core Areas are female (based on data gathered through surveying, monitoring, genetic analysis, etc.). (Factor E)

iv. Within each Core Area (Sonora and Jalisco), a network of ≥ 100-km^2 blocks (the minimum area capable of supporting at least three breeding females) of high-quality habitat (as described in Appendix E) and habitat connections between blocks has been mapped and conditions in each block and connective area are described based on field visits. (Factor A)

v. Within the Sinaloa Secondary Area, one or more potential linkages between the Jalisco and Sonora Core Areas sufficient to allow natural jaguar dispersal have been mapped based on documented use by jaguars, potential barriers and impediments have been mapped and/or identified based on field visits, and strategies for mitigating these impediments in the corridor have been developed and are being implemented. (Factor A)

vi. Within the Borderlands Secondary Area, two or more non-overlapping potential trans-border linkages sufficient to allow natural jaguar dispersal have been mapped, potential barriers and impediments have been mapped based on field visits, and strategies for mitigating impediments in the corridor are being implemented. Additionally, half of the mapped linkages are clear of impediments and have obtained a sufficient level of protection within the corridor such that jaguar passage is attainable as measured by jaguar movement or other appropriate surrogate species, such as mountain lions. (Factor A, D)

vii. The threat of direct human killing of jaguars is decreased or maintained at sustainable levels as measured by acceptable evidence or an index as described in Appendix F. (Factors D, E)

viii. Effective Federal, State, Tribal, and/or local laws are in place or are being developed in the NRU that ensure that killing of jaguars is prohibited or regulated such that viable populations of jaguars can be maintained, and jaguars are highly unlikely to need to protection of the ESA again. (Factors D, E).

3.3.2 Delisting Criteria

The jaguar should be considered for delisting when all of the above downlisting criteria are met, in addition to the following:

A. PARU

i. The status of the jaguar changes to Least Concern (LC) and maintain the LC status under the IUCN Red List criteria (as defined by the World Conservation Union, http://www.iucnredlist.org) for at least 15 more years after first qualifying for LC, which would mean threats have been reduced such that the jaguar population is no longer at risk of a ≥ 30% decline because its area of occupancy, extent of occurrence, and/or habitat quality, as well as actual or potential levels of exploitation, have been stable for at least 30 years (6 generations, inclusive of the 15 years (3 generations) required to downlist). (Factors A, C, D, E)

B. NRU

i. Maintain at least 60% occupancy (proportion of cells) in each of the Core Areas over 30 years (6 generations, inclusive of the 15 years (3 generations) required to downlist), as described in Appendix C. If baseline surveys reveal that occupancy is higher than 60%, then the higher level will be maintained over 30 years. (Factors A, C, D, E)

ii. Over 30 years (6 generations, inclusive of the 15 years (3 generations) required to downlist), genetic distance (e.g., F_{ST} or G_{ST}) between the Sonora and Jalisco Core Areas does not significantly increase, and inbreeding coefficients (F_{IS} or G_{IS}) within each of the Sonora and Jalisco Core Areas do not significantly increase, as described in Appendix D. (Factor A, D, E)

iii. Over a period of 30 years (6 generations, inclusive of the 15 years (3 generations) required to downlist), the average of at least 30% of the adult population within the Sonora and Jalisco Core Areas are female (based on data gathered through surveying, monitoring, genetic analysis, etc.). (Factor E)

iv. Agency policies and regulations (including transportation), land use regulations, and land owner agreements in Mexico are sufficient to ensure that the network of ≥ 100-km^2 blocks (the minimum area capable of supporting at least three breeding females) of high-quality habitat (as described in Appendix E) and habitat connections between blocks (as described in criterion 3.3.1.B.iv, above) within each Core Area (Sonora and Jalisco) will support genetically and demographically viable jaguar populations for the foreseeable future. Genetic and demographic viability will be demonstrated by meeting criteria i-iii, above. (Factors A, D, E)

v. Agency policies and regulations (including transportation), land use regulations, and land owner agreements in Mexico are sufficient to ensure that landscape permeability will be maintained for jaguars within the Sinaloa Secondary Area (as described in criterion 3.3.1.B.v, above). (Factors A, D, E)

vi. Agency policies and regulations (including transportation), land use regulations, and land owner agreements in the U.S. and Mexico are sufficient to ensure that landscape permeability, including at least two trans-border linkages (as described above in criterion 3.3.1.B.vi, above) will be maintained for jaguars throughout the Borderlands Secondary Area. (Factors A, D, E)

vii. The threat of direct human killing of jaguars is decreased or maintained at sustainable levels as measured by acceptable evidence or an index as described in Appendix F. (Factors D, E)

viii. Effective Federal, State, Tribal, and/or local laws are in place in the NRU that ensure that killing of jaguars is prohibited or regulated such that viable populations of jaguars can be maintained, and jaguars are highly unlikely to need protection of the ESA again. (Factors D, E).

3.3.3 Recovery Criteria with Justifications

Downlisting criteria 3.3.1.A.i:

The status of the jaguar changes to Least Concern (LC) under the IUCN Red List criteria (as defined by the World Conservation Union, http://www.iucnredlist.org), which would mean threats have been reduced such that the jaguar population is no longer at risk of a ≥ 30% decline because its area of occupancy, extent of occurrence, and/or habitat quality, as well as actual or potential levels of exploitation, have been stable for at least 15 years (3 generations). (Factors A, D, E)

Delisting criteria 3.3.2.A.i:

The status of the jaguar changes to Least Concern (LC) and maintain the LC status under the IUCN Red List criteria (as defined by the World Conservation Union, http://www.iucnredlist.org) for at least 15 more years after first qualifying for LC, which would mean threats have been reduced such that the jaguar population is no longer at risk of a ≥ 30% decline because its area of occupancy, extent of occurrence, and/or habitat quality, as well as actual or potential levels of exploitation, have been stable for at least 30 years (6 generations, inclusive of the 15 years (3 generations) required to downlist). (Factors A, D, E)

Justification: Criteria 3.3.1.A.i and 3.3.2.A.i (Listing Factors A, D, and E)

As a global organization, the IUCN helps the world find pragmatic solutions to the most pressing environment and development challenges. Conserving biodiversity is central to the mission of the IUCN, including developing and maintaining a species "Red List," which provides information on the status of wild species, including assessing their risk of extinction. Several categories are used to define risk, including Least Concern (LC), Near Threatened (NT), and Threatened, which is further divided into Vulnerable (VU), Endangered (EN), and Critically Endangered (CE). For more information about these categories, see the IUCN Red List website (http://www.iucnredlist.org/).

Jaguars are currently listed as NT, meaning they are not currently considered Threatened, but if threats continue at the current rate they could likely qualify for VU in the near future. Current levels of habitat loss indicate the species is trending toward Vulnerable (IUCN category); the jaguar's status is currently being reevaluated by the IUCN and a new analysis should be available by the end of 2016 (Quigley, pers. comm. 2016). Specifically, they may qualify for the categories VU A2cd or VU A3cd. These categories are fully described on the IUCN Red List website, but in brief can be explained as:

VU A2cd: a population reduction is observed, estimated, inferred, or suspected of ≥ 30% over 15 years (3 generations of jaguars) based on a decline in the area of occupancy, extent of occurrence, and/or habitat quality, as well as actual or potential levels of exploitation, where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

VU A3cd: a population reduction of ≥ 30% over 15 years (3 generations of jaguars) that is projected or suspected to be met in the future (up to a maximum of 100 years) based on a decline in the area of occupancy, extent of occurrence, and/or habitat quality, as well as actual or potential levels of exploitation.

The criteria used to determine IUCN categories are aimed at detecting symptoms of endangerment rather than causes. Consequently, the criteria are applicable to any process that results in symptoms of threat, such as past and future population decline, small population sizes, and small geographic distributions. Because it is extremely difficult to obtain demographic information about jaguars throughout the PARU, the IUCN uses increases and reductions in threats as surrogates for this information. If demographic information does become available for jaguars in the PARU, it will be incorporated into future drafts of this recovery plan.

Therefore, as the IUCN continues to evaluate the status of the jaguar worldwide, a change from NT to LC would mean the jaguar has not been at risk of becoming Vulnerable (either VU A2cd or VU A3cd) for at least 15 years (3 generations of jaguars). This would indicate that the threats resulting in a potential rangewide reduction of the jaguar population by ≥ 30% (based on area of occupancy, extent of occurrence, habitat quality, and/or exploitation) have been ameliorated, and the jaguar could be considered for downlisting at this point. An additional 15 years (3 more generations) at the LC Red List status would be required before delisting could be considered.

Downlisting criterion 3.3.1.B.i.:

Maintain at least 60% occupancy (proportion of cells) in each of the Core Areas over 15 years (3 generations), as described in Appendix C. If baseline surveys reveal that occupancy is higher than 60%, then the higher level will be maintained over 15 years.

Delisting criterion 3.3.2.B.i:

Maintain at least 60% occupancy (proportion of cells) in each of the Core Areas over 30 years (6 generations, inclusive of the 15 years (3 generations) required to downlist), as described in Appendix C. If baseline surveys reveal that occupancy is higher than 60%, then the higher level will be maintained over 30 years.

Justification: Criteria 3.3.1.B.i and 3.3.2.B.i (Factor E)

Many recovery plans set criteria that are expected to produce less than a specified risk of extinction (usually 1% to 10%) over a specified time period (usually 20-100 years) for each of several populations or subpopulations (usually 1-5), although acceptable risk levels vary for different species. Although the *VORTEX* software (used by our recovery team) can produce estimates of extinction risk, we used this software not to estimate extinction risk but rather to understand what combinations of vital rates, occupied areas, and inter-area dispersal could support a population that produced enough dispersing males to increase the number of jaguars recently observed in southern Arizona and northeastern Sonora. Our *VORTEX* analyses would be too circular (we adjusted unknown vital rates to produce a lambda near 1.0) and too uncertain to generate recovery criteria in terms of population sizes, geographic extent of each population, or number of populations at this time; however, we can use these analyses to understand what the species needs to be viable and move toward recovery. Therefore, we are using occupancy, as described and defined in Appendix C, as a measure of extinction risk rather than the *VORTEX* analyses.

Jaguar populations are decreasing in many areas and their range has diminished (Caso et al. 2008). To ensure representation, resiliency, and redundancy, and ultimately recover jaguars, their populations must remain stable or increase, and the range they occupy must be maintained or expanded. Occupancy of Core Areas will be used as a way to measure this (see Polisar et al. 2014b in Appendix C for the current methods to determine occupancy; this Appendix may be updated based on new methodologies). Additionally, IUCN recommendations will be used for the appropriate timeline over which to measure this (see justification for criteria 1.A.i and 2.A.i above).

We do not currently have baseline occupancy information for these Areas; therefore, we do not know the level of occupancy necessary for jaguars in the NRU. However, Panthera conducted an assessment of a JCU in Brazil (the Atlantic Forest JCU) that they consider to have a less-than-desirable level of occupancy, and found this JCU to have 40% occupancy. Taking this occupancy level into account and considering the NRU is at the edge of the species' range (therefore habitat may be of "poorer" quality than in tropical areas to the south), the JRT Technical Subgroup's expert opinion is that a target of 60% is a reasonable level of occupancy for the Core Areas in the NRU to be considered functional. In addition, as the NRU is at the edge of the jaguar's range, it is unlikely that more than 60% could be occupied (H. Quigley, pers. comm. 2015). While 60% occupancy may seem low, it represents a higher level of occupancy within suitable habitat, as occupancy modeling includes potentially sampling areas of non-habitat as well as habitat. Therefore, 60% represents the JRT's best assessment of the level of occupancy required in Core Areas to maintain a demographically and genetically robust population. After baseline surveys have been conducted, the Technical Subgroup recommends that this topic be revisited and these criteria be reevaluated and discussed.

Downlisting criterion 3.3.1.B.ii:

Over 15 years (3 generations), genetic distance (e.g., F_{ST} or G_{ST}) between the Sonora and Jalisco Core Areas does not significantly increase, and inbreeding coefficients (e.g., F_{IS} or G_{IS}) within each of the Sonora and Jalisco Core Areas do not significantly increase, as described in Appendix D. (Factor E)

Delisting criterion 3.3.2.B.ii:

Over 30 years (6 generations, inclusive of the 15 years (3 generations) required to downlist), genetic distance (e.g., F_{ST} or G_{ST}) between the Sonora and Jalisco Core Areas does not significantly increase, and inbreeding coefficients (e.g., F_{IS} or G_{IS}) within each of the Sonora and Jalisco Core Areas do not significantly increase, as described in Appendix D. (Factor E)

Justification: Criteria 3.3.1.B.ii and 3.3.2.B.ii (Factor E)

As explained in **1.11 Biological Constraints and Needs**, maintaining stable (large) population sizes and connectivity among jaguar populations is essential to the recovery of the species. Small, isolated populations can suffer from the deleterious effects of inbreeding and decreased genetic variation (Mills 2006, Frankham et al. 2007), resulting in loss of genetic representation and resiliency. Maintaining connectivity allows for gene flow and dispersal helps prevent these effects and avoids genetic divergence.

Because most other measures of connectivity, such as tracking jaguar movements and dispersal over long distances, would be logistically difficult and cost prohibitive, genetic distance will be used as a measure of connectivity between jaguar populations in the Sonora and Jalisco Core Areas for these criteria. Based on continuity of jaguar habitat features and known jaguar occurrences, we believe that potential movement within core areas is adequate, and needs only to be maintained. However, we do not know if gene flow currently occurs between the Core Areas. Gene flow is necessary to ensure long-term health and persistence. Therefore, these two Core Areas must remain connected to maintain genetic representation and resiliency and achieve recovery of jaguars in the NRU. No significant increase in genetic distance between these populations, and no significant increase in inbreeding within each population, is acceptable.

The timeframe of 15 and 30 years (three and six generations) was chosen based on criteria used to determine the IUCN NT status of the jaguar (see recovery criteria 1.A.i and 2.A.i). Using currently available genetic markers (e.g., microsatellites), it is unlikely that a change in genetic distance over 15 and 30 years would be detected (assuming all connectivity is lost between the Sonora and Jalisco Core Areas), if jaguar populations in Sonora and Jalisco maintain their current sizes of 300 and 350 individuals, respectively (Miller 2014). However, if either population were to fall much below 100 individuals (reduction in population size in addition to loss of connectivity), then a 15- and 30-year time frame would be responsive to shifts in genetic distance, and would indicate both a loss of connectivity, a reduction in genetic diversity, and a reduction in effective population size, in either or both Core Areas. Additionally, as new genetic technology is developed, the ability to detect subtle changes in the genetic distance between the Sonora and Jalisco Core Areas, due to a loss in connectivity, even if not accompanied by a reduction in population sizes, will likely be possible within a 15- and 30-year time frame. For example, single nucleotide polymorphism (SNP) technology using a SNP chip that includes approximately 10,000 or more markers for the jaguar could likely detect these subtle changes within 15 and 30 years. While SNP chips for the jaguar are not yet available, a jaguar SNP chip is currently in progress as part of the Genome 10K Project (https://genome10k.soe.ucsc.edu). See Appendix D for the protocol to monitor these downlisting and delisting criteria..

Downlisting criterion 3.3.1.B.iii:

Over a period of 15 years (3 generations), the average of at least 30% of the adult population within the Sonora and Jalisco Core Areas are female (based on data gathered through surveying, monitoring, genetic analysis, etc.). (Factor E)

Delisting criterion 3.3.2.B.iii:

Over a period of 30 years (6 generations, inclusive of the 15 years (3 generations) required to downlist), the average of at least 30% of the adult population within the Sonora and Jalisco Core Areas are female (based on data gathered through surveying, monitoring, genetic analysis, etc.). (Factor E)

Justification: Criteria 3.3.1.B.iii and 3.3.2.B.iii (Factor E)

Standard camera-trapping techniques appear to have a bias towards capturing male jaguars as opposed to females (Harmsen et al. 2009). Harmsen et al. (2009) captured 23 individual males during 100 days of camera trapping, but only captured 6 individual females during this same time period. This is likely because male jaguars roam farther and tend to use large pathways more than females, making it more likely they will be picked up using camera trap techniques (which often are located along open pathways to facilitate capturing recognizable photos). However, even when used off trail (such as along small streams, game trails, and landscape features), Harmsen (2006) found that camera trapping did not reveal any habitat characteristics associated with higher capture rates of females (as cited in Harmsen et al. 2009).

Additionally, Technical Subgroup expertise regarding the detectability of female jaguars vs. male jaguars within a population, as well as data from Gutiérrez-González et al. (in review), indicate that an average of 30% females within the adult population demonstrates a stable, reproductively healthy population and is a realistic criterion based on the various techniques used to determine individual jaguars.

Therefore, based on Harmsen et al. (2009, in which 6 of 29 total individuals captured, or 21%, were females), Technical Subgroup expertise, and Gutiérrez-González et al. (in review), a population can be considered stable if at least 30% of the adults, on average, are female. If this average percentage of females is demonstrated over 15 years (3 generations of jaguars), the jaguar can be considered for downlisting. An additional 15 years (30 years total, or 6 generations) is required before the species can be considered for delisting. If less than 30% of adult jaguars are female, researchers should investigate if this is linked to a female-biased mortality factor.

Downlisting criterion 3.3.1.B.iv:

Within each Core Area (Sonora and Jalisco), a network of ≥ 100-km^2 blocks (the minimum area capable of supporting at least three breeding females) of high-quality habitat (as described in Appendix E) and habitat connections between blocks has been mapped and conditions in each block and connective area are described based on field visits. (Factors A)

Delisting criterion 3.3.2.B.iv:

Agency policies and regulations (including transportation), land use regulations, and land owner agreements in Mexico are sufficient to ensure that the network of ≥ 100-km^2 blocks (the minimum area capable of supporting at least three breeding females) of high-quality habitat (as described in Appendix E) and the habitat connections between blocks (as described in criterion 3.3.1.B.iv, above) within each Core Area (Sonora and Jalisco) will support genetically and demographically viable jaguar populations for the foreseeable future. Genetic and demographic viability will be demonstrated by meeting criteria i-iii, above. (Factors A, D)

Justification: Criteria 3.3.1.B.iv and 3.3.2.B.iv (Factor E)

As discussed in section *1.5.3 Genetic Fitness*, to maintain genetically and demographically viable jaguar populations, jaguars require large blocks of quality habitat that are connected to other such areas. The PVA (Miller 2013) concludes that jaguar populations in the Jalisco and Sonora Core Areas can remain demographically viable as long as jaguar dispersal is possible. Maintaining metapopulation dynamics among core populations and secondary areas may be a vitally important component of a successful management strategy for jaguars in the northern part of the species' range (Miller 2014).

Understanding that jaguar habitat is not evenly distributed across Core Areas, it is important to maintain blocks of habitat within which breeding can occur and dispersal can be supported. Based on expert opinion, three breeding females would be the minimum number of females to support a breeding population within each habitat block, as long as connectivity to other habitat blocks is retained to allow for dispersal. Stoner et al. (2015) defined the mimimum size of this block to be 100 km^2, and, using version 13 of the jaguar habitat model developed by Sanderson and Fisher (2013), created a habitat suitability and connectivity model for jaguars in the NRU using circuit theory connectivity modeling. Their model is made up of 42 habitat blocks (including one large block connecting the Sonora and Jalisco Core Areas through the Sinaloa

Secondary Area) and the connections between them, and provides the basis for these recovery critiera (3.3.1.B.iv and 3.3.2.B.iv).

Because these areas have now been mapped, the next step to safeguard a network of blocks of habitat and the connections between them is to verify these areas based on field visits. Then, it is critical to ensure these areas are sufficiently protected to support and maintain genetically and demographically viable jaguar populations such that the occupancy criteria of 60% (3.3.1.B.i and 3.3.2.B.i) are met. The Technical Subgroup recommends revisiting this criterion after baseline occupancy information is acquired.

<u>Downlisting criterion 3.3.1.B.v</u>:

Within the Sinaloa Secondary Area, one or more potential linkages between the Jalisco and Sonora Core Areas sufficient to allow natural jaguar dispersal have been mapped based on documented use by jaguars, potential barriers and impediments have been mapped and/or identified based on field visits, and strategies for mitigating impediments in the corridor have been developed and are being implemented. (Factor A)

<u>Delisting criterion 3.3.2.B.v</u>:

Agency policies and regulations (including transportation), land use regulations, and land owner agreements in Mexico are sufficient to ensure that landscape permeability will be maintained for jaguars within the Sinaloa Secondary Area (as described in criterion 1.B.iii, above). (Factors A, D)

<u>Justification</u>: Criteria 3.3.1.B.v and 3.3.2.B.v (Factor E)

As discussed in section **1.11 Biological Constraints and Needs**, connectivity of jaguar breeding populations is essential for maintaining genetic and demographic viability. Therefore, ensuring connectivity between the Jalisco and Sonora Core Areas is critical to the recovery of the jaguar in the NRU. The PVA (Miller 2013) concludes that jaguar populations in the Jalisco and Sonora Core Areas can remain demographically viable as long as jaguar dispersal is possible. Maintaining metapopulation dynamics among core populations and secondary areas may be a vitally important component of a successful management strategy for jaguars in the northern part of the species' range (Miller 2014). The first step to safeguard habitat connectivity between the Core Areas is to map and field verify this linkage. While more than one linkage may occur, Rabinowitz and Zeller (2010) and Stoner et al. (2015) each modeled a similar northwest-southeast linkage as the primary linkage between the Sonora and Jalisco Core Areas. It is then critical to ensure this linkage is sufficiently protected to allow for continued jaguar movement between the two Core Areas.

<u>Downlisting criteria 3.3.1.B.vi:</u>

Within the Borderlands Secondary Area, two or more non-overlapping potential trans-border linkages sufficient to allow natural jaguar dispersal have been mapped, potential barriers and impediments have been mapped based on field visits, and strategies for mitigating impediments in the corridor are being implemented. Additionally, half of the mapped linkages are clear of impediments and have obtained a sufficient level of protection within the corridor such that jaguar passage is attainable as measured by jaguar movement or other appropriate surrogate species, such as mountain lions. (Factors A, D)

Delisting criteria 3.3.2.B.vi:

Agency policies and regulations (including transportation), land use regulations, and land owner agreements in the U.S. and Mexico are sufficient to ensure that landscape permeability, including two or more trans-border linkages (as described above in criterion 1.B.iv, above) will be maintained for jaguars throughout the Borderlands Secondary Area. (Factors A, D)

Justification: Criteria 3.3.1.B.vi and 3.3.2.B.vi (Factor E)

As discussed in section **1.11 Biological Constraints and Needs**, maintaining connectivity throughout the NRU is essential to recovering jaguars in this unit. It may be possible to recover jaguars in the NRU even if no breeding population occurs in the Borderlands Secondary Area. However, the evolutionary and adaptive capacity of the species may require recolonization of the Borderlands Secondary Area. For example, under some potential future climate conditions, the Borderlands Secondary Area might provide important jaguar habitat.

According to the PVA, maintaining metapopulation dynamics among core populations and secondary areas may be a vitally important component of a successful management strategy for jaguars in the northern part of the species' range (Miller 2014). The Borderlands Secondary Area supports some individuals during dispersal movements, provides patches of habitat, and provides areas for cyclic expansion and contraction of the nearest Core Area and breeding population in the NRU (U.S. Fish and Wildlife Service 2014). Individuals dispersing into the Borderlands Secondary Area are important because they occupy habitat that serves as a buffer to zones of regular reproduction and are potential colonizers of vacant range, thereby maintaining normal demographics, as well as allowing for possible range expansion (U.S. Fish and Wildlife Service 2014). Additionally, populations at the edge of a species' range, such as those in the NRU, play a role in maintaining the total genetic diversity of a species; in some cases, these peripheral populations persist the longest as fragmentation and habitat loss impact the total range (Lomolino and Channell 1995, 1998; Channell and Lomolino 2000). The NRU is essential for the conservation of the species; therefore, consideration of the spatial and biological dynamics that allow this unit to function and that benefit the overall unit is prudent. Providing connectivity between the U.S. and Mexico is a key element to maintaining those processes (U.S. Fish and Wildlife Service 2014). Therefore, trans-border connectivity in the Borderlands Secondary Area is an important component of jaguar recovery in the NRU.

The first step to safeguard trans-border habitat connectivity is to map and field verify these linkages. While more than two linkages may occur, modeling conducted by Stoner et al. (2015) shows two primary corridors (linkages) going from the Sonora Core Area to the U.S. At the U.S.-Mexico border, these corridors then split into three smaller corridors (Figure 4). These linkages need to be field verified and sufficiently protected to allow for continued trans-border jaguar movement.

Downlisting and Delisting criteria 3.3.1.B.vii. and 3.3.2.B.vii.:

The threat of direct human killing of jaguars is decreased or maintained at sustainable levels as measured by acceptable evidence or an index as described in Appendix F. (Factor D)

Justification: Criteria 3.3.1.B.vii and 3.3.2.B.vii (Factor E)

As discussed in section 1.9.5 Factor E, direct human killing of jaguars has been documented as one of the primary threats to jaguars across their range. To recover jaguars, this primary threat will need to be decreased and maintained at a sustainable level (see Appendix F). The PVA (Miller 2013 and 2014) suggests that jaguar populations may be at considerable risk of future population declines if additional mortality occurs from sources such as hunting, particularly if dispersal into these areas is not possible.

Downlisting criterion 3.3.1.B.viii:

Effective Federal, State, Tribal, and/or local laws are in place or are being developed in the NRU that ensure that killing of jaguars is prohibited or regulated such that viable populations of jaguars can be maintained, and jaguars are highly unlikely to need to protection of the ESA again (Factors D, E).

Downlisting criterion 3.3.1.B.viii:

Effective Federal, State, Tribal, and/or local laws are in place in the NRU that ensure that killing of jaguars is prohibited or regulated such that viable populations of jaguars can be maintained, and jaguars are highly unlikely to need to protection of the ESA again (Factors D, E).

Justification: Criteria 3.3.1.B.viii and 3.3.2.B.viii (Factor E)

As stated above and in section *1.9.5 Factor E*, direct human killing of jaguars has been documented as one of the primary threats to jaguars across their range. Ensuring laws are in place would deter illegal killing of jaguars and enable enforcement response if illegal killing occurs.

PART 4: RECOVERY PROGRAM

4.1. Threats Tracking Table

Summary of jaguar listing factors and threats and the recovery actions to control those threats.

<table>
<tr><th>LISTING FACTOR</th><th>THREAT</th><th>RECOVERY CRITERIA</th><th>RECOVERY ACTION NUMBERS (see Section 4.2, below)</th></tr>
<tr><td rowspan="2">A</td><td rowspan="2">Habitat loss, fragmentation, and degradation</td><td rowspan="2">3.3.1.A.i.,
3.3.2.A.i.,
3.3.1.B.iv.,
3.3.2.B.iv.,
3.3.1.B.v.,
3.3.2.B.v.,
3.3.1.B.vi.,
3.3.2.B.vi.</td><td>All of 4. Assess, protect, and restore sufficient quantity, quality, and connectivity of habitat to support viable populations of jaguars.</td></tr>
<tr><td>All of 5. Assess, minimize, and mitigate the effects of expanding human development on jaguar survival and mortality.</td></tr>
<tr><td>B</td><td>Overutilization for Commercial, Recreational, Scientific, Educational Purposes - This is not considered a threat to jaguars in the NRU at this time.</td><td>N/A</td><td>N/A</td></tr>
<tr><td>C</td><td>Disease</td><td>None</td><td>All of 2.5. Evaluate and improve health conditions of jaguar populations.</td></tr>
<tr><td rowspan="3">D</td><td rowspan="3">The inadequacy of existing regulatory mechanisms</td><td rowspan="3">3.3.1.A.i.,
3.3.2.A.i.,
3.3.2.B.iv.,
3.3.2.B.v.,
3.3.2.B.vi.,
3.3.1.B.vii.,
3.3.2.B.vii.,
3.3.1.B.viii.,
3.3.2.B.viii.</td><td>All of 3.4. Assess, evaluate, and implement wildlife management practices and laws that ensure sustainable prey bases for jaguars.</td></tr>
<tr><td>All of 4.2. Protect jaguar habitat and corridors.</td></tr>
<tr><td>All of 5.1. Minimize the impacts of roads on jaguars.</td></tr>
</table>

LISTING FACTOR	THREAT	RECOVERY CRITERIA	RECOVERY ACTION NUMBERS (see Section 4.2, below)
			All of 5.2. Assess, avoid, minimize, and mitigate the impacts of other human development on jaguars (e.g., mines, dams, border infrastructure, housing and urban development, energy projects, railroads, large scale agriculture, etc.).
			All of 6. Minimize direct human-caused mortality of jaguars.
E	**Illegal Killing of Jaguars**	3.3.1.A.i., 3.3.2.A.i., 3.3.1.B.vii., 3.3.2.B.vii., 3.3.1.B.viii., 3.3.2.B.viii.	All of 6. Minimize direct human-caused mortality of jaguars.
E	**Road Mortality**	None	All of 5.1. Minimize the impacts of roads on jaguars.
E	**Illegal and Legal Overhunting of Jaguar Prey**	None	3.1. Develop and conduct a study of jaguar prey abundance.
			All of 3.4. Assess, evaluate, and implement wildlife management practices and laws that ensure sustainable prey bases for jaguars.
E	**Border Issues**	3.3.1.B.vi., 3.3.2.B.vi.	4.1.1.3. Map and field verify a habitat connectivity matrix that provides at least two non-overlapping potential trans-border linkages in the Borderlands Secondary Area in the NRU.
			4.2.3. Ensure that landscape permeability for jaguars, including at least two trans-border linkages, will be maintained throughout the Borderlands Secondary Area.

LISTING FACTOR	THREAT	RECOVERY CRITERIA	RECOVERY ACTION NUMBERS (see Section 4.2, below)
			5.2. Assess, avoid, minimize, and mitigate the impacts of other human development on jaguars (e.g., mines, dams, border infrastructure, housing and urban development, energy projects, railroads, large scale agriculture, etc.).
			7.2.5. Develop and maintain partnerships with agencies, organizations, and citizens to conserve jaguars.
E	**Predator Control Programs -** Government authorized predator control programs are not considered a threat to jaguars in the NRU at this time and the status of these programs is unknown in the PARU.	N/A	N/A
E	**Reduction in Genetic Diversity**	3.3.1.B.ii., 3.3.2.B.ii.	All of 2.1. Assess conservation genetic criteria for jaguars.
			2.5.4. Establish a database of medical and genetic jaguar data.
E	**Climate Change**	None	1.4.4. Conduct a study on the effects of climate change on jaguars and their habitat and develop a strategic adaptation plan.
			3.3. Design and implement a study that would quantify the relationship between jaguars and their prey as it relates to climate change.

Listing Factors:

A. The Present or Threatened Destruction, Modification, or Curtailment Of Its Habitat or Range

B. Overutilization for Commercial, Recreational, Scientific, Educational Purposes (not a factor)

C. Disease or Predation

D. The Inadequacy of Existing Regulatory Mechanisms

E. Other Natural or Manmade Factors Affecting Its Continued Existence

4.2. Recovery Action Outline and Narrative

Underlined recovery actions represent the most stepped-down levels for the recovery program narrative. These items are discrete, specific actions and are the actions listed in the Implementation Schedule found at the end of this document. Rangewide actions would be applied only to the NRU when and where needed and feasible and encouraged where and when appropriate in the PARU. In some recovery actions, the word "tribal" is used; for the purposes of this recovery plan, "tribal" includes tribes and indigenous communities.

In 2009, Mexico developed and is actively implementing the PACE for the jaguar. The USFWS and JRT acknowledge the significant contribution of the PACE to jaguar conservation. See the section **1.10 Conservation Efforts** of this document for a detailed discussion on the Jaguar PACE actions implemented in Mexico. The USFWS and JRT will work with Mexico to ensure coordination in implementing actions from this plan and the PACE; these plans share many of the same recovery actions. See Appendix B for a translated version of the PACE and see http://www.fws.gov/southwest/es/arizona/Jaguar.htm for the original version (Spanish).

* = relate to measuring recovery criteria

1. Ascertain the status and conservation needs of the jaguar.

1.1. Survey and monitor jaguars.

1.1.1. Develop and update a jaguar survey and monitoring protocol.
Developing a single jaguar survey and monitoring protocol is required for assessing occupancy within the NRU and would include: 1) conducting a review of jaguar survey and monitoring techniques and methodologies; and 2) developing a jaguar survey and monitoring protocol for comparison across sites. Polisar et al. (2014a and b) conducted a literature review of jaguar survey and monitoring techniques and developed a jaguar survey and monitoring protocol, including methods for determining occupancy. Research and monitoring techniques are constantly evolving; however, Polisar et al. (2014b) may be considered a current reference and baseline for assessing occupancy across sites (see Appendix C). The survey and monitoring protocol should be updated to incorporate new information, such as technological and analytical advances in survey and monitoring, likely every 5 years.

1.1.2. Conduct jaguar surveys and monitoring in the NRU.

1.1.2.1. Train and equip appropriate groups to conduct jaguar surveys and monitoring.
To survey and monitor jaguars within the NRU, including measuring occupancy, appropriate groups will need to be trained and equipped in jaguar survey and monitoring methods. Equipment needs are discussed in Polisar et al. (2014b) (see Appendix C for equipment needs).

1.1.2.2. Implement the jaguar survey and monitoring protocol developed in 1.1.1. to obtain measures of occupancy in each Core and Secondary Area of the NRU.

To measure jaguar occupancy within the NRU, the jaguar survey and monitoring protocol as described in Polisar et al. (2014b) (Appendix C) will need to be implemented throughout the recovery unit.

1.1.2.3. Calculate and assess occupancy in each Core Area of the NRU using results of the survey and monitoring conducted in 1.1.2.2. (* Recovery Criteria 3.3.1.B.i. and 3.3.2.B.i.)

To assess jaguar occupancy within the NRU, the data collected in the aforementioned action will need to be analyzed using the techniques described in Polisar et al. (2014b) (Appendix C).

1.1.2.4. Assess jaguar use of Secondary Areas. (* Recovery Criteria 3.3.1.B.v., 3.3.1.B.vi., 3.3.2.B.v., and 3.3.2.B.vi.)

Use techniques including, but not limited to, social surveys, genetic sampling, or valid evidence (e.g., Class I, II, and III) to determine passage of jaguars through each Secondary Area.

1.1.2.5. Prepare reports of jaguar survey and monitoring results in the NRU for use in status reviews.

Data collected and assessed from different jaguar survey and monitoring studies, including occupancy analyses, conducted in the NRU will need to be synthesized into a report to assess the overall status of jaguars in the NRU, which will help the FWS and JRT determine if Recovery Criteria 1.B.i and 2.B.i have been met.

1.1.3. Survey and monitor jaguars in the PARU.

1.1.3.1. Assess the status of jaguars in the Sierra Madre Oriental.

More work is needed to understand jaguar status in the Sierra Madre Oriental to determine appropriate recovery actions for the area. This action should include implementing a jaguar survey in the Sierra Madre Oriental and evaluating the results.

1.1.3.2. Compile and evaluate survey data from jaguar populations in the PARU to assess status of the species.

Conducting surveys and monitoring of jaguars throughout the PARU is beyond the scope of this recovery plan; however, the JRT will assist the IUCN to compile and evaluate data on the status of jaguar populations in the PARU. This assessment will occur approximately every 5 years and will help the FWS and JRT in determining when Recovery Criteria 3.3.1.A.i. and 3.3.2.A.i. have been met.

1.1.4. Develop and implement citizen science programs to assess jaguar populations.

Citizen science programs can be helpful for assessing jaguar populations. When properly designed and operated, these programs can be effective at obtaining important data on jaguars and can supplement work done by professional biologists. A citizen science program to survey and monitor jaguars in Arizona is being conducted by the U.S. Geological Survey and University of Arizona. Citizen science programs can be replicated throughout the NRU. It will be important to track how many citizen science programs are implemented in the NRU, as well as their effectiveness at collecting reliable data. Citizen science programs could be integrated into community observer programs (see recovery action 6.5.) or vice versa.

1.1.5. Be prepared for jaguar captures.

1.1.5.1. Identify, compile, and update a jaguar capture and handling protocol.
Jaguar capture and handling techniques are continuously refined and different techniques are used by different groups throughout the range of the jaguar. A protocol that is developed and reviewed by jaguar capture experts would help ensure the most up to date and effective methods are followed and ultimately reduce the inherent capture risks to jaguars and people. The feline-specific protocol developed by Azuara et al. (2010) and general protocols, such as Kreeger et al. (2002), may serve as a foundation for the development of a jaguar-specific protocol.

1.1.5.2. Train and equip people in jaguar capture (both intentional and incidental) and handling techniques.
Where jaguars may be captured and handled, professionals will need to be trained and equipped in jaguar capture and handling techniques.

1.2. Increase collaboration with other carnivore researchers to gather information on jaguars in their study areas.
Researchers conducting studies on carnivores other than jaguars may collect valuable information on jaguars (e.g., they may obtain photos from trail cameras, observe jaguar tracks). It is important to collaborate with these researchers to ensure this valuable jaguar information is shared, including in study areas where no jaguar research is being conducted.

1.3. Develop and maintain jaguar observation report procedures and databases.
These procedures and databases may differ throughout the range of the jaguar, but developing and maintaining standard reporting procedures and databases is important to gathering and maintaining reliable information on jaguars. AGFD follows the criteria used by Tewes and Everette (1986), as shown in Appendix G. This could serve as a template for reporting procedures in other parts of the jaguar's range. Depending on the strength of the evidence provided to AGFD, jaguar sighting are classified as Class I, II, or III detections (Tewes and Everette 1986), with Class I considered the most reliable because physical evidence exists to prove the sighting was a jaguar. The FWS and contractors developed an on-line jaguar observations database that could serve as an example for data organization needs throughout the range of the jaguar (see http://jaguardata.info/).

1.4. Conduct ecological research on jaguars.

1.4.1. Conduct home range, movement, and habitat use studies on jaguars.
Although some studies have provided information on jaguar home range, movement, and habitat use, more studies are needed in variety of habitats and ecological settings to help better manage the species, including identifying key habitat and movement corridors. See Polisar et al. (2014a and b) for a review of jaguar home range, movement, and habitat use studies.

1.4.2. Investigate jaguar dispersal patterns.
Although some studies have provided information on jaguar dispersal patterns, more studies are needed in variety of habitats and ecological settings to help better manage the species, including identifying key habitat and movement corridors. Additionally, this information could be used to inform and update a

revised PVA and protection of priority habitats and corridors. See Polisar et al. (2014b) (Appendix C) for information on studying jaguar dispersal patterns.

1.4.3. Conduct a study to determine the extent to which poaching and depredation loss are compensatory with other types of jaguar mortality.

To better manage and control certain types of human caused mortality, additional studies are needed throughout the jaguar's range to compare (compensatory versus additive) poaching and depredation loss with other types of jaguar mortality. The results of these studies would increase our understanding of the significance of poaching and depredation loss of jaguars as a threat. Additionally, this information could be used to inform and update a revised PVA. See Foster (2014) (Appendix F) for information on monitoring anthropogenic mortality of jaguars.

1.4.4. Conduct a study on the effects of climate change on jaguars and their habitat and develop a strategic adaptation plan.

Climate change may affect jaguars and jaguar habitat in ways currently unknown; therefore to plan for the long-term conservation and recovery of the species, it is imperative to understand the effects that may occur as a result of climate change and plan accordingly.

1.4.5. Identify and conduct other research needed to conserve jaguars.

As important jaguar management and conservation questions arise, research should be conducted to address these.

1.5. Conduct periodic population viability analyses for jaguars as new information is acquired.

The reliability of the results of PVAs depends on the accuracy of the model input parameters. For the Jaguar PVA (Miller 2013 and 2014), some input parameters (e.g., litter size, age of first reproduction, age-specific mortality) were estimated based expert opinion and limited data. As new information is acquired, the PVA should be updated to inform jaguar management and recovery.

2. Assess and maintain or improve genetic fitness, demographic characteristics, and health of the jaguar.

2.1. Assess conservation genetic criteria for jaguars.

2.1.1. Conduct a genetic study to determine present and future levels of genetic variability, genetic distance between Sonora and Jalisco Core Areas, and inbreeding coefficients within the Sonora Core Area and within the Jalisco Core Area. (* Recovery Criteria 3.3.1.B.ii. and 3.3.2.B.ii.)

The genetic study is described in detail in Appendix D.

2.1.2. Monitor connectivity in the PARU through documenting changes in gene flow among JCUs.

Collect DNA samples from 30-40 jaguars per JCU in the PARU from as many JCUs as possible to document current level of gene flow and repeat sampling at reasonable intervals to document changes in connectivity. The FWS and JRT will solicit this information from international partners who are studying the jaguar throughout its range and collectively assess it to monitor connectivity in a similar way as described in Appendix D.

2.1.3. Investigate the need for a captive breeding program for jaguars.

This may include evaluating and assessing the need for a captive breeding program in the unlikely event of a future severe and unexpected population decline. The FWS and JRT will periodically coordinate with the Species Survival Plan Coordinator/International Jaguar Studbook Keeper and IUCN Species Survival Commission for the jaguar to assess this need.

2.2. Investigate the taxonomic status of jaguars.

Some studies of the taxonomic status of jaguars have been conducted (see section **1.3 Evolutionary History, Description, and Taxonomy**); however, molecular systematics should be used to reassess the validity of previously recognized subspecies. Additionally, the Culver and Ochoa Hein (2013) study of the taxonomic status of jaguars in the NRU should be updated with more genetic samples throughout the NRU. The investigation and comparison of the taxonomic status of jaguars between recovery units is also warranted.

2.3. Assess demographic/vital characteristics of jaguars.

2.3.1. Continue and expand studies to obtain more rigorous estimates of age-, gender-, and region-specific vital rates, including year-to-year variation.

Although some studies have provided information on jaguar vital rates, more studies are needed to help better manage the species, including identifying age-, gender-, and region-specific vital rates and year-to-year variation. Additionally, this information could be used to inform and update a revised PVA. Assessing basic vital rates is discussed in Polisar et al. (2014b) (Appendix C).

2.3.2. Analyze data (including survey, monitoring, genetic, etc.) collected on jaguars in the Sonora and Jalisco Core Areas to determine the percentage of adult females. (* Recovery Criteria 3.3.1.B.iii. and 3.3.2.B.iii.)

This analysis is needed as explained in the justification for Recovery Criteria 3.3.1.B.iii. and 3.3.2.B.iii., and to assess the demographic health and viability of jaguar populations.

2.4. Develop estimates of dispersal rates and travel distances through genetic methods within the NRU and neighboring populations.

Although some studies have provided information on jaguar dispersal rates and travel distances within the NRU, none of these studies have used genetic methods to determine this information. Genetic methods can be less invasive than traditional techniques (e.g., telemetry) and can provide information about dispersal rates and travel distances. Additionally, this information could be used to inform and update a revised PVA. Invasive and non-invasive genetic methods are discussed in Polisar et al. 2014b (Appendix C).

2.5. Evaluate and improve health conditions of jaguar populations.

2.5.1. Establish protocols for physiological assessment and treatment of injuries, diseases, and parasites as appropriate.

Protocols for jaguar physiological assessment and treatment of injuries, diseases, and parasites should be compiled, evaluated, and combined to help better manage the species.

2.5.2. Using above protocols, conduct serology and pathology surveys to determine overall health conditions of jaguars.

When an animal is captured for research or incidentally, serology and pathology surveys should be conducted to determine genetic profile, overall condition, and the presence and effect of diseases and parasites. Some of these collections can also be obtained from fresh (less than one day) carcasses.

2.5.3. Provide for storage of biological samples collected from jaguars.
The storage of biological samples has immense value for studying jaguar health and viability. For example, a tissue bank for the jaguar should be established for the purposes of research and education. Additional collections of parasites, disease agents, etc., should be sent to universities, museums, and medical facilities for long-term storage.

2.5.4. Establish a database of medical and genetic jaguar data.
A database of medical and genetic jaguar data should be established so that jaguar researchers may easily access this data and collaborate on medical and genetic studies.

2.5.5. Investigate and implement measures to prevent significant losses due to diseases.
As more is understood about diseases that may impact jaguar populations, measures should be implemented to prevent significant jaguar mortality. The JRT will periodically coordinate with experts in the field, IUCN, and the Association of Zoos and Aquariums to address this action.

3. Assess and maintain or improve the status of native prey populations.

3.1. Develop and conduct a study of jaguar prey abundance.
This may include: 1) developing a standardized survey methodology (e.g., aerial surveys, pellet counts, track or camera surveys) to quantify prey populations; and 2) conducting prey surveys to quantify jaguar prey populations. As discussed in section *1.9.5 Factor E. Other natural or manmade factors affecting its continued existence*, overharvest of jaguar prey in some areas has led to decreased prey availability, which is a threat to jaguars, and can also lead to increased livestock depredation and retaliatory killing of jaguars. Therefore, it is important to quantify prey populations to recover jaguars. An effective survey methodology will allow for the investigation of prey abundance, trends, and availability to determine the prey dynamics that are needed to sustain stable jaguar populations. Using this methodology, surveys of prey abundance, trends, and availability should be conducted.

3.2. Evaluate health conditions of jaguar prey populations, including the effects of diseases.
Diseases and other compromised health conditions can affect jaguar prey populations and, in turn, impact jaguar populations. To identify areas of potential concern (i.e., areas where prey populations are at risk due to poor health and diseases) for jaguars, coordination should be conducted with game agencies and researchers who collect data on health conditions of prey populations.

3.3. Design and implement a study that would quantify the relationship between jaguars and their prey as it relates to climate change.
Climate change may affect jaguars and their prey in a variety of ways; therefore to plan for the long-term conservation and recovery of the species, it is important to understand the effects that may occur as a result of climate change and plan accordingly.

3.4. Assess, evaluate, and implement wildlife management practices and laws that ensure sustainable prey bases for jaguars.

3.4.1. Assess and evaluate the laws for wildlife hunting.

Wildlife hunting laws in the NRU should be assessed and evaluated to determine if they ensure sustainable levels of jaguar prey through effective regulation and enforcement.

3.4.2. Assess and evaluate the process by which harvest levels are established.
The process of establishing harvest levels in the NRU should be assessed and evaluated to determine if it ensures sustainable levels of jaguar prey.

3.4.3. Assess and evaluate the impact of subsistence hunting and illegal killing on jaguar prey populations.
The impact of subsistence hunting and illegal killing on jaguar prey populations should be assessed and evaluated to determine their effects on jaguar recovery.

3.4.4. Determine, develop, and implement wildlife management practices, laws, and conservation tools that ensure sustainable prey bases for jaguars.
As discussed in section *1.9.5 Factor E. Other natural or manmade factors affecting its continued existence*, illegal killing of jaguar prey is a threat to jaguars. Therefore, components of ensuring sustainable prey bases for jaguars may include: 1) reducing unregulated hunting of jaguar prey; 2) implementing programs aimed at developing alternative food sources for local communities; 3) conducting education programs on the sustainable use of wildlife as food as well as other uses; 4) conducting education and outreach regarding sustainable subsistence hunting (e.g., reduce hunting of females), including assisting and training people with securing funds (in Mexico, for example, subsidy programs include the Programa de Conservación para el Desarrollo Sostenible (PROCODES; Conservation Program for Sustainable Development), Programa de Empleo Temporal (PET; Temporary Employment Program), PROCER, etc.); 5) developing and maintaining a community observer/guardian program (in Mexico, for example, guardian programs include the Programa de Vigilancia Comunitaria (PROVICOM; Community Wildlife Ranger Program), which is administered by PROFEPA/CONANP) to monitor local wildlife and habitat, including jaguar prey, in Protected Areas, Priority Conservation Regions, and indigenous communities in Mexico; and 6) improving components of the wildlife management system to provide for sustainable harvest of jaguar prey.

3.4.5. Monitor the effectiveness of wildlife management practices, laws, and conservation tools implemented above.
Wildlife management practices, laws, and conservation tools need to be monitored to determine how effective they are in ensuring sustainable prey bases for jaguars.

4. Assess, protect, and restore sufficient quantity, quality, and connectivity of habitat to support viable populations of jaguars.

4.1. Assess jaguar habitat and corridors and their use.

4.1.1. Map and field verify jaguar habitat and connective areas to guide conservation and planning efforts.

4.1.1.1. Map a network of blocks of high-quality habitat (with each block capable of supporting at least three breeding females) and habitat connections between blocks within each Core Area of the NRU (Sonora and Jalisco) and describe the conditions within the network through field visits (* Recovery Criteria 3.3.1.B.iv. and 3.3.2.B.iv.)

As described in the justification for recovery criteria 3.3.1.B.iv. and 3.3.2.B.iv., safeguarding a network of blocks of high-quality habitat and habitat connections between them within each Core Area of the NRU (Sonora and Jalisco) is necessary for jaguar recovery. The first step in this process is to map these areas and describe the conditions within them through field visits using appropriate techniques. Additionally, verifying jaguar use of these areas is an important step; see 1.1. Survey and monitor jaguars, above.

4.1.1.2. Map one or more potential linkages between the Jalisco and Sonora Core Areas (i.e., within the Sinaloa Secondary Area) sufficient to allow natural jaguar dispersal, including potential barriers and impediments identified based on field visits, and develop and implement strategies for mitigating these impediments in the corridor. (* Recovery Criteria 3.3.1.B.v. and 3.3.2.B.v.)

As described in the justification for recovery criteria 3.3.1.B.v. and 3.3.2.B.v., safeguarding at least one potential inter-core linkage in the Sinaloa Secondary Area in the NRU is necessary for jaguar recovery. The first steps in this process are to identify and map corridors (based on documented use by jaguars; see 1.1.2.4.) and potential barriers and impediments within this Secondary Area and verify these through field visits. Next, strategies for mitigating these impediments need to be developed and implemented.

4.1.1.3. Map two or more non-overlapping potential trans-border linkages within the Borderlands Secondary Area sufficient to allow natural jaguar dispersal, including potential barriers and impediments identified based on field visits, and develop and implement strategies for mitigating these impediments in the corridors. (* Recovery Criteria 3.3.1.B.vi. and 3.3.2.B.vi.)

As described in the justification for recovery criteria 3.3.1.B.vi. and 3.3.2.B.vi., safeguarding at least two non-overlapping potential trans-border linkages in the Borderlands Secondary Area in the NRU is necessary for jaguar recovery. The first steps in this process are to identify and map linkages (based on documented use by jaguars; see 1.1.2.4.) and potential barriers and impediments within this Secondary Area and verify these through field visits. Next, strategies for mitigating these impediments need to be developed and implemented.

4.1.1.4. Map connective areas between the NRU and PARU (including the Sierra Madre Oriental), including potential barriers and impediments identified based on field visits.

As discussed in section *1.5.3 Genetic Fitness,* section **1.11 Biological Constraints and Needs**, and in Rabinowitz and Zeller (2010), identifying corridors and maintaining connectivity between breeding jaguar populations is critical to jaguar recovery. Rabinowitz and Zeller (2010) mapped connective areas among Jaguar Conservation Units throughout the jaguar's range; however, this effort should be updated with region- and site-specific information and field verified. For example, see Petracca et al. (2014a) for information on the southern part of the Sierra Madre Oriental.

4.1.1.5. Develop and update as needed state-specific maps delineating land tenure/ownership patterns overlaid with jaguar distribution information throughout the NRU. (* Recovery Criteria 3.3.1.B.iv., 3.3.1.B.v., and 3.3.1.B.vi.)

To determine if recovery criteria 3.3.1.B.iv., 3.3.1.B.v., and 3.3.1.B.vi. have been met, land tenure/ownership must be mapped as a first step in understanding if jaguar habitat is sufficiently protected.

4.1.1.6. Incorporate results of jaguar habitat use studies from section 1 to help further refine maps above.

Information about jaguar habitat use is lacking in the NRU, but it is important to help characterize jaguar habitat and refine jaguar habitat maps.

4.1.2. Prioritize areas for conservation based on mapping and validation.

4.1.2.1. Prioritize the mapped and verified areas in the NRU.

Once 4.1.1.1. through 4.1.1.3. are complete, the next step is to prioritize these areas for conservation. An example of a high priority site may be an area with critical connectivity or a block with high quality habitat supporting reproduction.

4.1.2.2. Prioritize inter-JCU corridors throughout the PARU to highlight those corridors that most contribute to rangewide connectivity.

Given the number of JCUs and corridors present within the jaguar's range, regional prioritization analyses should be undertaken to focus resources on the most important areas for conservation. However, these regional core and corridor complexes should also be analyzed for their connectivity to adjacent metapopulations, thus facilitating rangewide connectivity.

4.2. Protect jaguar habitat and corridors.

4.2.1. Protect a network of blocks of high-quality habitat (with each block capable of supporting at least three breeding females) and the habitat connections between blocks within each Core Area (Sonora and Jalisco) that will support genetically and demographically vigorous jaguar populations for the foreseeable future. (* Recovery Criterion 3.3.2.B.iv.)

4.2.1.1. Identify existing and proposed conservation lands and assess the level of protection in current and potential jaguar range in the Core Areas of the NRU.

To determine if recovery criterion 3.3.2.B.iv. has been met, land tenure/ownership must be mapped as stated in action 4.1.1.5. Based on this mapping effort, it is then necessary to identify and assess the level of protection in current and potential jaguar range in the Core Areas of the NRU.

4.2.1.2. Increase the number and total area of protected areas (e.g., federal, state, tribal, local, private, etc.) in Core Areas in the NRU.

To achieve recovery criterion 3.3.2.B.iv. and to support genetically and demographically vigorous jaguar populations, it is likely that the number and total area of protected areas in the Core Areas must be increased. Multiple entities such as local, state, or federal governments, ejidos (Mexico only), tribes, private entities, NGOs, etc. could work to create or expand protections on additional land. These may include federally protected areas such as ANPs in Mexico; federally recognized private reserves; jaguar-friendly UMAs; conservation easements; land trusts; etc.

4.2.1.3. Maintain and improve connectivity between protected areas within the Core Areas.

To achieve recovery criterion 3.3.2.B.iv. and to support genetically and demographically vigorous jaguar populations, blocks of habitat must be connected by areas that are sufficiently protected.

4.2.1.4. Improve operation, administration, and infrastructure of protected areas that support jaguars in the Core Areas.

Many protected areas that support jaguars lack adequate funding and infrastructure to properly operate and administer these areas, resulting in reduced protections for jaguars. Improving their operation would require investments of funding and personnel.

4.2.2. Ensure that landscape permeability will be maintained for jaguars within the Sinaloa Secondary Area. (* Recovery Criterion 3.3.2.B.v.)

4.2.2.1. Identify existing and proposed conservation lands and assess the level of protection in current and potential jaguar range in Sinaloa Secondary Area.

To determine if recovery criterion 3.3.2.B.v. has been met, land tenure/ownership must be mapped as stated in action 4.1.1.5. Based on this mapping effort, it is then necessary to identify and assess the level of protection in current and potential jaguar range in the Sinaloa Secondary Area of the NRU.

4.2.2.2. Increase the number and total area of protected areas (e.g., federal, state, tribal, local, private, etc.) containing high-quality jaguar habitats or that serve as important corridors for jaguar movement in the Sinaloa Secondary Area.

To achieve recovery criterion 3.3.2.B.v. and to support genetically and demographically vigorous jaguar populations, it is likely that the number and total area of protected areas in the Sinaloa Secondary Area must be increased. This should provide for jaguar movement within the Sinaloa Secondary Area and between the Sonora and Jalisco Core Areas. Multiple entities such as local, state, or federal governments, ejidos (Mexico only), tribes, private entities, NGOs, etc. could work to create or expand protections on additional land. These may include federally protected areas such as ANPs in Mexico; federally recognized private reserves; jaguar-friendly UMAs; conservation easements; land trusts; etc.

4.2.2.3. Improve operation, administration, and infrastructure of protected areas that support jaguars in the Sinaloa Secondary Area.

Many protected areas that support jaguars lack adequate funding and infrastructure to properly operate and administer these areas, resulting in reduced protections for jaguars. Improving their operation would require investments of funding and personnel.

4.2.3. Ensure that landscape permeability for jaguars, including at least two trans-border linkages, will be maintained throughout the Borderlands Secondary Area. (* Recovery Criterion 3.3.2.B.vi.)

4.2.3.1. <u>Identify existing and proposed conservation lands and assess the level of protection in current and potential jaguar range in the Borderlands Secondary Area.</u>
To determine if recovery criterion 3.3.2.B.vi. has been met, land tenure/ownership must be mapped as stated in action 4.1.1.5. Based on this mapping effort, it is then necessary to identify and assess the level of protection in current and potential jaguar range in Borderlands Secondary Area of the NRU.

4.2.3.2. <u>Increase the number and total area of protected areas (e.g., federal, state, tribal, local, private, etc.) containing high-quality jaguar habitats or that serve as important corridors for jaguar movement in the Borderlands Secondary Area.</u>
To achieve recovery criterion 3.3.2.B.vi. and to support genetically and demographically vigorous jaguar populations, it is likely that the number and total area of protected areas in the Borderlands Secondary Area must be increased. This should provide for jaguar movement within the Borderlands Secondary Area and expansion of jaguar populations in the Sonora Core Area to the north. Multiple entities such as local, state, or federal governments, ejidos (Mexico only), tribes, private entities, NGOs, etc. could work to create or expand protections on additional land. These may include federally protected areas such as ANPs in Mexico; federally recognized private reserves; jaguar-friendly UMAs; conservation easements; land trusts; etc.

4.2.3.3. <u>Improve operation, administration, and infrastructure of protected areas that support jaguars in the Borderlands Secondary Area.</u>
Many protected areas that support jaguars lack adequate funding and infrastructure to properly operate and administer these areas, resulting in reduced protections for jaguars. Improving their operation would require investments of funding and personnel.

4.2.4. <u>Investigate, assess, protect, and/or restore connective areas between the NRU and PARU.</u>
To support genetically and demographically vigorous jaguar populations in the NRU, connectivity between the NRU and PARU may need to be maintained or improved. To do this, it is likely that the number and total area of protected areas between the NRU and PARU may need to be increased. Investigating and assessing may include understanding the extent to which gene flow between the recovery units is occurring, whether landscape conditions potentially support dispersal between the recovery units, and whether landscape connectivity could be restored (if it is currently lacking). A plan to conserve and restore landscape connectivity would likely require multiple entities such as local, state, or federal governments, ejidos (Mexico only), tribes, private entities, NGOs, etc. to create or expand protections on additional land.

4.2.5. <u>Protect high priority connective areas between JCUs in the PARU.</u>

To support genetically and demographically vigorous jaguar populations throughout the jaguar's range, connectivity between the JCUs in the PARU must be maintained or improved. To do this, it is likely that the number and total area of protected areas between the JCUs must be increased. Multiple entities should be encouraged to create or expand protections on additional land.

4.2.6. Develop, evaluate, improve, implement, and maintain governmental and non-governmental conservation incentive programs and tools to protect jaguars and their habitat.

4.2.6.1. <u>Compile and summarize information on governmental and non-governmental conservation incentive programs that are available to landowners within jaguar habitat.</u>
Conservation incentive programs for private land-owners within jaguar habitat are important to promote tolerance of jaguars and jaguar habitat conservation. These may include payments for ecosystem services, tax incentives, etc. A summary of these programs would not only identify existing incentives but also identify gaps where new programs could be developed to benefit jaguars and their habitat. A summary of these programs in the U.S. was conducted by U.S. Geological Survey and the University of Arizona (Lien et al. 2015a).

4.2.6.2. <u>Develop, improve, maintain, fund, and implement effective programs to protect jaguar habitat.</u>
Where gaps are identified above, new conservation incentive programs should be developed to benefit jaguar habitat. Also, many existing incentive programs lack adequate funding to properly operate, resulting in reduced protections for jaguars. Improving their operation and ensuring their long-term maintenance would require investments of funding and personnel. For example, in Mexico, CONAFOR could implement a continuous payment program in jaguar habitat; currently CONAFOR implements a 5-year payment program to conserve biodiversity and watershed management. Other forms of habitat conservation such as land easements may also be options to consider. In the U.S., the work of U.S. Geological Survey and the University of Arizona (see http://udallcenter.arizona.edu/jaguarproject/) could be expanded.

4.2.6.3. <u>Distribute a list of conservation incentive programs to landowners within jaguar habitat and assist them in applying for the programs.</u>
Once these programs are summarized, it will be important to ensure they are distributed to landowners within jaguar habitat and provide assistance with the application process. This assistance will require developing positive relationships between technical experts with knowledge of the incentive programs and private landowners in the NRU.

4.2.6.4. <u>Develop and implement other tools to protect jaguar habitat.</u>
This may include research, education programs, and the development of stakeholder groups to increase awareness of the value of jaguar habitat. It is also important to identify and support local and regional efforts to maintain connectivity such as corridor initiatives. As an apex predator, protection of

jaguar habitat and corridors will not only help conserve jaguars, but will also improve ecosystem resiliency and the health of natural communities.

4.2.7. Increase the number of sustainable, jaguar-friendly revenue producing alternatives in jaguar habitat.
This may include revenue producing business models such as ecotourism, jaguar-friendly products, and local crafts.

4.2.8. Establish guidelines and protocols for jaguar-compatible infrastructure construction and development projects (e.g., roads, power lines, housing, dams, mines, etc.).
This may include determining minimum buffer distances between jaguar habitat and infrastructure/development projects; maximum levels of light and noise tolerable to jaguars during construction and operation of projects; recommended jaguar corridor width, length, and habitat within or between projects to connect quality habitat patches; etc. These guidelines should provide recommendations on methods to reduce the footprint of projects, not only the physical footprint, but also the noise and light effects of the project.

4.2.9. Establish, improve, enforce, and/or fund implementation of laws and procedures to protect jaguar habitat.
Ensure environmental laws that affect land use within jaguar habitat are properly funded, implemented, and enforced. Where gaps occur, establish and fund new laws and procedures to protect jaguar habitat. Improve and enforce environmental impact assessment laws and regulations (e.g., those that regulate roads, dams, mining, etc.) within the NRU, including improving mitigation requirements to offset local impacts.

4.2.10. Monitor the effectiveness of actions implemented in 4.2.1. to 4.2.9.
Conservation incentive programs, revenue producing alternatives, jaguar-compatible infrastructure and development guidelines, and jaguar habitat protections laws need to be monitored to determine how effective they are in protecting jaguar habitat.

4.2.11. Provide jaguar information and scientific expertise to agencies involved in managing and protecting jaguar habitat.
Implementing 4.2. will require that jaguar information and expertise are available during analysis, development, implementation, and monitoring of all actions under this section.

4.3. Restore jaguar habitat and corridors.

4.3.1. Develop methodologies for jaguar habitat restoration.
Restoration methods will be site-specific, and may include methodologies already developed for different types of habitat (e.g., riparian, grassland, mangrove, tropical deciduous forest). Restoration techniques may include planting native vegetation, restoring soils, removing hazards, and other actions. Based on the lands identified and prioritized in action 4.3.2., these methodologies may be implemented to improve jaguar habitat, and new restoration methodologies should be developed for other types of vegetation communities, if needed.

4.3.2. Identify and prioritize lands for habitat restoration.
Some areas are degraded so that they no longer provide habitat for jaguars, but could be restored by reforestation and other methods. Identifying these areas

through aerial imagery, ground surveys, and other field work is necessary. These areas should then be prioritized for restoration, giving highest priority to those degraded areas that connect breeding populations, particularly when no other corridors exist between those populations.

4.3.3. Implement habitat restoration on a priority basis to benefit jaguars.
Jaguar habitat restoration should be funded and implemented to benefit jaguars.

4.3.4. Monitor the effectiveness of habitat restoration efforts above.
Jaguar habitat restoration will need to be monitored to determine how effective it is in supporting jaguars.

5. Assess, minimize, and mitigate the effects of expanding human development on jaguar survival and mortality.

5.1. Minimize the impacts of roads on jaguars.

5.1.1. Assess the impacts of roads on jaguars.

5.1.1.1. Conduct research to better understand the impacts of roads and highways on jaguars and their movements.
Currently, little information is available on the impacts of roads on jaguars and actions to decrease those impacts. Therefore, studies should be conducted to better understand these impacts.

5.1.1.2. Conduct a review of and develop recommendations for enhancements (e.g., underpasses, overpasses, guiding fences, etc.) that allow for passage of jaguars across road corridors that would be effective in a variety of different habitat types.
As discussed in section *1.6.1 Habitat Modeling*, it has been well documented that roads and associated traffic can detrimentally affect wildlife populations in four ways: 1) decrease habitat amount, availability, and quality; 2) increase mortality due to collisions with vehicles; 3) limit access to resources; and 4) fragment habitat and wildlife populations into smaller and more vulnerable subpopulations (sources as cited in Matthews et al. 2014). Carnivores are particularly susceptible to the effects of roads; therefore, it is important to reduce their effects. The first steps in doing this are to conduct a review and develop recommendations for enhancements that allow for passage of jaguars across road corridors. See Matthews et al. (2014 and 2015) for a comprehensive review of and recommendations for road passage designs for jaguars.

5.1.1.3. Identify areas where enhancements (e.g., underpasses, overpasses, guiding fences, etc.) would improve the passage of jaguars across different types of road corridors that would be effective in a variety of different habitat types.
Following from the action above (5.1.1.1.), the second step in reducing the effects of roads on jaguars is to identify optimal locations where enhancements would improve the passage of jaguars across different types of road corridors. See Stoner et al. (2015) for recommendations on locations where enhancements would improve the passage of jaguars across different types of road corridors in NRU.

5.1.1.4. Conduct field studies to determine where road enhancements should be constructed and the effectiveness of the enhancements post-construction.

Monitoring wildlife movements pre- and post-construction of enhancements is a key element in selecting optimal crossing structure locations and evaluating their success. Monitoring can range from a simple, jaguar-specific evaluation within the highway corridor to more complex ecological processes and functions within regional landscapes of conservation importance. See Matthews et al. (2015) for information on pre-and post-construction monitoring of enhancements and Polisar et al. (2014a) for jaguar monitoring techniques.

5.1.2. Avoid, minimize, and mitigate the impacts of roads on jaguars.

5.1.2.1. Based on the information from 5.1.1., implement design measures to facilitate jaguar movement across existing and new roads.
Road/highway underpasses, overpasses, and other design measures, such as fencing, should be developed, constructed, and maintained to facilitate jaguar movement where needed on existing and new roads (including the expansion of Highway 2 in northern Sonora, Mexico). Based on Stoner et al. (2015) and other studies (e.g., Beier et al. 2008), construction of road crossings should be examined on Arizona State Routes 82 and 83, Mexican Federal Highways 2, 15, and 16 in Sonora, Mexican Federal Highways 40 in Sinaloa, and Mexican Federal Highway 150 in Nayarit, in addition to others. After roads or road segments are identified, field studies will be needed to determine the exact location(s) along these roads where crossing structures should be constructed. See Matthews et al. (2014 and 2015) and Stoner et al. (2015) for information on road crossing design measures, recommendations, and potential locations within the NRU.

5.1.2.2. Minimize the impacts of new roads in jaguar habitat and corridors.
During planning for new roads, design roads to minimize jaguar habitat fragmentation and impacts on jaguar movement. See Matthews et al. (2014 and 2015) and Stoner et al. (2015) for information on minimizing the effects of roads on jaguars within the NRU.

5.1.2.3. Engage federal, state, and local departments of transportation and other appropriate authorities in jaguar conservation.
To minimize and mitigate the effects of roads and transportation infrastructure on jaguars and jaguar habitat, a representative group of stakeholders should be engaged, including, but not limited to the following: U.S. Federal Highway Administration; Secretaría de Comunicaciones y Transportes (Mexican Ministry of Communication and Transportation); federal and state transportation, natural resources, and regional planning agencies; wildlife conservation experts; and local communities in the U.S. and Mexico.

5.2. Assess, avoid, minimize, and mitigate the impacts of other human development on jaguars (e.g., mines, dams, border infrastructure, housing and urban development, energy projects, railroads, large scale agriculture, etc.).
Human development can affect jaguars, their movement, dispersal, and habitat; however, additional assessments of these impacts should be performed. Information gathered from these assessments will provide insight on ways to minimize and mitigate the effects of mines, dams, border infrastructure, housing and urban development, energy projects,

railroads, large scale agriculture, and other human development projects that may affect jaguars. Avoiding, minimizing, and mitigating the effects of human development on jaguars will require cooperation and planning among stakeholders. For example, proactive, cooperative urban planning efforts may deter some types of urban encroachment on jaguar habitat. Additionally, environmental laws that affect land use within jaguar habitat should be enforced and properly implemented.

5.3. Monitor the effectiveness of actions implemented in 5.1. and 5.2.
Measures to minimize the effects of roads and other human development need to be monitored to determine how effective they are increasing jaguar survival and recovery.

6. Minimize direct human-caused mortality of jaguars.

6.1. Measure direct human-caused mortality of jaguars. (* Recovery Criteria 3.3.1.B.vii. and 3.3.2.B.vii.)
As described in section *1.9.5 Factor E. Other natural or manmade factors affecting its continued existence,* illegal killing of jaguars is a primary threat in many areas and therefore needs to be measured. Retaliatory killing due to livestock depredation is likely the greatest source of human-caused mortality of jaguars; however, other causes of mortality may include illicit trade of jaguars and/or their parts. Measuring direct human-caused mortality of jaguars would include: 1) developing methods to measure direct human-caused mortality of jaguars; 2) and implementing these methods. Some methods to measure direct human-caused mortality of jaguars are described in Appendix F; however, as our understanding of this threat evolves, others may be developed. Measuring this threat is necessary for meeting recovery criteria 3.3.1.B.vii. and 3.3.2.B.vii.

6.2. Determine, develop, fund, and implement education, outreach, and/or incentive programs to prevent the illegal killing of jaguars (also see action 6.6. below).
This would include an assessment to determine the most effective region-specific landowner education, outreach, and/or incentive conservation tools to minimize illegal killing of jaguars. For example, if jaguar photo-incentive programs (as described in section **1.10 Conservation Efforts**) are determined to be effective, they may be expanded.

6.3. Analyze existing laws, strengthen and enact new laws, if needed, and enforce laws that control and reduce killing of jaguars. (* Recovery Criteria 3.3.1.B.viii. and 3.3.2.B.viii.)
Ensure laws that regulate the killing of jaguars are properly funded, implemented, and enforced. Where gaps occur, establish and fund new laws to protect jaguars. Work with CITES, USFWS law enforcement, and PROFEPA to develop a better understanding of illicit trade of jaguars and their parts, and work with them to methods to reduce this threat.

6.4. Implement community programs to monitor and protect jaguars.
In Mexico, this may include assessing, improving, expanding, and funding community observer/guardian programs (e.g., PROVICOM) to monitor and protect local wildlife and habitat, including jaguars in protected areas, Región Prioritaria para la Conservación (Priority Conservation Regions), and indigenous communities (community observer programs in Mexico are discussed in the PACE) (Appendix B). In the U.S., this may include developing and implementing a community observer program to monitor and protect local wildlife and habitat, including jaguars, on the Tohono O'odham Nation, as

well in other appropriate areas. Community observer programs could be integrated into citizen science programs (see recovery action 1.1.4.) or vice versa.

6.5. Monitor the effectiveness of the tools/programs/laws developed and implemented above in 6.2., 6.3., and 6.4.
Education, outreach, incentive programs, laws, and community programs to prevent and reduce the illegal killing of jaguars need to be monitored to determine how effective they are increasing jaguar survival and recovery.

6.6. Reduce conflicts between jaguars and livestock operations (the term livestock is used to include all hooved animals produced within the jaguar's range with which conflicts may occur; however, cattle are the primary concern).

6.6.1. Identify landowner concerns regarding damage to livestock from jaguars.
This could be done via in-person interviews and workshops with ranchers, as well as via surveys sent to ranchers. In Mexico, workshops should be conducted for landowners, livestock associations, municipal authorities, agriculture associations, ejidos, and conservation districts to discuss wildlife conservation issues and stakeholder needs. In the U.S. portion of the NRU, conduct local workshops to identify landowner, manager, and permittee concerns related to jaguar conservation and to develop possible solutions. The U.S. Geological Survey and the University of Arizona conducted interviews and surveys in the U.S. to assess these concerns (Lien et al. 2015b, Svancara et al. 2015). An example in the PARU includes Zimmerman et al. (2005).

6.6.2. Compile and develop a document that reviews jaguar-friendly livestock management practices.
Hoogesteijn and Hoogesteijn (2014) developed a document titled "Anti-predation Strategies for Cattle Ranching: A Guide" (http://www.panthera.org/sites/default/files/Anti-Predation-Manual_English.pdf). This could be updated with site specific concerns (obtained during recovery action 6.7.1.) incorporated as needed.

6.6.3. Support, encourage, and fund jaguar-friendly livestock management practices.
This may include: 1) developing capacity building materials on jaguar-friendly livestock management in English and Spanish for landowners and livestock managers and producers within jaguar range; 2) conducting workshops using the materials developed above focused on jaguar-friendly livestock management; and 3) developing, implementing, and funding a long-term rural outreach and assistance program for livestock producers to decrease conflicts between jaguars and livestock. Capacity building materials may include, for example, pamphlets, brochures, presentations, or websites that provide information on jaguar-friendly livestock management. These should be widely distributed throughout the jaguar's range. Workshops are an effective tool for disseminating information such as this, particularly in rural areas in the jaguar's range, and participants may include local ranchers and landowners, as well as reserve managers. Long-term rural outreach and assistance programs may include livestock insurance; livestock loss compensation (see action 6.6.4. below); building livestock fences, waters, etc., for ranchers to aid in jaguar-friendly livestock management; and pilot ranches implementing jaguar-friendly livestock management. These programs should be applicable to all livestock operations, small and large. Long-term

assistance positions should be supported by Ministries of Agriculture in different countries throughout the jaguar's range.

6.6.4. Compensate for livestock loss.
This may include: 1) assessing the effectiveness of programs to compensate landowners for livestock loss (due to jaguars); and 2) if effective, establishing and/or maintaining and funding programs to efficiently compensate landowners for livestock loss. Various livestock compensation programs exist in the NRU and throughout the jaguar's range; these should be assessed to determine rancher knowledge of and satisfaction with these programs, as well as their effectiveness at increasing tolerance of jaguars on ranch lands (i.e., decreasing direct killing of jaguars on ranch lands). Gaps in the programs should be identified and addressed to improve program performance, if needed. In the U.S. portion of NRU, the Malpai Borderlands Group livestock compensation program should be continued and similar programs for other areas in the U.S. should be established and maintained. In Mexico, the Fondo de Aseguramiento Ganadero (Livestock Assurance Fund) managed by Confederación Nacional de Organizaciones Ganaderas (National Confederation of Livestock Organizations) should continue to be implemented.

6.6.5. Improve native prey populations (see also actions under Objective 3).

6.6.5.1. Encourage livestock and habitat management practices that allow for the healthy presence of native prey species.
These practices may include proper husbandry and stocking rates that decrease the susceptibility of the herd to depredation and allow for adequate prey population forage. Encouraging these practices could be conducted simultaneously with actions 6.6.3. and 6.6.4.

6.6.5.2. Where the full complement of native prey species are not present or are not at natural densities, reintroduce native prey.
In the NRU, for example, peccary populations are depleted in some parts of Sonora. There are currently efforts to increase their populations through reintroductions. These efforts should be assessed and expanded if effective.

6.6.6. Monitor the effectiveness of the tools used to reduce conflicts between jaguars and cattle.
Tools to reduce conflicts between jaguars and cattle need to be monitored to determine how effective they are for increasing jaguar survival and recovery.

7. Ensure long-term jaguar conservation through adequate funding, public education and outreach, and partnerships.

7.1. Secure funding for jaguar conservation.

7.1.1. Secure funding for jaguar conservation including the creation and management of an endowment to implement USFWS jaguar recovery plan actions.
The implementation of this entire recovery effort is a very large undertaking that will require multiple sources of funding and prioritization of activities. Strategies should be carefully thought out with state, private, and federal sources for optimum coordination. For example, sources of such funding could include an endowment or trust that would provide secure long-term funding for jaguar recovery actions. Other efforts to secure funding at a local level may include

programs such an adopt-a-jaguar program or local festivals and raffles. Models for this may be the Adopt-an-Ocelot program administered by the Friends of Laguna Atascosa National Wildlife Refuge (http://friendsoflagunaatascosanationalwildliferefuge.org/Ocelots/Adopt-an-Ocelot); or the Adopt-a-Panther program administered by the Friends of the Florida Panther Refuge (http://floridapanther.org/adopt-a-panther/).

7.1.2. Develop an agreement between USFWS and CONANP with the goal of prioritizing, funding, and implementing jaguar recovery actions.
As the lead agency administering jaguar recovery in the U.S. and Mexico, coordination between FWS and CONANP, respectively, would be critical, particularly for high priority recovery actions. The agreement will outline how the funds will be secured and applied for long-term jaguar conservation.

7.1.3. Direct mitigation and violation revenues generated from actions that impact jaguars toward support of appropriate jaguar recovery actions.
In Mexico, this would include, but is not limited to, developing an agreement among appropriate agencies (e.g., PROFEPA, DGVS, and CONANP) to use mitigation fees (from projects that impact jaguar habitat) on jaguar conservation in the affected areas. The agreement will identify types of jaguar recovery projects from the Jaguar PACE that will be funded. In the U.S., this may include coordination and application of fines for illegal trade of jaguar products or other jaguar-related ESA violations.

7.2. Educate the public and professionals on jaguar conservation.

7.2.1. Survey residents' attitudes toward jaguars and jaguar conservation.
Questionnaires should be developed and utilized to survey residents' attitudes toward jaguars and jaguar conservation. A number of examples exist (Zimmerman 2005, Harris Environmental Group 2015, Lien et al. 2015b, Núñez Perez 2014).

7.2.2. Conduct education and outreach programs to increase awareness of the value and current status of jaguars and to promote jaguar conservation.
These education and outreach programs may include: 1) developing and distributing educational and outreach material on jaguar conservation for the general public; 2) developing and distributing formal educational curriculum materials on jaguar conservation for different educational levels; 3) conducting programs (using the information developed above) focused on the importance of jaguar conservation for school children and the general public; 4) promoting citizen science programs to assess jaguar populations as described under action 1.1.4.; 5) educating landowners and the public on the benefits of jaguar-friendly revenue generating sources, such as ecotourism programs; 6) promoting the use of the Jaguar Recovery Plan and PACE through outreach, workshops, and distribution of recovery materials; and 7) improving information sharing with the public on actions that may impact jaguars. Examples of education and outreach conducted in the U.S. are included on http://www.fws.gov/southwest/es/arizona/Jaguar.htm.

7.2.3. Provide adequate education and training for professionals working on jaguar conservation issues at Federal, State, Tribal, and local levels.

This may include: 1) identifying the type of training required, and 2) developing and providing training to target audiences, such as law enforcement and local authorities, on topics such as environmental laws and enforcement and reduction of ecological threats. These educational and training opportunities will need to be locally specific and should involve the support of legal experts and lawyers.

7.2.4. Monitor and assess the effectiveness of survey, education, and outreach efforts. Education, outreach, and training efforts need to be monitored to determine how effectively they are increasing knowledge of jaguar conservation and improving people's attitudes toward jaguars and jaguar conservation.

7.2.5. Develop and maintain partnerships with agencies, organizations, and citizens to conserve jaguars.
Given the overall size and the number of jurisdictional borders within jaguar recovery areas, it is imperative to develop and establish coordinated efforts with all relevant entities to avoid redundancy and improve efficacy of actions. This may include: 1) maintaining existing collaborative local efforts to conserve jaguars and establishing and maintaining new collaborative efforts with new stakeholders where possible; 2) continuing cooperation between U.S. and Mexico to recover jaguars in the NRU; 3) collaborating with local, state, and federal agencies and tribal governments involved in land management planning to voluntarily include jaguar conservation in their plans and activities; 4) providing technical assistance and conservation recommendations to the U.S. Border Patrol and other federal agencies in the U.S. on issues that might constrain jaguar movement between the U.S. and Mexico (e.g. border security actions, border infrastructure, and illegal immigration) or jaguar occurrence in the U.S.; 5) cooperating with partners to support rangewide conservation planning for the jaguar; and 6) distributing and promoting the use of the Jaguar Recovery Plan across all range states, as appropriate.

8. Practice adaptive management in which recovery is monitored and recovery tasks are revised by the USFWS in coordination with the JRT as new information becomes available.

8.1. Use adaptive management principles to evaluate this recovery effort on an ongoing basis, and make necessary changes, based on experience, outcomes, and changed circumstances.
Use adaptive management principles (e.g., The Open Standards for the Practice of Conservation by the Conservation Measures Working Group (http://cmp-openstandards.org/) and the Department of Interior's Technical Guide to Adaptive Management) to evaluate this recovery effort on an ongoing basis. Based on monitoring results, if actions are not effective, they should be revised or eliminated. If actions are effective but not broad enough in scope, efforts should be increased.

8.2. Compile and discuss jaguar recovery accomplishments and updates with the JRT at least once per year.
Discuss (via email, conference call, or meeting) recovery action implementation results, for example, updates on jaguar monitoring, habitat conservation successes, status of illegal jaguar killing, human-dimension surveys, legislative actions, and education and outreach activities.

8.3. Exchange information between agencies in Mexico and the U.S. to discuss progress in implementing state and federal jaguar recovery/conservation plans in the U.S. and Mexico.

Information exchange should occur annually and meetings should be held as necessary, or at least every 5 years. Information to be exchanged should include updates on actions implemented from both the PACE and recovery plan to track accomplishments of these plans, as well as their effectiveness in recovering jaguars within the NRU. Agencies in Mexico include: CONANP, DGVS, PROFEPA, state wildlife agencies, and other agencies as necessary. Agencies in the U.S. include: USFWS, AGFD, NMDGF, and other agencies as necessary.

8.4. Establish a binational agreement or letter of intent (Mexico-U.S.) to implement binational recovery actions in the Jaguar Recovery Plan and PACE.

A letter of intent between CONANP and the FWS would help Mexico and the U.S. coordinate on implementing joint recovery actions and this agreement could be integrated into the funding agreement discussed in 7.1.2.

PART 5: IMPLEMENTATION SCHEDULE

The following implementation schedule outlines priorities, potential or responsible parties, and estimated costs for the specific actions for recovering the jaguar. It is a guide to meeting the goals, objectives, and criteria from Part III of this recovery plan. The schedule: (a) lists the specific recovery actions, corresponding outline numbers, the action priorities, and the expected duration of actions; (b) recommends agencies or groups for carrying out these actions; and (c) estimates the financial costs for implementing the actions. These actions, when complete, should accomplish the goal of this plan—recovery of the jaguar. The JRT estimates the time required to accomplish recovery of the jaguar is 50 years to achieve all of the actions and meet the recovery criteria included in this recovery plan. For example, some of the recovery criteria require changes or additions to laws and regulations protecting jaguars, their prey, and habitat, as well as ensuring a significant amount of land protection, all of which require an extensive amount of time to complete. Additionally, changing people's perceptions of and attitudes toward jaguars may take decades to accomplish. The JRT also anticipates that, while it will take a minimum of 30 years to meet the demographic and genetic criteria, additional time may be required if jaguar demographic and genetic baselines are not maintained. The JRT anticipates that projecting beyond 50 years is unrealistic, given changes in the human population, technology, and the climate.

The JRT and USFWS made efforts to the maximum extent practicable to estimate costs for both the NRU and PARU. However, unless specified in the Implementation Schedule below, costs are only calculated for the NRU; many are not calculated for the PARU because it is beyond the USFWS and JRT's ability to predict the costs for actions in 16 additional countries outside of the NRU. The amount in the Total Cost column for each action is calculated based on the duration of that action until recovery, or over the next 50 years. The duration of each action is noted in the Comments column. Therefore, the sum of all costs in the Total Cost column is the estimated cost to recover the jaguar over the next 50 years.

Also, unless specifically stated, for all PARU actions the responsible parties will be considered all appropriate governmental and non-governmental authorities and/or organizations throughout the PARU. The USFWS and JRT will encourage the implementation of these actions where and when appropriate (see a more in-depth discussion on this in the Strategy section of the Recovery Plan). The time frame for each action in the PARU is estimated to be the same as each action in the NRU.

5.1 Responsible Parties and Cost Estimates

The value of this plan depends on the extent to which it is implemented; the USFWS has neither the authority nor the resources to implement many of the proposed recovery actions throughout the species' range outside of the U.S. The recovery of the jaguar is dependent upon the voluntary cooperation of many other organizations and individuals who are willing to implement the recovery actions. The implementation schedule identifies agencies and other potential "responsible parties" (private and public) to help implement the recovery of this species. This plan does not commit any "responsible party" to carry out a particular recovery action or to expend the estimated funds. It is only recognition that particular groups may possess the expertise, resources, and opportunity to assist in the implementation of recovery actions. Although collaboration with private landowners and others is called for in the recovery plan, no one is obligated by this plan to any recovery action or expenditure of funds. Likewise, this schedule is not intended to preclude or limit others from participating in this recovery program.

The cost estimates provided are not intended to be a specific budget but are provided solely to assist in planning. The total estimated cost of recovery, by priority, is provided in the Executive Summary. The schedule provides cost estimates for each action on an annual or biannual basis. Estimated funds for agencies included only project-specific contract, staff, or operations costs in excess of base budgets. They do not include ordinary operating costs (such as staff) for existing responsibilities.

5.2 Recovery action priorities and abbreviations

Priorities in column 1 of the following implementation schedule are assigned using the following guidelines:

Priority 1a = An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

Priority 1b = An action that by itself will not prevent extinction, but which is needed to carry out a Priority 1a action.

Priority 1c = An action that by itself will not prevent extinction, but which is needed to monitor a Priority 1a action.

Priority 2a = An action that must be taken to prevent a substantial decline in species population/habitat quality or some other substantial negative effect short of extinction.

Priority 2b = An action that by itself will not prevent a substantial decline in species population/habitat quality or some other substantial negative effect short of extinction, but which is needed to carry out a Priority 2a action.

Priority 2c = An action that by itself will not prevent a substantial decline in species population/habitat quality or some other substantial negative effect short of extinction, but which is needed to monitor a Priority 2a action.

Priority 3 = All other actions necessary to meet the recovery objectives.

The assignment of these priorities does not imply that some recovery actions are of low importance, but instead implies that lower priority items may be deferred while higher priority items are being implemented.

The following abbreviations are used in the Implementation Schedule:

AAI	Appropriate Academic Institutions
AASA	All Appropriate State Agencies
ADOT	Arizona Department of Transportation
AGFD	Arizona Game and Fish Department
All	All appropriate and pertinent agencies, groups, tribes, and individuals in the NRU
ANGADI	Asociación Nacional de Ganaderos Diversificados Criadores de Fauna (National Association of Diversified Livestock Producers)
ASLD	Arizona State Land Department
AZA	Association of Zoos and Aquariums
AZCARM	Asociación de Zoológicos, Criaderos y Acuarios de México A.C. (Mexican Association of Zoos, Nurseries, and Aquariums)
BLM	Bureau of Land Management
CBP	United States Customs and Border Protection
CBSG	Conservation Breeding Specialist Group
CDI	Comisión Nacional para el Desarrollo de los Pueblos Indígenas (Mexican National Commission for the Development of Indigenous Peoples)
CEDES	Comisión de Ecologia y Desarrollo Sustentable del Estado de Sonora (Commission of Ecology and Development of the State of Sonora)
COLPOS	Colegio de Postgraduados (Mexican Graduate College)
CONABIO	Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Mexican National Commission for Knowledge and Use of Biodiversity)
CONAFOR	Comisión Nacional Forestal (Mexican National Forestry Commission)
CONAGUA	Comisión Nacional del Agua (Mexican National Water Commission)
CONANP	Comisión Nacional de Áreas Naturales Protegidas (Mexican National Commission of Protected Areas)
DGIRA	Dirección General de Impacto y Riesgo Ambiental (Mexican Federal Office of Environmental Impact and Risk)
DGVS	Dirección General de Vida Silvestre (Mexican Federal Office of Wildlife)
DOT	Department of Transportation
FWS	United States Fish and Wildlife Service
IUCN	International Union for Conservation of Nature
IUCN-SSC	International Union for Conservation of Nature-Species Survival Commission
JRT	Jaguar Recovery Team
LA	Livestock associations
MBG	Malpai Borderlands Group
NGO	Non-governmental organization
NMDGF	New Mexico Department of Game and Fish
NMSLO	New Mexico State Land Office
NPS	United States National Park Service
NRCS	United States Natural Resources Conservation Service
NRU	Northwestern Recovery Unit
PARU	Pan American Recovery Unit

PGR	Procuraduría General de la República (Attorney General of Mexico)
PROFEPA	Procuraduría Federal de Protección del Ambiente (Mexican Federal Attorney General for Environmental Protection)
SAGARPA	Secretaría de Agricultura, Ganaderia, Desarrollo Rural, Pesca, y Alimentación (Mexican Federal Ministry of Livestock, Agriculture, Rural Development, Fisheries, and Foods)
SAGARHPA	Secretaria de Agricultura, Ganadería, Recursos Hidráulicos, Pesca y Acuacultura (Ministry of Agriculture, Water Resources, Fisheries and Aquaculture of Sonora)
SCT	Secretaría de Comunicaciones y Transportes (Mexican Secretariat of Communications and Transportation)
SDA	State Departments of Agriculture
SDR	Subsecretaría de Desarrollo Rural (Mexican Assistant Secretary of Rural Development)
SDWM	State Departments of Wildlife and Natural Resources in Mexico
SE	Secretaría de Economía (Mexican Ministry of Economy)
SEP	Secretaría de Educación Pública (Mexican Secretariat of Public Education)
SECTUR	Secretaría de Turismo (Mexican Secretariat of Tourism)
SEP	Secretaría de Educación Pública (Mexican Secretariat of Public Education)
UANL	Universidad Autónoma de Nuevo León (Autonomous University of Nuevo León)
UAQ	Universidad Autónoma de Querétaro (Autonomous University of Querétaro)
UJAT	Universidad Juarez Autónoma de Tabasco (Juárez Autonomous University of Tabasco)
UMA	Unidad para la Conservación, Manejo y Aprovechamiento Sustentable de la Vida Silvestre (Wildlife Conservation, Management, and Sustainable Utilization Unit)
USDA-APHIS-WS	United States Department of Agriculture-Animal and Plant Health Inspection Service-Wildlife Services
USGS	United States Geological Survey

IMPLEMENTATION SCHEDULE:

Note the amount in the Total Cost column for each action is calculated based on the duration of that action until recovery, or over the next 50 years. The duration of each action is noted in the Comments column. Therefore, the sum of all costs in the Total Cost column is the estimated cost to recover the jaguar over the next 50 years.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
NA	**1.**	**Ascertain the status and conservation needs of the jaguar.**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	1.1.	Survey and monitor jaguars.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	1.1.1.	<u>Develop and update a jaguar survey and monitoring protocol.</u>	3.3.1.A.i; 3.3.1.B.i, iii; 3.3.2.A.i; 3.3.2.B.i, iii	Periodic	FWS, JRT	Yes	315	90	0	0	0	0	Update every 5 years for $25,000 per update for 50 years (last update in 2061).
NA	1.1.2.	Conduct jaguar surveys and monitoring in the NRU.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	1.1.2.1.	<u>Train and equip appropriate groups to conduct jaguar surveys and monitoring.</u>	3.3.1.B.i, iii; 3.3.2.B.i, iii	Ongoing	JRT, FWS, CONANP, and All	No	2,805	155	5	5	155	5	Training would occur every year until 2066 at $5,000 per year. $150,000 of equipment would be purchased every 3 years until 2066.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	1.1.2.2.	Implement the jaguar survey and monitoring protocol developed in 1.1.1. to obtain measures of occupancy in each Core of the NRU.	3.3.1.B.i, iii; 3.3.2.B.i, iii	Periodic	JRT, FWS, CONANP, and All	No	4,535	0	0	0	453	454	Personnel costs are detailed in Polisar et al. (2014b). Additional costs incorporated include personnel time for photo analysis, cameras and related equipment, vehicles, mileage, computers, and miscellaneous equipment. The occupancy protocol should be implemented at the following intervals: years 1 and 2; years 8 and 9; and years 16 and 17; and then every 15 years until 2066.
3	1.1.2.3.	Calculate and assess occupancy in each Core Area of the NRU using results of the survey and monitoring conducted in 1.1.2.2. (*Recovery Criteria 3.3.1.B.i, 3.3.2.B.i)	3.3.1.B.i, iii; 3.3.2.B.i, iii.	Periodic	JRT, FWS, CONANP, and All	No	510	0	0	0	30	0	Every 3 years until 2066.
3	1.1.2.4.	Assess jaguar use of Secondary Areas.	3.3.1.B.v, vi.	Periodic	JRT, FWS, CONANP, and All	No	0	0	0	0	0	0	Costs included in actions 1.1.4, 1.4.1., 2.1.1.
3	1.1.2.5.	Prepare reports of jaguar survey and monitoring results in the NRU for use in status reviews.	3.3.1.B.i, iii; 3.3.2.B.i, iii.	Periodic	IUCN, All NRU and PARU	No	170	0	0	0	10	0	Every 3 years until 2066.
NA	1.1.3.	Survey and monitor jaguars in the PARU.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	1.1.3.1.	Assess the status of jaguars in the Sierra Madre Oriental.	3.3.1.A.i; 3.3.2.A.i	Periodic	COLPOS, CONANP, UAQ, UNAL, AAI	No	300	50	0	0	0	0	Costs are based on a current jaguar study in the Sierra Madre Oriental. Conduct every 10 years until 2066.
3	1.1.3.2.	Compile and evaluate survey data from jaguar populations in the PARU to assess status of the species.	3.3.1.A.i; 3.3.2.A.i	Periodic	JRT, FWS, CONANP, IUCN, and All	No	100	0	0	0	0	10	Every 5 years
3	1.1.4.	Develop and implement citizen science programs to assess jaguar populations.	3.3.1.B.i, iii; 3.3.2.B.i, iii	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below
See above		In the U.S.	See above	Ongoing	FWS, USGS, JRT	Yes	3,315	65	65	65	65	65	Every year until 2066. This includes 1.5 FTEs (volunteer coordinator and data manager). Equipment costs are included in action 1.1.2.2.
See above		In the Mexico portion of the NRU	See above	Continuous	JRT, CONANP, PROFEPA	No	4,000	0	80	80	80	80	Every year until 2066. This includes 6 FTEs (volunteer coordinators and data managers). Equipment costs are included in action 1.1.2.2.
3	1.1.5.	Be prepared for jaguar captures.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	1.1.5.1.	Identify, compile, and update a jaguar capture and handling protocol.	3.3.1.A.i; 3.3.1.B.i, iii; 3.3.2.A.i; 3.3.2.B.i, iii	Periodic	JRT, FWS	No	110	0	0	20	0	0	First time cost would be $20,000; updates would occur every 5 years until 2063 and cost $10,000.
3	1.1.5.2.	Train and equip people in jaguar capture (both intentional and incidental) and handling techniques.	3.3.1.B.i, iii; 3.3.2.B.i, iii	Periodic	All agency	No	280	0	0	0	0	28	Training and equipping would occur every 5 years until 2065. This includes 2 people per core and secondary area plus $1,000 for supplies in each area.
3	1.2.	Increase collaboration with other carnivore researchers to gather information on jaguars in their study areas.	3.3.1.A.i; 3.3.1.B.i, iii; 3.3.2.A.i; 3.3.2.B.i, iii	Ongoing	JRT, All	No	0	0	0	0	0	0	Costs included in other actions.
3	1.3.	Develop and maintain jaguar observation report procedures and databases.	3.3.1.A.i; 3.3.1.B.i, iii; 3.3.2.A.i; 3.3.2.B.i, iii	Ongoing	FWS, AGFD, CONABIO	Yes*	228	156	6	6	6	6	Development would occur in 2016; and then ongoing maintenance and data input would occur annually. * for publicly available records
2b	1.4.	Conduct ecological research on jaguars.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2b	1.4.1.	Conduct home range, movement, and habitat use studies on jaguars.	3.3.1.A.i; 3.3.1.B.iii, iv, v, vi; 3.3.2.A.i; 3.3.2.B.iii, iv, v, vi	Ongoing	JRT, CONANP, FWS, All	No	23,562	462	462	462	462	462	Costs include 2.25 FTEs, vehicles, gas, equipment, and materials per Core and Secondary area on an annual basis for studies utilizing cameras and telemetry.
2b	1.4.2.	Investigate jaguar dispersal patterns.	3.3.1.A.i; 3.3.1.B.iii, iv, v, vi; 3.3.2.A.i; 3.3.2.B.iii, iv, v, vi	Ongoing	JRT, CONANP, FWS, All	No	0	0	0	0	0	0	Costs included in action 1.4.1.
2b	1.4.3.	Conduct a study to determine the extent to which poaching and depredation loss are compensatory with other types of jaguar mortality.	3.3.1.A.i; 3.3.1.B.vii; 3.3.2.A.i; 3.3.2.B.vii	Periodic	All	No	0	0	0	0	0	0	Costs included in action 1.4.1.
2b	1.4.4.	Conduct a study on the effects of climate change on jaguars and their habitat and develop a strategic adaptation plan.	3.3.1.A.i; 3.3.1.B.iii, iv, v, vi; 3.3.2.A.i; 3.3.2.B.iii, iv, v, vi	Periodic	All	No	375	0	0	0	0	0	Costs of the field studies included in 1.4.1.; costs of data analysis and development of the plan are included here. Data analysis and plan development will be conducted every 10 years beginning in 2021 until 2061.
3	1.4.5.	Identify and conduct other research needed to conserve jaguars.	All	Periodic	JRT, All	No	0	0	0	0	0	0	Costs not determinable until actions are identified.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	1.5.	Conduct periodic population viability analyses for jaguars as new information is acquired.	All	Periodic	JRT, FWS, CBSG	No	250	25	0	0	0	0	Conduct PVA every 5 years until 2061.
NA	**2.**	**Assess and maintain or improve genetic fitness, demographic characteristics, and health of the jaguar.**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	2.1.	Assess conservation genetic criteria for jaguars.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2b	2.1.1.	Conduct a genetic study to determine present and future level of genetic variability, genetic distance between Sonora and Jalisco Core Areas, and inbreeding coefficients within the Sonora Core Area and within the Jalisco Core Area. (*Recovery Criteria 3.3.1.B.v. and 3.3.2.B.v.)	3.3.1.B.ii., 3.3.2.B.ii.	Periodic	JRT, FWS, All	No	305	0	0	0	61	0	Costs for most of the field study to collect genetic samples are included in actions 1.1.2.2. and 1.4.1.; however, additional costs of training, handling, and sampling with a scat dog; conducting genetic analyses in the lab; and writing reports are included here. This should be implemented at the following intervals: year 1; year 8; and year 16; and then every 15 years until 2064.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2b	2.1.2.	Monitor connectivity in the PARU through documenting changes in gene flow among JCUs.	3.3.1.A.i., 3.3.2.A.i.	Periodic	Panthera, FWS, JRT	No	204	0	0	12	0	0	The frequency of implementing this action may be similar to the action above. Costs calculated here only include time encouraging this action in the PARU. Encouraging this action would occur every 3 years until 2066.
3	2.1.3.	Investigate the need for a captive breeding program for jaguars.	None	1	AZA, AZCARM, IUCN-SSC, JRT	No	24	0	0	0	0	24	Costs include a meeting among parties and time for a meeting coordinator.
3	2.2.	Investigate the taxonomic status of jaguars.	None	5	JRT, All	No	100	0	20	20	20	20	Field costs are included in actions above; however, additional costs of coordinating with jaguar researchers; conducting genetic analyses in the lab; and writing reports are included here. This 5 year study would be conducted once.
NA	2.3.	Assess demographic/vital characteristics of jaguars.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2b	2.3.1.	Continue and expand studies to obtain more rigorous estimates of age-, gender-, and region-specific vital rates, including year-to-year variation.	All	Ongoing	JRT, All	No	0	0	0	0	0	0	Costs included in action 1.4.1.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2b	2.3.2.	Analyze data (including survey, monitoring, genetic, etc.) collected on jaguars in the Sonora and Jalisco Core Areas to determine the percentage of adult females. (*Recovery Criteria 3.3.1.B.vi. and 3.3.2.B.vi.)	3.3.1.B.iii.; 3.3.2.B.iii.	Periodic	CONANP, FWS, JRT, All	No	83	0	0	0	0	0	Data analysis would occur every 5 years starting in 2021 until 2066.
2b	2.4.	Develop estimates of dispersal rates and travel distances through genetic methods within the NRU and neighboring populations.	All	Periodic	JRT, All	No	54	0	0	0	0	13.5	The field and lab costs are included in actions above; however, additional costs are included here for conducting the analysis and report writing. This action should be conducted every 15 years until 2065.
NA	2.5.	Evaluate and improve health conditions of jaguar populations.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	2.5.1.	Establish protocols for physiological assessment and treatment of injuries, diseases, and parasites as appropriate.	None	Periodic	JRT, All	No	120	0	0	24	0	0	After development, the protocol should be updated every 10 years until 2058. Costs include a meeting among parties and time for a meeting coordinator.
3	2.5.2.	Using above protocols, conduct serology and pathology surveys to determine overall health conditions of jaguars.	None	Ongoing	JRT, All	No	153	3	3	3	3	3	The field costs are included in action 1.4.1.; however, additional costs to conduct lab analyses and write reports are included here.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	2.5.3.	Provide for storage of biological samples collected from jaguars.	None		All	No	102	2	2	2	2	2	Costs include storage equipment and sample cataloging.
3	2.5.4.	Establish a database of medical and genetic jaguar data.	3.3.1.B.ii., 3.3.2.B.ii.	Continuous	All	No	222	0	0	78	3	3	Development would occur in 2018; and then ongoing maintenance would occur annually.
3	2.5.5.	Investigate and implement measures to prevent significant losses due to diseases.	None	1	All	No	24	0	0	0	0	0	Costs are only included for investigating measures, not for implementing them. Implementation costs can be calculated after investigating. Investigation costs include a meeting among parties and time for a meeting coordinator (one month FTE)..
NA	**3.**	**Assess and maintain or improve the status of native prey populations.**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	3.1.	Develop and conduct a study of jaguar prey abundance.	3.3.1.A.i., 3.3.2.A.i.; 3.3.1.B.iv., v., vi.; 3.3.2.iv., v., vi.	Periodic	AGFD, NMDGF, SDWM, DGVS, CONANP	No	405	0	0	0	0	180	Costs are included only for developing the study, not for conducting it. After the study is developed, costs can be calculated for conducting the study. Study development costs are based on contract costs for jaguar protocol development. Additionally, costs include study plan updates every 5 years for $25,000 per update for 50 years (last update in 2061).
3	3.2.	Evaluate health conditions of jaguar prey populations, including the effects of diseases.	None	Ongoing	AGFD, NMDGF, USGS, USDA, SAGARPA, All	No	0	0	0	0	0	0	The costs for this action in the U.S. are incorporated into existing ongoing work the State Game Departments conduct; therefore no additional costs are included here. Costs for this action in Mexico are also likely incorporated into existing ongoing work of the States and SAGARPA; therefore no additional costs are included here.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	3.3.	<u>Design and implement a study that would quantify the relationship between jaguars and their prey as it relates to climate change.</u>	3.3.1.A.i., 3.3.2.A.i.; 3.3.1.B.iv., v., vi.; 3.3.2.iv., v., vi.	Periodic	All	No	115	0	0	0	0	0	Costs are included only for designing the study, not for implementing it. After the study is designed, costs can be calculated for implementing the study. Study design costs are based on contract costs for jaguar protocol development. Additionally, costs include one study design update for $25,000.
NA	3.4.	Assess, evaluate, and implement wildlife management practices and laws that ensure sustainable prey bases for jaguars.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	3.4.1.	<u>Assess and evaluate the laws for wildlife hunting.</u>	3.3.1.A.i., 3.3.2.A.i; 3.3.1.B.i., iv., v., vi.; 3.3.2.B.i., iv., v., vi.	Periodic	JRT, All	No	180	0	0	90	0	0	Costs are for two assessments (over the recovery period) and are based on contract costs for jaguar protocol development.
3	3.4.2.	<u>Assess and evaluate the process by which harvest levels are established.</u>	3.3.1.A.i., 3.3.2.A.i; 3.3.1.B.i., iv., v., vi.; 3.3.2.B.i., iv., v., vi.	Periodic	AGFD, NMDGF, SAGARPHA, SDWM, DGVS, CONANP	No	180	0	0	90	0	0	Costs are for two assessments (over the recovery period) and are based on contract costs for jaguar protocol development.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	3.4.3.	Assess and evaluate the impact of subsistence hunting and illegal killing on jaguar prey populations.	3.3.1.A.i., 3.3.2.A.i; 3.3.1.B.i., iv., v., vi.; 3.3.2.B.i., iv., v., vi.	Periodic	AAI, CDI	No	900	0	0	90	90	0	Costs include surveys of hunters and consumers (local community members), abundance of prey populations, and jaguar diet. This 2 year assessment would occur every 10 years until 2059.
2a, b	3.4.4.	Determine, develop, and implement wildlife management practices, laws, and conservation tools that ensure sustainable prey bases for jaguars.	3.3.1.A.i., 3.3.2.A.i; 3.3.1.B.i., iv., v., vi.; 3.3.2.B.i., iv., v., vi.	Continuous	AGFD, NMDGF, SAGARPHA, SDWM, DGVS, CONANP, UMAs	No	0	0	0	0	0	0	Costs will be calculated after 3.4.1 to 3.4.3 are completed.
2c	3.4.5.	Monitor the effectiveness of wildlife management practices, laws, and conservation tools implemented above.	3.3.1.A.i., 3.3.2.A.i; 3.3.1.B.i., iv., v., vi.; 3.3.2.B.i., iv., v., vi.	Continuous	All	No	0	0	0	0	0	0	Costs will be calculated after 3.4.4. is in progress.
NA	**4.**	**Assess, protect, and restore sufficient quantity, quality, and connectivity of habitat to support viable populations of jaguars.**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	4.1.	Assess jaguar habitat and corridors and their use.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
NA	4.1.1.	Map and field verify jaguar habitat and connective areas to guide conservation and planning efforts.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1b	4.1.1.1.	Map a network of blocks of high-quality habitat (with each block capable of supporting at least three breeding females) and habitat connections between blocks within each Core Area of the NRU (Sonora and Jalisco) and describe the conditions within the network through field visits (*Recovery Criteria 3.3.1.B.ii and 3.3.2.B.ii).	3.3.1.B.iv; 3.3.2.B.iv	Periodic	FWS, JRT	Yes*	824	0	0	177	116	0	Costs for mapping are included in Action 5.1.1.3. Costs for describing conditions within the network include 2 FTEs for 2 years plus vehicles, fuel, computers, communications, and miscellaneous. Costs for documenting jaguar use of these areas are included in Action 1.1. Describing conditions within the network should be updated every 15 years. * mapping only

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
1b	4.1.1.2.	Map one or more potential linkages between the Jalisco and Sonora Core Areas (i.e., within the Sinaloa Secondary Area) sufficient to allow natural jaguar dispersal, including potential barriers and impediments identified based on field visits, and develop and implement strategies for mitigating these impediments in the corridor. (*Recovery Criteria 3.3.1.B.iii and 3.3.2.B.iii)	3.3.1.B.v; 3.3.2.B.v	Periodic	FWS, JRT	Yes*	284	0	0	0	0	116	Costs for mapping are included in Action 5.1.1.3. Costs for describing conditions within the linkages include 2 FTEs for 1 year plus vehicles, fuel, computers, communications, and miscellaneous. Costs for documenting jaguar use of these areas are included in Action 1.1. Describing conditions within the linkages should be updated every 15 years. * mapping only

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2b	4.1.1.3.	Map two or more non-overlapping potential trans-border linkages within the Borderlands Secondary Area sufficient to allow natural jaguar dispersal, including potential barriers and impediments identified based on field visits, and develop and implement strategies for mitigating these impediments in the corridors. (*Recovery Criteria 3.3.1.B.iv and 3.3.2.B.iv)	3.3.1.B.vi; 3.3.2.B.vi	Periodic	FWS, JRT	Yes*	284	0	0	0	0	0	Costs for mapping are included in Action 5.1.1.3. Costs for describing conditions within the linkages include 2 FTEs for 1 year plus vehicles, fuel, computers, communications, and miscellaneous. Costs for documenting jaguar use of these areas are included in Action 1.1. Describing conditions within the linkages should be updated every 15 years. * mapping only
1b	4.1.1.4.	Map and field verify potential connective areas between NRU and PARU, including the Sierra Madre Oriental.	3.3.1.A.i.; 3.3.2.A.i; 3.3.1.B.ii.; 3.3.2.B.ii.	4	COLPOS, CONANP, Panthera	No	0	0	0	0	0	0	Costs are included in action 4.2.4.
1b	4.1.1.5.	Develop and update as needed state-specific maps delineating land tenure/ownership patterns overlaid with jaguar distribution information throughout the NRU. (* Recovery Criteria 3.3.1.B.ii, 3.3.1.B.iii, and 3.3.1.B.iv)	3.3.1.B.iv., v., vi.	Periodic	FWS, JRT	No	0	0	0	0	0	0	Costs, including updates every 15 years, are included in actions 4.1.1.1. through 4.1.1.3.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2b	4.1.1.6.	Incorporate results of jaguar habitat use studies from section 1 to help further refine maps above.	3.3.1.B.iv., v., vi.	Periodic	FWS, JRT	Yes	0	0	0	0	0	0	Costs are included in 4.1.1.1. through 4.1.1.3. Updates would occur every 15 years.
NA	4.1.2.	Prioritize areas for conservation based on mapping and validation.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2b	4.1.2.1.	Prioritize the mapped and verified areas in the NRU.	3.3.2.B.iv., v., vi.	Periodic	FWS, JRT	Yes	0	0	0	0	0	0	Costs included in action 8.2. Updates would every 15 years.
2b	4.1.2.2.	Prioritize inter-JCU corridors throughout the PARU to highlight those corridors that most contribute to rangewide connectivity.	3.3.1.A.i.; 3.3.2.A.i.	Periodic	Panthera	No	54	0	0	16	0	0	Costs include salary for 4 Panthera staff to meet for one week, plus travel and per diem. Updates would occur every 15 years.
NA	4.2.	Protect jaguar habitat and corridors.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	4.2.1.	Protect a network of blocks of high-quality habitat (capable of supporting at least three breeding females) and the habitat connectivity matrix between blocks within each Core Area (Sonora and Jalisco) that will support genetically and demographically vigorous jaguar populations for the foreseeable future. (*Recovery Criterion 3.3.2.B.ii.)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
1b	4.2.1.1.	Identify existing and proposed conservation lands and assess the level of protection in current and potential jaguar range in the core areas of the NRU.	3.3.2.B.iv.	Periodic	CONANP, FWS, JRT	No	170	0	34	0	0	0	Costs include .5 FTE, transportation, and equipment. This would be conducted every 10 years until 2057.
2a	4.2.1.2.	Increase the number and total area of protected areas (e.g., federal, state, tribal, local, private, etc.) in core areas in the NRU.	3.3.2.B.iv.	Continuous	CONANP, All	No	64,217	50	10,050	425	10,283	658	Costs include: planning; land purchase; hiring and maintaining a minimum of 11 FTEs per protected area; implementing subsidy programs (e.g., PET, PROVICOM); infrastructure development and maintenance; vehicles and fuel; equipment; and implementation of SMART for 2 protected areas in the Sonora Core Area and 1 protected area in the Jalisco Core Area.
2a	4.2.1.3.	Maintain and improve connectivity between protected areas within the core areas.	3.3.2.B.ii., iv.	Continuous	CONANP, All	No	0	0	0	0	0	0	Costs are included in action 4.2.6.2.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2a	4.2.1.4.	Improve operation, administration, and infrastructure of protected areas that support jaguars in the Core Areas.	3.3.2.B.iv.	Continuous	CONANP, SDWM, All	No	45,430	0	0	1,271	886	886	Costs are based on adding an average of 5 FTEs, according to protected area size, to each existing protected area in the Sonora and Jalisco Core Areas (there are currently 6 protected areas in these areas: Alamos, Manatlan, Marismas Nayarit, Marismas Sinoloa, Chamela-Cuixmala, and Distrito de Riego 043), plus improved transportation and communication, and implementing SMART.
NA	4.2.2.	Ensure that landscape permeability will be maintained for jaguars within the Sinaloa Secondary Area. (*Recovery Criterion 3.3.2.B.iii.)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2b	4.2.2.1.	Identify existing and proposed conservation lands and assess the level of protection in current and potential jaguar range in Sinaloa Secondary Area.	3.3.2.B.v.	Periodic	CONANP, FWS, JRT	No	170	0	34	0	0	0	Costs include .5 FTE, transportation, and equipment. This would be conducted every 10 years until 2057.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2a	4.2.2.2.	Increase the number and total area of protected areas (e.g., federal, state, tribal, local, private, etc.) containing high-quality jaguar habitats or that serve as important corridors for jaguar movement in the Sinaloa Secondary Area.	3.3.2.B.v.	Continuous	CONANP, All	No	20,453	0	0	0	0	0	Costs include: planning; land purchase; hiring and maintaining a minimum of 11 FTEs per protected area; implementing subsidy programs (e.g., PET, PROVICOM); infrastructure development and maintenance; vehicles and fuel; equipment; and implementation of SMART for 1 protected area in the Sinaloa Secondary Area. Planning would start in 2022.
2a	4.2.2.3.	Improve operation, administration, and infrastructure of protected areas that support jaguars in the Sinaloa Secondary Area.	3.3.2.B.v.	Continuous	CONANP, SDWM, All	No	7,791	0	0	0	229	155	Costs are based on adding 5 FTEs to the existing protected area in the Sinaloa Secondary Area (Cacaxtla), plus improved transportation and communication, and implementing SMART.
NA	4.2.3.	Ensure that landscape permeability for jaguars, including at least two trans-border linkages, will be maintained throughout the Borderlands Secondary Area. (*Recovery Criterion 3.3.2.B.iv.)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	4.2.3.1.	Identify existing and proposed conservation lands and assess the level of protection in current and potential jaguar range in the Borderlands Secondary Area.	3.3.2.B.vi.	Periodic	CONANP, FWS, JRT	No	170	0	34	0	0	0	Costs include .5 FTE, transportation, and equipment. This would be conducted every 10 years until 2057.
3	4.2.3.2.	Increase the number and total area of protected areas (e.g., federal, state, tribal, local, private, etc.) containing high-quality jaguar habitats or that serve as important corridors for jaguar movement in the Borderlands Secondary Area.	3.3.2.B.vi.	Continuous	CONANP, All	No	19,987	0	0	0	0	0	Costs include: planning; land purchase; hiring and maintaining a minimum of 11 FTEs per protected area; implementing subsidy programs (e.g., PET, PROVICOM); infrastructure development and maintenance; vehicles and fuel; equipment; and implementation of SMART for 1 protected area in the Borderlands Secondary Area. Expenses are based on costs in Mexico. Planning would start in 2024.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
3	4.2.3.3.	Improve operation, administration, and infrastructure of protected areas that support jaguars in the Borderlands Secondary Area.	3.3.2.B.vi.	Continuous	BLM, CONANP, FS, FWS, NPS, AGFD, NMDGF, SAGARPHA, CEDES, All	No	7,636	0	0	0	0	229	Costs are based on adding 5 FTEs to the existing protected area in the Borderlands Secondary Area (Ajos Bavispe) plus improved transportation and communication, and implementing SMART.
1a	4.2.4.	Investigate, assess, protect and/or restore connective areas between the NRU and PARU.	3.3.1.A.i; 3.3.2.A.i.; 3.3.1.B.ii.; 3.3.2.B.ii.	Continuous	CONANP, SDWM, Panthera	No	61,460	0	200	200	200	200	Costs include: investigating; assessing; planning; land purchase; hiring and maintaining a minimum of 11 FTEs per protected area; implementing subsidy programs (e.g., PET, PROVICOM); infrastructure development and maintenance; vehicles and fuel; equipment; and implementation of SMART for 3 protected areas between the NRU and Los Chimalapas JCU in southern Mexico.
1a	4.2.5.	Protect high priority connective areas between JCUs in the PARU.	3.3.1.A.i; 3.3.2.A.i.; 3.3.1.B.ii.; 3.3.2.B.ii.	Continuous	All	No	11,220	220	220	220	220	220	Costs include time encouraging these actions in the PARU, plus FWS Wildlife Without Borders Latin America jaguar conservation grant funding.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
NA	4.2.6.	Develop, evaluate, improve, implement, and maintain governmental and non-governmental conservation incentive programs and tools to protect jaguars and their habitat.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1b	4.2.6.1.	Compile and summarize information on governmental and non-governmental conservation incentive programs that are available to landowners within jaguar habitat.	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below
See above		In the U.S.	3.3.1.B.iii., vii., viii.; 3.3.2.B.iii., vii., viii.;	Periodic	FWS, USGS, UA	Yes	415	330	0	0	0	0	Update information on incentive programs every 10 years until 2066. Update cost includes 1/6 FTE.
See above		In the Mexico portion of the NRU	3.3.1.B.–all; 3.3.2.B.–all	Periodic	CONANP, DGVS, Panthera, All	No	43	0	19	0	0	0	Costs for compiling information include an FTE for 6 months. Update information on incentive programs every 10 years until 2057. Update cost includes 1/6 FTE.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
1a	4.2.6.2.	Develop, improve, maintain, fund, and implement effective programs to protect jaguar habitat.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Continuous	CONANP, DGVS, FWS, Panthera, All	No	147,000	0	0	3,000	3,000	3,000	Costs include developing, improving, maintaining, and implementing programs to protect jaguar habitat through 2066, including 10 FTEs. Additional costs for implementing programs are based on CONAFOR's payment for ecosystem services programs.
1b	4.2.6.3.	Distribute a list of conservation incentive programs to landowners within jaguar habitat and assist them in applying for the programs.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Continuous	FWS, USGS, UA, NRCS, CONANP, SAGARPA, SDWM	No	637	0	0	13	13	13	Costs here only include those in the U.S. (1/8 FTE). Costs for Mexico are included above.
1a, b	4.2.6.4.	Develop and implement other tools to protect jaguar habitat.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Continuous	All	No	100	0	0	0	50	50	Costs only include the cost to develop new tools. Implementation costs will be calculated after the tools are developed.
2a	4.2.7.	Increase the number of sustainable, jaguar-friendly revenue producing alternatives in jaguar habitat.	3.3.1.B.–all; 3.3.2.B.–all	Continuous	Panthera, SECTUR, SEDESOL, SE, All	No	16,300	0	326	326	326	326	Costs based on 2 FTEs to run a grant program plus annual funding for grants and microloans.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2b	4.2.8.	Establish guidelines and protocols for jaguar-compatible infrastructure construction and development projects (e.g., roads, power lines, housing, dams, mines, etc.).	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	4	JRT, SCT, DGIRA; County, State, Federal DOT, Energy, and Developme nt; All	No	200	0	0	50	50	50	Costs are based on the cost of developing recommendations for road crossings (action 5.1.1.2.), multiplied by four due additional protocols needed for different action types.
1a, b	4.2.9.	Establish, improve, enforce, and/or fund implementation of laws and procedures to protect jaguar habitat.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Continuous	PROFEPA; PGR; Local, State, and Federal Legislatures ; AGFD; NMGFD; FWS; All	No	71,548	0	0	2,112	1,382	1,382	Costs for improving enforcement of existing laws are based on adding a minimum of 6 additional PROFEPA agents per Core and Secondary Area in the NRU in Mexico (24 total additional agents), plus transportation, communications, and equipment. Costs for establishing and improving laws are included in action 6.3. below.
1c	4.2.10.	Monitor the effectiveness of actions implemented in 4.2.1. to 4.2.9.	3.3.1.B.–all; 3.3.2.B.–all	Continuous	FWS, JRT, All	No	0	0	0	0	0	0	Costs will be calculated after action 4.3.3. has begun.
1b	4.2.11.	Provide jaguar information and scientific expertise to agencies involved in managing and protecting jaguar habitat.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Ongoing	FWS, AGFD, NMDGF, JRT, CONANP, SDWM, AAI	Yes, in U.S. only	2,601	51	51	51	51	51	Costs include 1/8 FTE in the U.S. and 1 FTE in Mexico.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
	4.3.	Restore jaguar habitat and corridors.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	4.3.1.	Develop methodologies for jaguar habitat restoration.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	2	AAI, CONAFOR, SAGARPA, All	No	250	0	0	0	0	0	Costs based on the development of other protocols. The protocol would be developed in 2026 with an update in 2041.
3	4.3.2.	Identify and prioritize lands for habitat restoration.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Periodic	CONAFOR, FWS, JRT, AAI	No	32	0	0	0	0	8	Some costs are included in action 8.2. Additional costs added here include costs of salary for 2 people for 1 week, plus travel and per diem, every 15 years.
3	4.3.3.	Implement habitat restoration on a priority basis to benefit jaguars.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Periodic	CONAFOR, FWS, JRT, AAI	No	0	0	0	0	0	0	Costs will be calculated after the restoration methods are developed and the areas to restore are identified and prioritized.
3	4.3.4.	Monitor the effectiveness of habitat restoration efforts above.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Periodic	CONAFOR, FWS, JRT, AAI	No	0	0	0	0	0	0	Costs will be calculated after action 4.3.3. has begun.
NA	**5.**	**Assess, minimize, and mitigate the effects of expanding human development on jaguar survival and mortality.**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	5.1.	Minimize the impacts of roads on jaguars.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	5.1.1.	Assess the impacts of roads on jaguars.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2b	5.1.1.1.	Conduct research to better understand the impacts of roads and highways on jaguars and their movements.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Continuous	AAI, UJAT, Panthera,	No	0	0	0	0	0	0	Costs included in actions 1.4.1. and 5.1.1.4.
2b	5.1.1.2.	Conduct a review of and develop recommendations for enhancements (e.g., underpasses, overpasses, guiding fences, etc.) that allow for passage of jaguars across road corridors that would be effective in a variety of different habitat types.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	1	FWS, JRT	Yes	50	50	0	0	0	0	Costs based on executed contract.
2b	5.1.1.3.	Identify areas where enhancements (e.g., underpasses, overpasses, guiding fences, etc.) would improve the passage of jaguars across different types of road corridors that would be effective in a variety of different habitat types.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Periodic	FWS, JRT	Yes	150	50	0	0	0	0	Initial costs based on executed contract. Additional costs based on identifying areas every 20 years.
2b	5.1.1.4.	Conduct field studies to determine where road enhancements should be constructed and the effectiveness of the enhancements post-construction.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Continuous	AAI, UJAT, Panthera,	No	1,200	0	0	40	40	40	Costs include 5 studies in Mexico lasting 6 years each.
NA	5.1.2.	Avoid, minimize, and mitigate the impacts of roads on jaguars.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2a	5.1.2.1.	Based on the information from 5.1.1., implement design measures to facilitate jaguar movement across existing and new roads.	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below	
See above		In the U.S.	3.3.1.B.iii.; 3.3.2.B.iii.	12	Local, State, and Federal DOT, AGFD, FWS, UA	No	15,488	0	0	0	55	55	Costs are based on construction and pre- and post-monitoring of a total of 15 crossings and associated infrastructure on existing highways (Highways 82 and 83—see Stoner et al. 2015). Costs for future crossings will be calculated as needed. Currently, approximate costs for highway crossing infrastructure in the U.S. are $1,000,000 each; however, costs can vary significantly depending on the type and size of the crossing.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
See above		In the Mexico portion of the NRU	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Continuous	Local, State, and Federal DOT, CONANP, All	No	4,679	0	0	75	75	75	Costs are based on construction and monitoring of a total of 40 crossings and associated infrastructure on existing highways. This includes 5 crossings at 8 areas in Mexico (see Stoner et al. 2015). Costs for future crossings will be calculated as needed. Currently, approximate costs for highway crossing infrastructure in Mexico are $100,000; however, costs can vary significantly depending on the type and size of the crossing.
2a	5.1.2.2.	Minimize the impacts of new roads in jaguar habitat and corridors.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Periodic	FWS, DGIRA, Local, State, and Federal DOT in U.S. and Mexico	No	0	0	0	0	0	0	Costs will be calculated on a case-by-case basis as new roads are proposed in jaguar habitat.
2b	5.1.2.3.	Engage federal, state, and local departments of transportation and other appropriate authorities in jaguar conservation.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Ongoing	CONANP, FWS, JRT, Local, State, and Federal DOT in U.S. and Mexico	Yes, for U.S. only	357	7	7	7	7	7	Costs include personnel time for jaguar biologists and transportation department representatives to meet once a year.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2a	5.2.	Assess, avoid, minimize, and mitigate the impacts of other human development on jaguars (e.g., mines, dams, border infrastructure, housing and urban development, energy projects, railroads, large scale agriculture, etc.).	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Ongoing	All	No	0	0	0	0	0	0	Costs will be calculated on a case-by-case basis as needed.
2c	5.3.	Monitor the effectiveness of actions implemented in 5.1. and 5.2.	3.3.1.B.i.-vi; 3.3.2.B.i.-vi.	Continuous	FWS, JRT, All	No	0	0	0	0	0	0	Costs will be calculated after 5.1. and 5.2. are in progress.
NA	**6.**	**Minimize direct human-caused mortality of jaguars.**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1b	6.1.	Measure direct human-caused mortality of jaguars. (*Recovery Criterion 3.3.1.B.vii and 3.3.2.B.vii)	3.3.1.B.vii.; 3.3.2.B.vii.	Periodic	SDWM, PROFEPA, FWS	No	250	0	0	0	0	25	Costs include time for 1/4 FTE for 4 coordinators and 4 field technicians in Mexico to conduct the study every 5 years.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
1a, b	6.2.	Determine, develop, fund, and implement education, outreach, and/or incentive programs to prevent the illegal killing of jaguars (also see action 6.6 below).	3.3.1.B.vii.; 3.3.2.B.vii.	Ongoing	AAI, SDWM, CONAGUA, CONANP, FWS, JRT, NRCS, USGS, All	No	3,978	78	78	78	78	78	Costs are based on action 7.2.2. and include the development, funding, and implementation of education and outreach, including online modules, CDs and booklets, workshops, teacher trainings, and roadside signs. Costs also include the development of incentive programs; however, the cost to fund and implement them will be determined after the programs are developed.
1a, b	6.3.	Analyze existing laws, strengthen and enact new laws if needed; and enforce laws that control and reduce killing of jaguars. (*Recovery Criteria 3.3.1.B.viii. and 3.3.2.B.viii.)	3.3.1.B.vii., viii; 3.3.2.B.vii., viii.	Continuous	DGVS, CONANP, PROFEPA, PGR, SDWM	No	1,900	0	76	152	152	152	Costs are based on 2 FTEs for 1 year to analyze laws; 4 FTEs to strengthen and enact new laws for 8 years; 4 FTEs for 4 years to train judges, law enforcement, attorneys. Majority of costs for enforcement in the field are included in action 4.2.9. above.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility: Parties	Responsibility: Is FWS Lead?	Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s): 2016	2017	2018	2019	2020	Comments
2a	6.4.	Implement community programs to monitor and protect jaguars.	3.3.1.B.vii.; 3.3.2.B.vii.	Ongoing	FWS, USGS, AAI, CONANP, PROFEPA, CONAFOR, All	Yes, for U.S. only	12,954	254	254	254	254	254	Costs include 1/4 FTE per area in the NRU to coordinate community vigilance groups, plus fuel. Additionally, costs include annual grants (to cover training and incidentals for community participants) for 2 communities per area in the NRU. Some overlap in participants is anticipated with action 1.1.4. Additionally, some costs for this action, such as vehicles and communications, are covered in action 1.1.4.
1c	6.5.	Monitor the effectiveness of the tools/programs/laws developed and implemented above in 6.2, 6.3, and 6.4.	3.3.1.B.vii., viii; 3.3.2.B.vii., viii.	Continuous	FWS, JRT, All	No	0	0	0	0	0	0	Costs will be calculated after 6.2. to 6.4. are in progress.
NA	6.6.	Reduce conflicts between jaguars and livestock operations (the term livestock is used to include all hooved animals produced within the jaguar's range with which conflicts may occur; however, cattle are the primary concern).	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
1b	6.6.1.	Identify landowner concerns regarding damage to livestock from jaguars.	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below
See above		In the U.S.	3.3.1.B.vii.; 3.3.2.B.vii.	Ongoing	NRCS, UA, USDA-APHIS-WS, SDA	No	200	Included in costs in 4.2.6.1.	4	4	4	4	Initial costs included in 4.2.6.1. Update information annually until 2066. Update costs include an FTE for 1 week for 2 people.
See above		In the Mexico portion of the NRU	3.3.1.B.vii.; 3.3.2.B.vii.	Ongoing	LA, SAGARPA, SDA, SDR	No	6,950	0	139	139	139	139	Costs include time for 7 half-time field/community personnel and 4, 1/8-time government personnel, as well as vehicle, mileage, computer, and miscellaneous equipment, annually until 2066.
1b	6.6.2.	Compile and develop a document that reviews jaguar-friendly livestock management practices.	3.3.1.B.vii.; 3.3.2.B.vii.	Periodic	Panthera, UA	No	209	0	0	0	38	0	Costs include personnel time to initially compile and update existing documents, and then update the compiled document every 5 years.
1b	6.6.3.	Support, encourage, and fund jaguar-friendly livestock management practices.	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility: Parties	Responsibility: Is FWS Lead?	Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s): 2016	2017	2018	2019	2020	Comments
See above		In the U.S.	3.3.1.B.vii.; 3.3.2.B.vii.	Ongoing	FS, BLM, FWS, NMLSO, ASLD, NRCS, UA, USDA-APHIS-WS, SDA	No	200	Included in costs in 4.2.6.1.	4	4	4	4	Support and encouragement initial costs are included in 4.2.6.1. Continued support and encouragement annually until 2066; these costs include an FTE for 1 week for 2 people. Costs for funding will be calculated after the need for assistance is determined.
See above		In the Mexico portion of the NRU	3.3.1.B.vii.; 3.3.2.B.vii.	Continuous	LA, SAGARPA, SDA, SDR, CONANP	No	10,990	0	139	159	539	539	Support and encouragement costs include time for 7 half-time field/community personnel and 4, 1/8-time government personnel, as well as vehicle, mileage, computer, and miscellaneous equipment, annually until 2066. These personnel will likely be the same as identified in action 6.6.1. (meaning the half-time personnel identified here and in 6.6.1. will work full-time between these two projects). Additional costs include 8 rancher workshops and 80 pilot ranches, funded at $10,000 per year for 5 years.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2a	6.6.4.	Compensate for livestock loss.	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below
See above		In the U.S.	3.3.1.B.vii.; 3.3.2.B.vii.	Ongoing	MBG	No	6	0	0	0	0	0	Costs include full market value of 1 head of livestock every 20 years.
See above		In the Mexico portion of the NRU	3.3.1.B.vii.; 3.3.2.B.vii.	Ongoing	LA, SAGARPA, SDA, SDR, CONANP	No	306	6	6	6	6	6	Costs include payment for an average 15 head of cattle annually at an average cost of $400 per head, or about 50% of the market value of the animal.
NA	6.6.5.	Improve native prey populations (see also actions under Objective 3).	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2a	6.6.5.1.	Encourage livestock and habitat management practices that allow for the healthy presence of native prey species.	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below
See above		In the U.S.	3.3.1.B.vi, vii.; 3.3.2.B.vi., vii.	Ongoing	BLM, FS, FWS, Tribes, NRCS, UA, AGFD, NMDGF	No	200	Included in costs in 4.2.6.1.	4	4	4	4	Continued encouragement annually until 2066; these costs include an FTE for 1 week for 2 people.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
See above		In the Mexico portion of the NRU	3.3.1.B.i., iv.-vii.; 3.3.2.B.i., iv.-vii.	Ongoing	SDWM, SAGARPA, DGVS, ANGADI	No	11,950	0	239	239	239	239	Costs include time for 7 half-time field/community personnel and 4, 1/8-time government personnel, as well as vehicle, mileage, computer, and miscellaneous equipment; plus costs for a small grant program to improve habitat for prey on ranches ($10,000 per ranch; 10 ranches per year) in the NRU annually until 2066.
3	6.6.5.2.	Where the full complement of native prey species are not present or are not at natural densities, reintroduce native prey.	3.3.1.B.i., iv.-vii.; 3.3.2.B.i., iv.-vii.	Periodic	SDWM, AGFD, NMDGF, DGVS, UMAs	No	0	0	0	0	0	0	Costs will be calculated on a site-specific basis as research indicates that prey are not present or not at natural densities.
1c	6.6.6.	Monitor the effectiveness of the tools used to reduce conflicts between jaguars and cattle.	3.3.1.B.i., iv.-vii.; 3.3.2.B.i., iv.-vii.	Continuous	FWS, JRT, All	No	0	0	0	0	0	0	Costs will be calculated after all of 6.6. is in progress.
NA	**7.**	**Ensure long-term jaguar conservation through adequate funding, public education and outreach, and partnerships.**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NA	7.1.	Secure funding for jaguar conservation.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility: Parties	Responsibility: Is FWS Lead?	Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s): 2016	2017	2018	2019	2020	Comments
1b	7.1.1.	Secure funding for jaguar conservation including the creation and management of an endowment to implement USFWS jaguar recovery plan actions.	All	Continuous	FWS, JRT, NGOs	No	1,275	0	0	0	100	25	Initial costs include 1 FTE to create the endowment, then 1/4 FTE to manage it annually through 2066.
3	7.1.2.	Develop an agreement between USFWS and CONANP with the goal of prioritizing, funding, and implementing jaguar recovery actions.	All	2	CONANP, FWS	Yes	31	0	0	10	21	0	Costs include salary for U.S. and Mexican government personnel to develop and sign the agreement.
2b	7.1.3.	Direct mitigation and violation revenues generated from actions that impact jaguars toward support of appropriate jaguar recovery actions.	All	Continuous	CONANP, DGVS, PROFEPA, DGIRA, SECTUR	No	1,862	0	0	38	38	38	Costs include salary for Mexican government personnel to manage mitigation revenue funds for jaguar conservation through 2066.
NA	7.2.	Educate the public and professionals on jaguar conservation.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	7.2.1.	Survey residents' attitudes toward jaguars and jaguar conservation.	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below
See above		In the U.S.	All	Periodic	FWS, JRT	Yes	270	54	0	0	0	0	Costs based on Survey of Attitudes contract. Update survey every 10 years until 2056.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
See above		In the Mexico portion of the NRU	All	Periodic	JRT	No	540	0	0	0	0	108	Costs based on Survey of Attitudes contract, but accounting for salary costs in Mexico. Update survey every 10 years until 2060.
2a, b	7.2.2.	Conduct education and outreach programs to increase awareness of the value and current status of jaguars and to promote jaguar conservation.	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below	See below
See above		In the U.S.	All	Ongoing	FWS, USGS, UA, JRT, NGOs	Yes	1,405	105	26	26	26	26	Costs for 2016 based on a 2-year Intra-agency Agreement for Education and Outreach. Costs for subsequent years include 50% the annual agreement costs continuing through 2066.
See above		In the Mexico portion of the NRU	All	Ongoing	JRT, CONANP, SEP, NGOs	No	2,652	52	52	52	52	52	Annual costs based on 50% of the annual agreement costs above, but based on Mexican salaries, and multiplied times 4 to account for work in every Area continuing through 2066.

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2b	7.2.3.	Conduct education and outreach programs to increase awareness of the value and current status of jaguars and to promote jaguar conservation.	All	Ongoing	CONANP, AAI, JRT	No	1,183	13	13	65	13	13	Every 5 years, a workshop for government and tribal personnel will be held. Costs for these workshops are based on estimated workshop costs from Wildlife Without Borders Mexico grants. In interim years, costs include 1 month of an FTE to support and education and training. Work will be continued through 2066.
2c	7.2.4.	Monitor and assess the effectiveness of survey, education, and outreach efforts.	All	Continuous	FWS, JRT, All	No	0	0	0	0	0	0	Costs will be calculated after 7.2.1. to 7.2.3. are in progress.
2b	7.2.5.	Develop and maintain partnerships with agencies, organizations, and citizens to conserve jaguars.	All	Ongoing	FWS, JRT, All	No	0	0	0	0	0	0	Costs for this action are included in all other recovery actions.
NA	**8.**	**Practice adaptive management in which recovery is monitored and recovery tasks are revised by the USFWS in coordination with the Jaguar Recovery Team as new information becomes available.**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Priority Number	Action Number	Action Description	Recovery Criterion Number	Action Duration (Years)	Responsibility		Total Cost[3] ($1,000s)	Cost Estimate by FY (by $1,000s)					Comments
					Parties	Is FWS Lead?		2016	2017	2018	2019	2020	
2b	8.1.	Use adaptive management principles to evaluate this recovery effort on an ongoing basis, and make necessary changes, based on experience, outcomes, and changed circumstances.	All	Ongoing	FWS, JRT	Yes	0	0	0	0	0	0	Costs covered below.
3	8.2.	Compile and discuss jaguar recovery accomplishments and updates with the Jaguar Recovery Team at least once per year.	All	Ongoing	FWS, JRT	Yes	1,091	20.5	4.5	20.5	4.5	70	Costs include 1) biannual meetings via webex with the Jaguar Recovery Team; 2) biennial meetings with the Jaguar Recovery Team Co-Leaders; 3) meetings every 6 years with the full Jaguar Recovery Team (on years with full meetings, no Co-Leader meetings or webexes will be held).
3	8.3.	Exchange information between agencies in Mexico and the U.S. to discuss progress in implementing state and federal jaguar recovery/conservation plans in the U.S. and Mexico.	All	Ongoing	FWS, CONANP, AASA	Yes	0	0	0	0	0	0	Costs covered above.
3	8.4.	Establish a binational agreement or letter of intent (Mexico – U.S.) to implement binational recovery actions in the Jaguar Recovery Plan and PACE.	All	1	FWS, CONANP	Yes	20	0	0	20	0	0	Costs include personnel time and travel to Mexico.

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Figure 1. Map of the extent of the Northwestern Jaguar Recovery Unit (NRU), as updated by Sanderson and Fisher (2013). The NRU covers 226,826 km^2 (87,578 mi^2) extending from southwestern New Mexico and southeastern Arizona in the United States, south into Mexico along the Sierra Madre Occidental mountain range to Colima. Core Areas are areas with persistent, verified records of jaguar and recent evidence of reproduction. Secondary Areas are areas with historical and/or recent records of jaguar but no or very few recent records of reproduction.

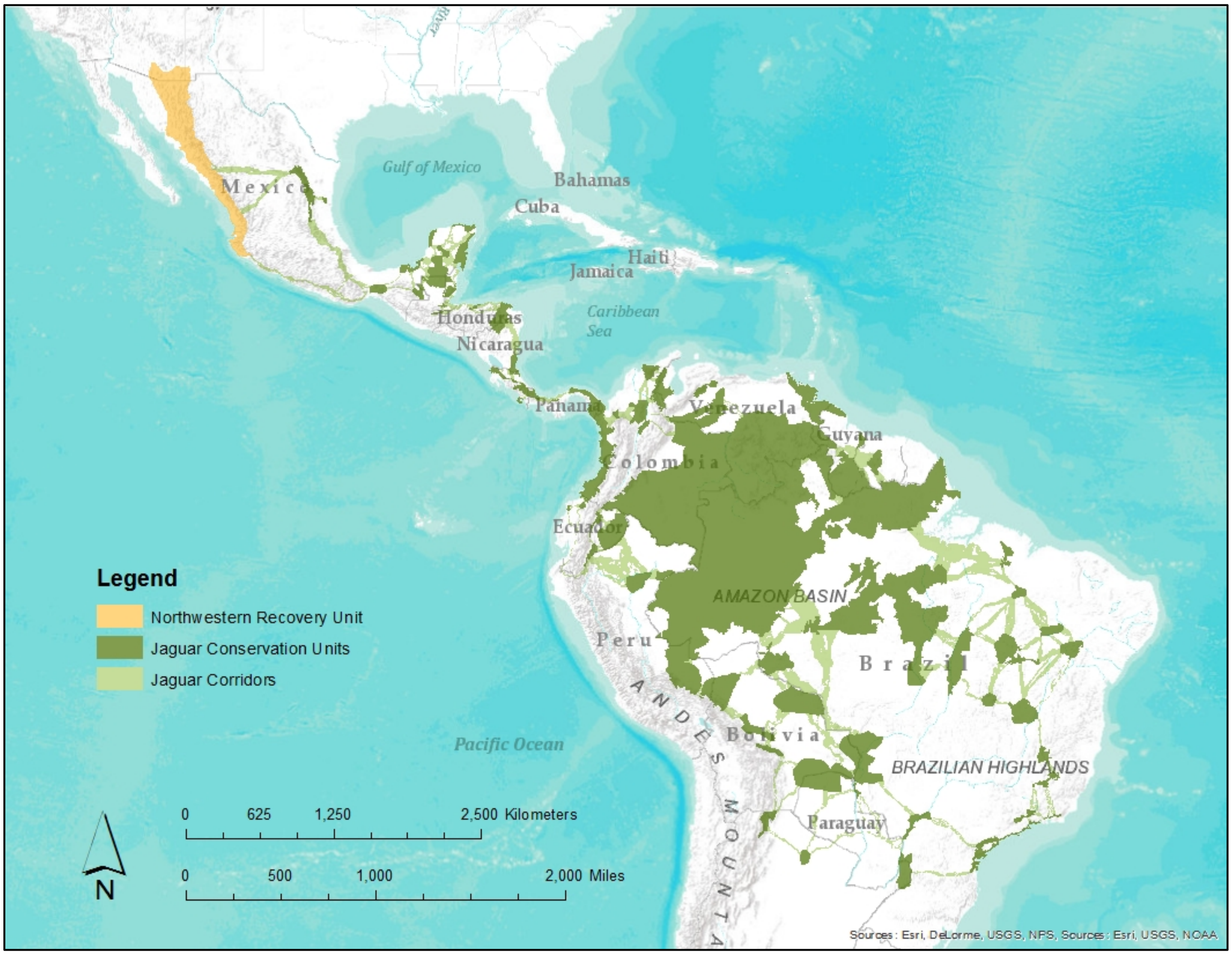

Figure 2. Map of the extent of the Pan American Jaguar Recovery Unit (PARU) in relation to the Northwestern Recovery Unit, modified from Rabinowitz and Zeller (2010). The PARU encompasses 18 countries from Mexico to Argentina and 82 of 84 core areas (modified from Zeller 2007), as well as all potential corridors connecting these areas and the PARU to the NRU (modified from Rabinowitz and Zeller 2010), totaling 6,745,849 km^2 (2,604,587 mi^2). For purposes of this recovery plan, Jaguar Conservation Units are considered Core Areas and Jaguar Corridors are considered Secondary Areas.

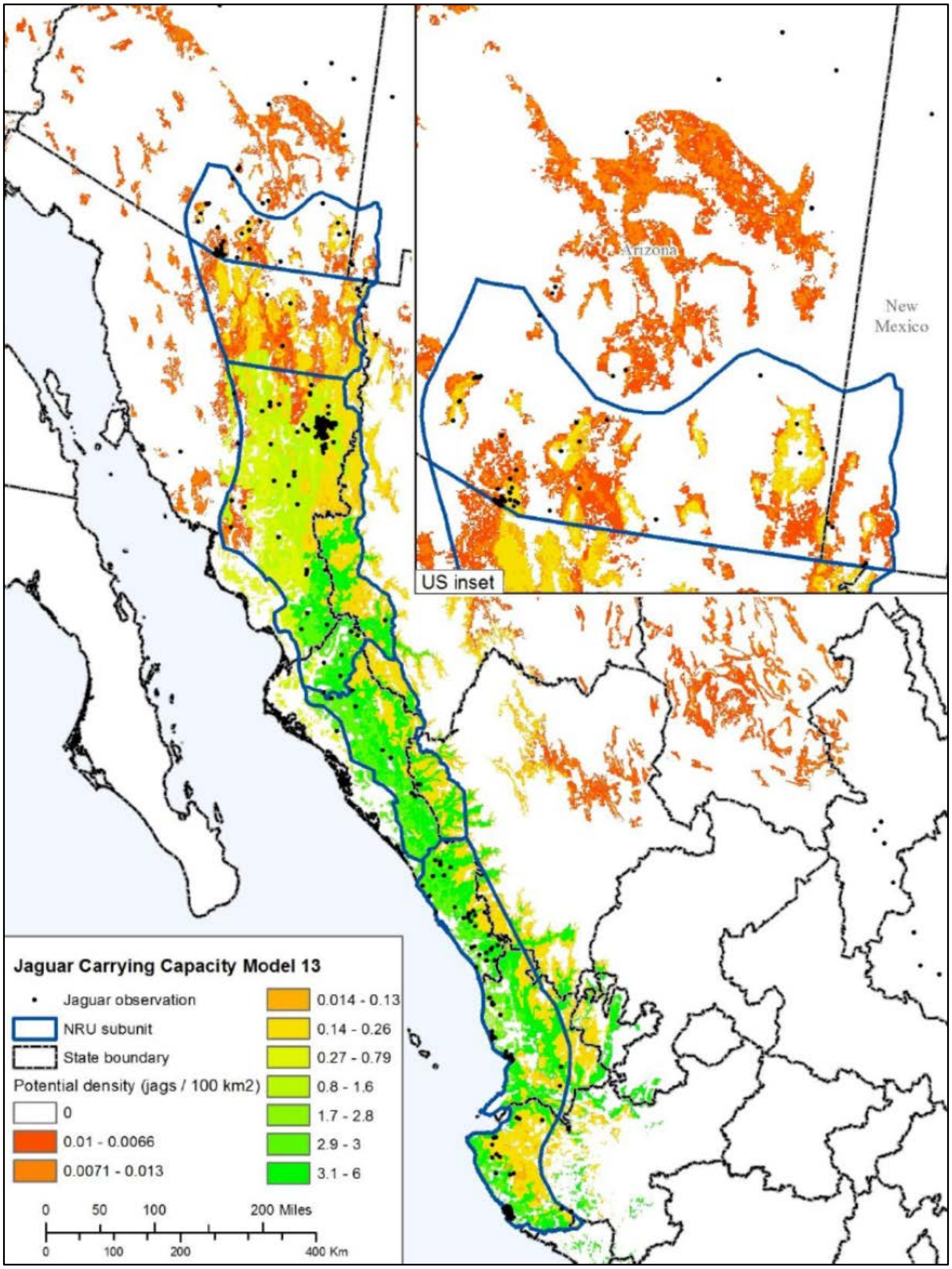

Figure 3. Map of potential jaguar carrying capacity in the Northwestern Recovery Unit using jaguar habitat model version 13 (Sanderson and Fisher 2013).

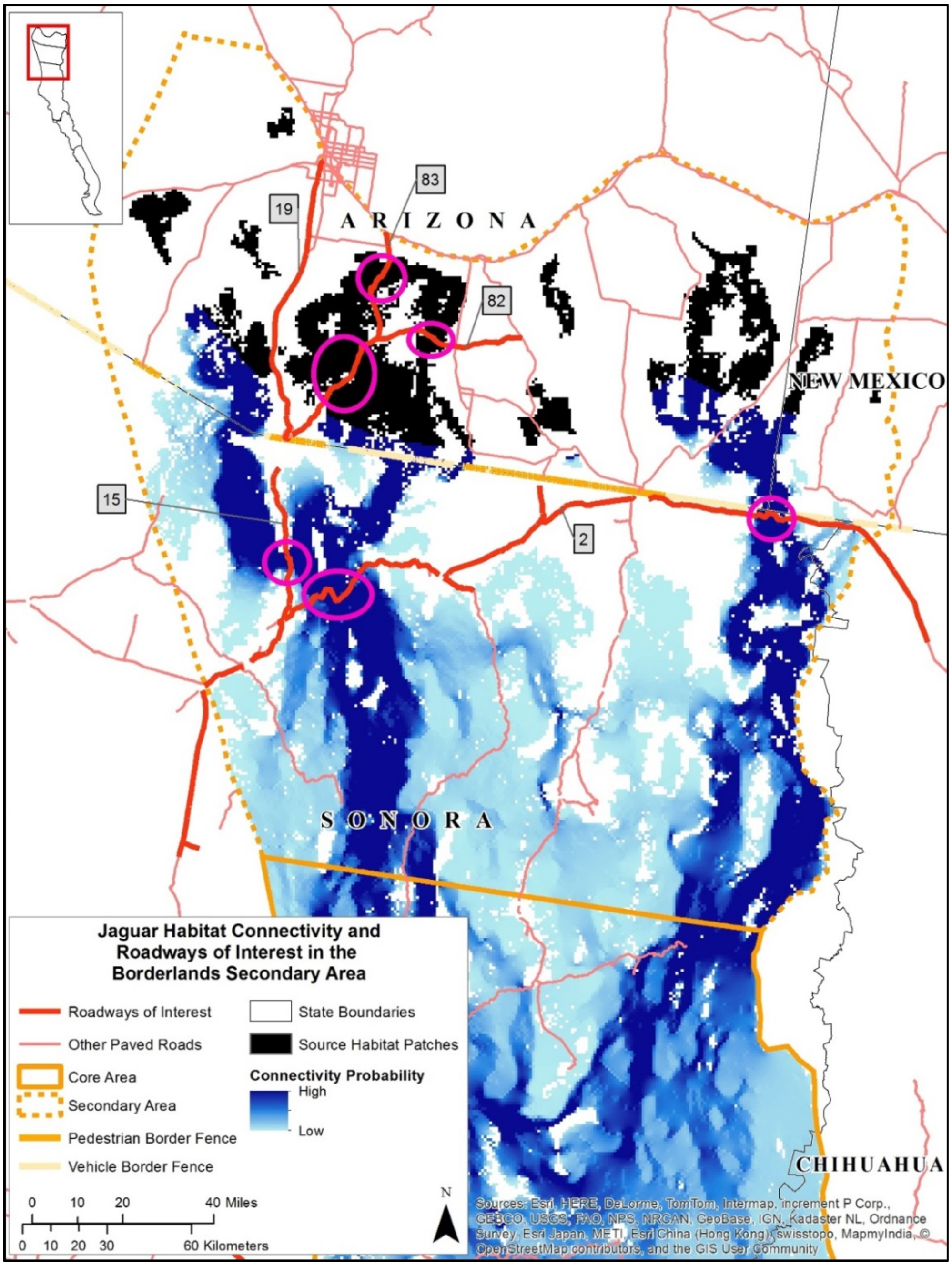

Figure 4. Map of habitat connectivity and roadways of interest in the Borderlands Secondary Area as modeled by Stoner et al. (2015) (some road segments in densely populated areas omitted). A visual examination of this connectivity model, which extends across the entirety of the Northwestern Recovery Unit, reveals three corridors that extend across the U.S.-Mexico border. These corridors are intersected by Mexico Federal Highways 2 and 15. U.S. State Routes 82 and 83 also intersect with "source" habitat patches (used for modeling purposes), which may impact jaguar habitat connectivity. These areas are good candidates for further assessment to determine the potential for road crossing mitigation structures.

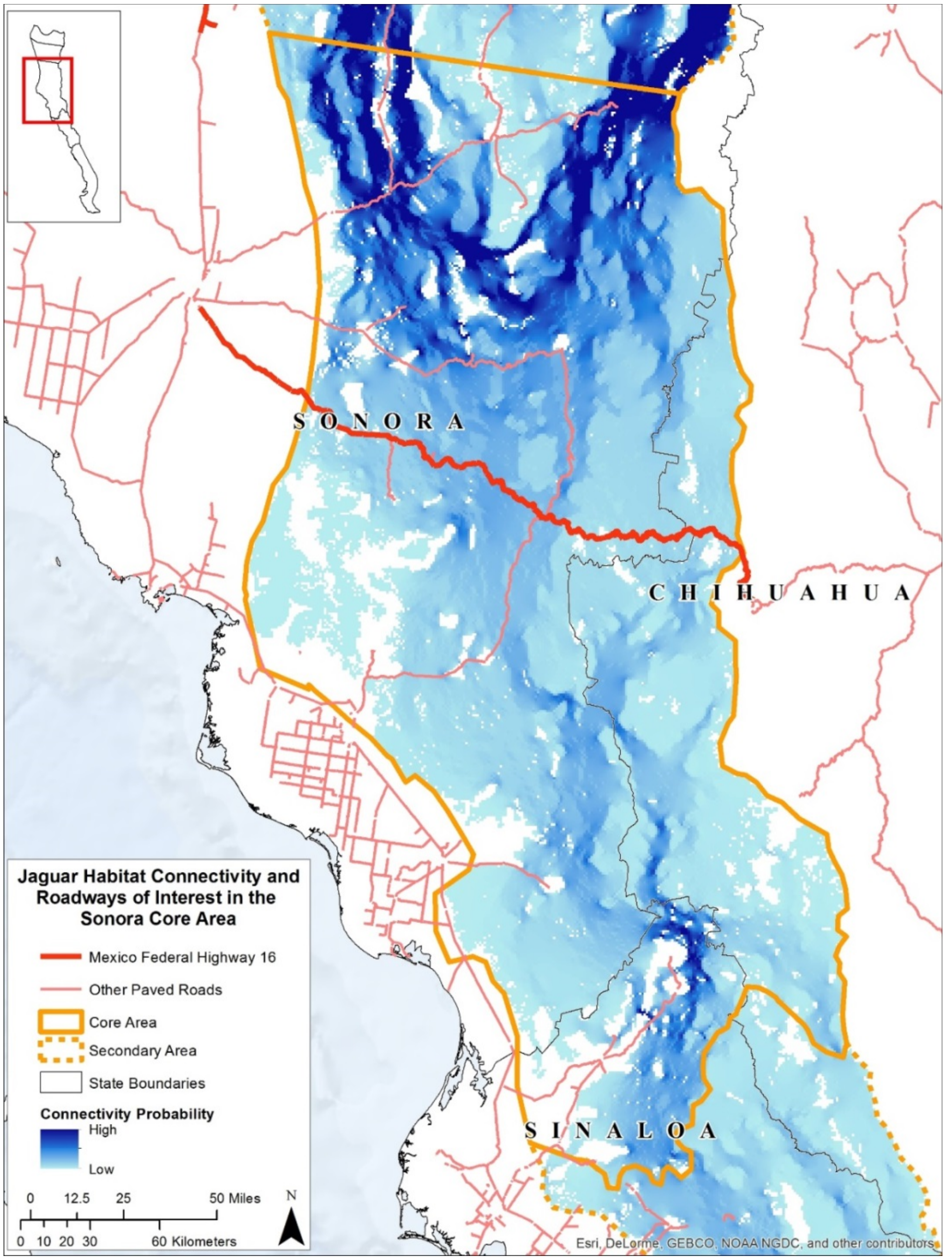

Figure 5. Map of habitat connectivity and a roadway of interest through the Sonora Core Area of the Northwestern Jaguar Recovery Unit as modeled by Stoner et al. (2015) (some road segments in densely populated areas omitted). Connectivity is diffuse in the central part of the Sonora Core Area, but narrows to a more obvious corridor in the southern part of the Area. Although Mexico Federal Highway 16, depicted here, does not intersect with any corridors, it still has the potential to act as a barrier to jaguar dispersal. Additional site-based assessments are needed to identify precise locations for future road mitigation efforts.

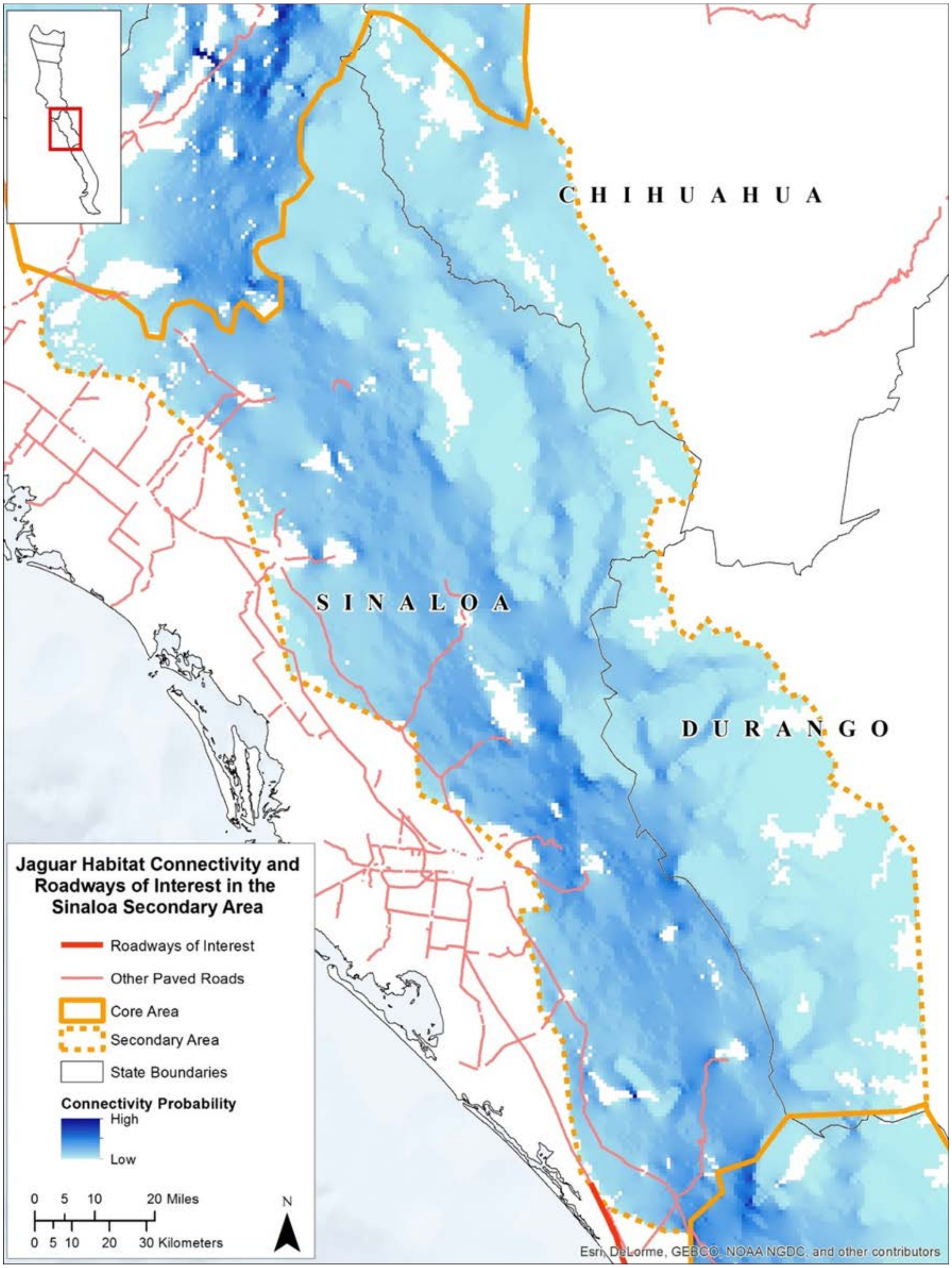

Figure 6. Map of habitat connectivity and roadways of interest in the Sinaloa Secondary Area in the Northwestern Jaguar Recovery Unit as modeled by Stoner et al. (2015) (some road segments in densely populated areas omitted). Connectivity probabilities are diffuse across the Area, but a clear corridor running from north to south is still apparent in the central part of the Area. There are no roads of interest bisecting this Area.

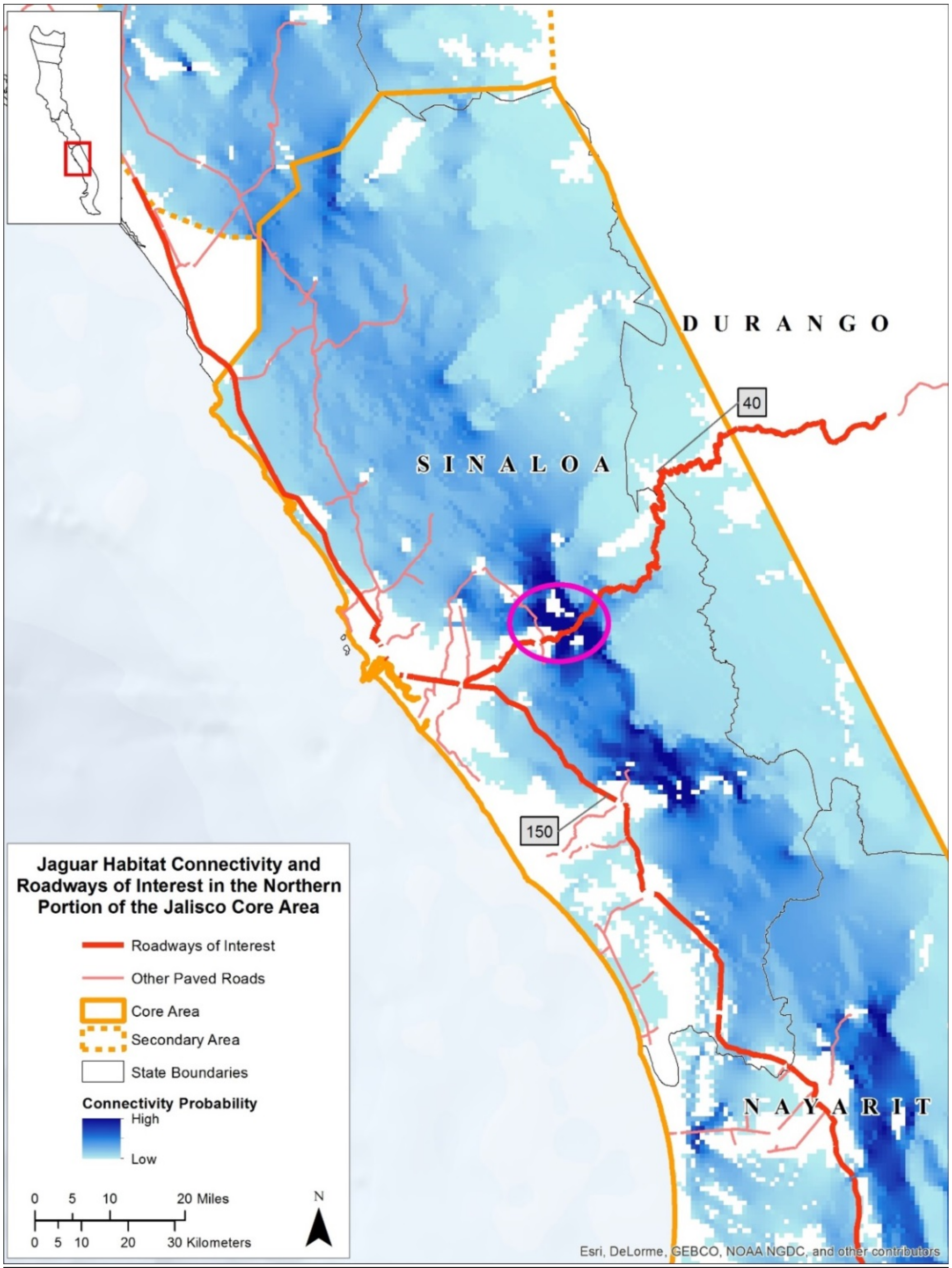

Figure 7. Map of habitat connectivity and roadways of interest through the northern portion of the Jalisco Core Area of the Northwestern Jaguar Recovery Unit as modeled by Stoner et al. (2015) (some road segments in densely populated areas omitted). Connectivity is concentrated near the center of the Core Area, running primarily from north to south. Mexico Federal Highway 40 intersects one corridor, indicated by the circle. The highlighted area is suitable for further assessment and potential road crossing mitigation structures.

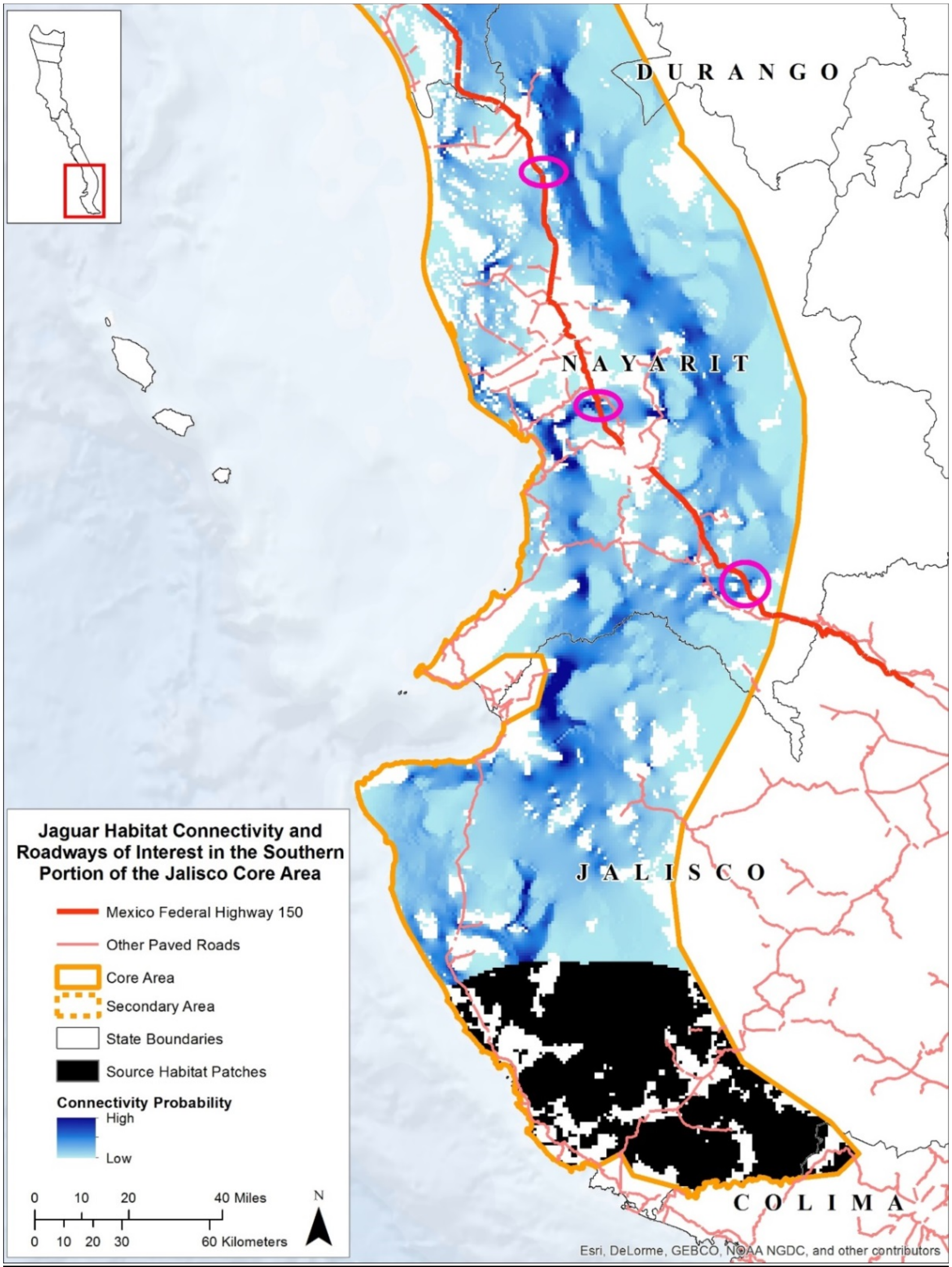

Figure 8. Map of habitat connectivity and roadways of interest through the southern portion of the Jalisco Core Area of the Northwestern Jaguar Recovery Unit as modeled by Stoner et al. (2015) (some road segments in densely populated areas omitted). The connectivity is concentrated along several north-south corridors in this part of the Core Area. In particular, Mexico Federal Highway 150 intersects with three corridors, circled in pink, suitable for further assessment and potential road crossing mitigation structures.

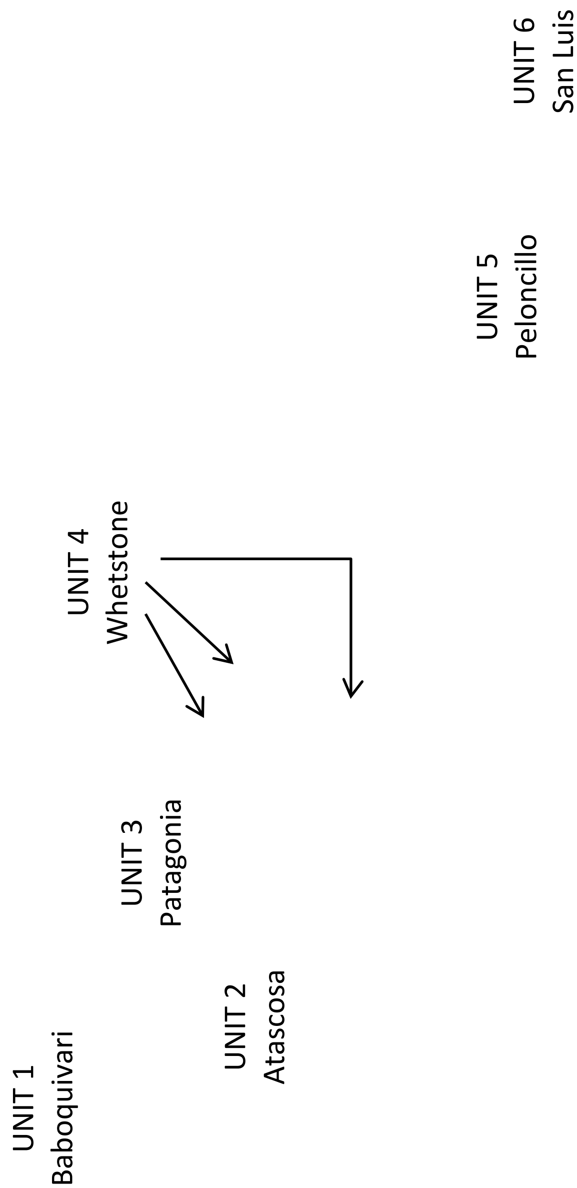

Figure 9. Map of the extent of designated critical habitat units for the jaguar (U.S. Fish and Wildlife Service 2014) and the Northwestern Recovery Unit of the jaguar (Sanderson and Fisher 2013).

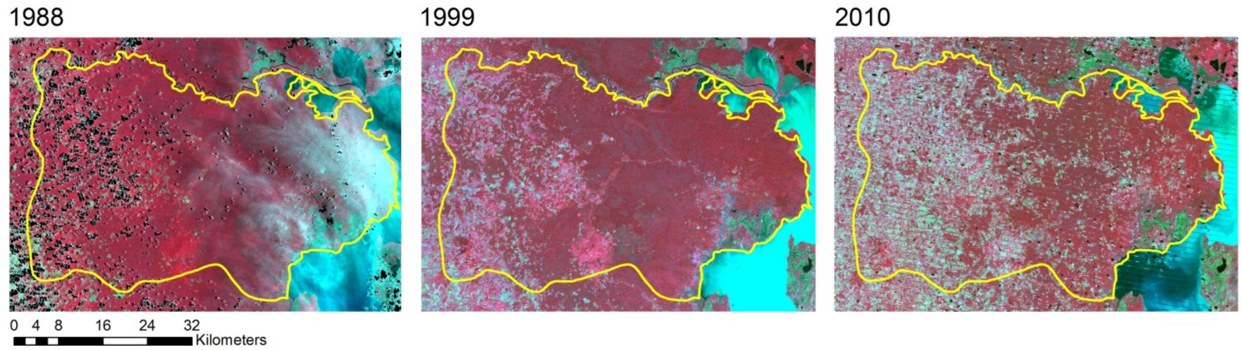

Figure 10. False-color satellite imagery (30-m resolution) of Wawashan Nature Reserve in Nicaragua over a 22-year period. Dark red denotes forested areas, while light shades of red and green denote cleared forest and agricultural lands. Imagery courtesy of Petracca et al. (2014b).

ACRONYMS AND ABBREVIATIONS

Ac	Acres
AGFD	Arizona Game and Fish Department
ANP	Areas Naturales Protegidas (Natural Protected Areas)
CE	Critically Endangered (IUCN Red List criteria)
CENJAGUAR	Censo Nacional del Jaguar (National Jaguar Census)
CFR	Code of Federal Regulations
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CONABIO	Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (National Commission for Knowledge and Use of Biodiversity**)**
CONAFOR	Comisión Nacional Forestal (National Forestry Commission)
CONANP	Comisión Nacional de Areas Naturales Protegidas (National Commission of Protected Areas)
Corridors	Cat Conservation Corridors
DGVS	Dirección General de Vida Silvestre (Mexican Federal Office of Wildlife)
DNA	Deoxyribonucleic acid
Ejido	Community-run ranch in Sonora
EN	Endangered (IUCN Red List criteria)
ESA	Endangered Species Act
ESCA	Endangered Species Conservation Act
Ft	Feet
FR	Federal Register
GIS	Geographic Information System
GPS	Global positioning system
Ha	Hectares
HII	Human Influence Index
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JCMA	Jaguar Conservation Management Area
JCU	Jaguar Conservation Unit
JGR	Jaguar Geographic Region
JRT	Jaguar Recovery Team
Kg	Kilogram
Km	Kilometers

km^2	Square kilometers
Lb	Pound
LC	Least Concern (IUCN Red List criteria)
LGEEPA	Ley General Del Equilibrio Ecológico y Protección al Ambiente (General Act for Ecological Balance and Protection of the Environment)
LGVS	Ley General de Vida Silvestre (General Wildlife Law)
M	Meters
Mi	Miles
mi^2	Square miles
Mb CAPTURE	Behavioral model using program CAPTURE
MEA	Modelo del encuentro aleatorio (model of random encounter)
Mh CAPTURE	Heterogeneous model using program CAPTURE
MMDM	Mean maximum distance moved
Mo CAPTURE	Null model using program CAPTURE
NGO	Non-governmental organization
NMDGF	New Mexico Department of Game and Fish
NOM	Norma Oficial Mexicana (Mexican federal law)
NRU	Northwestern Recovery Unit
NT	Near Threatened (IUCN Red List criteria)
PACE	Programa de Acción Para la Conservación de la Especie (Species Conservation Action Plan – Mexico's equivalent of a recovery plan)
PARU	Pan American Recovery Unit
pers. comm.	Personal communication
PES	Payment for Ecosystem Services
PET	Programa de Empleo Temporal (Temporary Employment Program)
PREP	Proyectos de Recuperación de Especies Prioritarias (Recovery Projects for Priority Species)
PROARBOL	Esquema para combatir la pobreza, recuperar la masa forestal e incrementar la productividad de bosques y selvas de México (Plan to combat poverty, restore forest cover, and increase productivity of forests of Mexico)
PROCER	Programa de Conservación de Especies en Riesgo (Conservation Program for Species at Risk)
PROCODES	Programa de Conservación para el Desarrollo Sostenible (Conservation Program for Sustainable Development)
PROFEPA	Procuraduría Federal de Proteccion del Ambiente (Federal agency of environmental protection)
PROVICOM	Programa de Vigilancia Comunitaria (Community Wildlife Ranger Program)
PVA	Population Viability Analysis

SAGARPA	Secretaría de Agricultura, Ganaderia, Desarrollo Rural, Pesca, y Alimentación (Federal Ministry of Livestock, Agriculture, Rural Development, Fisheries, and Foods)
SCR	Spatial capture-recapture
SECR	Spatially explicit capture-recapture
SEMARNAP	Secretaría de Medio Ambiente, Recursos Naturales y Pesca (Ministry of the Environment, Natural Resources, and Fish)
SEMARNAT	Secretaría de Medio Ambiente y Recursos Naturales (Federal Ministry of the Environment and Natural Resources)
SNP	Single nucleotide polymorphism
Team	Jaguar Recovery Team
TON	Tohono O'odham Nation
UMA	Unidad para la Conservación, Manejo y Aprovechamiento Sustentable de la Vida Silvestre (Wildlife Conservation, Management, and Sustainable Utilization Unit)
Units	Cat Conservation Units
U.S.	United States
USFWS	U.S. Fish and Wildlife Service
VHF	Very high frequency
VU	Vulnerable (IUCN Red List criteria)
WCS	Wildlife Conservation Society

APPENDICES

APPENDIX A: Summary of status, threats, and conservation efforts of jaguars in range countries

Argentina

In Argentina, the jaguar is classified as endangered and as a National Natural Monument (De Angelo et al. 2011). The status of National Natural Monument provides a species with protection at the same level as National Parks in Argentina (Ley 22351). In some parts of Argentina, it is also considered a Provincial Natural Monument (Di Bitetti et al. 2005), allowing the creation of local laws for its protection. Argentina is the country with the highest national rate of jaguar range contraction (De Angelo et al. 2011), with an estimated 90% population decline over the past 100 years (Quiroga et al. 2014).

The Upper Paraná Atlantic Forest of Argentina, Brazil, and Paraguay holds the world's southernmost jaguar population (De Angelo et al. 2013). Based on estimates from their study area (approximately 20,000 square kilometers (km^2) (7,722 square miles (mi^2)), De Angelo et al. 2013 extrapolated that the entire eco-region contains about 200 adult jaguars; however, within the Argentinian portion of their study area, the estimated population is 33-54 individuals (Schiaffino et al. 2011). De Angelo et al. (2013) mention that only 3% of the Upper Paraná Atlantic Forest contains viable habitat patches for the species (approximately 90,500 km^2 (39,942 mi^2)), with a rate of habitat loss around 1,000 hectares (ha) (2,471 acres (ac)) per year. In the Misiones region of Argentina, the jaguar population is estimated at 60-65 individuals (www.minutouno.com). Di Bitetti et al. (2003) estimate that 525,000 ha (1,297,303 ac) of habitat are needed to sustain a viable jaguar population of 150 individuals in Argentina.

The main threats to the jaguar in Argentina are hunting as a response to cattle depredation (Barbarán 2004, Quiroga et al. 2014), and habitat loss due to oil exploration, forestry (Barbarán 2004), and ranching (Perovic and Herrán 1998). In the Chaco region, Di Bitetti et al. (2005) reported that, despite the jaguar's protected status, jaguar hunting still occurs for commercial purposes, a fact also supported by Merelle (2011) and Rumiz et al. (2012). Additionally, in the Chaco region, an estimated 80% of the region has been transformed (Rumiz et al. 2012). De Angelo et al. (2013) found that reducing human persecution is urgently needed to increase the core areas for jaguars, and that improvements in land conditions are important for sustaining connectivity among jaguar populations.

There are some conservation efforts being implemented for the species within Argentina, such as the "Ley de Consevación de Grandes Felinos" (Big Cats Conservation Law) implemented in 2004, which focuses on jaguar conservation (www.anima.org.ar), and the Plan de Acción para la Conservación de la Población de Yaguareté (*Panthera onca*) del Corredor Verde de Misiones (Action Plan for Jaguar Conservation in the Green Corridor), which focuses on increasing the jaguar population size to 250 adults in the Misiones province of Argentina, and additional areas in Brazil (Schiaffino et al. 2011). Additionally, the Red Yaguarete non-governmental organization (NGO) developed and is maintaining a national database containing genealogical information for all jaguars in captivity (Merelle 2011).

Belize

In Belize, the jaguar is classified as a Near Threatened species according to the National List of Critical Species (Meerman 2005). The government of Belize has imposed laws banning the hunting of jaguars since 1981 (Miller 2002).

In terms of jaguar population size and stability, Ruiz-García et al. (2012) cited a Rabinowitz (1991) estimate of 600-1,000 jaguars for Belize. In their fourth annual report to the United Nations, the Belize Environmental Technologies organization mentioned that the species is considered a national concern, but the population is stable (Belize Environmental Technologies 2010). More recently, Figueroa (2013) estimated a jaguar population between 446 and 754 individuals based on the reports of different researchers in the country, mentioning that because camera-trapping studies could overestimate densities, it was possible that the actual jaguar population in Belize was around 450 individuals.

Approximately 67% of the country of Belize (2,326 km^2 (898 mi^2)) could be potential habitat for the jaguar, with the main threats to the species including agricultural expansion and changes in land use due to tourism (Belize Environmental Technologies 2010).

Conservation activities began in the 1980s, when Dr. Alan Rabinowitz of Panthera radio-collared the first jaguars in Belize, leading the country to establish the world's first jaguar preserve and Belize's first wildlife protected area, the Cockscomb Jaguar Preserve (http://www.panthera.org/node/622). In 1988, an ecolodge was established with the ecotourism vision that included jaguar protection (Miller 2002). A second reserve, the Labouring Creek Jaguar Corridor Wildlife Sanctuary, was created for jaguar protection in 2011. This preserve was established to ensure connectivity and maintenance of a viable population throughout Belize. More recently, a critical conservation agreement was signed by the government of Belize, Panthera (a global wild cat conservation organization), and the Environmental Research Institute of the University of Belize, representing a pledge by all parties to collaboratively implement science-based conservation initiatives that secure and connect jaguars and their habitats in Belize and beyond its borders, facilitate land development that is both ecologically sustainable and economically profitable, and mitigate human-jaguar conflict throughout the country (http://www.panthera.org/sites/default/files/Panthera%20Press%20Release_Belize%20MOU.pdf).

Bolivia

In Bolivia, the jaguar is classified as Vulnerable according to El Libro Rojo de la Fauna Silvestre de Bolivia (Bolivia's Red List) (Ayala and Wallace 2009). Swank and Teer (1989) cited a Schaller and Crawshaw (1980) estimate of 1,400 jaguars in the Guapore River Basin of Bolivia and Brazil, and, in 2011, the Wildlife Conservation Society (WCS) estimated a jaguar population in the Gran Chaco of Paraguay and Bolivia of 1,000 jaguars (http://www.wcs.org/press/press-releases/dramatic-jaguar-photo-shows-conservation-success-in-bolivia.aspx). The main threats to the jaguar in the Gran Chaco are the expansion of human settlements, agriculture, and livestock; conflicts with cattle depredation, game hunting, and hunting for commerce; and mining and road construction (Rumiz et al. 2012).

Conservation activities in Bolivia include a core area of 120,000 km^2 (46,332 mi^2) for jaguar protection in the frontier between Bolivia and Paraguay protecting part of the Chaco region (Rumiz et al. 2012). Additionally, Rumiz et al. (2012) mentioned that most of the Gran Chaco in Bolivia is still intact because of low human population density in the region. From 2001 to the present, WCS has been researching the distribution, abundance, food habits, and activity patterns of jaguars by means of camera traps in the states of La Paz and Santa Cruz. All of the information collected is being used to develop jaguar conservation strategies across the region (Ayala and Wallace 2009).

Brazil

The jaguar in Brazil is federally recognized as vulnerable (Barbosa et al. 2008), but every state has its own status for the species. The local status of the jaguar in the Caatinga region is critically endangered (population size lower than 250 individuals, in decline and no subpopulation estimated to contain more than 50 mature individuals) (de Paula et al. 2012), while in Amazonia, the jaguar is classified as vulnerable (considered to be facing a high risk of extinction in the wild, population size fewer than 10,000 mature individuals, and an estimated continuing decline of at least 10% within 10 years or three generations) (de Oliveira et al. 2012). In Pantanal, the jaguar is classified as Heritage of the State (Sollmann et al. 2013).

In 2002, de Oliveira presented an estimate of 20,000 to 129,000 jaguars in the eastern Amazon and northeastern Brazil (de Oliveira 2002). The population estimate for the country within protected areas in 2008 was 55,000 individuals (Sollmann et al. 2008) distributed across 87,325 km^2 (33,716 mi^2) (de Paula et al. 2012). Of those jaguars, 93.6% occupy Amazonian protected areas, followed by 4.2 % in the Cerrado, 0.9% in the Atlantic Forest, 0.8% in Pantanal, and 0.6% in the Caatinga (Sollmann et al. 2008). In 2012, de Oliveira et al. (2012) estimated the jaguar population for the Amazonian region at less than 10,000 individuals and, according to their analysis, if the threats (habitat loss and hunting) continue in the region, they determined that within 100 years jaguars would remain only in the Carajás Protected Area in this region.

In their study, Sollmann et al. (2011) mentioned that the populations in the central part of Brazil are considered stable; however, as part of the same analysis, the authors mentioned that in the Iguaçu National Park the jaguar population will disappear in 58 years if threats continue. Leite et al. (2002) estimated (based on jaguar tracks) an approximate jaguar population of around 200 individuals in the Atlantic Forest of Brazil, and Galetti et al. (2013) estimated around 250 mature jaguars in the Atlantic Forests of Brazil, Argentina, and Paraguay.

The Pantanal region (which also includes parts of Bolivia and Paraguay), the largest continental wetland in the world, is home to the highest density of jaguars anywhere (http://www.panthera.org/programs/jaguar/pantanal-jaguar-project), and, according to De Angelo et al. (2013), the highest jaguar density is found in the Upper Paraná region. Results from Leite et al. (2002) suggest that only 28% of the natural protected areas in Brazil can sustain long term viable populations because of their low human density and habitat quality.

The main threats to the species in Brazil are habitat fragmentation (Sollmann et al. 2013), hunting in retaliation to cattle depredation (Beisiegel et al. 2012), and the continuous increase of large-scale agriculture (Sollmann et al. 2008). According to Sollmann et al. (2008), jaguar distribution is limited mainly by the separation between habitat patches; additionally, there is an urgent need to diminish direct threats to the species and habitat loss in each of the patches, to increase the size of each habitat patch and reduce human persecution within them, and to maintain or restore connectivity among them.

A study by Zimmerman et al. (2005) surveyed the attitudes of cattle ranchers in the Pantanal region to livestock depredation by jaguars. The results suggest that most respondents support conservation of the Pantanal but that attitudes towards jaguars specifically were mixed. Although efforts to reduce cattle losses are needed, it may be equally as important for conservation initiatives to focus on the inherent appreciation of the natural value of the Pantanal within the ranching community. A similar study was conducted by Marchini and Macdonald (2012) in Pantanal and Amazonia; they found that people kill jaguars as part of a need to engage with society and be part of the community, as well as because of fear and tradition, indicating these attitudes go beyond the usual framework of human-jaguar conflicts.

Jaguar conservation within Brazil includes Panthera's Pantanal Project, which intends to establish a model for cattle ranching that is both financially profitable and compatible with jaguar conservation. This model will be applicable and replicable inside of one of the world's largest, intact, protected jaguar corridors (http://www.panthera.org/node/28). Additionally, the Biodiversity Vision for the Upper Paraná Atlantic Forest is designed to sustain a viable population of jaguars by considering this species as an umbrella species for the rest of the biodiversity in the region (de Angelo et al. 2013). Additionally, there is Plan de Acción para la Conservación de la Población de Yaguareté (Panthera onca) del Corredor Verde de Misiones (Action Plan for Jaguar Conservation in the Green Corridor), which focuses on increasing the jaguar population size to 250 adults in the Misiones province of Argentina, and additional areas in Brazil (Schiaffino et al. 2011).

Pro-Carnivoros is an NGO focused on carnivore conservation across Brazil (http://procarnivoros.org.br/index.php/quem-somos/). Their strategy for conservation includes: 1) scientific research to generate information necessary for the conservation of species and their habitats, 2) proposing strategies and management actions to ensure the survival of carnivores in the long term, 3) identification and protection of priority areas for conservation of carnivores, 4) guidance in cases of domestic animal depredation by carnivores, 5) training and capacity building of professionals specialized in management and conservation of natural predators, 6) environmental education and outreach and the production of educational materials, and 7) the support and development of public policies for the conservation of species and their habitats.

Colombia

The jaguar is classified as near threatened in Colombia (Payán and Soto 2012). According to Ruiz-García et al. (2006) estimates, the historical jaguar population in Colombia was 10,000 individuals. Payan et al. (2010), as cited by Gutiérrez-González (pers. comm. 2014), estimates the actual population is around 2,000 individuals in the protected areas of Colombia. Ruiz-García et al. (2006) cited a calculation by Zuloaga (1995) of one jaguar per 19-39 km^2 (7-15 mi^2) in the Monpox depression of northern Colombia, which could represent 150-300 jaguars for this area. The presence of several other small populations was noted. Payán Garrido et al. (2013) estimate that the jaguar's range in Columbia has declined 39% since 1957. Ruiz-García et al. (2006) cited one natural barrier for jaguar dispersion, the Andean mountain chain, which could cause genetic separation of the populations. However, Ruiz-García et al. (2012) conducted a genetic analysis and did not find this a barrier for gene flow between the populations.

The main threats to jaguars in Columbia are habitat fragmentation (Castaño-Uribe et al. 2013) and illegal hunting for their pelts (Restrepo et al. 2010). In the northern part of the country, the annual deforestation rate is estimated at 245 km^2 (94.6 mi^2) (Restrepo et al. 2010). According to the authors, if this rate continues, the vegetation in the Antioquia region could disappear in less than 30 years. Payán and Soto (2012) mentioned that mining is also a major threat to the species.

In 2005, the government imposed the "Política Nacional de Conservación de Felinos" (Feline Conservation National Policy) with the purpose of establishing national conservation and management policies for all feline species in the country (Castaño-Uribe et al. 2013). This effort was planned to involve local and scientific knowledge to strengthen cultural and territorial identities, which, as part of the initiative, has led to some natural protected areas connected by corridors.

Costa Rica

All feline species in Costa Rica are classified as endangered (Sáenz and Carrillo 2002) and receive various levels of protection through numerous environmental laws. The law most specific to the jaguar is the Law on Wildlife Conservation, N. 7317, which imposes steep fines and prison time for violations of this law.

The largest jaguar populations in Costa Rica are in the northern part of the country (Sáenz and Carrillo 2002). Sáenz and Carrillo (2002) cite Vaughan (1983), who mentioned that in 1983 there were between 136 and 980 jaguars in the northern part of Costa Rica. Vaughan and Temple (2002) cited several population estimates for jaguars in various areas within Costa Rica, including 50 jaguars in the Guanacaste Conservation Area (Janzen, pers. comm.), 107 in the Osa Conservation Area (Rabinowitz 1991), 100 in the La Amistad International Park at the Panama-Costa Rica frontier (Rabinowitz 1991)**,** and 200 in the Tortuguero National Park in Costa Rica-Nicaragua (Rabinowitz 1991). In 2008, González-Maya et al. (2008) calculated 448 individuals for the Talamanca region, mentioning that suitable habitat for the jaguar in the region was estimated at 8,260 km^2 (3,189 mi^2). Soto (2014) cited Vaughan (1983) and mentioned that, in Costa Rica, only 34% of the territory is suitable habitat for the jaguar.

In 2002, the rate of jaguar hunting was estimated at 12 individuals per year, mainly because of jaguar-cattle conflicts, although this estimate could be conservative (Sáenz and Carrillo 2002). Dirzo et al. (2013) reported that between 2009 and 2013, at least 20 jaguars were killed in the Osa Peninsula, and, if this rate continues, jaguars could disappear from the region in 5 years.

Sandoval et al. (2013) mentioned that the main threats to the jaguar in Costa Rica are habitat isolation, deforestation, and anthropogenic activities. In their study, the authors tested several variables for jaguar distribution and found that the extent of suitable habitat for the jaguar is the main limiting factor in the Osa Peninsula. In 2014, Alvarez (2014) conducted interviews of people from Tapanti National Park and found that most of the interviewees recognized that deforestation and hunting they did themselves are the main threats to jaguars in the park.

One conservation strategy being implemented in Costa Rica is for the government to pay ranch owners for forest protection (Certificado para la Protección del Bosque (Forest Protection Certificate), Sáenz and Carrillo 2002). Additionally, WCS is seeking to develop new ways to sustainably enhance livelihoods for local people while promoting wildlife conservation in jaguar territory. For example, in the Nari Awari Indigenous Reserve of Costa Rica, live fences (barriers made from woody plants and hedges, in lieu of barbed wire) are being experimented with to keep wildlife out of livestock pens (http://www.wcs.org/saving-wildlife/big-cats/jaguar.aspx). At a binational level, Costa Rica and Panamá implemented a monitoring program for jaguar populations to establish management and conservation strategies in six natural protected areas in both countries (Fonseca 2012). In 2012, Costa Rica became the first country in Latin America to ban hunting as a sport (http://www.huffingtonpost.com/2012/12/11/costa-rica-hunting-ban_n_2275529.html).

Ecuador

The jaguar has been protected in Ecuador since 1970, when hunting of the species was banned (Registro Oficial No. 818 1970). This status was confirmed in 2002 and 2003 by the Ecuadorian government (Quigley, pers. comm. 2015). Little information on the status of jaguars in Ecuador is available. In the 2011 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) reassessment for the jaguar (CITES 2011), Espinosa et al. (2010) reported a population of 1,600 individuals in the eastern part of the country.

The main threats to jaguars in Ecuador are deforestation, as well as prey and jaguar hunting http://www.ambiente.gob.ec/11699/). Conservation efforts in the country mainly include WCS's Amazon-Andes program, which works to protect seven massive Amazonian landscapes, one of which is located in Ecuador (http://www.wcs.org/where-we-work/latin-america/ecuador.aspx).

El Salvador

No information on the legal status, estimated extent of decline, threats or limiting factors to, or recovery of/conservation efforts for the jaguar is currently available for El Salvador. The species is thought to be extirpated in the country (Swank and Teer 1989).

French Guiana

The jaguar is classified as endangered in French Guiana (Kerman 2010). The CITES reassessment for the jaguar (2011) cited De Thoisy's (2010) estimate of jaguar abundance in French Guiana and Suriname as around 2,500 and 3,000 individuals.

Kerman (2010) mentioned that the main threats to the species are illegal trade of jaguar parts to the U.S., Europe, and Japan, as well as trade for local consumption. The author mentioned that Chinese people have the most interest in the meat, teeth, bones, and skin of the jaguar, believing that the meat and bones have medicinal power. de Thoisy and Poirier (2009) reported that two unprotected sites in northern French Guiana (the region of the Guiana Shield) had densities of 3.3 adult jaguars per 100 km^2 (38.6 mi^2) and 4.9 adults per 100 km^2 (38.6 mi^2). These sites face low-impact logging and jaguar populations have moderate pressure from subsistence hunting. Additionally, at the country scale, increasing illegal gold mining could potentially threaten wildlife if it continues. While the region of the Guiana Shield has been identified for conservation of large terrestrial mammals, it currently is not protected and the U.S. Fish and Wildlife Service (USFWS) and Jaguar Recovery Team (JRT) are not aware of any other conservation actions in place for jaguars in French Guiana.

Guatemala

The status of the jaguar in Guatemala is endangered (McNab and Polisar 2002). Swank and Teer (1987), as cited by Ruiz-Garcia et al. (2012), estimated there were 500-800 jaguars in the Peten area of Guatemala. In 1990, Aranda (1990) estimated 590-730 jaguars in the Maya-Calakmul-Rio Bravo Biosphere Reserves of Guatemala-Belize-Mexico, and in 2002, Ceballos et al. (2002) estimated around 400 individuals in the region. A current population of 345 jaguars in Guatemala's Maya Biosphere Reserve is estimated by WCS (Wildlife Conservation Society 2015). According to McNab and Polisar (2002), this reserve makes up the largest habitat patch in the country (~7,500km^2 (~2,895 mi^2)) and is the most likely to sustain a long-term jaguar population in Guatemala. This reserve, in addition to the Sierra de las Minas, are priority areas for jaguar conservation because they are the only populations in Guatemala with long-term viability (McNab and Polisar 2002). They mentioned that jaguar populations in Guatemala are connected with the populations in Mexico and Belize, but within the country they are separated from each other.

The main threats to jaguars in Guatemala are the expansion of agriculture and livestock, logging, oil exploration, human population growth, and illegal hunting of jaguars and their prey, as well as hunting for commercial purposes (fur sales mainly to Mexico). The USFWS and JRT are not aware of any conservation actions in place for jaguars in Guatemala.

Guyana

The jaguar is protected in Guyana by the new Wildlife Management and Conservation Regulations (Government of Guyana 2013), under which it is listed as a strictly protected species. Prior to these regulations, the jaguar was only protected from international trade under CITES without any protection at the national level. Most of the country is identified as suitable habitat for the jaguar if threats are controlled (Kwata Association 2013).

Kerman (2010) mentioned that in Guyana and French Guiana, the main threats to the species are illegal trade to the U.S., Europe, and Japan, as well as trade for local consumption. Kwata Association (2013) identified that if prey hunting continues, this will also be a limiting factor for jaguar survival.

Conservation efforts for the jaguar include the Community Owned Conservation Area, which is the largest natural protected area in Guyana and is managed by an indigenous group of people. Its purpose is to secure a pristine, biologically-important habitat that includes the jaguar as a resident species (Baksh 2008).

Honduras

It is estimated that in Honduras, the deforestation rate is around 3% per year (Instituto Nacional de Conservación y Desarrollo Forestal, Àreas Protegidas y Vida Silvestre (ICF) 2011). Rabinowitz (1991), as cited by Ruiz-Garcia et al. (2012), estimates 233 jaguars in the Rio Platano Biosphere Reserve. Most of the jaguars in Honduras are in the Mosquitia region, but there are jaguar populations throughout almost all of the country (ICF 2011).

In 2011, ICF (2011) reported the main threats to jaguars in Honduras as deforestation, changes in land use, illegal hunting, and prey diminishment, as well as livestock-jaguar conflicts.

In the Rio Platano Biosphere Reserve and Caribbean Jaguar Corridor of Honduras, WCS is implementing a project to work with ranchers on their concerns about jaguar-related conflicts, and pursue solutions that will include marketing, model ranches, and education (http://www.wcs.org/saving-wildlife/big-cats/jaguar.aspx).

The Rio Platano Biosphere Reserve was the first reserve in the country created for jaguar protection (Swank and Teer 1989). In 2011, the government created the Plan Nacional para la Conservación del Jaguar (*Panthera onca*), Honduras (National Plan for Jaguar Conservation, Honduras) (ICF 2011), with the vision to establish 400,000 ha (988,422 ac) of forest conserved in the country through the identification of critical habitat for the species. The objective of the plan is to preserve long-term jaguar populations in the country by means of habitat connectivity.

Mexico

The jaguar is listed as endangered under Mexican law (Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT; Federal Ministry of the Environment and Natural Resource) 2010). During a November 2010 symposium, "El Jaguar Mexicano en el Siglo XXI" (The Mexican Jaguar in the XXI Century), experts estimated that Mexico has approximately 4,100 jaguars, of which 1,800 are located in the Yucatan Peninsula, 550 in the North Pacific (Sinaloa and Sonora), 420 in the Central Pacific (Nayarit, Jalisco, Colima, and Michoacán), 670 in the South Pacific (Guerrero, Oaxaca, and Chiapas), and 620 in the northeastern-central part of the country (Nuevo Leon, Tamaulipas, San Luis Potosí, Querétaro, and Hidalgo) (Zarza et al. 2010).

The main threats reported for the species in the country are illegal hunting, and habitat loss and fragmentation (Rosas-Rosas and Bender 2012, Rodríguez-Soto et al. 2013, Zarco-González et al. 2013). Mexico has made significant progress in conserving jaguars, including writing a recovery plan for the jaguar entitled "Programa de Acción para la Conservación de la Especie [PACE]: Jaguar (*Panthera onca*)," (Comisión Nacional de Areas Naturales Protegidas (CONANP;

National Commission for Natural Protected Areas) 2009) as well as implementing many recovery actions for the species.

See the following sections for more information regarding the status, threats, and conservation efforts for jaguars in Mexico: **1.4 Distribution, Connectivity, Abundance, and Population Trends**; **1.9 Reasons for Listing/Threats Assessment**; and **1.10 Conservation Efforts**.

Nicaragua

The jaguar is endangered under Nicaraguan law (Genoways and Timm 2005). Rabinowitz (1991), as cited by Vaughan and Temple (2002), estimated 200 jaguars in the Tortuguero National Park in Costa Rica-Nicaragua. The CITES reassessment (2011) cited Polisar and Diaz's (2010) estimation of 336 individuals.

According to Petracca et al. (2014b), the main threat to jaguars and their prey is habitat loss due to agricultural encroachment. Illegal hunting of jaguars and their prey is also a threat. The USFWS and JRT are not aware of any conservation actions in place for jaguars in Nicaragua.

Panama

In Panama, the jaguar is classified as endangered (Centro de Información Ambiental de la Cuenca 2011). Rabinowitz (1991), as cited by Ruiz-Garcia et al. (2012), estimates 333 jaguars in the Panamanian Darien region and 100 jaguars in the La Amistad International Park at the Panama-Costa Rica frontier (also included in the Costa Rica section above). The best conserved jaguar populations in Panama are in Chagres National Park, although there are some dispersed populations in other protected areas (Centro de Información Ambiental de la Cuenca 2011). A binational (Costa Rica-Panama) monitoring project was proposed in 2012 for the jaguar in the Rio Sixaloa Watershed (Fonseca 2012).

The main threats to the jaguar in Panama are hunting for pelt trafficking, as well as habitat destruction and modification (Centro de Información Ambiental de la Cuenca 2011). Conservation efforts in Panama include Darien National Park, which was the first reserve created for jaguar protection in Panama in 1981 (Swank and Teer 1989). Additionally, as mentioned above, at a binational level Costa Rica and Panama implemented a monitoring program for jaguar populations to establish management and conservation strategies in six natural protected areas in both countries.

Paraguay

The jaguar is classified as endangered in Paraguay (Secretaría del Ambiente Paraguay 2010). Ruiz-García et al. (2012) cited an estimate of 2,347 (up to 7,040) jaguars in the Paraguayan Gran Chaco by Redford et al. (1990). In 2011, WCS estimated a jaguar population in the Gran Chaco of Paraguay and Bolivia of 1,000 jaguars (http://www.wcs.org/press/press-releases/dramatic-jaguar-photo-shows-conservation-success-in-bolivia.aspx).

De Angelo et al. (2013) estimated 200 jaguars for the Atlantic forest of Paraguay and stated that populations in this area are not stable. They also stated that the Atlantic forest still has 42% of suitable habitat for jaguar conservation, but habitat fragmentation and direct persecution are the main threats for the species (De Angelo et al. 2011). For the Gran Chaco region in Paraguay, Rumiz et al. (2012) identified deforestation, livestock expansion, fire, killing of jaguars because of conflicts with cattle, and overhunting of prey as the main threats for jaguar populations. They also identified specific threats for the region, including the transoceanic road and some hydroelectric construction.

In their study, De Angelo et al. (2011) found that most of the jaguar records were inside the largest protected areas. In 2013, De Angelo et al. (2013) found that only a few core jaguar habitats are protected (Mbaracayu and San Rafael Reserves), and many of them are in recently fragmented areas at risk of further modification. They also found that jaguar movements are restricted by the distance between patches, as well as the amount of forest in the area. Jaguars still move between recently fragmented patches, and these areas are a priority for management and conservation.

Conservation efforts include the Biodiversity Vision for the Upper Paraná Atlantic Forest with Brazil and Argentina, which is designed to sustain a viable population of jaguars by considering this species as an umbrella species for the rest of the biodiversity in the region (De Angelo et al. 2013). Additionally, at a national level, proposed conservation efforts include developing a Plan de Acción Nacional del Jaguareté (National Jaguar Action Plan), as well as a project to genetically identify all furs and captive individuals in the country (Rumiz et al. 2012).

Peru

The jaguar is classified as near threatened in Peru (Sistema Peruano de Información Jurídica 2004). Monsalve (2009) mentioned that the jaguar's population decline in Peru was due to the high international trade in jaguar skins prior to the 1970s. Tobler et al. (2013) estimated that their study area in the Madre de Dios region of the Peruvian Amazon could harbor as many as 6,000 jaguars, although gold mining, logging, and clear-cutting for agriculture will likely fragment the remaining habitat. The Peruvian Amazon basin is considered a high priority area for jaguar conservation based on the large expanse of forests and the assumed health of jaguar populations in the region (Tobler et al. 2013).

Suriname

The jaguar is endangered in Suriname according to Kerman (2010). As stated above (in the French Guiana section), the CITES (2011) reassessment for the jaguar cited De Thoisy's (2010) jaguar abundance in French Guiana and Suriname of around 2,500 and 3,000 individuals, respectively.

The Rapid Biological Assessment of the Kwamalasamutu region in Suriname (O'Shea et al. 2011) showed that the region contains almost pristine habitat that must be preserved for the maintenance of wildlife. Kerman (2010) mentioned that the main threats to the species in the country are illegal trade of jaguar parts to the U.S., Europe, and Japan, and trade for local consumption. The author mentioned that Chinese people have the most interest in the meat, teeth, bones, and skin of the jaguar, believing that the meat and bones have medicinal power. O'Shea et al. (2011) also included illegal hunting and the fur trade as threats to the jaguar.

Conservation efforts include planning efforts by the government in Suriname to begin ecotourism activities, including many charismatic wildlife species (such as the jaguar) as flagship species for the improvement of tourism and promotion of conservation (O'Shea et al. 2011).

United States

The jaguar is classified as endangered in the U.S., as well as throughout its range, under the authority of the ESA (see the see section **1.2 Legal Status of the Species** for the legal status and history of the species at the federal level in the U.S.). Jaguars are also protected by state law in Arizona and New Mexico. See more about Arizona and New Mexico state jaguar protections in section *1.9.4 Factor D. The inadequacy of existing regulatory mechanisms*.

See the following sections for more information regarding the status, threats, and conservation efforts for jaguars in the U.S.: **1.4 Distribution, Connectivity, Abundance, and Population Trends**; **1.9 Reasons for Listing/Threats Assessment**; and **1.10 Conservation Efforts**.

Uruguay

Because the jaguar is believed to be extirpated from Uruguay (Swank and Teer 1989), little information on the legal status, estimated extent of decline, threats or limiting factors to, or recovery of/conservation efforts for the jaguar is currently available for the country. In 2010, one jaguar was seen in the Marin lagoon in the frontier between Brazil and Uruguay (http://viajes.elpais.com.uy/2015/08/26/uruguay-cronica-de-un-depredador/), but it is likely that this individual came from a jaguar population in Brazil.

Venezuela

In Venezuela, the jaguar is classified as Vulnerable (Rodríguez and Rojas-Suarez 2008). According to the authors, the only stable populations are in the Amazonas and Bolivar regions (Hoogesteijn and Mondolfi 1991a, as cited by Rodriguez and Rojas-Suarez 2008). In the northern part of the Orinoco region, the jaguar is classified as Endangered (Venezuela 1996a and 1996b, as cited by Rodriguez and Rojas-Suarez 2008). In 1976, jaguars were listed as a game species, but in 1996 the Venezuela government prohibited jaguar hunting because of the species' low populations; this prohibition remains to the present day (Gaceta Oficial de la República de Venezuela 1996).

Rodriguez and Rojas-Suarez (2008) cited an estimate by Hoogesteijn and Mondolfi (1987) of 2,500-3,600 jaguars in Venezuela.

The main threats to jaguar populations in Venezuela are hunting of jaguars and their prey, logging, and habitat loss (Hoogesteijn et al. 2002). The authors mentioned that jaguar hunting is mainly due to the fear that people have towards the jaguar. They also highlight that people continue to hunt inside natural protected areas, which is increasingly becoming a problem for jaguar conservation.

Literature Cited

For the literature cited in this appendix, see **PART 6: LITERATURE CITED**.

APPENDIX B: English translation of Mexico's Action Program for the Conservation of the Species (PACE) – Jaguar

ACTION PROGRAM FOR THE CONSERVATION OF THE SPECIES
Jaguar (*Panthera onca*)

United States of México
Federal Government
SEMARNAT

April 2009

Presentation

The present document is called the Action Program for the Conservation of the Species: Jaguar (*Panthera onca*), which revisits the main guidelines established in the first document in a practical fashion, which is the result of an effort among experts in the field and respective Federal authorities. By consensus, the former document was named Project for the Conservation and Management of the Jaguar in Mexico, from the Series: Recovery Projects for Priority Species (PREP) Number 14, published by the Secretary of Environment and Natural Resources (SEMARNAT) in March 2006.

This program also aims to resume earlier efforts by establishing a schedule for actions, strategies, and short, medium and long term goals, using the respective indicators in order to work systematically, through the assignment of actors and budgets to provide continuity and certainty to the actions proposed for the recovery of this iconic species and its habitat.

Considering the enormous distribution and variety of habitat for this species, through common factors such as priority areas for conservation, threats they face and active working groups, it is sought to coordinate activities with Action Programs of other species, which perform ecological roles equally important and share habitats with the jaguar in order to synergize actions, actors and resources to be implemented, and thus optimize them.

It is worth clarifying that this Action Program is developed in the framework of the Risk Species Conservation Program, which is the governing document of the Directorate of Priority Species for Conservation within the General Directorate of Regional Operation of CONANP, that is part of the strategic line of "Restoration" which along with the programs of "Restoration of Ecosystems" and "Ecological Connectivity" constitute the basic tools to meet one of the strategic objectives of the National Program of Protected Areas from 2007 to 2012.

I. Introduction

Commonly known throughout the various distribution sites in the continent and our country as jaguar, onza, yaguar, yaguarete, tiger, royal tiger, panther, balam, barum, onca, etc. This is the third largest cat after the tiger and lion, and the largest in the Americas. In Mexico records show males with an average weight of 56 kg, and females at 42 kg average (Aranda, 1991), and although jaguar body measurements change with respect to geographic variation, with the largest specimens found in South America (Oliveira, 1994), recently Eizirik et al. (2001) concluded after an analysis of the genetic structure of the jaguar populations across the continent that there exists only a single species.

The jaguar has skin color that ranges from pale yellow to reddish brown and changes to white on the cheeks, chest and insides of the limbs. Throughout the body it has black spots, which change to rosettes on the sides; within these there may be one or more small spots (Ceballos and Oliva, 2005). The jaguar breeding season varies geographically. Offspring have been reported in South America in June, August, November and December (Seymour, 1989), but in areas with strong seasonality, the young are often born in the season when food is abundant. In various parts of southern and southeastern Mexico, farmers indicate that the mating season of the "Jaguar" occurs during the months of December and January (Aranda, 1990). There is an average gestation period of 100 days and the litter can consists of one to four cubs. However, usually only one or two cubs are developed (Ceballos and Oliva, 2005).

Jaguars are the biggest predators in the Neotropics, and therefore play a major ecological role in affecting the population densities of its prey and are one of the limiting factors for these (Medellín et al., 2002; Tewes and Schmidly, 1987). The jaguar is an important element in the ecosystem because it is a keystone, flagship and umbrella species (Miller et al., 1998, 1999). This species is considered the cornerstone for conservation planning at regional and country levels because it has a wide distribution, it requires extensive areas for survival and it inhabits a huge variety of ecosystems (Ceballos et al., 2002, Medellín et al., 2002).

Precisely because of its requirements for space and fragmentation, coupled with hunting and stigmas that still prevail, the populations of this species are still declining. Although hunting has been permanently banned since 1987 (SEDUE, 1987), this action has not been sufficient to ensure the preservation of the jaguar. Even after implementing activities such as the creation of natural protected areas and other conservation tools, which have contributed greatly in the conservation of habitat areas for this species, it is still considered a species at risk and a priority for conservation.

That is why the National Commission of Natural Protected Areas, through the Directorate of Priority Species Conservation, has promoted and supported the creation of a guiding document that is exclusively focused on the conservation and recovery of this species, which is so emblematic and has such high ecological importance. This document is not only intended as a brief with ideas, opinions and good intentions, but must also reflect the current needs and problems facing the conservation of the jaguar.

The Action Program for the Conservation of the Jaguar (PACE Jaguar) is a comprehensive plan that incorporates six complementary strategic lines that are composed of actions and activities planned in the short and medium term.

II. Background

Although recognized as an ecologically key species with great cultural importance, jaguar populations unfortunately have declined throughout their area of distribution. In the case of Mexico this has happened especially in the last 40 years as a result of habitat loss, growth of farmland, livestock, and illegal hunting (Nowell and Jackson, 1996).

To address the problems affecting this species the National Technical Advisory Subcommittee for the Conservation and Sustainable Management of the Jaguar was formally established in 2000 as the technical advisory body for the Secretary of Environment and Natural Resources (SEMARNAT). Composed of representatives of the academic society and nongovernmental organizations (NGOs), its primary mission was to propose a national strategy for the conservation and sustainable management of jaguars through the formulation of a Priority Species Recovery Program that would establish the foundations in order to promote the joint participation of federal, state and municipal government agencies, as well as the society as a whole, such that conservation of the jaguar in Mexico can be achieved through an assessment of the status of the species, control of major threats to their populations and habitat, and the implementation of priority conservation actions.

Following the important work of organizing information generated by specialists of the Technical Subcommittee members in collaboration with the National Commission on Protected Areas (CONANP), the information integration phase for an Action Plan for Jaguar Conservation in Mexico was initiated. In the short and medium term, the plan had the task of integrating, coordinating and strengthening the regional efforts that took place in the country involving civil society organizations, academic organizations, research agencies, government institutions and all public, private and social sectors that would be interested in the conservation of this species.

Thus, in October 2004 two working meetings were held with experts on the subject belonging to different institutions and organizations, one of which was supported and attended by the Secretary of Environment and Natural Resources, who agreed to support the concept of "The Year of the Jaguar in Mexico" in 2005. At the second meeting the short and medium term actions were identified for the Action Plan for Jaguar Conservation in Mexico. This meeting, which was coordinated by the CONANP, presented the progress of the document "Recovery Projects for Priority Species" (PREP) by the National Technical Advisory Subcommittee for the Conservation and Sustainable Management of the Jaguar, as well as the presentation of eleven research projects and conservation efforts carried out in the states of Sonora, Tamaulipas, Jalisco, Nayarit, Oaxaca, Chiapas, Campeche, Quintana Roo and Yucatan. Two regional priority actions to be undertaken in the short term were mentioned. Targets and indicators for evaluating actions were also presented, as well as the expected results for 2005 and 2006, and the responsible actors by priority. A schedule was made for the action plan 2005-2006 with estimated costs. All documentation was copied and delivered to CONANP.

For the follow-up to this first approach, in January 2005 the CONANP again convened with the leaders of the jaguar conservation projects that were working in the country in order to consolidate the Action Plan. At the same time CONANP looked to coordinate the various central and decentralized bodies of the Secretariat to carry out the necessary collaboration and coordination of institutional efforts.

In February of that year CONANP and PROFEPA agreed to promote a program for Social Participation for the Conservation of the Jaguar in Mexico and later in August formalized through the signing of an agreement with CONABIO for $1.2 million (pesos) to equip Community Monitoring Committees in 14 states of the country. Later in March, the President publicly declared 2005 the "Year of the Jaguar" at the Calakmul Biosphere Reserve, Campeche, where he also declared an extension to the Biosphere Reserve of more than 150,000 hectares making it the largest protected region that is home to one of the most important jaguar populations in the country.

That year many activities were promoted for the conservation, dissemination, education and social promotion of jaguars. Distribution of promotional material, posters, flyers, brochures, postage stamps, videos, television spots, radio, etc., was also carried out as part of actions aimed at conservation of the jaguar and its habitat. One of the most relevant activities within the year of the jaguar was the development of the First Symposium of the Jaguar, conducted in the month of October in Cuernavaca, Morelos, during which approximately 50 experts recorded the outcomes of the 7 working groups in the reports of the First Symposium: The Mexican Jaguar in the XXI Century: Current Status and Management (Chávez and Ceballos, 2006).

In 2006 the Second Symposium of the Jaguar was held in Cuernavaca, Morelos, where a Population and Habitat Viability Analysis (PHVA) workshop was conducted in which specialists participated from the six major regions within the jaguar's range. Priority and critical areas for conservation were identified in this workshop, as well as key factors for the survival of the species.

At the beginning of the Six-Year Program 2007-2012 of the National Commission of Natural Protected Areas (CONANP), the Conservation Program of Endangered Species, known as PROCER, was announced. It provides general guidelines for conservation strategies for species at risk in Mexico, and determines the implementation of the Action Programs for the Conservation of Endangered Species, known as PACE, under the Presidential Declaration of the 5 Commitments for Conservation of Biodiversity in Mexico made in March 2007. It is in the framework of PROCER that in 2007 two sessions of the Technical Advisory Subcommittee for the Conservation and Sustainable Management of the Jaguar were carried out, integrating and defining the present Program of Action for the Conservation of Species Jaguar (PACE: Jaguar).

It is noteworthy that key factors to achieve and reach the objectives were identified: prioritize coordinated, integrated and participatory work of the different stakeholders; involve rural communities, indigenous people and those interested in the topic; strengthen the work of the Regional Project leaders to consolidate and, in turn, support the development of new social work projects; trigger processes for species conservation across the country; and improve the relationship between this emblematic species with communities and priority conservation areas under the triad approach: Species, Spaces and Ethnic groups.

III. Status and Threats

Historical distribution

The historical distribution of the species was a continuous area from the southern United States of America to Argentina, while in Mexico it was distributed along the coastal plain of the Atlantic and the Pacific, in the south and southeast region of the country in the Yucatan Peninsula and in the states of Oaxaca, Tabasco and Chiapas (Seymour, 1989).

Figure 1. States with historical jaguar records. Taken from SEMARNAP-INE, 1999.

Current distribution and sightings

The probable range of the jaguar currently includes a considerable portion of the historical range, from Sonora and Tamaulipas to the Yucatan Peninsula and Chiapas. The four states where there are the most important populations are Campeche, Chiapas, Oaxaca and Quintana Roo (Flores and Gerez, 1994). There are recent records in the states of Sonora, Sinaloa, Nayarit, Jalisco, Estado de México, Guerrero, Oaxaca, Chiapas, Yucatán, Quintana Roo, Campeche, Tabasco, Querétaro and Tamaulipas (Faller et al., 2005, López-González and Brown, 2002, Monroy et al., 2005, Ortega Huerta and Medley, 1999, Rosas-Rosas and López-Soto, 2002, Valdez et al., 2002).

The jaguar resides mainly in tropical evergreen and deciduous forests, mangroves, cloud forest, thorn forest and occasionally in dry shrubland and pine and oak forest. It is found from sea level to 2,000 meters; however, most records are from localities below 1,000m (Ceballos and Oliva, 2005).

Figure 2. Distribution of resident jaguars in Mexico (from Howell and Webb, 1995; modified from SEMARNAP-INE, 1999).

Threats

In the Action Plan for the Recovery and Management of the Jaguar (Series PREP) and in the records of the First Symposium of Mexican Jaguar in the XXI Century, experts agreed that one of the most important problems that threatens the existence of the jaguar population is the human growth that leads to degradation, destruction and fragmentation of the habitat, which is aggravated by poaching and changes in land use in many areas of the country unsuitable for these activities or without any control.

In addition, one of the studied factors that is increasingly worrisome is related to the impact caused by infections and diseases that can affect wild populations, both belonging to wild species as well as those originating from domestic animals invading their territory (May, 1988.)

It is considered that one of the most important, yet often ignored factors for the loss of jaguar populations is the lack of recognition of the ecological role that this species meets in the ecosystem and hence the social benefit that can be generated through its role as a flagship and umbrella species (Miller and Rabinowitz, 2002). Unfortunately in many places it is still considered simply as a dangerous animal.

In order to develop a comprehensive strategy for the conservation of the jaguar, a proper diagnosis of its current distribution and population status is required, including key information on its biology and ecology to determine what factors contribute to its deterioration.

IV. Objectives

General objectives

Strengthen, promote and implement specific actions and conservation strategies arising from the Project for the Conservation and Management of the Jaguar in Mexico and other relevant considerations (PREP), in order to conserve and recover populations of jaguar in Mexico.

Specific objectives

• Promote the generation of biological and ecological information, and information on social perception of the species, as inputs for the decision-making process aimed at the recovery of the species and its habitat.

• Promote action and increase participation focused on strengthening an environmental culture of protection and conservation of biodiversity, with emphasis on vulnerable species.

• Promote social participation as one of the key strategies aimed at the conservation and protection of the populations of the jaguar as an umbrella species.

• Generate synergy among stakeholders across all sectors of Mexican society, and have them participate actively within the scope of their expertise to achieve recovery of the species.

• Promote the consolidation of a specialists group through ongoing consultation of technical issues as well as providing several economic resources for the conservation and recovery of the jaguar.

V. General Goals

• Complete a comprehensive and systematic status review of jaguar populations at the national and regional situation level.

• Increase the area covered under some conservation status to facilitate the distribution and the biological and ecological processes of jaguar populations with the purpose of recovering the species.

• Create an active institutional participation system framed in mainstream agendas that allow the opening of actions routes for the protection and conservation of jaguar populations.

• Manage and provide the necessary resources to carry out actions aimed at conserving the species and its habitat.

VI. Goals for 2012

• Maintain a robust group of experts who collaborate with other working groups for the conservation of species that share habitats, developing actions and strategies with an ecosystem approach, in order to achieve a greater impact to ensure the continuity of ecological and evolutionary processes.

• Develop a robust database at a national level for projects and monitoring and conservation programs conducted within the jaguar's range during the last decade.

• Incorporate 1,000,000 hectares of the species range into a conservation system (ANP (Natural Protected Areas), UMA (Wildlife Management Unit), Certified Lands for Conservation, Payment Programs for Environmental Services (PSA), etc.) by promoting conservation systems and/or agreements with Environmental Sector Institutions at the Federal, State and Municipal government level, as well as with private citizens.

• Comply with 80% of the activities proposed in this document (PACE: Jaguar) through management, entailment, evaluation and timely monitoring in adherence to the Conservation Program of Endangered Species (PROCER), considering each and every one of the proposed Conservation Subprograms.

VII. Conservation strategies

(Components)

1. PROTECTION

1.1 Habitat Protection Component

Objective

Support and coordinate the processes to incorporate new areas of jaguar habitat under some conservation and protection status.

Activities

a. Promote the conservation and protection of priority areas as either Natural Protected Areas, Certified Lands for Conservation, communal and/or private reserves of Federal and State recognition, or UMAS.

b. Incorporate lands where conservation of the jaguar and its habitat is occurring, both formally and informally, into payment for environmental services (PSA - Carbon capture, Hydrological, and Biodiversity Conservation) and Conservation Programs for Sustainable Development (PROCODES).

c. Promote municipal territorial ordinances in the priority areas for conservation of the jaguar through interinstitutional coordination.

d. Promote the inclusion of priority areas for conservation of the jaguar as scoring criteria for the PROARBOL program within the CONAFOR, as well as strengthen interinstitutional coordination.

e. Establish a robust link between the Technical Subcommittee as a consultative organ of SEMARNAT in order to consider their observations regarding their opinions about Environmental Impact Statements (MIA) for megaprojects in public or private works in the priority conservation areas, which may hinder or disturb jaguar habitat.

f. Promote the legal recognition of the concept of "biological corridors" to ensure availability of land and optimal conditions for the conservation of the jaguar and its great importance as an umbrella species.

1.2 Prey Population Protection Component

Objective

Promote actions to strengthen appropriate measures for the conservation and sustainable management of key prey populations in the priority areas of jaguar conservation.

Activities

a. Among different sectors, coordinate actions to promote the necessary measures to ensure the conservation and sustainable management of key jaguar prey.

b. Design and implement conservation and sustainable management strategies for key prey populations, according to their status and threats.

1.3 Legal Framework Component

Objective

Identify the legal framework and implement the mechanisms and strategies to ensure its proper application and management towards conservation of the jaguar and its habitat.

Activities

a. Promote mechanisms for evaluating and modifying the legal framework and establish efficient mechanisms to disseminate updates on legal and regulatory issues.

b. Establish mechanisms for interinstitutional coordination to promote compliance with the conditions of Environmental Impact Statements for projects that are implemented in priority conservation areas of the jaguar.

c. Propose methods to strengthen compliance with environmental regulations in the national territory, including close coordination with neighboring countries involved in existing international projects ("Jaguars without Borders" and "Northern Jaguars").

d. Promote evaluation mechanisms for management plans and utilization rates for UMAs established in the priority regions for jaguar conservation (minimum viable protocols).

1.4 Inspection and Surveillance Component

Inspection

Objective

Create an efficient system of receiving and distributing complaints to the responsible authorities who can act immediately to discourage illegal actions within the priority conservation areas of the jaguar.

Activities

a. In close coordination with the Federal Environmental Protection Agency (PROFEPA), promote timely attention to complaints and grievances that relate to direct and indirect effects to jaguars, prey species and their habitats.

- Direct effects are those related to hunting for marketing of products and byproducts, removal of wildlife, and retaliatory hunting in response to livestock depredation.
- Indirect effects refer to all of those related to their habitat (e.g., changes in habitat structure, indiscriminate hunting of prey).

b. Develop a map of directly and indirectly affected critical areas and routes for jaguars to prioritize preventive and punitive actions as required.

c. Reduce poaching by developing management strategies for each type of hunting identified and recognizing and engaging the legally-established hunting sector as a crucial collaborator in disseminating regulations and conservation efforts for the species and their prey to other stakeholders.

Surveillance

Objective

Promote social participation strategies for environmental monitoring under different approaches and agency strategies, including the concept of community networks for conservation in priority conservation areas within the jaguar's range.

Activities

a. In close coordination with the various government agencies involved, promote social participation in priority conservation areas for jaguars, supported by Temporary Employment Programs (PET) and Conservation Projects for Sustainable Development (PROCODES).

b. Establish interagency coordination mechanisms to promote social participation in a collaborative way that promotes rural sustainable development, optimizing resources and strengthening the interest and permanent active participation in the conservation of jaguar habitat and prey.

- Participatory Environmental Surveillance Community Program of PROFEPA.
- Program of Environmental Promoters and Community Networks for Conservation of CONANP.
- Fire Brigades Program of CONAFOR.
- Payments for Environmental Services for Biodiversity Conservation Program of the CONAFOR.
- Social Promoters Program of CDI.
- Rural Police Program (environmental focus) of SEDENA.

c. Promote actions inside and outside the communities involved in the Community Surveillance Committees, in coordination with Ejido, Municipal and Federal authorities, to discourage land use change in priority areas for jaguar conservation.

2. RESTORATION

2.1 Restoration of Habitat and Ecosystems Component

Objective

Promote the restoration of disturbed areas that are located within the priority areas for jaguar conservation, with emphasis on Natural Protected Areas (ANPs).

Activities

a. Identify "critical" disturbed areas inside and outside natural protected areas, including priority areas for jaguar conservation that are potentially key for the continuity of gene flow.

b. Coordinate interagency actions for restoration programs in disturbed areas identified as "critical."

c. Implement land restoration activities in conjunction with ANPs in priority areas for jaguar conservation.

3. MANAGEMENT

3.1 Habitat Management Component

Objective

Promote actions and activities to ensure permanence of sufficiently connected habitat that can maintain viable jaguar populations in both formally declared Natural Protected Areas, as well as in priority areas without any protection status.

Activities

a. Ensure land where formal and informal jaguar and jaguar habitat conservation actions are implemented receive the benefits of following programs: Environmental Services (PSA), Temporary Employment Program (PET) and Conservation Programs for Sustainable Development (PROCODES). In priority areas under some protection status or that have been identified as important for this species, limit and/or regulate production activities and infrastructure that may threaten these areas. For example: Michoacan Coast, Sierra de Tamaulipas, Zoque Forest, Coastal Plain Sinaloa, Sierra Norte de Oaxaca, Wetlands of the Gulf of Mexico and Sierra of Guerrero.

b. Promote the review and monitoring of management programs of ANPs and UMAs located in priority areas to adjust and improve them, in concert with the owners and holders of UMAs.

c. Promote and monitor the Territorial Land Programs in municipalities and communities located in priority areas for jaguar conservation to promote continuity of habitat providing biological corridors allowing for species gene flow.

d. Propose the inclusion of an extra score in the Terms of Reference of the PROARBOL program for areas that maintain jaguar populations.

e. Establish and promote guidelines or liaison strategies for the Subcommittee and the Secretaries for the provision of technical elements in the development of mega projects of public or private works in conservation priority areas, focusing on the review of Environmental Impact Statements to ensure as much as possible that the conditions are met.

f. Promote the recognition of strategic conservation areas through the legal definition of "critical habitat of the jaguar" in accordance with the LGVS and its regulations.

3.2 Livestock Management Component

Objective

To promote, design and deliver informational programs focused on reducing cases of depredation by jaguars and other wild carnivores, in coordination with academia, NGOs and government agencies related to the promotion of sustainable rural development.

Activities

a. Develop a database with the help of the National Livestock Confederation SAGARPA identifying hotspots of jaguar-livestock conflict in priority areas with emphasis on Level I areas: Northwest of the Yucatan Peninsula, Yucatan; Sian Ka'an, Quintana Roo; Calakmul, Campeche and Quintana Roo; Lacandona, Chiapas; Chimalapas, Oaxaca; Chamela Cuixmala, Jalisco; West Corridor Region (Nayarit, Michoacan, Jalisco); Northeast Sonora and Tamaulipas.

b. Develop regional diagnostics to promote interagency meetings according to the priorities identified in the jaguar-livestock conflict issue.
c. Develop and implement the Manual for the Attention of Depredation Cases of Livestock by Wild Carnivores in coordination with specialists, environmental authorities and government agencies in agricultural and livestock development, which will be disseminated to all environmental authorities and NGOs in agricultural and livestock development.

d. Modify and promote the Livestock Development Program (PROGAN), mainly in the Natural Protected Areas located within the priority areas for jaguar conservation, in order to organize livestock activities in areas within the jaguar’s range.

e. Promote an agreement between SEMARNAT and SAGARPA to implement a program of improved livestock management, as well as notification strategies and immediate attention to conflicts related to livestock depredation by jaguars, mainly in priority areas for jaguar conservation.

f. Develop and promote an incentive program of tolerance for large predators within the range of the jaguar and other felines under a strategic approach of sustainable rural development (avoiding resorting to programs of "compensation" for damages).

g. Distribution to Government authorities in the environmental sector, of the Directory of regional experts and working groups for the immediate attention of livestock depredation conflicts (which is supported by the Technical Advisory Subcommittee for the Conservation and Sustainable Management of Jaguar).

4. KNOWLEDGE

4.1 Priority Areas Component

Objective

Confirm through a national census identification of Priority Conservation Areas. Meaning those natural areas, protected or not, that maintain viable wild jaguar populations and those that are important to maintain the species (mainly biological corridors).Taking into account this definition, the PREP of Jaguar in Mexico identified six Priority Areas (AP), which overlap significantly with the results of the First Mexican Jaguar Symposium in the XXI Century, where it was determined that these of Priority Conservation Areas be classified into three levels or categories according to the conservation priorities identified so far.

PRIORITY LEVEL I
Northwest Yucatan
Sian Ka'an, Quintana Roo
Calakmul, Campeche and Quintana Roo
Lacandona, Chiapas
Chimalapas, Oaxaca
Chamela Cuixmala, Jalisco
West Corridor Region (Nayarit, Michoacan, Jalisco)
Northeast Sonora
Tamaulipas
PRIORITY LEVEL II
Sinaloa
Nayarit Coast
Cabo Corrientes, Jalisco
Michoacán Coast
Guerrero Coast
Northern Oaxaca
Coast and Sierra Madre del Sur Chiapas
Campeche Coast

PRIORITY LEVEL III
Querétaro
Nuevo León
Veracruz
San Luis Potosí
Estado de México

Activities

a. Identify critical areas for the recovery of the jaguar in Mexico, particularly source populations and connectivity between populations through a monitoring and population density study nationwide.

b. Strengthen the coordination of actions towards jaguar habitat conservation with ANPs, mainly focused on:

- Promote the use of the jaguar's image as an umbrella species as a strategy for conservation of ecosystems in areas of influence of ANP.

- Promote, in a coordinated manner, technical assistance programs in agriculture and livestock in the communities in areas of influence.

- Promote coordinated actions for the Municipal and Statewide Ecological Territorial Ordering aimed at preventing changes in land use in priority areas for jaguar conservation.

- Promote active social participation in the protection of the jaguar and its habitat based on the recognition of the cultural and environmental diversity existing in each region.

4.2 Scientific Research Component

Objective

In coordination with the Technical Advisory Subcommittee for the Conservation and Sustainable Management of the Jaguar, support and promote research in priority areas that generates robust information in order to develop local and regional strategies that lead to the conservation and recovery of jaguar populations.

Activities

a. Standardize research protocols regarding monitoring, physical health and genetics, PHVA, food habits, current distribution, and population density of jaguars, as well as socio-economic situations within the jaguar's range. In addition, follow up with and strengthen the activities in the Mexican Jaguar Symposium in the XXI Century (2005, 2006).

b. Establish a population simulation model that defines the number of jaguars in the country, as well as the minimum population required to consider the species viable and safe from extinction.

c. Quantify the main prey species and the minimum number required to maintain the baseline population of jaguars.

d. Every 5 years, evaluate the rate of change and forest cover fragmentation within critical areas for jaguar conservation at a national scale with the National Forest Inventory 2000-2001 (and subsequent forest inventories), the Vegetation Series and Land Usage from the INEGI (e.g., Series 3), and/or by analyzing satellite images (e.g., MODIS images, resolution 1 km).

e. In coordination with the Technical Advisory Subcommittee for the Conservation and Sustainable Management of the Jaguar, develop the terms of reference for the implementation of a study to identify critical areas for jaguar conservation in Mexico.

f. Manage the search for funding for projects identified as key for the conservation strategy of the species.

g. Every six months, assess and monitor the progress of actions implemented for the protection and conservation of the jaguar and its habitat in order to make modifications or corrections to achieve the objectives.

4.3 Biological Monitoring Component

Objective

Promote a standardized system for biological monitoring of the jaguar at the national level within and outside of Natural Protected Areas.

Activities

a. In coordination with ANPs and the Technical Advisory Subcommittee for the Conservation and Sustainable Management of the Jaguar, design a jaguar monitoring protocol in ANPs in order to have uniform monitoring criteria for all priority areas and initiate the creation of a database for CONANP.

b. Systematically implement the National Census of the Jaguar (*Panthera onca*) every three years to measure the changes and threats to which jaguar populations are exposed.

c. Implement and continuously update a database and a Geographic Information System for jaguars that reflect baseline population information, extension of areas, areas under protection, and prey information to support decision-making for conservation and recovery projects.

5. CULTURE

5.1 Environmental Education Component

Objective

To achieve awareness and influence new behavior for the general population by promoting a culture of conservation of the jaguar as a keystone species in the conservation of ecosystems, based on knowledge of its cultural, biological and ecological value.

Activities

a. Convene and promote a working group of governmental and non-governmental organizations (in areas of environmental education and social communication) in order to standardize criteria and join efforts for a comprehensive environmental education campaign in both rural and urban settings. (CONANP, CECADESU, CONABIO, INE, PROFEPA, CONACYT, conservation NGOs, civil society, state governments, SEP, CDI and SAGARPA).

5.2 Communication and Information Component

Objective

In coordination with the Technical Advisory Subcommittee for the Conservation and Sustainable Management of the Jaguar, promote a communications and outreach campaign using formal and informal media individually targeting rural and urban audiences. Promote the jaguar as a charismatic species to the general population, address each particular problem with a concrete outreach product, reclaim the traditional values that people held toward jaguars to recover the jaguar's enormous cultural value and sense of belonging among Mexicans throughout its range.

Activities

a. Translate and disseminate scientific information concerning the jaguar to the different sectors of society in a language appropriate for their understanding, awareness and greater participation.

b. Design and define content and optimal media under a regional approach.

c. Develop a Marketing Program for the species (corporate image design (logo, mascot, etc.) that provokes feelings).

d. Promote and manage pro- jaguar conservation events (Conferences, Day of the Jaguar, contests, etc.).

e. Promote the integration, dissemination and participation of all stakeholders involved in setting up an informational website for specialists and the general public in order to achieve interest and participation in the conservation of the jaguar nationally and internationally.

f. Promote and manage a communication strategy to sensitize the population on two levels:

- In rural areas, ensure coexistence and respect for the species using the following media: talks, lectures, videos, radio spots, television, and brochures in general.
- Promote the use of government programs, such as PROCODES and PET, in jaguar priority areas focused on the creation of Environmental Promoters and Community Networks for Conservation, under the management of CONANP.
- In the urban sector, use mass media with messages that are explicit and accessible to the population as a whole.

5.3 Community Training Component

Objective

Reduce activities likely to cause habitat fragmentation and direct loss of individuals and /or populations of jaguars in the priority areas for conservation by searching for and promoting social participation, represented by a greater degree of information, participation and involvement by *ejidatarios* and/or small landowners located in these areas.

Activities

a. In coordination with governmental and non-governmental organizations, within the strategies of environmental education, communication and dissemination, promote exchanges of inter-community experiences in order to raise awareness of local people about the importance of their work in reclaiming the cultural value of the jaguar and its relevance in the ecosystem as an umbrella species. Likewise, develop community training workshops focused on:

- Promotion of profitable activities compatible with conservation of the jaguar and its habitat (ecotourism, UMAS, forestry production chains, etc.).

- Environmental regulations.

- Biological monitoring of the species.

b. Raise awareness of local people about the importance of conserving habitat as a resource of ecological value and use.

6. MANAGEMENT

6.1 Involved Stakeholders Component

Objective

Promote the integration and cooperation of all national and international stakeholders involved to achieve effective collaboration in strategic planning to optimize resources and efforts to ensure achievement of the jaguar conservation objectives.

Ensure coordination between Technical Advisory Subcommittees and working groups of species that share habitat with the jaguar to collaborate on an ecosystem approach to conservation.

Activities

a. Promote and disseminate the benefits and advantages of the conservation strategy of the jaguar under the "umbrella" species approach, within and throughout institutions.

b. Create opportunities and forums to share experiences to ensure a process of adaptation to a changing reality, for which flexible mechanisms and effective communication and interaction will be designed among all those involved in a national and international scope.

c. Strengthen research, conservation, environmental education and sustainable development projects that are currently carried out by communities, civil society organizations and academic institutions, including coordinating activities with neighboring countries.

d. Promote a SEMARNAT-CONACYT joint fund for studies on the jaguar to manage and generate financial and human resources for scientific research in states where the species is distributed.

e. Establish partnerships between SEMARNAT-SECTUR, SEMARNAT-CFE, SEMARNAT-PEMEX, SEMARNAT-SCT for the detailed evaluation of Environmental Impact Statements (or

MIAs) for development projects in priority areas for jaguar conservation in compliance with the Transversal Agenda on Environmental Agreements (with the collaboration of the Technical Advisory Subcommittee).

6.2 Programming Component

Objective

To operate in a manner that is both systematic and linked to the Technical Advisory Subcommittee for the Conservation and Sustainable Management of the Jaguar in compliance with a scheduled 2007-2012 Work Program establishing short, medium and long term goals.

Activities

a. Schedule semi–annual meetings for evaluating and monitoring strategies actions implemented in the 2007-2012 Work Program in coordination with the Technical Advisory Subcommittee for the Conservation and Management of the Jaguar.

b. Promote, support and insert state and regional strategies for the conservation of the jaguar and its habitat into the Program of Action in order to highlight the importance of biological corridors of natural vegetation preferably allowing for the gene flow of jaguars and other species in order to have the ability to maintain biological and genetic richness because it is essential for this species to have large areas to maintain viable populations (State Programs of Jaguar Conservation in: Oaxaca, Jalisco, Nayarit, Michoacán, Northeast Regional Program).

c. Strengthen coordination with the Natural Protected Areas located in priority areas for jaguar conservation in order to strengthen programs that promote community development alternatives and reduce pressure on the habitat, primarily in biological corridors currently identified.

d. Strengthen and consolidate links with international projects for the conservation of the jaguar and its habitat:

- Mesoamerican Biological Corridor Project.
- Jaguars without Borders Project (Guatemala, Belize and Mexico).
- Northern Jaguar Project (Arizona, New Mexico and Mexico).
- Trilateral Committee for the Conservation and Management of Wildlife and Ecosystems (promote strengthening of the jaguar conservation theme).
- Project Puebla Panama Plan following the actions of the Jaguars without Borders initiative.

e. Implement jaguar habitat conservation actions and strategies of in compliance with the Transversal Agenda on Environmental Agreements of the Environment and Natural Resources Sector Program 2007-2012.

6.3 Monitoring and Evaluation Component

Objective

To ensure full compliance with the objectives and goals of this program by timely assessment and monitoring of actions and strategies implemented for which indicators and targets established must be measurable, specific, temporally defined, achievable and meaningful in the short, medium and long term.

Activities

a. Identify critical moments for interim evaluations during implementation of projects independent of those scheduled with the Technical Advisory Subcommittee for the Conservation and Sustainable Management of Jaguar.

b. Increase forums and strengthen mechanisms to distribute the preliminary and final results of the actions implemented, so as to identify degrees of progress and performance through which a feedback exercise might suggest changes and corrections.

c. Design analysis and feedback mechanisms to allow the program to evolve in accordance with the needs and circumstances of conserving the jaguar and its habitat.

VIII. Success Indicators

Note: Short Term 1-2 years, Medium Term 3-4 years, Long Term more than 5 years.

Conservation Strategy	No.	Success Indicator	Short Term	Medium Term	Long Term
Protection	1	Decrease in complaints about hunting, commercialization and capture of specimens.			X
	2	Increased number of social participation groups under various schemes (participatory environmental monitoring committees, Community Networks for Conservation and environmental advocates) focused on jaguar conservation.		X	

Conservation Strategy	No.	Success Indicator	Short Term	Medium Term	Long Term
	3	Number of meetings, exchanges of experience, community workshops, with participation of social groups interested in the conservation of the species and its habitat.			X
Restoration	4	Increased number of stakeholders and programs focused on habitat identification and restoration actions.		X	X
	5	Number of hectares of land restored that contribute to increasing the extent of jaguar habitat.		X	X
Management	6	Increase in the number of hectares of habitat available for the conservation of jaguars and their prey incorporated into conservation programs (ANP, UMA, UMAFOR, PSA, PCC, etc.)			X
	7	Increased abundance of potential jaguar prey.	X	X	
	8	Decreased jaguar loss from livestock conflicts.	X	X	
	9	Increased livestock production programs under technical assistance in priority areas.		X	
Knowledge	10	Number of scientific studies focused on biological and ecological monitoring of the species.		X	X
	11	Increased number of priority areas where jaguar conservation work and research is developed.		X	X
	12	Increase the dissemination and outreach in electronic and print media available, with emphasis on regions within the jaguar's natural range.	X	X	X

Conservation Strategy	No.	Success Indicator	Short Term	Medium Term	Long Term
Culture	13	Increased number of training, outreach and environmental education events.	X	X	X
	14	Increased participation in informational forums about the species and efforts to conserve it.	X	X	X
Management and Programing	15	Increase the number of interagency agreements focused on jaguar habitat conservation programs.	X		
	16	Increases in financial and human resources applied to jaguar conservation programs and actions.	X	X	
	17	Increase in communities participating in ecotourism.		X	X
	18	Increased international agreements focused on conservation of the jaguar and its habitat.		X	X
	19	Increase in the number of stakeholders involved in the conservation of the jaguar and its habitat.		X	X
Monitoring and Evaluation	20	Number of goals achieved with the development and implementation of the actions planned in PACE Jaguar.		X	X
	21	Number of evaluation meetings with the Group of Specialists (Technical Advisory Subcommittee).		X	X

X. Table of Activities

Activities	**Success Indicator**	**Short Term**	**Medium Term**	**Long Term**
1.1 Habitat Protection Component				
Promote the conservation and protection of priority areas as either Natural Protected Areas, Certified Lands for Conservation, communal and/or private reserves of Federal and State recognition, or UMAS.	6, 5, 1 1	X	X	X
Incorporate lands where conservation of the jaguar and its habitat is occurring, into payment for environmental services and PROCODES.	5, 6, 7, 2	X	X	X
Promote municipal territorial ordinances in the priority areas for jaguar conservation through interinstitutional coordination.	6, 9, 11, 15			X
Promote the inclusion of priority areas for jaguar conservation as scoring criteria for the PROARBOL program within the CONAFOR, as well as strengthen interinstitutional coordination.	6, 12, 19		X	X
Establish a robust link between the Technical Subcommittee as a consultative organ of SEMARNAT in order to consider their observations regarding opinions about Environmental Impact Statements works, which may hinder or disturb the jaguar habitat.	11, 15, 21	X	X	
Promote the legal recognition of the concept of "biological corridors" to ensure availability of land and optimal conditions for the conservation of the jaguar and its great importance as an umbrella species.	6, 15, 19, 20	X	X	
1.2 Prey Population Protection Component				
Among different sectors, coordinate actions to promote the necessary measures to ensure the conservation and sustainable	7, 9, 10, 11		X	X

Activities	Success Indicator	Short Term	Medium Term	Long Term
management of key jaguar prey.				
Design and implement conservation and sustainable management strategies for key prey populations according to their status and threats.	2, 5, 6, 7, 16		X	X
1.3 Legal Framework Component				
Promote mechanisms for evaluating and modifying the legal framework and establish efficient mechanisms to disseminate updates on legal and regulatory issues.	15, 18	X	X	
Establish mechanisms for interinstitutional coordination to promote compliance with the conditions of Environmental Impact Statements for projects that are implemented in priority conservation areas of the jaguar.	13, 15, 21	X	X	
Propose methods to strengthen compliance with environmental regulations in the national territory, including close coordination with neighboring countries involved in existing international projects ("Jaguars without Borders" and "Northern Jaguars").	15, 16, 21	X	X	X
Promote evaluation mechanisms for management plans and utilization rates for UMAs established in the priority regions for jaguar conservation (minimum viable protocols).	5, 6, 7		X	X
1.4 Inspection and Surveillance Component				
In close coordination with the PROFEPA, promote timely attention to complaints and grievances that relate to direct and indirect effects to jaguars, prey species and their habitats.	1, 2	X	X	X
Develop a map of directly and indirectly affected critical areas and routes for jaguars to prioritize preventive and punitive actions as	1, 2	X		

Activities	**Success Indicator**	**Short Term**	**Medium Term**	**Long Term**
required.				
Recognize and engage the legally-established hunting sector as a crucial collaborator in disseminating regulations and conservation efforts for the species and their prey to other stakeholders.	1, 4, 15	X		
In close coordination with the various government agencies involved, promote social participation in priority conservation areas for jaguars, supported by PET and PROCODES.	2, 5, 9, 17	X	X	
Establish interagency coordination mechanisms to promote social participation in a collaborative way that promotes rural sustainable development, optimizing resources and strengthening the interest and permanent active participation in the conservation of jaguar habitat and prey.	3, 15, 19	X	X	
Promote actions inside and outside the communities involved in the Community Surveillance Committees, in coordination with Ejido, Municipal and Federal authorities, to discourage land use change in priority areas for jaguar conservation.	6, 9, 12, 13, 14	X	X	
2.1 Restoration of Habitat and Ecosystems Component				
Identify “critical” disturbed areas inside and outside ANP, including priority areas for jaguar conservation that are potentially key for the continuity of gene flow.	4, 5, 10, 15	X	X	
Coordinate interagency actions for restoration programs in the disturbed areas identified as "critical."	4, 5, 15, 16	X	X	
Implement land restoration activities in conjunction with ANPs	4, 5, 6, 15, 16	X	X	

Activities	**Success Indicator**	**Short Term**	**Medium Term**	**Long Term**
in priority areas for jaguar conservation.				
3.1 Habitat Management Component				
In priority conservation areas or other identified as key areas, ensure lands receive the benefits of PSA (CABSA, hydrological and biodiversity), PET and PROCODES.	5 ,6, 9	X	X	
Promote the review and monitoring of management programs of ANPs and UMAs located in priority areas to adjust and improve them.	6, 9		X	
Promote and monitor the Territorial Land Programs in municipalities and communities to promote continuity of habitat providing biological corridors.	9, 15, 19, 20			X
Propose the inclusion of an extra score in the Terms of Reference of the PROARBOL program for areas that maintain jaguar populations.	15, 19, 21	X		
Establish liaison strategies for the Technical Advisory Subcommittee and the Secretaries for the provision of technical elements in the development of mega projects in conservation priority areas, focusing on the review of Environmental Impact Statements.	15, 19, 21	X		
Promote the recognition of strategic conservation areas through the legal definition of "critical habitat of the jaguar".	10, 15, 21	X		
3.2 Livestock Management Component				
Develop a database to identify hotspots of jaguar-livestock conflict in priority areas with emphasis on Level I areas.	2, 10, 16	X	X	
Develop regional diagnostics to promote interagency meetings according to the priorities identified in the jaguar-livestock conflict issue.	2, 3, 4, 10, 16	X	X	

Activities	**Success Indicator**	**Short Term**	**Medium Term**	**Long Term**
Develop and implement the Manual for the Attention of Depredation Cases of Livestock by Wild Carnivores in coordination with specialists, environmental authorities and government agencies in agricultural and livestock development.	1, 8, 10, 16	X	X	
Modify and promote the Livestock Development Program (PROGAN), mainly in the Natural Protected Areas located within the priority areas for jaguar conservation.	1, 4, 8, 16		X	
Promote an agreement between SEMARNAT and SAGARPA to implement a program of improved livestock management and strategies to reduce conflicts related to livestock depredation by jaguars.	1, 4, 8, 10, 16	X	X	
Distribute the Directory of regional experts and working groups for the immediate attention of livestock depredation conflicts to Government authorities in the environmental sector.	4, 12, 21	X		
4.1 Priority Areas Component				
Identify priority areas for jaguar recovery.	10, 11	X	X	
Identify critical areas for persistence and recovery of the jaguar in Mexico, particularly source populations and connectivity between populations.	10, 16	X	X	
Promote and manage support and funding for jaguar and jaguar habitat research and conservation projects in priority areas.	10, 11, 16	X	X	X
Strengthen the coordination of actions for jaguar habitat conservation with the ANPs located in the priority areas.	2, 15, 19	X	X	
4.2 Scientific Research Component				

Activities	Success Indicator	Short Term	Medium Term	Long Term
Standardize research protocols regarding monitoring, physical health and genetics, PHVA, food habits, current distribution, and population density of jaguars, as well as socio-economic situations within the jaguar's range.	10, 16, 19	X	X	
Every 5 years, evaluate the rate of change and forest cover fragmentation within critical areas for jaguar conservation at a national scale with the National Forest Inventory 2000-2001 (and subsequent forest inventories), INEGI Series 3.	10, 16, 19	X		X
Develop the terms of reference for a study to identify critical areas for jaguar conservation.	10, 16, 19	X	X	
Manage the search for funding for projects identified as key for the conservation strategy of the species.	15, 16, 18, 19	X	X	
Every six months, assess and monitor the progress of actions implemented.	20, 21	X	X	X
4.3 Biological Monitoring Component				
In coordination with the ANPs and the Technical Advisory Subcommittee, design a jaguar monitoring protocol in ANPs in order to have uniform monitoring criteria for all priority areas and initiate the creation of a database for CONANP.	6, 10	X	X	
Systematically implement the National Census of the Jaguar every three years.	7, 10, 16	X	X	X
5.1 Environmental Education Component				
Convene and promote a working group of governmental and non-governmental organizations in order to standardize criteria and join efforts for a comprehensive environmental education campaign	12, 13, 14	X	X	

Activities	**Success Indicator**	**Short Term**	**Medium Term**	**Long Term**
in both rural and urban settings. (CONANP, CECADESU, CONABIO, INE, PROFEPA, CONACYT, conservation NGOs, civil society, state governments, SEP, CDI and SAGARPA).				
5.2 Communication and Information Component				
Translate and disseminate scientific information concerning the jaguar to the different sectors of society in a language appropriate to their understanding, awareness and greater participation.	10, 12, 13, 14	X	X	X
Design and define content and optimal media under a regional approach.	12, 13, 14	X	X	
Develop a Marketing Program for the species (corporate image design, logo, mascot, etc.).	14, 16, 19, 20		X	X
Promote and manage a communication strategy inform people at the rural and urban levels.	12, 13, 14, 15	X	X	
Promote and manage pro-jaguar conservation events.	12, 13, 14	X	X	X
Promote the integration and participation of all stakeholders involved in setting up an informational website for specialists and the general public in order to achieve interest and participation in the conservation of the jaguar nationally and internationally.	12, 16, 19	X		

Activities	**Success Indicator**	**Short Term**	**Medium Term**	**Long Term**
5.3 Community Training Component				
In coordination with governmental and non-governmental organizations, within the strategies of environmental education, communication and dissemination, promote exchanges of inter-community experiences in order to	2, 3, 13, 14	X	X	X

raise awareness of local people about the importance of their work in reclaiming the cultural value of the jaguar and its relevance in the ecosystem as an umbrella species.				
Raise awareness of local people about the importance of conserving habitat as a resource of ecological value and use.	2, 3, 16	X	X	X
6.1 Involved Stakeholders Component				
Promote and disseminate the benefits and advantages of the conservation strategy of the jaguar under the "umbrella" species approach, within and throughout institutions.	12, 13, 15, 16	X	X	
Create opportunities and forums to share experiences to ensure a process of adaptation to a changing reality, for which flexible mechanisms and effective communication and interaction will be designed among all those involved in a national and international scope.	2, 14, 16, 18	X	X	X
Strengthen research, conservation, environmental education and sustainable development projects that are currently carried out by communities, civil society organizations and academic institutions, including coordinating activities with neighboring countries.	2, 3, 10, 14, 16, 19		X	X
Activities	**Success Indicator**	**Short Term**	**Medium Term**	**Long Term**
Promote a SEMARNAT-CONACYT joint fund for studies on the jaguar to manage and generate financial and human resources for scientific research in states where the species is distributed.	10, 15, 16		X	X
Establish partnerships between SEMARNAT-SECTUR, SEMARNAT-CFE, SEMARNAT-	10, 15, 16, 21	X	X	

PEMEX, SEMARNAT-SCT for the detailed evaluation of Environmental Impact Statements for development projects in priority areas for jaguar conservation, in compliance with the Transversal Agenda on Environmental Agreements (with the collaboration of the Technical Advisory Subcommittee).				
6.2 Programming Component				
Schedule semi–annual meetings for evaluating and monitoring strategies and actions implemented in the 2007-2012 Work Program in coordination with the Technical Advisory Subcommittee for the Conservation and Management of the Jaguar.	16, 20, 21	X	X	
Promote, support and insert state and regional strategies for the conservation of the jaguar and its habitat into the Program of Action in order to highlight the importance of biological corridors of natural vegetation preferably allowing for the gene flow of jaguars and other species in order to have the ability to maintain biological and genetic richness because it is essential for this species to have large areas to maintain viable populations.	11, 15, 16	X	X	X
Strengthen coordination with the Natural Protected Areas located in priority areas of jaguar conservation in order to strengthen programs that promote community development alternatives and reduce pressure on the habitat, primarily in currently identified biological corridors.	2, 11, 12, 15, 16	X	X	
Strengthen and consolidate links with international projects for the conservation of the jaguar and its habitat.	18, 19	X	X	X
Implement jaguar habitat	14, 15, 16,	X	X	

conservation actions and strategies of in compliance with the Transversal Agenda on Environmental Agreements of the Environment and Natural Resources Sector Program 2007-2012.	20			
6.3 Monitoring and Evaluation Component				
Identify critical moments for interim evaluations during implementation of projects independent of those scheduled with the Technical Advisory Subcommittee for the Conservation and Sustainable Management of Jaguar.	20, 21	X		
Increase forums and strengthen mechanisms to distribute the preliminary and final results of the actions implemented, so as to identify degrees of progress and performance through which a feedback exercise might suggest changes and corrections.	12, 13, 14, 21	X		
Design analysis and feedback mechanisms to allow the program to evolve in accordance with the needs and circumstances of conserving the jaguar and its habitat.	15, 19, 21	X	X	X

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XI. Appendices

Appendix I. Legal Framework

Legislation in Mexico		
Legal Instrument	**Description**	**Scope**
Political Constitution of the United States of Mexico	Maximum legal governing statute. Art.27.	National
Federal Penal Code	Federal statute establishing environmental criminal offenses in Mexico. Art. 414 to 423.	National
General Law of Ecological Equilibrium and Environmental Protection (LGEEPA)	This Law regulates the provisions of the Political Constitution of the United States of Mexico relating to the preservation and restoration of ecological balance, as well as environmental protection in the country and the areas over which the nation exercises sovereignty and jurisdiction. Its provisions are of public order and social interest and are intended to encourage sustainable development and establish the foundation to guarantee the right of everyone to live in an adequate environment for their development, health and welfare; define the principles of environmental policy and instruments for its implementation; preservation, restoration and enhancement of the environment; the preservation and protection of biodiversity, and the establishment and management of protected areas; sustainable use, preservation and, where appropriate, restoration of soil, water and other natural resources.	National
Regulations of the LGEEPA on Protected Areas.	Regulations of LGEEPA Article 5, section VIII. This regulation is generally observed throughout the country and in areas where the Nation exercises sovereignty and jurisdiction. Aims to regulate the General Law of Ecological	National

Legislation in Mexico		
Legal Instrument	**Description**	**Scope**
	Equilibrium and Environmental Protection, in regards to the establishment, administration and management of Federal protected areas.	
General Wildlife Act and Regulations	Regulation of the third paragraph of Article 27 and the fraction XXIX, paragraph G of constitutional Article 73; is of public order and social interest. Its purpose is to establish the concurrence of the Federal, State and Municipal Governments, within their respective powers, on the conservation and sustainable use of wildlife and its habitat in the territory of Mexico and in areas where the Nation exercises its jurisdiction. The sustainable use of timber resources and aquatic species are excluded from the application of this law and remain subject to forestry and fishery laws respectively, except for species or populations at risk.	National
NOM-059-SEMARNAT 2001	Official Mexican Regulation. Environmental Protection - Mexican native species of wild flora and fauna - risk categories and specifications for inclusion, exclusion or change - list of endangered species.	National
Convention on International Trade in Endangered Species of Wild Fauna and Flora, CITES.	CITES is an international legal instrument governing wildlife threatened by trade through a system of permits and certificates that are issued for export, re-export, import and introduction from the sea; of animals and plants, alive or dead and their parts	International (Signatories)

Legislation in Mexico		
Legal Instrument	**Description**	**Scope**
	and derivatives.	
Indefinite ban on the exploitation of the Jaguar 1987.	Agreement declaring an indefinite ban the use of the jaguar species (*Panthera onca*) throughout the national territory, including strict prohibitions on jaguar hunting, capture, transportation, possession and trade.	National
NPA Management Programs.	Policy instrument of the Internal Regulations of SEMARNAT. Art. 145, Section V and VI Chapter Two.	Limited to the respective Natural Protected Area.
Federal Animal Health Law	This law is a regulation of Article 27 of the Constitution of the Mexican United States, its provisions are of public order and interest and observed throughout the country, and aims to regulate and promote the conservation, protection, restoration, production, cultivation, management and utilization of forest ecosystems in the country and its resources, and distribute forestry authorities that correspond to the Federation, the States, the Federal District and the municipalities, under the principle of competition under Article 73 fraction XXIX subsection G of the Political Constitution of the Mexican United States, in order to promote sustainable forestry development. In the case of forest resources whose ownership corresponds to indigenous peoples and communities, the provisions of Article 2 of the Constitution of the Mexican United States will be observed.	National
Sustainable Rural Development Act	Regulatory art. 27 Section XX of CPEUM, its provisions are mandatory and are aimed at: promoting sustainable rural development in the country,	National

Legislation in Mexico		
Legal Instrument	**Description**	**Scope**
	providing a suitable environment, in terms of paragraph 4, of Article 4, and ensuring the guidance of the State and its role in promoting equity in terms of Article 25. It includes the planning and organization of agricultural production, processing and marketing and other goods and services, and all those actions to raise the quality of life of the rural population, as provided in Article 26 of the Constitution.	
National Water Law	Regulatory art. 27 of the CPEUM in national waters, generally observed throughout the country, its provisions are of public order and social interest and seeks to regulate exploitation or use of such waters, distribution, control, and the preservation of their quantity and quality to achieve sustainable integrated development.	National

Appendix II. Directory Technical Advisory Subcommittee on Conservation and Sustainable Management of the Jaguar and other felines.

Name	Institution / Organization	Protection Area
Antonio Rivera	Jaguar Conservancy	Southeast
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Carlos Manterola	Jaguar Conservancy	Southeast
Cuauhtemoc Chavez	Instituto de Ecologia UNAM	Southeast
Dalia Conde	Duke University	Southeast
Danae Azuara	Jaguar Conservancy	Southeast
Diego Woolrich	Oaxaca mvz. (Investigador Sierra Norte Oaxaca)	Oaxaca y Guerrero
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Erik Saracho Aguilar	Alianza Jaguar A.C.	Nayarit
Eugeia Pallares Cadena	Jaguar Conservancy	Southeast
Fernando Colchero	Duke University	Southeast
Gerardo Ceballos González	Instituto de Ecología UNAM	Southeast
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Ivan Lira Torres	Dirección General de Zoológicos de la Ciudad de México	Oaxaca
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Juan Carlos Faller Menéndez	Pronatura Península de Yucatán A.C.	Yucatán
Manuel Valdés	Independent Consultant	Southeast
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Juan Carlos Gutierrez B	Naturalia A.C.	Sonora
Gerardo Carreón	Naturalia A.C.	Sonora

Appendix III. Acronyms.

ANP. Área Natural Protegida: Natural Protected Area.
CDI. Comisión Nacional para el Desarrollo de los Pueblos Indígenas: National Commission for the Development of Indigenous Peoples.
CEDADESU. Centro de Educación y Capacitación para el Desarrollo Sustentable: Centre for Education and Training for Sustainable Development.
CFE. Comisión Federal de Electricidad: Federal Electricity Commission.
CITES. Convención sobre el Comercio Internacional de Especies Amenazadas de Fauna y Flora Silvestres: Convention on International Trade in Endangered Species of Wild Fauna and Flora.
CONABIO. Comisión Nacional para el Uso y Conocimiento de la Biodiversidad: National Commission for the Knowledge and Use of Biodiversity.
CONACYT. Concejo Nacional de Ciencia y Tecnología: National Council of Science and Technology.
CONAFOR. Comisión Nacional Forestal: National Forestry Commission.
CONAGUA. Comisión Nacional del Agua: National Water Commission.
CONANP. Comisión Nacional de Áreas Naturales Protegidas: National Commission of Natural Protected Areas.
CPEUM. Constitución Política de los Estados Unidos Mexicanos: Political Constitution of the Mexican United States.
DEPC. Dirección de Especies Prioritarias para la Conservación: Directorate of Priority Species for Conservation.
INE. Instituto Nacional de Ecología: National Institute of Ecology.
INEGI. Instituto Nacional de Estadística, Geografía e Informática: National Institute of Statistics, Geography and Computing.
IUCN. Unión Internacional para la Conservación de la Naturaleza: International Union for Conservation of Nature.
LGVS. Ley General de Vida Silvestre: General Wildlife Act.
LGEEPA. Ley General del Equilibrio Ecológico y la Protección al Ambiente: General Law of Ecological Equilibrium and Environmental Protection.
MIA. Manifestación de Impacto Ambiental: Environmental Impact Statement.
NOM-059-SEMARNAT-2001. Norma Oficial Mexicana: Official Mexican Standard.
OET. Ordenamiento Ecológico Ambiental: Ecological Environmental Management.
ONG. Organismos No Gubernamentales: Nongovernmental Organization.
PACE. Programa de Acción para la Conservación de Especies en Riesgo: Action Program for the Conservation of Species at Risk.
PACE Jaguar. Programa de Acción para la Conservación de Especies: Jaguar: Action Program for the Conservation of Species: Jaguar.
PCC. Predios Certificados para la Conservación: Certified Conservation Lands.
PET. Programa de Empleo Temporal: Temporary Employment Program.
PEMEX. Petróleos Mexicanos: Mexican Petroleum.
PHVA. Análisis de Viabilidad para Especies y Hábitat: Population and Habitat Viability Assessment.
PREP. Proyectos de Recuperación de Especies Prioritarias: Priority Species Recovery Projects.

PROARBOL. Esquema para combatir la pobreza, recuperar la masa forestal e incrementar la productividad de bosques y selvas de México: Scheme to combat poverty, restore forest cover and increase productivity of forests of Mexico.
PROCER. Programa de Conservación de Especies en Riesgo: Conservation Program for Species at Risk.
PROCODES. Programa de Conservación para el Desarrollo Sostenible: Conservation Program for Sustainable Development.
PROFEPA. Procuraduría Federal de Protección al Ambiente: Federal Attorney for Environmental Protection.
PROGAN. Programa de Producción Pecuaria Sustentable y Ordenamiento Ganadero y Apícola (antes Programa de Estímulos a la Producción Ganadera): PROGAN. Sustainable Livestock Production Program and Livestock Management and Beekeeping (before Livestock Production Incentives Program).
PSA. Pago por Servicios Ambientales: Payment for Environmental Services.
SAGARPA. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación: Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food.
SARH. Secretaría de Agricultura y Recursos Hidráulicos: Ministry of Agriculture and Water Resources.
SCT. Secretaría de Comunicaciones y Transportes: Secretariat of Communications and Transportation.
SECTUR. Secretaría de Turismo: Ministry of Tourism.
SEDENA. Secretaría de la Defensa Nacional: Secretariat of National Defense.
SEDUE. Secretaría de Desarrollo Urbano y Ecología: Ministry of Urban Development and Ecology.
SEMARNAT. Secretaría de Medio Ambiente y Recursos Naturales: Secretariat of Environment and Natural Resources.
SEP. Secretaría de Educación Pública: Ministry of Education.
SHCP. Secretaría de Hacienda y Crédito Público: Secretariat of Finance and Public Credit.
UMA. Unidades de Manejo para la Conservación de Vida Silvestre: Wildlife Conservation Management Units.
UMAFOR. Unidades de Manejo Forestal: Forest Management Units.

Appendix IV. Acknowledgements.

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APPENDIX C: Jaguar survey and monitoring protocol (Polisar et al. 2014b)

Protocol of Jaguar Survey and Monitoring Techniques and Methodologies

A Submission to the U.S. Fish and Wildlife Service
in Partial Fulfillment of Contract F13PX01563

16 October 2014

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John Polisar, Sean M. Matthews, Rahel Sollman, Marcella J. Kelly, Jon P. Beckmann, Eric W. Sanderson, Kim Fisher, Melanie Culver, Rodrigo Núñez, Octavio C. Rosas Rosas, Carlos A. López González, Bart J. Harmsen, Tim G. O'Brien, Carlos De Angelo, and Fernando C. C. Azevedo

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EXECUTIVE SUMMARY

Jaguars (*Panthera onca* L.) have lived in the America's for more than 2 million years, but thousands of years of range expansion were reversed in the last few hundred years, particularly on the margins of their range. Along the northern margin in the United States, 20th-century records with photographic evidence, skins, and skulls are available from New Mexico, Arizona, and Texas, while 21st-century observations are limited to southern Arizona and extreme southwestern New Mexico. Throughout this period, northwestern Mexico has remained a harbor for jaguar populations supplying individuals to the United States. The pattern of retracting jaguar range in the historic northern limits of the species' distribution has been mirrored in the southern limits, and range retraction yet underway in much of the jaguar's range. The species is listed as Near-Threatened on the International Union for Conservation of Nature (IUCN) Red List, in Appendix 1 of the Convention on Trade in Threatened and Endangered Species of Fauna and Flora (CITES). The jaguar is recognized as an endangered species in Mexico (SEMARNAT 2010), and is a national priority for conservation (Ramírez-Flores and Oropeza-Huerta 2007). The U.S. Fish and Wildlife Service (USFWS) has determined that the jaguar is an endangered species throughout its range, including in the United States, under the definitions of the Endangered Species Act (U.S. Fish and Wildlife Service 1997).

The 226,826-km^2 Northwestern Jaguar Recovery Unit (NRU) straddles the United States-Mexico border with approximately 29,021 km^2 in the United States and 197,805 km^2 in Mexico (Figure 11) (Sanderson and Fisher 2013). The scale of the NRU, its gradients of jaguar abundance, and the threats to jaguar persistence in it, echo the situation across much of jaguar range. The USFWS contracted the Wildlife Conservation Society (WCS) to: 1) conduct a comprehensive literature review of jaguar survey and monitoring techniques and methodologies (Polisar et al. 2014); and 2) draft a jaguar survey and monitoring protocol for application in the NRU, with relevance for monitoring the species range wide. In this second half of the task, we present a survey and monitoring protocol for jaguars in the NRU and guidance for monitoring range wide.

In April 2014 WCS convened a group of fifteen jaguar and quantitative sampling scientists and agency personnel for a 4-day workshop at the Ladder Ranch in Caballo, New Mexico (see Appendix 2). Our goal was to develop a jaguar survey and monitoring protocol based on expert recommendations tailored to the habitats and social contexts of the NRU with application across the remainder of jaguar range. We considered the full range of possible sampling methods and modeling employed to document jaguar and other large carnivore population trends across time and space, before reaching consensus on a survey and monitoring protocol with a foundation in occupancy modeling centered on the NRU Core Areas using remote camera stations. We also discussed variations of that protocol and methods to evaluate abundance and density, population genetic characteristics, demographic parameters, components of jaguar spatial ecology, and mechanisms for data capture and curation. This multi-scale, expert-designed jaguar survey and monitoring protocol is a prescription for a package of complementary methods that can measure trends in a cost-effective way across the gradient of habitats and jaguar densities of core and

secondary areas in the NRU, as well as range wide. A summary of the application of recommended techniques is provided in Appendix 3.

A critical question for jaguar conservation is are jaguar populations increasing, decreasing, or stable? The scales of jaguar range demands cost-effective repeatable metrics that can be applied across vast areas and multiple countries. At the core of our recommendations for monitoring large areas is occupancy to: 1) evaluate the current spatial distribution and estimate the proportions of areas occupied by jaguars; and 2) provide a low-cost baseline for evaluations of trends across time and space. Occupancy sampling provides indirect measures of jaguar abundance, and opportunities to test the influence of covariates of biological and management importance. Through occupancy the baseline of exactly where jaguars are and coarse indications of why they are there can be established.

Occupancy should be complemented by capture-recapture (CR) studies to estimate abundance in key areas and establish a baseline for numerical trends and demographic patterns. Constraining occupancy and CR surveys to 1 season can reduce variation due to jaguars making seasonal movements. Occupancy studies can provide an unbiased selection of study sites. In the case of camera-trap-based CR methods, we recommend numerous stations and ample spacing of stations. Multi-year scat surveys can also be used for genetic-based CR. For both methods of CR, we recommend very large sample areas. When human habitations occur near an area, preliminary work with local people to obtain consent and cooperation for the study helps develop communication and collaborations needed to effect jaguar conservation. We recommend spatially explicit capture-recapture models (SCR), but non-SCR models can be used to compare to previous studies, and to look at population trends. We provide guidance on study design, data collection during study, incidental data collection, data processing, storage, and analyses for all the above.

Camera-trap-based CR can provide a foundation for long-term studies of numerical trends and demographic patterns, but the information they provide on movements is limited. Dispersal data is best obtained through GPS satellite telemetry. Population genetics can also provide data about movements and relatedness.

Habitat selection can be analyzed using occupancy covariates, CR covariates, and detailed location data obtained through telemetry data. Although environmental correlates may be coarse-scale data drawn from remote sensing, when fine-grained data are obtained from telemetry, they should be complemented by equally fine-grained real-time data about the distribution of resources, threats, and environmental parameters in the study area. We provide recommendations on the estimation of study animal home ranges, and suggestions on how to assess resources within them.

Demographic patterns can be estimated using camera traps or telemetry, but in both cases require long-term, data-rich studies. Occupancy can serve as a metric of jaguar status and recovery in the

NRU, on a 5-year jaguar generation level or on a 15-year level (3 jaguar generations). Occupancy also has applications on a larger scale, for assessments of the status of jaguars, either range wide, or at eco-regional levels. Studies on numerical trends, demography, and dispersal are an important component of regional jaguar study plans. Ultimately, the conservation of jaguars is effected by counteracting indirect and direct threats. Large-scale monitoring of jaguars will inform us on how well we are doing.

MONITORING AND JAGUAR CONSERVATION

Monitoring threatened and endangered species is needed to inform management actions. One can monitor status of a species, pressures (threats) to that species, and responses of that species to management interventions (Jones et al. 2013). One also can monitor social factors such as the efficacy of outreach intended to change the public's attitudes and practices for those who coexist with threatened and endangered species. Population parameters (spatial distribution, density, population size, survival, and recruitment) reflect responses to management interventions. Monitoring of indirect threats, while not emphasized here, is also recommended for a comprehensive species conservation and recovery program.

In wildlife ecology, a survey is a study conducted to collect data often over a broad spatial scale and through some sampling scheme (Williams et al. 2002, Long and Zielinski 2008, Boitani et al. 2012). Surveys are intended to define distribution, abundance, and other population attributes of species and their habitats at one time and in one area. Long and Zielinski (2008:8) defined a survey as "the attempt to detect a species at one or more sites within the study area, where 'attempt' involves one or more field sampling occasions, through proper methods, procedures and sampling design." Surveys are exploratory, but done well they provide the baseline for repeated measures.

Monitoring can be viewed as the repetition of survey methods to make inferences about trends in abundance, and/or distribution, and the relative importance of management or ecological attributes. This can provide measures of recruitment, survival, dispersal, and local colonization and extinction. Every hypothesis requires a research design that will address the question it poses, and an analytical framework to draw inferences from the data at an adequate level of accuracy. The relationship between the data collected (usually some form of counts and covariates to explain counts) and the variable of interest (e.g., abundance or occupancy: Royle et al. 2008) needs to be predefined. The cost of the monitoring needs to be considered in the context of the value of the improved decision making it enables (Jones et al. 2013).

Which foci of monitoring should be deployed depends in part on a gradient of a species status, ranging from secure populations to dispersing animals in peripheral areas. Jaguars (*Panthera onca* L.) currently occupy 61% of their former pre-1900 range (Sanderson et al. 2002, Zeller 2007), which was once continuous from the southern United States to central Argentina (Swank and Teer 1989). It is not clear what biogeographic or climatological factors limit jaguar range (Sanderson and Fisher 2011). We do know that jaguars can be extirpated from areas through hunting for the fur trade, persecution in response to livestock depredation, and habitat loss (Swank and Teer 1989, Sanderson et al. 2002, Yackulic et al. 2011*a*, *b*). Because the jaguar still occurs in over 50% of its historical range, range-wide monitoring implies an immense scale that includes Jaguar Conservation Units (JCUs; Sanderson et al. 2002), which function as sources, and a matrix of secondary and peripheral areas, which may connect to other JCUs and be used as corridors by dispersing individuals.

The 226,826-km^2 Northwestern Jaguar Recovery Unit (NRU) straddles the United States-Mexico border with approximately 29,021 km^2 in the United States and 197,805 km^2 in Mexico (Figure 11) (Sanderson and Fisher 2013). Due to habitat conditions and local eradication, jaguars in the NRU may currently be at low densities compared to some other parts of the jaguar's range, but the configuration of core areas, secondary areas, and peripheral areas in the NRU mirrors the challenges of monitoring across gradients range wide.

Monitoring habitat is an important complement to population-focused monitoring. The availability of habitat suggests potential for occupancy and potential for recovery, but habitat status alone does not translate directly to jaguar status. Prey abundance and biomass may be more reliable indicators of potential high quality habitat for jaguars. Even when correlations can be established between habitat type and jaguar presence or abundance, population focused sampling is necessary.

Because monitoring requires a baseline, initial surveys should be accurate, yet sufficiently cost-effective to allow long-term repeated measures. Where jaguar densities are extremely low, spatial presence-absence approaches will cover large areas with less cost. In source areas where jaguars are secure, intensive capture-recapture and telemetry studies can assess abundance, demographics, and dispersal.

The current net measure of the jaguar's status across its range (stable, decreasing, or increasing) has yet to be established. Significant parts of the jaguar's range are still experiencing escalating land conversion, prey depletion, and direct killing of jaguars. In other areas, the jaguar's status is relatively constant, and in some areas, recovery is taking place. Thus far we have lacked adequate repeated measures from a sufficient subset of significant JCUs to comment authoritatively on global trends. Establishing this framework for repeated measures and trend assessment is a step towards range-wide, integrated assessments and monitoring.

The U.S. Fish and Wildlife Service (USFWS) contracted the Wildlife Conservation Society (WCS) to: 1) conduct a comprehensive literature review of jaguar survey and monitoring techniques and methodologies (Polisar et al. 2014); and 2) draft a jaguar survey and monitoring protocol for application in the NRU, and with relevance for monitoring the species range wide. In this second task, we present a survey and monitoring protocol for jaguars. The protocol is designed for professionals seeking appropriate techniques and methodologies to estimate jaguar presence, occupancy, abundance, and density. The protocol balances the effectiveness of the techniques and methodologies, and accuracy and quality of the results, with the cost of conducting the protocol. The protocol includes a thorough overview of each technique with illustrations and descriptions of data storage and analysis techniques.

The goal of this protocol is to provide recommendations for jaguar survey and monitoring techniques and methodologies for the NRU, with relevance for monitoring the species range wide. We provide a suite of survey and monitoring methods requiring a range of survey intensities, resource requirements, and degrees of precision. We begin with a review of jaguar records and the physical, ecological, and management characteristics of the NRU. We describe ecological and logistical realities to provide the necessary on-the-ground context for the recommended survey and monitoring techniques. We then discuss survey and analytical methods to determine jaguar presence-absence and occupancy. These survey methods are centered on the Sonora and Jalisco Core Areas using remote camera stations. We then discuss methods used to adapt presence-absence and occupancy surveys to quantify estimates of jaguar abundance and density using spatially explicit capture-recapture techniques. We continue with a discussion of the use of scat-detection dogs (*Canis lupus familiaris*) to survey for scats in areas of high probabilities of jaguar occupancy. Genetic material is necessary to evaluate metrics of genetic distance and inbreeding coefficients. We then discuss the use of biotelemetry in areas with high jaguar densities to estimate jaguar survival, reproduction, dispersal, home ranges, and habitat selection. We conclude with a discussion on data capture and curation, and monitoring recommendations for the NRU and beyond.

Where there are multiple possibilities, we review each, discussing strengths and weaknesses. Likewise, if there is a very effective but costly approach, we offer a lower cost option and describe the differences. The recommendations we present will be relevant for source areas, their margins, and the corridors between them.

JAGUARS ACROSS THE NORTHWESTERN RECOVERY UNIT

Jaguars in the Americas

The jaguar is a large, wide-ranging felid, whose presence or absence provokes strong feelings and conservation concern throughout the Americas (Medellín et al. 2002). Jaguars are the largest (extant) felids in the New World, with adults typically having a head and body length of 1-2 m and body mass from 36-158 kg (Seymour 1989). They are robust and successful predators, able to hunt, kill, and consume over 85 different wildlife species (Seymour 1989), as well as domesticated animals such as cattle and sheep (e.g., Rosas-Rosas et al. 2010). They compete successfully with pumas (*Puma concolor* L.), but less so with human beings for prey (Rosas-Rosas et al. 2008). Jaguars occupy a wide range of habitats, from deserts to tropical rain forests (Seymour 1989, Sanderson et al. 2002); they occur in mountains up to 2,000 m and utilize beaches (Troeng 2001). It is not well understood what limits their range beyond the need for cover, food, and freedom from human persecution (Seymour 1989, Crawshaw and Quigley 1991, Hatten et al. 2005).

Jaguars have lived in the Americas for more than 2 million years (Antón and Turner 1997, Brown and López-González 2001). Jaguars evolved in Eurasia along with the ancestors of the other roaring cats from the *Panthera* genus and immigrated across the Berengia land bridge, expanding across North America and into South America. In the United States, remains of jaguars from the Pleistocene have been found in Florida, Georgia, Tennessee, Nebraska, Washington, and Oregon (Kurten 1980, Antón and Turner 1997). Human cultures, following the ancestral cats from Asia 1.9 million years later, formed strong cultural and spiritual affinities with the jaguar, especially in Central and South America (Benson 1998), and also in North America (see review by Merriam 1919, see Pavlik 2003).

Range Retraction on the Limits of Jaguar Range

Thousands of years of range expansion have been reversed in the last few hundred years, particularly on the margins of the range. We focus here on the losses in the northern part of the jaguar's range, in particular. The details of that loss, however, are in debate, especially in areas that are now the United States and Mexico (Sanderson and Fisher 2011). Accounts of the range collapse are complicated by the paucity of records and the different standards for scientific observation over the last 200 years, leading to lively debates about how range maps should be constructed, what different range maps imply for conservation actions, and how those actions interact with the language of specific statutes like the Endangered Species Act (Sanderson et al. in prep).

In the United States, 19th century written accounts (without accompanying physical proof or photographic evidence) of large spotted cats, possibly jaguars, exist from Louisiana, Texas, Oklahoma, New Mexico, Arizona, California, and Colorado (e.g., Sage 1846, Audubon and Bachman 1854, Whipple et al. 1856, Merriam 1919, Strong 1926, Nowak 1973, Brown and

López-González 2001). A much smaller number of difficult-to-interpret, but intriguing, observations are found from the 18th century from points much farther east than what is now commonly considered jaguar range in the United States (e.g., Brickell 1737, Ford 1904). Twentieth century records with photographic evidence, skins, and skulls are available from New Mexico, Arizona, and Texas, and generally indicate a diminishing range within the United States (e.g., Schufeldt 1929, Brown and López-González 2001). Twenty-first century observations within the United States are limited to southern Arizona and extreme southwestern New Mexico (McCain and Childs 2008, Lacey 2011) and continue rarely, but regularly, to the present day (U.S. Fish and Wildlife Service 2014).

Throughout the last 100 years, Mexico has remained a harbor for jaguar populations at the northern end of the range, including in wilder parts of Sonora (Burt 1938, Leopold 1959, Landis 1967, Carmony and Brown 1991, Brown and López-González 2001, Grigione et al. 2009). Numerous summary reviews of the observational history of jaguars in the U.S.-Mexico Borderlands over time have been published (Seton 1929, Goldman 1932, Householder 1958, Lange 1960, Brown 1983, Rabinowitz 1999, Brown and López-González 2001, Schmitt and Hayes 2003, Grigione et al. 2007), including a recent attempt to comprehensively document all observations in the NRU in a searchable, relational database (Sanderson and Fisher 2011, 2013). The loss of jaguar range in the United States and extreme northern Mexico mirrors losses at the southern end of the range and in other places where human land use has driven out jaguar prey (Swank and Teer 1989, Sanderson et al. 2002, Zeller 2007).

Jaguar Conservation 1973 to Present

As a result of decreases in jaguar distribution, habitat, and prey base, jaguars are a species of conservation concern, listed as Near-Threatened on the IUCN Red List (Caso et al. 2011) and under Appendix 1 of the Convention on Trade in Threatened and Endangered Species of Fauna and Flora (CITES). The USFWS determined the jaguar is an endangered species throughout its range, including the United States, under the definitions of the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service 1997). The jaguar is recognized as an endangered species in Mexico (SEMARNAT 2010) and is a national priority species for conservation (Ramírez-Flores and Oropeza-Huerta 2007). Despite these listing decisions and the protections they afford, jaguar populations throughout their range, and in the NRU, remain at risk from illegal killing of jaguars, habitat destruction and modification, overhunting of jaguar prey, anthropogenic activities reducing connectivity (e.g., border infrastructure), limitations in enforcing regulatory mechanisms across national boundaries, and climate change (U.S. Fish and Wildlife Service 2012). Although the fur trade stopped in the 1970s, direct killing has remained a significant source of mortality, and population declines occur, especially in areas where poorly-managed ranching overlaps occupied jaguar habitat, and individuals learn to take livestock. Often in these situations, both targeted control and indiscriminant killing of jaguars ensues.

In 1999, a range-wide meeting of 35 jaguar researchers and conservation practitioners conducted a range workshop that established an eco-regional basis for range-wide conservation of jaguars (Sanderson et al. 2002). The participants defined JCUs as either: 1) areas with a stable prey community, known or believed to contain a population of resident jaguars large enough (at least 50 breeding individuals) to be potentially self-sustaining over the next 100 years, or 2) areas containing fewer jaguars but with adequate habitat and a prey base, such that jaguar populations in the area could increase if threats were alleviated (Sanderson et al. 2002). At that time, no jaguar populations were known in the United States (just a small set of recent observations) and the nearest confirmed JCU was in Sonora State, Mexico, about 150 km south of the border.

The Sonoran JCU is listed as one of two highest priority JCUs in Mexico, and the only JCU representing that biome (ecosystem), thus enhancing its global conservation status (Sanderson et al. 2002). It is connected to pockets of potential habitat north of the border by dry, desert conditions and steep mountain ranges. Anthropogenic activity (e.g., urbanization, roads, land development, and border fence construction to deter illegal human immigration and terrorism threats from entering into the United States) may negatively impact connectivity for wildlife (Atwood et al. 2011), including jaguars (U.S. Fish and Wildlife Service 2012). Yet jaguars have been moving through from Mexico into the United States (McCain and Childs 2008).

Jaguars in Mexico

In 2005, the Instituto de Ecología de la Universidad Nacional Autónoma de Mexico (UNAM), with support of the Comisión Nacional de Áreas Naturales Protegidas (CONANP), sponsored its first national symposium on jaguar conservation (Chávez and Ceballos 2006). The current status of the jaguar in Mexico was assessed, threats to jaguar existence were identified, and priority conservation actions at local, regional, and national scales were determined. Further, the need to conduct a population viability analysis and habitat assessment for jaguars in Mexico at a national scale was recognized (Carrillo et al. 2007). Annual national symposia were held to develop an action plan to determine conservation strategies for the jaguar in Mexico, select a standard methodology to use for the National Jaguar Census (CENJAGUAR; Chávez and Ceballos 2006, Carrillo et al. 2007), and outline general conservation guidelines for the jaguar and its habitat (Ramírez-Flores and Oropeza-Huerta 2007). The National Jaguar Census started in 2008 in Mexico. The goal of the census is to estimate the population status of jaguars and jaguar prey in priority conservation areas in Mexico (Chávez et al. 2007). Additional research, inventory, and monitoring programs were implemented in various parts of the jaguar’s range. Currently the Mexico government is supporting efforts to evaluate jaguar populations in the NRU through the Programa de Conservación de Especies en Riesgo (PROCER; Program for the Conservation of Species At Risk) of the Dirección de Especies Prioritarias para la Conservación (Priority Species Division) of CONANP.

Monitoring Jaguars in the NRU and Range Wide

The monitoring challenges posed by the 226,826 km^2 NRU echo those faced in much of jaguar range, where issues of scale, poor access, difficult logistics, and gradients of jaguar and prey abundance require a mix of sampling intensities. The NRU includes extremely rugged terrain in Mexico's Sierra Madre Occidental, low dry forests in hilly areas near the Pacific coast, vast stretches of Sonoran desert, and isolated rugged mountain ranges crossing the international border and scattered throughout the United States portion of the Borderlands Secondary Area (see Figure 11). It is likely different methods will be required for the core areas (Jalisco 54,949 km^2 and Sonora 77,710 km^2), as compared to the secondary areas (Sinaloa 31,191 km^2, Borderlands – Mexico 33,955 km^2 and United States 29,021 km^2), based on cost-benefit ratios.

Within the NRU, recent surveys include López-González et al. (2000), López-González (2001), Navarro-Serment et al. (2005), McCain and Childs (2008), Rosas-Rosas et al. (2008), Núñez-Pérez (2011), Gutiérrez-González et al. (2012), Rosas-Rosas and Bender (2012), Núñez (2013), Núñez y Vazquez (2013), and Culver et al. (2016). Despite these recent efforts, jaguar presence, occupancy, abundance, density, population trends, and demographic parameters are not well known in the NRU (U.S. Fish and Wildlife Service 2012). The area's wealth of wild, rugged terrain, possibilities of improved wildlife management, and increased appreciation of jaguars, translate to enormous potentials for recovery. The combination of core areas and the connections among them provides an exciting opportunity to design effective large-scale monitoring

Monitoring jaguar populations across the vast NRU and in similar strongholds and secondary areas throughout jaguar range will provide for the detection of growth or retraction in space occupied, estimation of jaguar numbers, and evaluation of population trends. Based on the logistical challenges and varied terrain and habitat types, a mix of the methods prescribed in this document will be necessary. A cost-effective mix of methods should begin with presence and presence-absence spatial approaches. Abundance studies, which monitor numbers of jaguars, are merited for areas where jaguars are more abundant (core areas).

Jaguar Status and Habitats in the NRU

Jaguar presence in the NRU has recently been documented from the Arizona and New Mexico borders south through the Sierra Madre Occidental to Colima, encompassing a variety of habitat types from pine-oak forest to semi-tropical thorn-scrub to tropical deciduous forest (López-González and Brown 2002, Valdez et al. 2002, Núñez-Pérez 2007, 2011, McCain and Childs 2008, Núñez 2012). The threats that jaguars face range wide (habitat modification and fragmentation, reduction of prey populations, and predator control practices) also prevail in northern Mexico (Valdez 1999, López-González and Brown 2002, Rosas-Rosas et al. 2008), where the main threats to jaguar conservation are illegal predator control, illegal hunting of prey species, and habitat degradation (López-González and Brown 2002, Rosas-Rosas and Lopez-Soto 2002, Valdez et al. 2002, Rosas-Rosas et al. 2008, Rosas-Rosas and Valdez 2010, Rosas-

Rosas and Bender 2012). The current lack of adequate law enforcement, inadequate community and landowner conservation programs, and unsustainable natural resource extraction play a role in habitat modification and fragmentation, reduction of prey populations, and predator control practices. There is an urgent need to address both indirect and direct threats to maintain existing jaguar populations and achieve recovery in the NRU.

Borderlands Secondary Area

The 62,976 km^2 Borderlands Secondary Area includes 29,597 km^2 of suitable habitat and 431 km^2 of core habitat in portions of southeastern Arizona, southwestern New Mexico, northwestern Sonora, and northeastern Chihuahua (Kim Fisher, Wildlife Conservation Society, personal communication; Table 5; Figure 11). The area is a region of north-south trending, forested and shrub covered mountain ranges surrounded by lower desert valleys and plains, straddling the current United States-Mexico border (Brown 1983, Brown and López-González 2000, 2001). Habitat conditions suitable for jaguars include vegetative cover, access to water, and freedom from persecution (Hatten et al. 2005) and primarily found in the area in the topographically complex mountain areas frequently referred to as “Sky Islands.” Madrean evergreen woodland, a mixture of oak and pine forest, is an important habitat, as are higher elevation montane conifer forests and piñon-juniper woodlands (Rabinowitz 1999, Brown and López-González 2001, Hatten et al. 2005). These habitats are uncommon across the jaguars entire range (Sanderson et al. 2002), making this area of potentially global significance for jaguar conservation. However, the area is compromised by its limited extent of suitable habitat as currently defined, its relatively high human footprint (compared with some areas in other subsections of the NRU), and the presence of the border security fence, potentially separating habitat areas in the United States and Mexico. The desert valleys, which comprise most of the areal extent of this secondary area, are thought to provide little habitat value, although repeat captures in camera track studies indicate that at times jaguars do cross these areas (McCain and Childs 2008).

Potential prey species in the Borderland Secondary Area include collared peccary (*Tayassu tajacu*), white tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), coatis (*Nasua nasua*), skunk (*Mephitis* spp., *Spilogale gracilis*), raccoon (*Procyon lotor*), jack rabbit (*Lepus* spp.), domestic livestock, and horses (Brown and López-González 2001, Hatten et al. 2005).

Jaguars appear to take advantage of north-south trending mountain ranges to facilitate movements in the Borderlands Secondary Areas. The US-Mexico Barrier crosses these mountain ranges on an east-west axis in order to inhibit illegal human movements across the border. Special management considerations or protections should address threats posed by increased human disturbances into remote locations through construction of impermeable fences and widening or construction of associated infrastructure. Jaguars have been heavily hunted within the United States in the past and are currently hunted in parts of Mexico (Brown and López-González 2001). A jaguar was killed illegally in 1986 in the Dos Cabezas Mountains of Arizona, for example. Given the small population in this part of the NRU, any hunting pressure is a threat.

Hunting of jaguar prey may also represent a threat, particularly if it leads to jaguars utilizing domestic livestock rather than native prey. Human-wildlife conflict over depredation of domestic animals, whether caused by jaguars or sympatric predators (like pumas) increases the threat to jaguars in other parts of the range (Zimmerman et al. 2005, Michalski et al. 2006). Finally, the habitat is so limited in the Borderlands Secondary Area it is unclear whether it can sustain a viable population of jaguars as currently delimited (Miller 2013). Habitat limitations are the result of the natural topography of the area, the distribution of native vegetation, and the development of human settlements and infrastructure in valley bottoms and foothills. The lack of habitat for a wide-ranging carnivore can be considered a threat in this part of the range (Eric Sanderson, Wildlife Conservation Society, personal communication).

Jaguars have long been documented in the Borderlands Secondary Area (Brown 1983, Brown and López-González 2000, 2001). Native American groups from this area have specific names for jaguars (Daggett and Henning 1974, Brown and López-González 2001, Pavlik 2003), some of which may predate European settlement during the 16th and 17th century. The first scientific survey in the area was associated with the survey of rail routes after the Mexican-American War by Baird (1857), who observed a jaguar in the Santa Cruz Valley. American settlers and ranchers in the Arizona territory in the late 19th and early 20th century left numerous accounts of jaguar hunts, summarized by later scientists from press accounts, interviews, and historical records (Schufeldt 1929, Bailey 1931, Cahalane 1939, Halloran 1946, Hock 1955, Brown 1983, Brown and López-González 2001, Grigione et al. 2007, Sanderson and Fisher 2011); similar accounts are also known from adjacent parts of Mexico (Burt 1938, Leopold 1959, Brown and López-González 2001).

In the U.S. portion of the Borderlands Secondary Area, government hunters and trappers working on behalf the United States government killed jaguars in this area in 1917, 1919, 1924, 1926, 1932-1933, and 1964 (Brown and López-González 2001). Jaguars were occasionally taken through the 1950s-1970s, although some of these animals may have been brought to the area as part of "canned hunts" (Brown and López-González 2001, Grigione et al. 2007, Brown and Thompson 2010, Sanderson and Fisher 2011). A jaguar was killed in the Dos Cabezas Mountains of Arizona in 1986 (U.S. Fish and Wildlife Service 1994). Two jaguars were photographed in 1996, 1 by Warner Glenn in Hog Canyon, near the Arizona / New Mexico border (Glenn 1996), and the other by Jack and Anna Childs in the Baboquivari Mountains in extreme southern Arizona (Childs and Childs 2008). McCain and Childs (2008) were later able to identify 2 different jaguars through camera trapping surveys in 2003, Macho A and Macho B. Macho A disappeared shortly thereafter, but Macho B was photographed repeatedly in the Baboquivari and Atascoca Mountains through March 2009. As of 2011, at least 1 jaguar is known to occur in the United States (Ames and Wasu 2011) in the Borderlands Secondary Unit.

In the Mexico portion of the Borderlands Secondary Area, since 2009, 2 jaguars have been documented at Rancho El Aribabi, Sonora, about 48 km southeast of Nogales, and 1 jaguar has been documented in the Sierra Los Ajos within the Reserva Forestal Nacional y Refugio de

Fauna Silvestre Ajos-Bavispe, about 48 km south of the U.S. border near Naco, Mexico (USFWS 2012). This individual was photographed in 2009 and 2013 in the area. In August 2012, in Papigochic, Sonora about 60 km south of the U.S. border, near of Cananea a jaguar track was seen in a private cattle ranch. In 2013, 1 jaguar male was photographed inside Janos Biosphere Reserve in the limits between Chihuahua and Sonora about 70 km south of the U.S./Mexico border (Carlos López González, University of Querétaro, personal communication).

There are numerous protected areas on the U.S. side of the border managed by a variety of different federal, state, and tribal entities which collectively protect 3,674 km^2 (Conservation Biology Institute 2012, CONAP). There are also a number of privately managed conservation areas. On the Mexico side of the border there is only one protected area, the Janos Biosphere Reserve, which only intersects the Borderlands Secondary Area slightly on the eastern edge.

In March 2014, the USFWS designated approximately 3,092 km^2 in Pima, Santa Cruz, and Cochise Counties, Arizona, and Hidalgo County, New Mexico, as critical habitat for the jaguar (U.S. Fish and Wildlife Service 2014). Critical habitat is designated in 6 units organized to encapsulate mountain ranges used by jaguars at least once since 1962.

The Borderlands Jaguar Detection Project led by Jack Childs monitored jaguars in southern Arizona from 2002-2010. McCain and Childs (2008), following 2 sightings of jaguars in 1996, established a remote camera survey using approximately 40 cameras extending from the crest of the Baboquivari Mountains east to the San Rafael Valley and approximately 80 km north of the U.S.-Mexico border. The study area encompassed biotic communities of Madrean evergreen woodland and semidesert scrub grassland. McCain and Childs (2008) documented 2 adult male and possibly a third unidentified jaguar with 69 photographs taken by remote cameras and 28 sets of tracks.

A 3-year project for detection and monitoring of jaguars and other wildlife biodiversity, in southern Arizona and southern New Mexico, was started in October 2011 by a team of biologists at the University of Arizona led by Melanie Culver. Researchers are using approximately 280 remote cameras and noninvasive genetic methods across 16 mountain ranges. As of October 2014 this effort has documented one male jaguar. The project will conclude in June 2015. Mexican investigators Jesus Moreno and Rodrigo Medellín have been monitoring wildlife, including jaguars, in an UMA in the Aros-Bavispe area of Sonora, Mexico from 2000 until present.

Led by Dianna Hadley, the Northern Jaguar Project together with Naturalia has also been conducting remote camera surveys, in the Aros-Bavispe area, but on privately owned lands. The Sky Island Alliance has been monitoring jaguars at the Rancho El Aribabi in Sonora Mexico, using remote cameras and has detected 2 jaguars to date.

Sonora Core Area

The 77,710 km^2 Sonora Core Area includes 67,889 km^2 of suitable habitat and 28,294 km^2 of core habitat in portions of southwestern Chihuahua, northeastern Sinaloa, and Sonora (Kim Fisher, Wildlife Conservation Society, personal communication; Table 5; Figure 11). The northernmost known breeding population of jaguars in North America is located in northeastern Sonora, Mexico (López-González and Brown 2002, Valdez et al. 2002). The area is located in the northern portion of the Sierra Madre Occidental, which is the largest mountain range in northwestern Mexico. The Sierra Madre Occidental encompasses a variety of habitats including pine, oak-pine, semitropical deciduous forests, oak woodlands, and semitropical thorn-scrub (Brown 1982). The jaguar population in Sonora represents the potential dispersal center for movements farther north, and is critical to any naturally occurring re-establishment of a jaguar population in the southwestern United States (McCain and Childs 2008).

There are diverse potential jaguar prey species in Sonora, but the most common ungulates present are white-tailed deer and collared peccary. Carnivores present other than jaguars and puma are coyote (*Canis latrans*), gray fox (*Urocyon cinereoargenteus*), bobcat (*Lynx rufus*), ocelot (*Leopardus pardalis*), river otter (*Lontra longicaudis*), badger (*Taxidea taxus*), skunks (*Mephitis* spp., *Spilogale* sp., *Conepatus* sp.), white-nosed coatimundi (coati), and ring-tailed cat (*Bassariscus astutus*), raccoon, and margay (*Leopardus weidii*) (Leopold 1959, Hall 1981). The primary prey for jaguars in this area are Coues white-tailed deer (*Odocoileus virginianus couesi*) and collared peccary, and, to a lesser extent, coati, opossum (*Didelphis virginiana*), and lagomorphs (Rosas-Rosas et al. 2008). Cattle are the predominant domestic mammals, and also constitute a prey item in northern Sonora.

With cattle ranching being one of the most important economic activity and culture in Sonora, cattle losses due to predation by jaguars and pumas are considered a major threat and nuisance, regardless of their economic impact. Hence, human-jaguar conflicts constitute one of the main factors limiting jaguar populations, numerically and spatially, in the northernmost part of the species' range, and may represent the primary limitation to incremental jaguar recovery farther north. That said, fairly recent innovative efforts have been made to motivate ranchers to tolerate jaguars, including the work conducted Rosas-Rosas and Valdez (2010) and the NJR Rosas-Rosas and Valdez (2010) worked with ranchers to develop a jaguar conservation program based on white-tailed deer trophy hunts to compensate cattle losses from predation by jaguars.

In Sonora, most jaguar records are from semi-tropical thorn-scrub, oak and oak-pine forest, and tropical deciduous forest (Martínez-Mendoza 2000, López-González and Brown 2002, Rosas-Rosas 2006). The majority of records are from cattle ranches, private refuges, and Àreas Naturales Protegidas (ANPs). There are a number of areas that were established for the protection of jaguars or that contribute to jaguar conservation in Sonora, including 2 in northeastern Sonora, the Northern Jaguar Reserve (NJR) and the Unidad de Manejo para la Conservación de Vida Silvestre (UMA) of the Asociación para la Conservación del Jaguar en la

Sierra Alta de Sonora (Asociación para la Conservación del Jaguar en la Sierra Alta de Sonora UMA), and 1 in southern Sonora, the Área de Protección de Flora y Fauna Silvestre (APFF) Sierra de Álamos-Río Cuchujaqui (APFF Álamos-Río Cuchujaqui).

Northern Sonora

In northeastern Sonora, 2 areas that were established to benefit jaguars include the Asociación Alianza para la Conservación del Jaguar en la Sierra Alta de Sonora UMA and the NJR. While there are several UMAs in Sonora that benefit the jaguar and its habitat, the Alianza para la Conservación del Jaguar en la Sierra Alta de Sonora UMA, established in 2003 and located 210 km south of the United States-Mexico border in northeastern Sonora, is the only one formally created to benefit jaguars. Eleven properties of the 8 participating landowners encompass 400 km^2. The purpose of this unit is to compensate cattle ranchers for livestock depredation by predators and to generate alternative income for cattle ranchers. Coues white-tailed deer trophy hunting and associated ecotourism are the main economic activities. Scientific advisory of the UMA Sonora is executed by the Instituto de Ecología of the Universidad Autónoma de México in Mexico City.

The NJR began in 2003 with the purchase of 1 ranch in northeastern Sonora, about 220 km south of the United States-Mexico border, and, over time, has grown to a total of approximately 200 km^2 through the purchase of additional property. The reserve was established to safeguard and restore wildlife habitat (particularly for jaguars), to support wildlife research and educational programs, and to reduce conflicts between carnivores and humans. This private protected area is managed jointly by Naturalia (a Mexican conservation organization) and the Northern Jaguar Project (NJP). .

Jaguar research projects have been conducted in northern Sonora within both the NJR and Asociación para la Conservación del Jaguar en la Sierra Alta de Sonora UMA (referred to as Sahuaripa-Huasabas in Figure 12), as well as some areas adjacent to the NJR. Gutiérrez-González et al. (2012) conducted a capture-recapture study to estimate jaguar density in the NJR and adjoining cattle ranches that had agreed not to hunt wildlife. The vegetation in this 330 km^2 area was a mosaic of dry thorn-scrub, semi-deciduous forest, riparian vegetation including palms and oaks, and natural grasslands. Mean annual precipitation was less than 400 mm annually, distributed throughout the year but with winter rains accounting for 18%. Mean annual temperatures ranged from 16-30° C with extremes between -7 and 43° C. Camera-trap sampling across 16 months, with a variable number of camera traps (25-111) and a total of 7,718 trap-nights, yielded 63 jaguar photo-captures of 10 individuals. Using the Jolly-Seber open population model, the authors estimated jaguar density at 1.05/100 km^2 in this area (Gutiérrez-González et al. 2012).

Rosas-Rosas and Bender (2012) combined camera-trap and track surveys to assess jaguar and puma status in a 400 km^2 study area in the Alianza para la Conservación del Jaguar en la Sierra

Alta de Sonora UMA in the foothills of the Northern Sierra Madre Occidental in an area of rocky and rugged topography. The main vegetative community in this area was a semi-tropical thorn-scrub. This area contained intermittent and perennial streams, and, depending on elevation (which ranged from 500-1,500 m above sea level), an annual precipitation of 400-1,000 mm. The area experiences a dry season (October-June) and a wet season (July-September), the latter of which is characterized by short-duration, high intensity downpours. , Camera traps were deployed in 26 stations for 60 days. Intensive track surveys recorded 208 jaguar tracks, identifying 12 individuals through idiosyncratic features of their forefeet. Transients were also identified. From 159 puma tracks, 14 different pumas were identified. Discriminant functions based on track measurements complemented visual identifications and confirmed an 87.4, 84.9, 73.7, and 82.3% correct classification of male and female jaguars and pumas, respectively. Based on information collected during 1,560 trap-nights augmented by track observations, the authors estimated 4 jaguars/360 km^2, or approximately 1 jaguar/100 km^2 in this area (Rosas-Rosas and Bender 2012).

Additionally, Primero Conservation and the Asociación para la Conservación en la Sierra Alta de Sonora operated camera traps continuously on several ranchlands within the Asociación para la Conservación del Jaguar en la Sierra Alta de Sonora UMA in mountainous, dry-tropical thorn scrubs ranging between 440 m and 1,230 m above sea level between April 2009 and September 2011. Cameras were checked opportunistically during ranch operations (Cassaigne 2014). Camera traps in 38 stations sampled an area of approximately 408 km^2 (it is not clear if the area was formed by the mean or maximum outer band of the camera trap stations or if that dimension was increased by an estimated buffer) for 8,408 trap-days over 2.5 years (Moreno et al. 2013).

For each camera location in this study, independent pictures of a single species were defined to be those pictures taken more than 1 hour apart. Sequential pictures of the same species at the same location were considered redundant. Eleven jaguars and 9 ocelots were individually identified, and densities of each species were estimated with SPACECAP (2.7 jaguars/100 km^2, ocelots 2.2/100 km^2). Moreno et al. (2013) documented species occurrence rates (species recorded at a station) at the 38 stations of: 34 puma 33white-tailed deer, 31 cows, 30 coati, 23 bobcat, 19 desert cottontail (*Sylvilagus audubonii*), 12 collared peccary, and 6 raccoon which provides a useful sketch of the spatial distribution of these species and coverage of the study area. Relative abundances, based on percent of all the independent photos, were puma 3.32, deer 13.25, cows 35.43, coati 1.92, bobcat 2.20, jaguar 0.96, desert cottontail 7.59, collared peccary 0.18, and raccoon 0.20. The contrasts seen between very low relative abundance of peccaries (a natural prey item throughout much of jaguar range), and the high relative abundance of cattle (something we really hope to not see in jaguar diets), points to a potential source of human-jaguar conflicts and a conservation issue that needs to be rectified.

Collared peccary frequencies in this study area were notably low. With the exception of white-tailed deer, the biomass of natural jaguar prey was low, while cattle biomass was high and appeared to have been evenly distributed throughout the study area. The survey results suggested that the resident jaguars were subsidized by livestock which tends to increase jaguar mortality due to retaliatory killing. Primero Conservation initiated analyses of exposure to canine distemper virus (CDV) in peccaries, feral dogs, coyotes (*Canis latrans*), puma, and jaguar (Cassaigne 2014). To reduce the risk of retaliatory killing due to jaguars depredating livestock, Primero Conservation responded to the low peccary populations by translocating peccaries vaccinated against canine distemper virus from Arizona after governmental inspection and permitting, with soft releases planned for 2013. The preliminary assessments of jaguar prey indicated depressed collared peccary populations, with the above efforts intended to improve peccary status, hence potentially reducing human-jaguar conflicts.

Southern Sonora

Farther south in Sonora in the municipality of Alamos (Figure 12), the APFF Álamos-Río Cuchujaqui is a 928-km^2 area that was established in 1996 to regulate the sustainable use of water, soil, and wildlife. Ranging between 300 and 1,720 m above sea level, the reserve includes tropical deciduous forest, pine-oak forests, Sinaloan thorn-scrub, and riparian vegetation, and is considered a Biosphere Reserve by the United Nations Educational, Scientific, and Cultural Organization, as well as the state of Sonora. Additionally, the Arroyo Verde ecosystem within the Biosphere Reserve is a Ramsar Site based on 3 streams included in the reserve and its notably high biodiversity due to a mix of northern and tropical biota. Land ownership within this reserve is primarily ejido (communally-owned lands) and private, although a small portion is federal. This area is recognized as an ANP by CONANP, and is managed as such.

Gutiérrez-González (2013) deployed 25 camera-traps for 3 months during a recent jaguar survey in the APFF Álamos-Río Cuchujaqui. Six individual jaguars were identified from the estimated effective sampling area of 330km^2. Jaguar density was estimated to be 2.13 ± 1.06 individuals/100 km^2 using the capture-recapture models in Program MARK.

Sinaloa Secondary Area

The 31,191 km^2 Sinaloa Secondary Area includes 28,753 km^2 of suitable habitat and 18,847 km^2 of core habitat across approximately one third of eastern Sinaloa (Kim Fisher, Wildlife Conservation Society, personal communication; Table 5; Figure 11). Tropical deciduous forest and higher elevation oak-pine forests cover 40 and 15% of the state, respectively (Navarro-Serment et al. 2005). The coastal plain (35% of Sinaloa) is being transformed for agriculture, aquaculture, and human settlement, leaving few adequate habitat patches for jaguars. Although there are areas that have been identified as priorities for conservation by CONABIO, none of them currently are formally protected.

Potential jaguar prey in the area include armadillo, coatimundi, collared peccary, white-tailed deer, and introduced European wild boar or feral hog (*Sus scrofa*).

The Sinaloa Secondary Area, which is thought to support a smaller population that may suffer the ill effects of inbreeding depression, demonstrates less vigorous growth potential, especially when dispersal amongst nearest neighbors is rare (Miller 2013). Poaching and killing of jaguars by ranchers protecting livestock can significantly increase mortality in Core Areas, which could in turn reduce the number of dispersing individuals received by smaller population units like those in the Borderlands Secondary Area (Navarro-Serment et al. 2005, Miller 2013).

Interview-based surveys by Navarro-Serment et al. (2005) found most jaguars occurred in the tropical deciduous forest that still covers 40% of Sinaloa. Only 2 records came from the higher-elevation oak-pine forests that cover 14.7% of the state. Only 1 record was obtained in riparian vegetation. Prey densities (armadillo, coatimundi, white-tailed deer, and collared peccary) appeared to be high in the mountains of Sinaloa, where extensive areas of tropical deciduous forest remain. The records in 2005 suggested that a jaguar population still existed in Sinaloa, but the information gathered through interviews needs to be confirmed through field studies.

Camargo-Carrillo carried out an interview survey throughout the State of Sinaloa that documented a total of 133 jaguar records, most coming from the southern portion of the state (i.e., the Jalisco Core Area; Carlos López-González, University of Querétaro, personal communication); however, few records were obtained from within the Sinaloa Secondary Area. Additionally, Camargo-Carrillo identified an area of occupied jaguar habitat south of the APFF Álamos-Río Cuchujaqui as vulnerable to human development.

Gutiérrez-González et al. (2013) deployed 25 remote cameras were for 3 months, yielding 1 individual jaguar photographed in the area known as El Fuerte in the Sinaloa Secondary Area.

Jalisco Core Area

The 59,949 km^2 Jalisco Core Area includes 44,404 km^2 of suitable habitat and 26,315 km^2 of core habitat in southern Sinaloa, Nayarit, and Jalisco (Kim Fisher, Wildlife Conservation Society, personal communication; Table 5; Figure 11). Along the northern coast in Cabo Corrientes and Puerto Vallarta municipalities, an area of high topographic relief (0-1,800 m above sea level), jaguars use tropical dry and semi-deciduous forest.

In protected areas of Jalisco and Nayarit, white-tailed deer, collared peccary, nine-banded armadillo, raccoon, and coati area are the main jaguar prey (Núñez et al. 2002). In the wetlands, raccoons are important prey (Rodrigo Núñez, Proyecto Jaguar, personal communication). However, in areas with a high presence of livestock and lack of natural prey, livestock comprise a food item (Rodrigo Núñez, Proyecto Jaguar, personal communication).

Tropical dry and semi-deciduous forests have been reduced and fragmented due to pressure from agriculture and cattle ranching, and infrastructure development (roads and tourism development associated with the world class beach resorts of western Mexico) may bring increasing fragmentation.

Most jaguar records in the Jalisco Core Area come from hilly terrain covered by low-growing, tropical dry and sub-deciduous forest, with a smaller proportion of locations from oak-pine forest. Núñez (2007) described 6 priority jaguar conservation sub-units in the Jalisco Core Area: 3 in Jalisco and 3 in Nayarit. Research within the region has been focused in 4 sites: 1 in Nayarit and 3 in Jalisco. The most intensive surveys have been conducted in 3 federally-recognized Biosphere Reserves: la Reserva de la Biosfera Chamela-Cuixmala (RBCC), la Reserva de la Biosfera Sierra de Manantlán (RBSM), and la Reserva de la Biosfera Marismas Nacionales Nayarit (RBMNN). The only long-term study has been conducted in the RBCC. Two additional areas where jaguar surveys are ongoing are volunteer-protected UMAs.

Jalisco

The 130-km^2 RBCC in Jalisco (Núñez et al. 2000, Núñez-Pérez 2006, 2011) is a private reserve also recognized as an ANP. It was established in 1993 and could be considered the core of the Jalisco Core Area. The reserve extends east from the Pacific Ocean and reaches elevations of about 700 m above sea level. The terrain is rugged with arroyos separating prominent hills. Because the average of 700 mm of precipitation is seasonal, falling between June and October, streams are ephemeral and restricted to scattered pools in the arroyos during the dry season. Nearly 90% of the forest is classified as tropical deciduous dry forest and is relatively short (10-15 m in height) and thickly distributed over the hills. A taller, semi-deciduous forest (15-25 m in height) occurs at lower elevations along the coast and extends inland along the arroyos. Land ownership is mainly protected private land (owned and managed by UNAM and Cuixmala Foundation), with a smaller proportion federally-owned (coastal and wetland areas).

Another area important for jaguars is the 1,396-km^2 RBSM straddling Jalisco and Colima. Elevations in this rugged area range from 360 to 2,900 m above sea level. Vegetation types include oak and pine forest and cloud forest. Camera-trapping surveys report low jaguar abundance, but abundant prey such as deer and peccary (Rodrigo Núñez-Perez, Proyecto Jaguar, personal communication). Approximately 60% of the land ownership is ejido-communal and 40% is privately-owned, with 8,000-10,000 inhabitants inside the reserve and 32,000 in agricultural communities along its edges (http://www2.inecc.gob.mx/publicaciones/libros/2/manan.html).

While not an officially-recognized protected area, the northern Jalisco coast, Cabo Corrientes Municipality, is also an important area for jaguars (Núñez-Pérez 2007). The land tenure in this area is mainly ejido and indigenous communities, with a smaller proportion privately-owned. Timber, extensive livestock operations, and subsistence agriculture are the main activities here.

In the RBCC, Núñez et al. (2000) and Núñez-Pérez (2006) used camera-trapping and telemetry studies to document jaguar and puma space use and diet, and Núñez-Pérez (2011) utilized camera traps to determine jaguar density estimates within the reserve. Núñez et al. (2000) and Núñez-Pérez (2006) determined that jaguars and pumas use the arroyos extensively, overlapping in both space and diet. Analyses of 50 jaguar and 65 puma scats identified the 4 main prey species of jaguars as white-tailed deer, collared peccary, coati, and armadillo (*Dasypus novemcinctus*), while the 5 main prey species of pumas were white-tailed deer, collared peccary, armadillo, black iguana (*Ctenosaurus pectinata*), and coati (Núñez et al. 2000). Average telemetry-based annual home ranges in this area were 110 km^2 for male jaguars, and 66 km^2 for females. Home ranges varied seasonally in size and sometimes in location (e.g., individual variation of 23.8 km^2 versus 38 km^2 and 56 km^2 versus 92 km^2 for females and males, for dry and wet seasons respectively; Núñez-Pérez 2006). Because jaguar home ranges and movements are more restricted during the dry season (due to the scattered and restricted nature of water sources during this time, which also influences prey availability), capturing photos of jaguars during this season may be more efficient (Núñez-Pérez 2006). Núñez-Pérez (2011) identified 8 individual jaguars from 26 photo-captures using 29 camera trap stations arranged in a polygon of 72 km^2. Using this information and information from telemetry work to estimate the effective sampling area, Núñez-Pérez (2011) determined density estimates of 4-5 jaguars/100km^2 in the RBCC.

Where jaguar and prey are protected in Jalisco, home ranges of both appear to be small, and likely smaller than in Sonora where more arid conditions and lower primary productivity may result in lower herbivore densities and larger jaguar home ranges. Home-range estimates for prey species are orders of magnitude smaller than jaguar home-range estimates. Collared peccary home ranges average 0.48-0.59 km^2 and range between 0.17-1.0 km^2 (Miranda et al. 2004). White-tailed deer homes ranges average 0.4 km^2 (Sánchez-Rojas et al. 1997).

Núñez (in prep) has been using camera-trapping and social surveys to evaluate jaguar status and human-jaguar conflicts along the northern Jalisco coast, Cabo Corrientes Municipality. The questionnaire effort has covered 1,400 km^2 and the camera trapping has focused on 300 km^2 in the Comunidad Indigena de Santa Cruz del Tuito. This area is covered by tropical deciduous and semi-deciduous forest, with hilly terrain reaching elevations of about 1,000 m above sea level (Núñez in prep). The terrain is rugged, with arroyos separating prominent hills. Precipitation is 700-1,000 mm and seasonal, falling between June and October. Streams are ephemeral and restricted to scattered pools in the arroyos during the dry season. Deer, peccary, and coati are the most common prey species. Preliminary results indicate this area maintains a reproductive jaguar population (Núñez in prep), but further results regarding the jaguar's status and human-jaguar conflicts are not yet available.

Nayarit

In Nayarit, 2 sites have been surveyed in recent years: the RBMNN (Núñez and Vazquez 2013) and the Área de Protección de Recursos Naturales en la Sierra de Vallejo-Río Ameca (Núñez et al. in prep). The terrain in the 1,338 km^2 RBMNN, a wetland dominated by mangroves and swamps, is punctuated by ravines and coastal lagoons in the north of the Nayarit. In the south, the hilly 659 km^2 Sierra de Vallejo Biosphere Reserve includes a range of habitats including various statures of semi-deciduous forest, oak forest, and a 20 km^2 jaguar sanctuary. There are ongoing camera-trap and human-dimension surveys in the RBMNN (2011 to present) and in Sierra de Vallejo (Núñez et al. in prep). Both areas are considered terrestrial conservation priority areas by the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (National Commission on Biodiversity; CONABIO), include reproducing jaguar populations, and are national jaguar conservation priority areas. Elsewhere in Nayarit, areas like the Huicholes and Nayar have rugged mountains (250-1,900 m above sea level) that offer opportunities for jaguar conservation due to large areas lacking human populations. These 2 areas are in the process of being decreed as natural protected areas (http://www.conanp.gob.mx/que_hacemos/areas_prot.php).

Colima and Michoacán

Technically, the southern boundary of the NRU is in Colima, but the status of jaguars just south of that in Michoacán merit mention. Jaguar records are scarce for both Colima and Michoacán. The only recent data are from Michoacán and come from a part of La Sierra Madre del Sur covered by tropical dry and semi-deciduous forest, oak, and oak pine forest, with peak temperatures ranging from 29° C along the coast, 26° C in the Sierras, and 40° C in the Balsas Depression River, with annual precipitation ranging from 500 to 2,500 mm based largely on elevation (Núñez 2012). Recent jaguar records are from the southern part of the state (Charre-Medellín et al. 2013) and the abundance is relatively low (1.8 jaguar/100km^2; Núñez-Pérez 2011, Núñez 2012).

PRESENCE-ABSENCE AND OCCUPANCY

Presence and distribution of species are important state variables in ecology and conservation. Occupancy surveys can be used to evaluate the spatial distribution or estimate the proportion of a given area occupied by jaguars and jaguar prey (MacKenzie et al. 2002, 2003, 2006). Occupancy models account for imperfect species detection, i.e., the fact that a sample unit might be occupied, but we fail to detect the species during our surveys. Occupancy surveys consist of detection/non-detection surveys conducted at a number of sample units (e.g., a grid cell or habitat fragment) over a number of repeated visits. In practice, a set of sampling units that is representative of the area of interest is surveyed repeatedly, using any method that allows detecting either the species itself or indirect signs of it, such as tracks or scats. Detection of the species of interest at each site during each repeat visit, or occasion, is recorded, resulting in a site-by-occasion data matrix, with entries of "1," meaning the species was detected, and "0" if it was not detected. Multiple detections at a site-visit combination are condensed to a single entry of "1."

To analyze these data, occupancy models combine a component describing whether or not a sample unit is occupied by the species of interest – this process is governed by the probability of occupancy, and, conditional on occupancy, whether or not the species is detected, governed by the probability of detection. Repeat visits to survey sites are necessary to inform this detectability model component.

Both probabilities (occupancy and detection) can be modelled as functions of covariates, such as habitat, climatic, or other variables. There are a range of different occupancy models, discussed briefly in the section Types of Occupancy Models, the simplest being the single-season model. By model definition, in single-season models, occupancy at each survey site remains stable, i.e., it does not change during the survey (this is analogous to the "population closure" assumption in capture-recapture modelling). Detection probability, however, is allowed to vary and time-specific covariates can be included if deemed important. In addition, so-called multi-season (or dynamic) models are useful if you have data from surveys repeated over a longer time frame. These allow you to model changes in occupancy over time and investigate environmental drivers of local extinction and recolonization.

In this section of the survey protocol, we focus on the design of a single-season occupancy survey for jaguars in the core areas of the NRU. First, we discuss some general practical aspects of occupancy modelling. This is followed by specific suggestions of how to survey for jaguar occupancy in the core areas of the NRU. We finish with a brief discussion of analytical methods and ways to refine or adjust survey design.

Practical Considerations

Definition of occasion—Estimating the probability of detection requires repeated visits to each sample site. Camera-trap sampling is continuous (cameras are operational and collect data throughout the entire study), such that the definition of an occasion is somewhat arbitrary. There are certain factors to be considered: occasions should not be chosen so short as to generate an overload of zeroes in the data set. This can cause detection probability to be close to 0, which in turn can lead to computational problems. On the other hand, overly long occasions will result in loss of information, because records are condensed to a binary format (detected or not) for each occasion. In situations where occupancy of low density animals in a sampling unit, such as a habitat fragment, is assessed with a single sampling point (e.g., a single camera trap), an occasion should be long enough to allow the 1 or few individuals occurring in the area to pass the camera and thereby be available for sampling during their movements through their territories. Occasion length should be held constant, but different lengths can be accommodated if necessary by including effort per occasion as a covariate on detection probability. Missing occasions, due to camera malfunctioning, for example, can also be accommodated during data analysis. Jaguar studies have used from 1 to 14 days as a single sampling occasion (Silver et al. 2004, Sollmann et al. 2012*a*). Seven days (1 week) may be an appropriate time period to consider as a sampling occasion for jaguars in the NRU, but the length of time for a single occasion can also be decided upon later once data has been collected (see section Sampling Duration). Sampling occasions may differ between portions of the NRU, given differences in jaguar density and home-range sizes (see Jaguar Status and Habits in the NRU). Differences in occasion length between portions of the NRU will not affect estimates of occupancy but will render estimations of detection non-comparable because they will refer to different timeframes. Given detection is simply a nuisance parameter requiring estimation to calculate occupancy, we suggest occasion length can differ between portions of the NRU if deemed necessary.

Definition of sampling units—Occupancy is a measure that refers to an area. Occupancy surveys, however, have been used extensively to sample continuous space (e.g., Linkie et al. 2007, Sollmann et al. 2012*a*). Surveying the designated core areas in the NRU for jaguar occupancy also qualifies as a survey in continuous space. In this situation, careful thought must be given to the definition of a sampling unit. To define the area a certain occupancy state refers to, researchers usually use a square, circle, or hexagon of the approximate home-range size of the species of interest (see Spatial Autocorrelation).

Allocation of effort—Accuracy and precision of parameters estimates – in the present case occupancy probability and its relationships with environmental covariates – are influenced by sample size. In occupancy surveys, sample size has 2 components, the number of sites surveyed and the number of repeat visits made to each site. Several studies have used simulation-based approaches to examine the trade-off between surveying more sites versus surveying more time. Overall, they found that the optimum strategy depends on detection and occupancy probabilities: when occupancy is low, more sites should be surveyed, whereas when occupancy is high, surveying fewer sites more often yields better results (Field et al. 2005, MacKenzie and Royle 2005). On the other hand, lower site numbers will limit the number of covariates that can be included in the model and will most likely affect the power of surveys to detect important relationships between occupancy and covariates, or to detect temporal trends in occupancy (see also Power Analysis). Bailey et al. (2007) found that when surveying a higher number of sites for more repeat visits, model estimates were more robust to misspecification of the detection model (e.g., failure to include covariates on detection). MacKenzie et al. (2002) showed that increasing the number of sites surveyed, as well as the number of repeat surveys, resulted in better estimator properties. Similarly, O'Brien (2010) showed that if detection probability were low (0.02), even at high true occupancy values (60%), more than 100 sampling locations were necessary to achieve precise estimates (CV < 20%). At double the detection probability, 60 sampling points were sufficient for adequate accuracy and precision. The number of sampling points necessary for good estimator properties increased at lower occupancy rates. In the case of camera trapping, repeat visits are generally not limited – once a camera is set up it will continue to collect detections until its battery or storage capacity is exhausted. Therefore, because large felids usually have low detection probabilities (due to low densities and elusive behavior), it seems advisable to aim for the maximum spatial coverage of the study area that financial and logistical constraints allow.

Spatial autocorrelation—Detections and occurrence of species are assumed to be spatially independent. In practical terms, that means that sampling units should be spaced far enough apart so that a single individual is unlikely to be recorded in more than 1 unit, usually at least the distance corresponding to a home-range diameter. Most frequently, this distance criterion is applied to the centers of neighboring sampling units. Spatial autocorrelation in occupancy can be taken into account by using autologistic or conditional autoregressive (CAR) modelling approaches (see Types of Occupancy Models). These models, however, are more complicated to implement and can have convergence problems. The effects of autocorrelation in occupancy, and the importance and best methods to formally account for spatial autocorrelation, are somewhat controversial (e.g., Dormann 2007). It seems most prudent to avoid spatial autocorrelation in occupancy whenever possible by using adequate spatial study design. Certain survey techniques can induce autocorrelation of detections. For example, when surveying for tracks along a road, using spatial (e.g., distinct trails or predetermined grid cells) rather than temporal repeats (e.g., searching an entire study site for a predetermined number of kilometers over a predetermined number of days [considered 1 encounter/capture occasion], and then repeat the search) can induce autocorrelation. Hines et al. (2010) developed a model that can account for this data structure.

Survey Protocol for Monitoring Jaguar Occupancy

The following survey protocol aims to evaluate and monitor jaguar occupancy across the core areas of the NRU over 15 years. We focus on suggestions for a single-season survey, but also provide guidance on how to evaluate the power of multi-season surveys to detect changes in occupancy. Our recommendations are based on experiences of the authors with survey and analytical methodologies, as well as with jaguar ecology and logistical concerns in the NRU. It should be noted that we developed suggestions without specific consideration of budgetary constraints. Further, we believe that the suggested study design can be refined based on a thorough review of existing jaguar occurrence data and/or smaller scale pilot studies. We touch on all of these issues in the following sections.

Defining and Choosing Sample Units

In occupancy analysis, the sampling unit is a location or area where data are gathered with an assumed outcome of either a species detection or non-detection by 1 or more detection devices in each sampling unit (MacKenzie et al. 2006, Long and Zielinski 2008). MacKenzie et al. (2006) suggested a sampling unit should be large enough to have a reasonable probability of the species being there (i.e., a probability between 0.2 and 0.8), but small enough so any measure of occupancy is meaningful and the site can be surveyed with a reasonable level of effort. Thus, sample unit areas are often based on the largest home-range estimates of the target species.

Gutíerrez-González et al. (2012) estimated jaguar densities of 1.05/100 km^2 in the NJR. Rosas-Rosas and Bender (2012) estimated jaguar densities at 1/100 km^2 in the Alianza para la Conservación del Jaguar en la Sierra Alta de Sonora UMA. Moreno et al. (2013) estimated 2.7 jaguars/100 km^2 in in the Sierra Madre Mountains of northeastern Sonora. Núñez-Pérez (2011) estimated jaguar densities of 4-5/100 km^2 in Chamela-Cuixmala Biosphere Reserve in Jalisco, likely the highest reasonable estimate from the NRU, in an area where male home ranges averaged 110 km^2 (Núñez-Pérez 2006).

Estimates from several other areas include densities of 5.7-5.8/100 km^2 and male home ranges of 140-170 km^2 in the fertile and well-watered flood plains of the Pantanal (Soisalo and Cavalcanti 2006, Cavalcanti and Gese 2009); densities of 2.47/100 km^2 and male home ranges of 280-299 km^2 in the humid Atlantic forest of Brazil (Cullen Jr 2006); and from the low stature and often dry and hot forests of the Chaco near the southern limit of jaguar range, densities (averaged over 10 surveys) in Bolivian Chaco of 0.866/100 km^2 (Noss et al. 2012), with male home ranges in the Paraguayan Chaco of 692 km^2 (McBride 2009).

Because published information on the scale of home ranges in the NRU is limited, some guesswork is required to assign an appropriate sampling scale for an efficient occupancy survey. As a reference, 2 density estimates from Sonora (Gutiérrez-González et al. 2012, Rosas-Rosas and Bender 2012) are less than half those in the Atlantic forests of Brazil, where male home ranges average nearly 300 km^2 (Cullen Jr 2006), yet higher than in the Chaco (Noss et al. 2012), where male homes ranges can average nearly 700 km^2 (McBride 2009). Our expectation is that on a large scale jaguar densities are low in Sonora and home ranges are large. We recommend hexagons of 500 km^2 as the sample units across the NRU. To survey a representative set of units, we suggest overlaying a grid of 500-km^2 hexagons on the NRU (Figure 13), then surveying 50% of the resulting hexagons to ensure sufficient data are collected for reliable occupancy modeling. These units can be chosen completely randomly, or, preferably, systematically with a random starting point. This second option will result in better spatial coverage of the overall area of interest. Following this approach, the Sonora Core Area consists of 155 hexagons (Figure 14), 78 of which should be sampled, while the Jalisco Core Area consists of 109 hexagons, 55 of which should be sampled. In addition to these core area hexagons, we suggest choosing additional sample units beyond the border of the core areas to investigate possible range expansion or contraction. Despite probable variation in home-range sizes between Jalisco and Sonora, we suggest using the same sampling units to maintain comparability of surveys between the 2 core areas.

When designing studies in other parts of the jaguar's range, similar considerations should apply; sample units (cells) should tailored by knowledge or estimates of local jaguar home-range size to reduce auto-correlation and assess occupancy in a biologically meaningful way. Depending on the outcome of the initial survey, it is conceivable that spatial coverage of the core areas in subsequent surveys could be reduced to 30% of all hexagons, but this option should be evaluated carefully based on the data and study objectives (see Power Analysis).

Spatial Coverage of the Sample Unit

Each hexagon should be sampled with 5 camera trap stations (Figure 15; see Setting Cameras), with 1 camera per station (see Setting and Checking Cameras). This represents a compromise between achieving spatial coverage of the sample unit and maintaining logistical feasibility. If more manpower and cameras are available, an additional 2 cameras can be installed in the sample unit, in the event some of the cameras malfunction or are stolen. Cameras should be installed in a regular grid within a hexagon for optimal spatial coverage (e.g., Figure 16). This arrangement is easily adjustable to other numbers of cameras. This regular grid should be understood as a guideline for where to set up cameras within the hexagon; specific locations should be chosen to optimize jaguar detection probability (see Setting Cameras).

Sampling Duration

Single-season occupancy models assume that the occupancy state at each sampling unit does not change over the course of the survey. Therefore, survey duration should be limited to a time frame that ecologically approximates this assumption. For a large-scale survey like the one suggested here, logistics, the necessity to acquire sufficient data for modelling, and the closure assumption must be weighed against each other. Based on experience of some authors with camera trapping in the NRU, approximately 3 months will be required for camera set up and retrieval (see also Logistical Challenges). We suggest sampling at each site for 3 months to acquire sufficient data. Logistical constraints make it impossible to set up all cameras throughout the NRU in 1 or a few days. Therefore, considering the entire NRU, camera traps will be set up successively throughout the study area. We suggest an overall survey duration – from the first camera's first day to the last camera's last day – of 6 months. This period could be subdivided into 24 1-week sampling occasions, 18 10-day sampling occasions, or 12 2-week sampling occasions. As mentioned before, defining occasions in a continuous survey is somewhat arbitrary, and occasion length can be adjusted depending on the data at hand (see Practical Considerations – Definition of occasion). Overall survey length could also potentially be reduced if sufficient detections were obtained in a shorter time frame, or extended, if data appear to be too sparse. As a frame of reference, in areas known to hold jaguar populations in the Sonora Core Area, it takes approximately 2 weeks to record the species for the first time (Carlos López-González, Northern Rockies Conservation Cooperative, personal communication). Because setting up camera traps is time consuming and logistically challenging, it will be beneficial to leave camera traps in the field as long as the equipment and the constant occupancy assumption permit.

We further suggest sampling over the course of the dry season, to avoid camera-trap malfunctions related to rain/humidity and logistical difficulties due to inclement weather. Constraining the survey to a single season will also help approximate constant occupancy states. In Jalisco, the dry season lasts from October to May, in Sonora from November to June.

Setting Cameras

The approximate location of a camera trap will be determined in the lab using GIS software, following the approach outlined above. When in the field, however, these locations need to be adjusted to suitable spots for camera-trap setup. Jaguars are known to travel preferentially along small dirt roads and trails (Salom-Pérez et al. 2007, Sollmann et al. 2011), males more so than females (Conde et al. 2010). Therefore, camera traps for large cats are frequently placed along roads or other landscape features (like arroyos or washes) that provide easy movement paths and "funnel" the animals in front of the camera. These features, and other micro-habitat characteristics of the setup location, likely influence detection probabilities. The more the landscape funnels the animal towards the camera, the higher the chance to record it when it is in the area. Therefore, clear travel routes (trails, roads, rivers, or other habitat edges) in overall more closed habitat often have higher detection probabilities than cameras placed in open habitat with little structure and where animal movement is less constrained. The specific setup situation should therefore be carefully documented.

A standardized protocol should be developed beforehand by people familiar with the study area, including clear descriptions of the features to be recorded. This will ensure that data are collected systematically. Characteristics should include, but are not limited to, presence of a road or trail along which the camera is set up, width or the trail or road, presence of another kind of habitat edge (e.g., grassland/scrubland), presence of a stream/river, mountain ridge, or gully along which the camera is set up, density of habitat surrounding the camera (e.g., can animals move around freely or are they likely to stay to defined paths), canopy cover, etc. For data organization and storage, see Data Recording. Local residents can be of great help when it comes to finding suitable spots to set up camera traps, as they might know of locations where tracks or other sign of jaguars have been seen before. Guidance on collecting data from incidental observations of jaguars is provided in Appendix 4. Guidance for collecting data on tracks and scats encountered in the field is provided in Appendix 5.

Below are suggestions for setting camera traps for jaguars adjusted from the literature review by Polisar et al. (2014). See Figure 17-8 for photographs illustrating the setting of a camera trap and a photograph of a jaguar captured by a camera trap.

- Find a spot where there is a suitable tree or post. Suitable trees have trunks that are reasonably straight, thin enough to tie a chain or wire around, but not so thin that wind, people, or other animals can shake them excessively. In open areas, it might be necessary to bring appropriate stakes into the field to set up camera traps in suitable spots without being restricted by the presence of appropriate trees. Try to minimize direct sunlight on the cameras, as excessive heat can reduce the sensitivity of the sensors to warm-blooded animals and/or create false triggers when clouds block the sun. Cameras should be set back at least 2 m from the nearest point where a target animal might travel across the sensor. This allows for clear, focused pictures and a large enough field of detection from the sensor. Because the sensor beam should be approximately shoulder high, for a jaguar the camera should be set approximately 50 cm off the ground and parallel to it.

- Once the camera is set, clear the area between the camera and the path of travel of all vegetation that obstructs the beam or the field of view of the camera. Leaves and vegetation that are easily windblown can result in false triggers when the sun heats up a frond blowing in the wind. Also, try to avoid pointing the cameras at objects in direct sunlight that may absorb heat and trigger sensors, such as large rocks or sunlit streams.

- Test the aim of the camera by passing in front of it. Do this on both the edges and the middle of the path. Most camera trap brands come equipped with an indicator light that will light up when the camera's sensor detects you. Approximate a target animal by walking in a crouch, and then walking in a more relaxed fashion. Make sure that every conceivable angle at which the target animal can pass in front of the camera is tested, and that in each instance a photograph is triggered.

- Occasionally, limitations in terrain or suitable trees hamper complete coverage of a trail. In that case, lay brush or other obstructions down 1 side of the trail to influence where the target species will walk. This technique is also useful if you are unable to set the camera well back from the trail, and wish to deter a target animal from passing so closely to a camera that it cannot take a well-focused picture. Appropriate fencing can also keep livestock away from cameras while permitting target animals to pass (Rosas-Rosas and Valdez 2010). Especially in the Sonora Core Area of the NRU, presence of cattle and their frequent triggering of camera traps need to be taken into account.

- Some studies have used scent attractants such as Calvin Klein's Obsession®, Chanel N° 5® (original or imitations), or predator scent lures to attract jaguars into the camera's sensor field. The lure can be sprayed on a piece of fabric or tampon attached to a stick, protected either by a cut-off plastic bottle or in a small baby food jar with the top sealed with tape but punctured with fine holes, which prevents animals from removing the lure or rain from washing it away while allowing the scent to dissipate in the air. The device is then fixed in or above the ground in the center of the camera's sensor field. The scent has to be replenished regularly, which may pose a problem in logistically challenging environments. The lure probably does not draw animals from significant distances, but it can cause them to linger in front of the cameras, resulting in larger numbers of photos from various angles during each "capture" event, and thereby facilitating individual identification. If the lure cannot be replaced frequently enough to ensure constant coverage, there is the possibility that, as the scent wears off, detection probability decreases. Because occupancy modeling does not rely on individual identification, application of a lure is not essential, and not using any attractant may be an easier option where lure cannot be replaced frequently.

Data Recording

Photographic records—All photographic records should be entered into a comprehensive database with a single line for every independent record of every species, including humans and domestic animals (see Sunarto et al. 2013 for an example of a Microsoft Excel spreadsheet). Data can easily be reduced to a detection/non-detection format for jaguars or other species of interest. This basic format also provides flexibility to adjust occasion length after the survey has been completed. Information associated with each record should include, but is not limited to, species, individual identification, sex and age if possible, number of individuals in the picture, time of day, date, camera-trap station identifier and/or coordinates, study site, and survey identifier (if multiple surveys are run in a study site). For ease of post-processing, nomenclature and spelling of entries, including missing values, should be standardized.

Photographs should be stored in a manner that makes locating a specific record easy, e.g., in a folder structure that identifies the camera trap site and date range. Specific software is available to store camera-trap data and link spreadsheet records to photographs. For example, Camera Base (http://www.atrium-biodiversity.org/tools/camerabase/) extracts metadata (time, date, etc.) from digital images, allows batch read-in of pictures from secure digital (SD) cards, and includes functions to extract certain data formats from the database, such as capture-recapture detection histories or activity patterns. DeskTEAM (http://www.teamnetwork.org/) is another platform for camera-trap data entry, from trap deployment to photographs and their associated information; a new version based on open source database management systems is currently being developed. General photo handling software such as ExifPro (http://www.exifpro.com/) can also be used to manage camera-trap pictures. Ultimately, as long as the same information is stored, it is up to the researchers' preference which system to use for data storage.

Regardless of the chosen platforms to manage and archive data, we provide a standardized spreadsheet for jaguar detections in Figure 19. This spreadsheet is designed for compatibility with the Jaguar Event-Record Database (http://jaguardata.info/) developed by WCS. The necessary user interface for easy batch import of jaguar observations from camera-trap data (and other data sources) using this standard spreadsheet could be developed to increase the time and efficiency with which large datasets from camera trapping or telemetry could be incorporated into the existing database. Importing jaguar observations into this overall presence database will help centralize information on jaguar occurrence and allow researchers to find out about jaguar studies throughout the species' range.

Survey information—In addition to the actual camera-trap data, it is important to keep track of survey related information, such as camera-trap location (in latitude and longitude), date of installation and retrieval, and local characteristics of camera setup (see Setting Cameras). If upon checking or retrieving a camera trap, the unit is not working (because it is malfunctioning, out of battery, out of storage space, or vandalized), this should be recorded. Often, the date of the last record on that particular camera trap is used as an approximation of the last day the unit was working. Taking test pictures using a trigger card that has the station code, date, and time, when installing, checking, and retrieving cameras, helps keep track of camera functioning and aids in organizing and labeling of the large number of folders of camera-trap data. Some cameras can also be programed to take a picture every day without an external trigger, which can later be used to determine any days the camera was not functioning. Once the survey is completed, a survey effort spreadsheet for all cameras should be constructed, with a line for each camera-trap station and a column for each day of the survey, from the day the first camera was set up to the day the last camera was removed, with entries of "0" or "1," depending on whether a given camera trap was installed and working on any given day (1) or not (0).

Covariates—Both occupancy probability and detection probability can be modeled as functions of covariates. In single-season occupancy models, occupancy probability can only be a function of spatial covariates. If the objectives of the study include predicting occupancy to non-sampled areas, covariates need to be available for the entire area of interest (here, the core areas of the NRU), not only for the actual camera-trap sites. This generally limits possible covariates to remotely sensed or other GIS-based data, or covariates from some area-wide census data (settlements, roads, human population density, etc.), because covariates collected in-situ around camera traps will not be available for the larger area of interest. Detection probability can be modeled as a function of location-specific and time-specific covariates. If the latter is of interest, the covariates matrix also needs to include a section with site-by-date values of covariates varying with time, such as rainfall, temperature, etc. Because extrapolation of occupancy probability to non-sampled areas does not require extrapolation of detection probability, spatial covariates on detection can be collected in-situ. Examples for such covariates are given in the section Setting Cameras.

Occupancy model input data format—Depending on which software is used for implementing occupancy models, the structure of the input files might vary slightly. The general idea, however, is the same across analytical platforms: the input data consists of a site-by-occasion detection/non-detection matrix for the species of interest; a matrix with site-specific habitat covariates; and site- and occasion-specific time-dependent detection covariates (some programs might require a separate matrix for occupancy covariates and detection covariates). Some programs, such as Camera Base, allow you to extract the detection/non-detection matrix automatically from the database. The free software R (R Core Team 2014) is another option to manipulate the raw data matrix easily and repeatedly.

Data Analysis

A number of platforms exist for analysis of occupancy survey data. PRESENCE (Hines 2014) provides an easy-to-use interface for data input, model building, and reading output. Plenty of documentation and working examples are available online. For people familiar with the program R, the package "unmarked" (Fiske and Chandler 2011) provides a range of functions for occupancy modelling. Both PRESENCE and R/unmarked implement occupancy models in an Information Theoretic framework. Implementing occupancy models in a Bayesian framework is straightforward using programs such as WinBUGS (Gilks et al. 1994) or JAGS (Plummer 2003). Kéry (2010) and Kéry and Schaub (2012) provide easily accessible introductions to using these programs for ecological analyses including occupancy modelling. These platforms afford the user additional flexibility in model building. In addition, for certain models, Bayesian implementation is easier. For a brief discussion of useful types of occupancy models see section Occupancy Modelling.

Equipment and Costs

Personnel—Field work should always be conducted in teams of at least 2. A field assistant will cost approximately 750 USD per month in salary. As a frame of reference, in a 300-km^2 survey of Mexican wolves and their prey, 3 teams spent 3 days in the field to set up 30 camera traps (Carlos López González, University of Querétaro, personal communication). This translates to 1 team-day (i.e., 1 team working 1 day) per 3.3 camera traps. Scaled up to the suggested design, the core-area-wide survey would require approximately 118 team-days for Sonora (78 hexagons times 5 cameras) and 83 team-days for Jalisco (55 hexagons times 5 cameras) for installing camera traps. Camera retrieval will likely be faster, but nevertheless requires additional team-days. The costs estimated here do not include vehicle purchase or rental, or vehicle running costs, which for a study this large may be substantial. Also, the amount of person-hours needed to identify species on photographs and transfer the photo-records into a database after the survey has been concluded should also be taken into account.

Camera traps—Depending on the model, camera traps (including storage card, cable, and lock) cost between 250-450 USD. For each core area, a full study would require approximately 500 cameras, including cameras for additional hexagons along the core area border, and back-up units to replace malfunctioning cameras. Depending on the specific model, this results in a total cost for camera traps of 125,000-225,000 USD. There are many different brands constantly developing new models, such that it is not feasible to provide a comprehensive review of current models without the list being outdated almost immediately. We suggest checking user reviews of different brands and models available at www.trailcampro.com.

Different models come equipped with a range of functions. Two fundamental camera features to consider are the kind of sensor and the kind of flash. Most camera traps come with a passive infrared heat-in-motion sensor. These are activated as a warm-blooded animal walks through the sensor field. There are, however, models with active infrared beams (most notably, Trailmaster® cameras). These cameras are triggered when an animal (or any object) breaks the beam. They require setup of a transmitting and a receiving unit on opposite sides of the trail or focal point, which can be more complicated. The great advantage of active traps is that they are not triggered by mere sunlight. A falling leaf or heavy rain, however, will activate the camera if it breaks the infrared beam (although a minimum beam break time can be programmed).

Modern camera traps are available either with white-light or infrared flash. White light provides sharp, colored night-time pictures, which increases the chance of individual identification. This is not necessary for occupancy modeling, but would provide additional information on the minimum number of jaguars in the landscape and individual movements. On the other hand, white light alerts people to the camera's presence and may increase the risk of theft; additionally, some studies have argued that the flash may induce a behavioral response to the device (Wegge et al. 2004). Finally, white flash usually requires some time to recharge, so that minimum time intervals between subsequent pictures may be longer (in the order of seconds). However, some models have circumvented this limitation by having the flash stay on for the duration of the number of photos taken per trigger event. In contrast, infrared flash does not "freeze" the object in motion and therefore may result in blurry pictures, allowing species identification but complicating identification of details (individual, sex), especially for animals walking quickly past the camera. Scent devices can be installed to slow cats down in front of the camera to increase the chance of a high quality, non-blurry picture allowing for individual identification even with infrared flash (see Setting Cameras for details). In addition, a number of sequential pictures can be taken to improve identification success.

Others—Camera traps should be equipped with 16 gigabyte (GB) memory cards. These should provide sufficient storage capacity for 3 months, even in areas where cattle may frequently trigger the camera. In areas with human presence, it might be advisable to install cameras inside metal boxes that can be locked to a tree or post using a cable lock. Battery needs (size, type, quantity) will depend on the camera-trap model and survey duration. Additional equipment needed for camera-trap surveys includes global positioning systems (GPS) units, tools to remove vegetation, and possibly others. With a large-sized study like the present one, costs for these additional items need to be taken into account.

Logistical Challenges

A major component of implementing a large-scale survey in the Sonora and Jalisco Core Areas is the contact and communication with landowners. Due to the local land tenure system, each hexagon in northern Sonora can be expected to consist of at least 15-20 independent properties. In southern Sonora and Jalisco this number increases to approximately 400 (Carlos López González, University of Querétaro and Rodrigo Núñez-Perez, Proyecto Jaguar, personal communication). Establishing contact with landowners to obtain permission to access their land and set up a camera trap on it is not necessarily straightforward. Especially in Sonora, many landowners spend large parts of the year elsewhere. The staff generally does not provide their employer's address or phone number, nor are they in the position to grant permission themselves. To streamline the actual camera-trap survey, permissions to work on private lands should ideally be obtained before camera installation begins. This will require extensive preparatory work and is the most challenging logistical aspect of implementing a large-scale study in this landscape.

Occupancy Modeling

Types of Occupancy Models

Occupancy modeling has a flexible framework and includes a number of different models. The simplest one, and the one we have focused the present document on so far, is the single-season occupancy model, where occupancy remains constant during the study. This model can be extended to multiple surveys, where occupancy is allowed to change from one survey to the other; to multiple states, for example "absent" versus "present but rare" versus "present and abundant"; and multiple species or community models. The Royle-Nichols model (Royle and Nichols 2003) makes use of the link between abundance and detection probability to estimate local abundance of focal species. Other classes of occupancy models deal with situations where either the occupancy state or the detections are thought to be spatially correlated. This is by no means an exhaustive list, and different frameworks can be combined with each other (for example, multi-state models can be combined with multi-season models). But the following models are those that we deem most useful for the purpose of monitoring jaguar (and prey) occupancy in the NRU. In this section, we provide brief outlines of these models. We refer the reader to the extensive literature that exists on these models for further details (Polisar et al. 2014).

Single-season models—This is the basic occupancy model described briefly in the Background section, which allows for simultaneous estimation of the probability of occupancy and the detection probability (MacKenzie et al. 2002). Occupancy and detection parameters may be constant across the sampling area or can be estimated as functions of site- and survey-specific covariates (the latter only for detection). Random effects can be used to deal with unobservable heterogeneity, resulting in so-called mixture models. Substitution of species from a regional species list for sample units permits estimation of relative species richness in a study area and exploration of the covariates that affect species richness (MacKenzie et al. 2006). When covariates are used to estimate occupancy, predictive maps can be developed to estimate occupancy for sites that were not sampled, but fall within the study area and have the same type of covariate information as the sampled sites.

Multi-season models—These are an extension of single-season models and can be used for inferences about occupancy over time and meta-population dynamics (MacKenzie et al. 2003). Sites can change from occupied to unoccupied between seasons. These processes are governed by probabilities of local extinction and colonization, which are estimated within the model. We discuss these models in more detail in the section on Measuring Trends in Occupancy.

Multi-state models—These are used when we are interested in not only whether a site is occupied, but whether there are different states that the occupied site might attain (Nichols et al. 2007, Mackenzie et al. 2009). For example, occupancy models can be used to estimate if a species is absent, rare, or abundant, or, alternatively, if different life history stages are present, such as: absent, present, breeding/reproducing. These models can incorporate uncertainty in state observations (Nichols et al. 2007) and can also be extended to multiple seasons (Mackenzie et al. 2009).

Multi-species model—These models combine detection/non-detection data from a community of species to estimate both species-level and community-level parameters (Dorazio and Royle 2005, Dorazio et al. 2006). Essentially, they are a form of mixed (or random effects) model, where species-level parameters are assumed to have a common underlying distribution that is governed by community-level parameters. In that manner, information is shared across species and even species that are rarely detected (and therefore cannot be modeled independently) can be incorporated in the analysis. These models can be of interest to model the medium- to large-sized terrestrial mammal community from camera-trapping data, which constitutes the prey community for jaguars.

Abundance-induced heterogeneity (Royle-Nichols) models—These models are based on the idea that heterogeneity in abundance generates heterogeneity in detection probability (Royle and Nichols 2003), i.e., the more locally abundant a species, the easier it is to detect at least 1 individual of that species during a survey. Based on this concept, the Royle-Nichols model uses detection/non-detection data to estimate point abundance of the focal species. This model may be of particular interest to model prey abundance, because most prey species cannot be individually identified.

Models for autocorrelation in detection—These models are used when we have correlated observations, either spatially or temporally, violating the assumption of independence of detections (Hines et al. 2010). For example, when conducting sign surveys along trails, we may detect the same individual repeatedly along the survey transect, leading to spatially autocorrelated detections. Ignoring this data structure can lead to biased estimates of occupancy.

The model developed by Hines et al. (2010) subdivides transects into segments and uses a first order Markov process to describe dependency of detection in 1 segment conditional on detection in the previous segment to yield unbiased estimates of occupancy. The trail/sign survey example deals with spatial replicates, but a similar data structure can arise if temporal replicates are not independent of each other.

Models for autocorrelation in occupancy—The above described model for autocorrelation deals with the situation where detections are not independent from each other. But occupancy models also assume that species occurrence at the different sample sites are independent of each other. This assumption can be violated if sample sites are too close to each other so that a single individual can occur at more than 1 site. The survey design we outlined in the present document attempts to avoid this issue by choosing sampling units on the scale of a home range. But additional, finer scale information on jaguar habitat use can be obtained from this survey design when we consider within-hexagon camera stations as sample units (in contrast, in the suggested design outlined in this protocol, each hexagon is a sample unit). Given the species' large movements, we cannot consider these within-hexagon camera stations to be fully independent of each other. The most common ways to account for spatial autocorrelation are by using: 1) an autologistics regression type of occupancy model, where occupancy at a given site is a function of occupancy at neighboring sites; or 2) by using a conditional autoregressive (CAR) model (Besag et al. 1991), where a spatially correlated error term is added to the predictor of occupancy probability. In both cases, the neighborhood of a given site can be defined based on knowledge of the species' movements (e.g., Mohamed et al. 2013) or based on analysis of residuals (Moore and Swihart 2005, Sollmann et al. 2012*a*). Autologistic and CAR models are most easily fit in a Bayesian framework.

Pilot Data

The suggested survey is a logistically and financially challenging endeavor. It seems wise to conduct some smaller-scale pilot studies to assess the feasibility and reliability of the outlined survey approach. Such pilot studies could be implemented in 1 or a few hexagons, following the setup and design recommendations outlined in this document, and could be carried out in different regions of the NRU. Although the collected data would likely not be suitable for occupancy (or other) modeling, it would provide information that could be used to parameterize data simulations for a simulation-based assessment of the accuracy and precision of estimates under different sampling scenarios (see Power Analysis; for examples of such assessments, see MacKenzie and Royle 2005, Bailey et al. 2007). Alternatively, or in addition, existing camera-trapping data could be compiled and used in an analogous fashion, allowing refinement of the survey protocol. In addition to scientific and gray literature, the Jaguar Event-Record Database (http://jaguardata.info/) provides a reasonable starting point for compiling existing information on jaguar presence and detection.

Measuring Trends in Occupancy

One major objective of the occupancy survey outlined in this protocol is to support assessment of the jaguar recovery criteria, which include an increase in (or at least stability of) occupancy. Multi-season occupancy models provide the opportunity to explicitly model changes in occupancy from one survey/season to the next. The design for a multi-season (also called dynamic) occupancy model is the same as for a single-season one, but the single-season survey is repeated at certain larger time intervals. This reflects the "robust design" idea developed by Pollock (1982) in the framework of capture-recapture models, where a survey is repeated over *T* primary occasions (seasons, years, etc.), and within each primary occasions there are repeat visits to sample sites – so-called secondary occasions. Occupancy remains constant within a primary occasion (across secondary occasions), but is allowed to change between primary occasions. Occupancy in the first primary occasion ($t = 1$) is modeled as in a single-season occupancy model; in subsequent occasions, it becomes a function of occupancy in the previous year: if a site was occupied at time t, it can either become unoccupied at time $t + 1$ (local extinction), with probability ε (extinction probability), or remain occupied (with probability $1 - \varepsilon$). A site that was unoccupied at time t can either become occupied at time $t + 1$ (recolonization) with probability γ (recolonization probability), or remain unoccupied (with probability $1 - \gamma$). Both ε and γ can be modeled as functions of spatial and temporal covariates, but accurate and precise estimation of these parameters generally requires a reasonable number of primary occasions (Bailey et al. 2007).

As an alternative to modeling these mechanisms explicitly, data from several surveys can be combined and a time effect can be included in the predictor for occupancy. A positive coefficient for time would indicate an increase in occupancy probability. Again, to detect a significant effect will likely require a reasonable number of seasons/surveys. The necessary number of primary occasions can be determined (at least approximately) using the approach outlined in the section on Power Analysis. Such an approach might be of interest to determine how often and at which intervals the outlined survey would have to be repeated to detect changes in occupancy as outlined in the Recovery Criteria.

Power Analysis

Statistical power is the probability of detecting a significant effect or trend, despite "noise" such as natural variation. Statistical power increases as sample size and effect size increase, and as variance decreases. Power analyses evaluate the probability that a certain study design will detect a change in the event of authentic change, in relation to the probability that monitoring will detect a change when there is no change, or a type-1 error (α).

Depending on the objectives of a study, it might be better to detect false change rather than missing a change. For example, when dealing with a critically endangered species, it might be more prudent to accept higher type-1 error rates (e.g., Hayward et al. 2002). Having a clear understanding of what the study objective is and what level of power or error is acceptable are crucial to performing a power analysis.

Power analyses are often performed using simulation-based methods, following some basic steps (adjusted from Bailey et al. 2007):

1. Define model of interest (single-seasons, multi-season, etc.);
2. Define sample design for which power is being investigated (number of sites, number of repeat visits, etc.);
3. Parameterize the model (define true values of detection probability, occupancy probability, covariate relationships, etc.) – this step requires information from pilot studies or studies carried out under similar circumstances/on similar species;
4. Generate detection/non-detection data from model;
5. Analyze simulated data with model under consideration;
6. Extract parameter estimates, measures of uncertainty/variance, and bias;
7. Repeat steps 5 and 6 for a large number of times;
8. Summarize results to assess average bias and precision.

For occupancy models, both single-season and multi-season, the program GENPRES (Bailey et al. 2007, Hines 2014) lets users perform such power analyses, as well as analyses of other aspects that might impact accuracy and precision of parameter estimates.

Occupancy Modeling for Prey Species

Camera traps collect a wealth of data on non-target species, including potential mammalian prey species for the jaguar. In the NRU, such species include white-tailed deer, collared peccaries, armadillos, and others (Núñez et al. 2000, Rosas-Rosas et al. 2010). Most of these species have much smaller home ranges than jaguars, so the above suggested spacing of camera traps *within* hexagons should be wide enough to provide or approximate spatially independent survey locations. Under these circumstances, the photographic data can be used to model prey occupancy, using the methods outlined above. Analogous to the jaguar, prey occupancy could be predicted for the NRU, and potentially serve as an explanatory variable to predict jaguar occurrence.

To account for the presence of a range of prey species, binary criteria can be developed, such as "at least an *X*% chance of *Y* prey species occurring." It should be noted that the camera-trap setup suggested above attempts to maximize jaguar detections, and will not necessarily optimize detection for other species, based on 2 factors. First, prey home ranges are small in the NRU, and in some cases will be much less than the approximately 100 km^2 sampling accomplished by 5 camera traps distributed across 500 km^2. Second, several herbivores have been shown to have higher detection probabilities off of roads (e.g., Harmsen et al. 2010), either because of different movement patterns, or because of active avoidance of carnivore travel paths. The suggested study design could potentially be adjusted in several ways to increase detections of target prey species. For example, if logistics, equipment, and manpower permit, additional cameras could be added to the existing camera-trap stations (or to some of them) and placed in a manner that optimizes detection of species that do not travel preferentially on roads. Differences in setup would have to be accounted for in the analysis. Alternatively, if the existing survey design is extremely efficient in detecting jaguars in hexagons, some of the stations in each hexagon could be set up to target prey. If home ranges for prey species with large movements (such as peccaries) are in excess of 100 km^2, then occupancy analysis using camera stations as sample sites might have to account for spatial autocorrelation in occupancy, as outlined in the section Types of Occupancy Models, or use hexagons as sampling units. The Royle-Nichols model for abundance-induced heterogeneity in detection is of particular interest for prey species, as these generally cannot be identified to the individual level for capture-recapture analysis.

Hines et al. (2010) designed and Karanth et al. (2011*a*) tested a model that could accommodate serial, spatially-replicated sign-based occupancy sampling across a 38,000-km^2 landscape that included 21,167 km^2 of potential tiger (*Panthera tigris*) habitat, including 5,500 km^2 of wildlife reserves. Roads and trails made active searches for sign feasible in this test of tiger occupancy. On a spectrum of efficiency, when study areas have good access and a system of roads and trails, an active search for sign will collect more data, more quickly, and more comprehensively, at the presence-absence level, than camera traps. Rather than waiting for jaguars to pass, biologists can quickly cover many kilometers and find where jaguars have passed, generating data faster. The limitations of universal application of this method with large cats and most prey include rocky, mountainous substrates, hard clay substrates, deep forest litter, and a complete lack of any road and trail system; all are quite common conditions in the jaguar's range. On substrates which yield no tracks, and areas with few roads and trails, camera traps will be more efficient. The semi-arid, often rocky habitats of the northern portion of the NRU fit the latter description; thus, camera traps are a logical choice.

Because camera traps passively wait in space for resident and transient jaguars to pass, an alternative design might consider elevating the "search" by moving the camera traps halfway through a large scale study. Intuitively, the outlined design of 5 camera traps simultaneously sampling has a passive spatial component, and a temporal component bounded by arbitrary occasions (a range of occasion lengths can be considered). Standardized moves halfway through a study might add data with 2 sets of sequential occasions and a more comprehensive search of the area. Increased staff familiarity with a cell as units are checked in time A might suggest alternative sites for time B, which then could be sampled with no increased equipment, minimal additional labor costs, and perhaps a biologically more accurate assessment of jaguars and prey across a large cell. Alternatively, the semi-systematic allocation of stations depicted in Figure 16 could guide switches into additional "pie segments" of a hexagon, more comprehensively providing opportunities for jaguar detection, and more closely approximating prey home ranges. During analyses, the 2 different sample times would both be sequential from day 1 using identical occasion lengths. This might represent a trade-off between length of occasion and/or depth of resampled occasions to generate detection histories, and greater opportunities to intersect jaguars in space. Duration of sampling could be adjusted accordingly.

Sign-based Occupancy Sampling for Jaguars

Some parts of the jaguar's range do possess characteristics that may allow efficient serial sign surveys as the basis for occupancy modeling design suggestions (due to road systems, semi-open habitats, or dropping water levels along river and lake beds at onset of the dry season, for example). We offer interpretations based on the work of Karanth et al. (2011*a*) and Gopalaswamy (2012*a*) on tigers and their prey for areas with these characteristics.

Sample area: Predicted and potential occupied habitat within the area of interest based on previous mapping and modeling, excluding all areas judged unsuitable.

Cell size: An area which is on average larger than an estimated maximum male jaguar home range.

Season: That which provides maximum sign availability in the study area (the end of the rainy season can be good due to moist substrates and dropping water levels).

Allocation of effort: Because the cell size may be large, and therefore sampling may be physically and logistically intensive, a sampling design covering representative proportions of the study area might be required (30-50% of cells as suggested in camera-trap based occupancy design).

Within cell sampling: Skilled and experienced trackers who have received training in the standardized methods conduct transects composed of connected serial 1-km sections, starting from or passing through a randomly located point in the cell. Sampling within the cell is proportional to habitat availability, excluding sample areas that are not jaguar habitat. All detected sign types are recorded at 1 time only (present-absent) within 100 m intervals (jaguar, conspecific carnivores, potential prey, livestock, humans) along with a habitat classification, according to a predetermined template for data collection. All sign is photographed, recorded, and geo-referenced.

Modelling and analysis of data: Use the Hines et al. (2010) refinement of the standard occupancy model (MacKenzie et al. 2002) to deal with Markovian dependence of animal sign detections on spatial replicates as outlined in Karanth et al. (2011*a*). The sign can be aggregated at 1-2 km intervals to form spatial replicates within the sample cell. It may be logical to aggregate at finer levels for smaller prey to more biologically accurately reflect their level of occupancy (e.g., 500 m or 200 m). Disjunct trail segments due to habitat unsuitability can be combined sequentially (Karanth et al. 2011*a*). The cell-specific occupancy parameter should be weighed by the proportion of potential jaguar habitat in each cell. The "prey-density covariates" for each cell can be the proportion of 1-km replicates containing sign of each prey species (Karanth et al. 2011*a*), although a more finely tuned assessment according to shorter segments can be considered. Karanth et al. (2011*a*) used livestock as a proxy for human-disturbance. The same interpretation merits exploration in jaguar habitat. Because jaguar densities are high in some high livestock biomass areas, remote sensing additional covariates can and should be added (such as distance to human settlement, presence of water bodies, distance to water, habitat type, topography).

Sign-based occupancy studies by Sunarto et al. (2012) on tigers in Sumatra serve as a useful example for sign-based jaguar occupancy surveys. Field staff recorded tiger detections and habitat variables along 100-m segments along 40, 1-km transects in each of 47, 17 km x 17 km grid cells (Sunarto et al. 2012). These nested designs (Karanth et al. 2011*a*, Sunarto et al. 2012) allow estimates of the probability of large cat occupancy at a large landscape level (e.g., large landscape grid of 17 km x 17 km = 289 km^2 cells in the Sunarto et al. (2012) tiger study in Sumatra, and 188 km^2 in the Karanth et al. (2011*a*) tiger study in a prey rich habitat in India) and also the probability of habitat use at the finer level based on the data recorded in 100-m segments along 1-km transects.

The advantage of the clear 100-m segments is a coarse assessment of prey distribution and abundance even when sampling at the jaguar home-range scale. Start points for transects should be selected randomly within sample cells, then the searches should follow landscape features that yield jaguar sign (tracks, scats, scrapes). See Polisar et al. (2014) for a discussion of jaguar sign. Within each 1-km transect, habitat variables and GPS location are recorded at 100-m intervals. As examples, Sunarto et al. (2012) recorded altitude, assigned scores for overall vegetative cover, canopy cover, sub canopy cover, understory cover, and slope, and included assessments of impact or risk of logging, encroachment, fire, settlement, and hunting at the start of each 100-m section. Because the latter 4 categorical assignations might be subjective, and risk observer bias, they should be complemented by GIS-based assessments of distance from roads, distance from communities, distance from agricultural fields, and distance to discernible water, all feasibly linked to start points of 100-m segments, if GPS locations are recorded faithfully in the field. Recording prey sign along the 100-m segments (Karanth et al. 2011*a*) will allows a resource-based assessment of habitat quality and threats.

Conclusion

Assessing occupancy of jaguars across the core areas of the NRU will be a challenging project that requires thorough planning. This survey protocol, in combination with general background on occupancy modeling, should provide practitioners with a toolkit to plan such a project.

Considering the scope of such a study, we stress the usefulness of collecting pilot data, either in the field or by assembling data from existing studies, to refine and further assess the outlined study design.

Ideally, an occupancy-modeling-based evaluation of the status of the jaguar across the NRU will be complemented by more intensive assessments of abundance, demographics, and population genetics. The extensive camera-trapping surveys we propose to assess jaguar occupancy will allow the identification of focal areas for more intensive studies of jaguar population abundance and/or density. Areas where jaguars are detected by this large-scale effort can be surveyed with scat-detection dogs (or scat dogs) for genetic analyses; can be targeted with more intensive camera-trap surveys to estimate jaguar population size and demographic parameters using capture-recapture models; and can be foci for capture and collaring efforts to understand jaguar space use, ranging behavior, and social behavior. In these focal areas, the coarse evaluations of prey abundance obtained through occupancy methods can be refined by more rigorous methods, such as distance sampling (Buckland et al. 2008) or fine-grained, prey-focused occupancy sampling (Gopalaswamy et al. 2012). As such, the outlined occupancy survey will provide the necessary knowledge base to target further conservation-oriented research on jaguars and their prey in the NRU.

ABUNDANCE AND DENSITY

While presence and distribution of species are important state variables that are highly informative and can be reliably estimated through occupancy analyses (see Occupancy Protocol), it also is important to determine abundance and/or density. Abundance is another way to describe the state or status of a target species, and when converted to density, can be extrapolated to larger areas of similar habitat, potentially to better inform management about a species' overall status. In addition, monitoring abundance through time can tell us whether populations are increasing, decreasing, or remaining stable, giving us insight into whether management actions designed to reverse downward population trends are needed.

Abundance estimation refers to the counting of individuals using a sampling scheme appropriate for the target species, while accounting for imperfect detection, often through a capture-recapture framework. This should be contrasted with a descriptive summary variable such as a trapping rate or capture frequency (i.e., number of captures per some unit of time) because even though trapping rate has been found in some studies to correlate with abundance (O'Brien 2011), other studies have not found such a correlation (Maffei et al. 2011*a*). Therefore, using a trapping rate as an index of abundance remains controversial (Carbone et al. 2001, Jennelle et al. 2002). However, descriptive variables such as trapping rates can be easily calculated and can give very useful information on hotspots of animal activity or aid in comparing effort and success across studies. But, unless trapping rates have been independently calibrated to abundance, they should not be used as a surrogate for abundance because they do not account for imperfect detection or that the probability of observing a species (or an individual of a given species) is unlikely to remain constant across space and time (Link and Sauer 1998, Pollock et al. 2002). Failure to account for imperfect detection can lead to biased results. Analytical approaches to account for imperfect detection in abundance estimation through capture-recapture analyses are well developed and, below, we describe useful approaches for jaguar abundance/density estimation.

Occupancy analysis refers to the detection of a *species* during repeated visits to a particular site, whereas capture-recapture refers to detection of distinct *individuals* of the target species during repeated surveys at a site. We use the term capture-recapture rather than capture-mark-recapture or mark-recapture, because, in our case, jaguars are already distinctly marked and our proposed methods do not require us to physically mark the individual animals. To conduct a capture-recapture study, we must be able to "capture" unique individuals and "recapture" them later in order to build capture histories for each individual in the population. In our case, the "captures" do not entail physically capturing the animal, but rather we can capture and recapture them noninvasively through remote camera photographs or through DNA from field collected scat (fecal) samples (see also Kelly et al. 2012). The resulting capture histories are used to determine detectability (and what influences detectability) across the population.

In traditional capture-recapture models, detections are recorded in an individual-by-occasion data matrix (the capture history) with entries of "1" meaning the individual was detected, and "0" that the individual was not detected, during each sampling occasion. The repeat surveys/occasions are needed to inform the detectability model component and ultimately give insight into how many individuals may have been missed entirely (never detected) during the survey. In the more recent spatial (or spatially explicit) capture-recapture framework (e.g., Efford 2004, Royle et al. 2014), the location of capture is also recorded, resulting in an individual-by-trap-by-occasion data array. Detections are not required to be binary, but can instead be counts (i.e., the number of detections of an individual at a given trap in a given occasion). This is particularly useful in camera-trap studies, where data are not limited to "detected or not" (as opposed to, for example, hair snare studies, where we can only determine whether or not an individual has visited a trap during an occasion or not).

Factors that are known to impact detectability and thus the resulting abundance estimates, and that are commonly included in capture-recapture models, are: time M(t) variation related to survey-specific details such as good or bad weather during surveys; behavioral variation M(b) due to a trap response such as trap happiness or trap shyness; individual variability or heterogeneity M(h), which can result from unobserved sources, or be caused by differences between males and females or young and old animals; and combinations of these factors. Spatially explicit capture-recapture (SCR) models further allow us to model trap-level effects on detectability. For large cats, for example, camera traps set up along small, dirt roads often have much higher detection rates than cameras set off of roads (Conde et al. 2010, Harmsen et al. 2010, Sollmann et al. 2011).

Like occupancy modeling, there is a large range of capture-recapture models and the most relevant to this protocol are discussed briefly in the section Types of Abundance/Density Models. The simplest model is the "closed-capture" or "closed-population" model, which is analogous to the single-season occupancy model. In this case, we assume that abundance is constant during the survey period such that there are no births/deaths (demographic closure) and no immigration/emigration (geographic closure). Detectability is allowed to vary according to factors listed above. The closed-capture model can be extended to an "open-population" or "robust-design" model, analogous to the multi-season model in occupancy. This allows us to determine what drives changes in population abundance (e.g., survival and recruitment) from data collected over a longer time frame, such as multiple years.

The following protocol focuses on the design of closed-capture surveys for jaguar abundance estimation in targeted core areas of the NRU. We suggest 2 ways to do this through remote camera capture-recapture, and through genetic capture-recapture. We give suggestions regarding practical aspects of capture-recapture (hereafter often denoted CR) modeling along with jaguar-specific CR suggestions for the NRU. We also suggest extending the closed-capture protocol to conduct open-population, robust-design modelling using remote camera data only. Finally, we suggest analytical methods to address jaguar prey abundance and sympatric predator abundance, which can be determined from the non-target data collected via remote camera traps set for jaguars.

Practical Considerations

Definition of occasion—As with occupancy estimation, determining detection probability (in this case for individual jaguars) requires repeat surveys of the target area. Surveys can be conducted by using remotely-triggered infrared cameras to "capture" images of jaguars, which have natural markings on their coats that allow identification of individuals by their distinctly different rosette patterns (Silver et al. 2004). Traditionally, repeat surveys are achieved by surveying the study area over multiple temporal occasions. Camera "traps" are operational continuously throughout the designated survey time. While it would seem reasonable to use a 24-hour time period as a repeat survey occasion, this often results in an overload of zeroes in the data set because cameras may go many days or weeks without photographing a jaguar, which can lead to computational problems caused by detection being close to zero. Therefore, most jaguar studies "collapse" data into somewhat arbitrary time periods such as 3, 5, or 7 (sometimes up to 14 days; Noss et al. 2013). However, if occasions are too long, loss of information important to determining detectability can occur because an animal captured 3 days in a row would only be counted as detected once in a 3-day, collapsed data set (Polisar et al. 2014). There is a trade-off between computational problems caused by too many zeroes in the data set, and loss of information on individual detectability when collapsing data into multi-day occasions. Seven days (1 week) may be an appropriate time period for data collapsing for abundance estimation in the NRU, but this length of time can be decided upon after exploratory analysis preformed on data in hand to determine appropriate occasion length. For genetic capture-recapture, surveys can be conducted by searching the study site and "capturing" animals through collecting their scats and determining both the species and the individual through DNA analysis (i.e., molecular scatology; Kohn et al. 1995). There are 2 approaches for determining occasions. Researchers can search an entire study site for a predetermined number of kilometers over a predetermined number of days (considered 1 encounter/capture occasion), and then repeat the search (i.e., temporal replicates) of the full study site up to 4 or 5 times to create 4 or 5 encounter occasions (Wultsch 2013). Alternatively, researchers can search a study site only once, but use spatial replicates – usually distinct trails or predetermined grid cells. These spatial replicates can be used as repeated encounter occasions. While this may be more efficient and quicker, it precludes the analysis of time M(t) models, as spatial replicates cannot be all surveyed at the same time (i.e., there are no temporal replicates). Additionally, the spatial replicate design may not yield a high enough number of captures and recaptures to estimate abundance in an area such as the NRU with low jaguar densities.

In theory, spatial capture-recapture models do not require temporal repeats to estimate detection probability, because they make use of the spatial information in the data (Borchers and Efford 2008). In practice, however, we are unlikely to ever collect enough data on a single sampling occasion to obtain reliable density estimates. But even when an area is surveyed for several weeks or months, there is no need to subdivide the survey into discrete occasions (e.g., Borchers et al. 2014), unless temporal variation in detectability is to be modeled. In the special case of camera traps, the sum of records of each individual at each trap can be used as input data. This has the great advantage, especially for rare species, that we do not lose information by condensing data into a 0/1 format. Borchers et al. (2014) show that using all records does lead to more accurate and less biased parameter estimates. It is important to note, however, that records are assumed to be independent. As a result, some sort of threshold should be established for what constituted independent records of the same individual at the same camera trap (e.g., at least an hour between subsequent records, or 1 day). While Polisar et al. (2014) cite the threshold of 0.5 hours that O'Brien (2003) also followed in Kinnaird and O'Brien (2012) for considering consecutive photographs of the same individuals independent for relative abundance indices, a suitable range of thresholds for jaguars in the context of spatial capture-recapture input has yet to be established.

Definition of sampling units—When estimating abundance, the individuals detected are the sampling units, in contrast to occupancy, where the sites surveyed are the sampling units. For abundance, the number of times jaguars are recaptured also determines whether the sample size is large or small. There is no set number of sampling units (jaguars) needed for sampling, but a sample of 30 or more individuals will yield more precise estimates (Tobler and Powell 2013). Unfortunately, jaguars exist at such low density that most jaguar camera-trapping studies do not reach 30 individuals sampled despite large amounts of effort. In Sonora, 1,560 trap-nights in a relatively small area yielded 4 individual jaguars (Rosas-Rosas and Bender 2012), and 7,718 trap-nights in an area of variable size in another area yielded ten individual jaguars. Moreno el at. (2013) reported 11 jaguars from 8,408 camera trap days across an area whose total dimensions were estimated at 408 km^2, with samples drawn for 2.5 years. In Chamela-Cuixmala in Jalisco, 725 trap-nights photographed 8 individual jaguars (Núñez-Pérez 2011). Because jaguars use large spaces, the "net" of camera trap stations needs to be large to sample a substantial proportion of the population, and for analytical models to function well. Therefore, in general, we suggest aiming for large trapping grids to increase the potential to capture more individuals (Maffei and Noss 2008, Maffei et al. 2011*a*, *b*, Noss et al. 2013, Tobler and Powell 2013).

Sample size, survey area size, camera spacing, and allocation of effort—In occupancy analysis, sample size has 2 components that are the number of sites surveyed and the number of repeat surveys at each site, both of which can be defined/controlled by the researcher. In abundance estimation, however, we can only control the number of detectors (e.g., camera traps) and of repeat surveys, and must "guesstimate" (or conduct a pilot study) how much area needs to be surveyed in order to obtain enough distinct individuals, and recaptures of those individuals, to obtain accurate and precise abundance estimates. The area covered in camera-trapping surveys is determined by a combination of how many traps are used and how far apart we place those traps on the landscape. Traditional CR models required that spacing between traps should be such that individuals with the smallest recorded home ranges (usually females) would not be missed by putting camera traps too far apart. For example, camera spacing for jaguars in Belize is often 3 km based on the smallest home range recorded for 1 female radio-collared jaguar of 10 km^2

(Rabinowitz and Nottingham 1986). This ensures every 9 km^2 will contain a camera trap; hence, no individual jaguar should be missed due to holes in the trapping grid. This ensures that every animal has a probability of being captured, a necessary assumption of CR models (Otis 1978). With spatial capture-recapture models, this is no longer required. Still, because we require that individuals are recaptured at multiple sites, it is advisable that, on average, camera traps are spaced narrower than animal movements. But "holes" in the trapping grid that are large enough to contain an entire animal's home range do not constitute an assumption violation to spatial CR models. This allows for much more flexibility in spatial study design. For example, for surveys of large areas, it is possible to distribute multiple clusters across a landscape, where narrow spacing within a cluster allows recaptures of individuals at multiple traps, whereas the wider spacing among clusters allows exposing more individuals to the survey (Efford and Fewster 2013, Sun et al. 2014). Careful consideration should go into spatial study design and we suggest conducting simulation studies under several sampling scenarios to determine whether a design is adequate for the study area (Sollmann et al. 2012*b*, Efford and Fewster 2013, Tobler and Powell 2013, Sun et al. 2014).

As for spatial extent of the survey, the larger the area covered, the more individuals will be captured, thus increasing sample size. Original recommendations were to cover an area using at least 20 camera stations that encompassed 3 to 4 times the average home-range size (Maffei and Noss 2008). These recommendations have recently given way to a newer, more convincing study by Tobler and Powell (2013) showing that even twenty stations might be inadequately small and that increased area and camera numbers are needed to improve accuracy and precision of density estimates (see Trap Distance, Camera Numbers, and Spatial Extent**).**

The duration of the study should be such that it satisfies the assumption of population closure while still acquiring enough captures and recaptures to enable (spatial) CR modeling. For demographic closure, this can be done by keeping the duration of the survey short (on the order of 2 to 3 months) relative to lifespan of the animal.

For conducting genetic capture-recapture, the sample size is going to be based on the number of individual jaguars captured and recaptured, not simply the number of scat samples collected. An additional complication is that not all the samples will amplify, meaning that we will not be able to obtain DNA from every scat sample. Some information will be lost, similar to the lost information from unidentifiable, blurry photographs. Therefore, we suggest intensively searching for scat samples across the same large area where camera traps are deployed to potentially encounter more individuals. It is likely that temporal replication will be needed (see *Definition of Occasion*) to obtain enough scat samples (specifically recaptures) to conduct genetic capture-recapture. Temporal replication can easily be done within the same amount of time that remote cameras are deployed (3 months), thus satisfying population closure for genetic sampling.

Survey Protocol for Monitoring Jaguar Abundance and Density

The following survey protocol aims to evaluate and monitor jaguar abundance and density across the core areas of the NRU over fifteen years. Jaguar cubs remain with their mothers for 1.5 to 2 years (Seymour 1989). Female jaguars become reproductively mature at 2-3 years (Seymour 1989). Few jaguars live beyond 12-13 years (U.S. Fish and Wildlife Service 2012). A 5-year period spans the maturation of female jaguars, and the maturation of at least some of their female offspring. Because 5 years constitutes a generation, it is a reasonable and cost-effective interval to measure numerical population trends (increasing, decreasing, stable). Fifteen years includes 3 generations, and thus, is a good benchmark to assess progress towards recovery goals.

We focus on closed-capture modeling for a single season but also provide guidance on extending surveys over multiple seasons in order to detect changes in population abundance through time. Our recommendations are based on jaguar ecology, experience of the authors with jaguar-specific surveys and the logistical constraints of the NRU, and our experience with analytical methods for abundance and density estimation from remote camera or genetic capture-recapture surveys. The following study design touches on these issues and can be refined based on review of pilot study data from suggested target areas.

Abundance/Density Estimation Field Techniques

There is now a relatively long history of using remotely triggered camera traps combined with (spatial) CR modeling for estimating abundance and density of large wild cats, beginning with tigers in the mid-1990s (Karanth 1995, Karanth and Nichols 1998). The first studies using remote cameras for jaguars followed nearly 10 years later (Kelly 2003, Wallace et al. 2003, Silver et al. 2004). More recently, advances in genetic techniques, specifically molecular scatology (see Population Genetics), have opened the door to estimating abundance through combining genetics with CR techniques for large cats. Below we suggest a protocol for using remote camera CR and genetic CR for estimating jaguar abundance and density.

Choosing Sampling Sites

For abundance estimation, it is most efficient to choose an area where a known jaguar population exists, and intensively study that area with systematically-spaced camera traps or scat surveys. While other areas of low population density might be of interest ecologically, the amount of effort needed to accumulate a sufficient sample size is likely prohibitive. In the NRU, data describing breeding populations comes from the Sahuaripa-Huasabas area in northern Sonora and in Chamela-Cuixmala in Jalisco (Núñez-Pérez 2006, 2011, Gutiérrez-González et al. 2012, Rosas-Rosas and Bender 2012). Additional information suggesting intact populations is being collected from Cabo-Corrientes along the Northern Jalisco Coast, RBSM straddling Jalisco and Colima, and RBMNN (wetlands) and Sierra de Vallejo in Nayarit (Núñez and Vazquez 2013; Núñez in prep).

Jaguar populations are also being monitored in the APFF Álamos-Río Cuchujaqui (Gutiérrez-González et al. 2013).

In the mega-landscape monitoring scenario we recommend, occupancy surveys are used to evaluate a large matrix where jaguars may or may not occur to discern distribution and occupancy trends. The occupancy probabilities and detection rates will identify core areas where jaguar populations are concentrated, as well as clarify the environmental and management covariates associated with jaguar distribution. Focused studies of abundance, as well as demographic and dispersal characteristics, can increase our understanding of the factors that influence jaguar distribution in the larger matrix, and are essential for recovery. Due to the labor and expense involved in more intensive studies, these focal areas for long-term research need to be selected carefully. While occupancy evaluates where jaguars are, an essential metric for recovery, more intensive studies in focal sites evaluate the dynamics that drive that distribution.

<u>Trap Distance, Camera Numbers, and Spatial Extent</u>

In the Chamela-Cuixmala Biosphere Reserve in Jalisco, Núñez (2006) recorded average female home ranges of 23.8 km^2 in the dry season, and 38 km^2 in the wet season. Using 25 km^2 as an approximation of the smallest female jaguar in the NRU, we suggest systematic camera station placement at 4-km intervals. This will ensure that every 16-km^2 block contains a camera station and therefore each individual should have a probability of being detected by a camera, and most individuals should be exposed to several cameras. Camera station placement across the landscape can be done in 2 ways. A grid of 4 km x 4 km blocks can be overlaid across the area of interest and 1 camera station placed in each block in the best possible location that increases probability of capture (e.g., on known travel paths of jaguars such as roads, trails, junctions, water holes). Another approach is to set cameras at regular intervals such that each station is 4 km (±200 m) from at least 2 other stations, except for cameras on the outer edge that may be 4 km from only 1 other station (a technique used for jaguars in Belize; Marcella Kelly, Virginia Polytechnic Institute and State University, personal communication).

Recent work by Tobler and Powell (2013) offers new guidance on camera numbers and size of the camera grid needed to deliver robust estimates of abundance and density. They reviewed over 74 studies and showed that 90% produced biased results that overestimated jaguar density, largely due to covering too small of an area. This overestimation is in large part an artifact of using non-spatial CR models, where abundance is converted to density in an ad hoc manner, using information on how far individuals moved among traps. These “movement estimates,” used to derive an effective sampled area, are limited by the extent of the trap array and heavily influenced by trap spacing (Maffei et al. 2011*a*, *b*). Spatial CR models have largely overcome these problems by integrating the spatial information of capture (Noss et al. 2013, Tobler and Powell 2013). Therefore, spatial CR models are much more robust to spatial study design than traditional CR models (e.g., Sollmann et al. 2012*b*). Overestimation would be a serious problem for conservation of jaguars in the NRU and we do not want to obtain flawed, overly optimistic estimates for an endangered species. Simulations showed that as camera grid size approached the size of 1 home range, precision increased rapidly and that the maximum camera spacing that still gave accurate results was about half a home-range diameter (Tobler and Powell 2013). The radius and diameter of home ranges from 25-200 km^2 are provided in Noss et al. (2013). Our suggested camera spacing of 4 km is larger than the suggested spacing of half a home-range diameter for females, which would be 2.8 km for a 25 km^2 home range in Jalisco. However, this value represents the minimum home-range size, and we assume that male home ranges in the NRU can be as large as 500 km^2. Therefore, this spacing is a compromise between these disparate home-range sizes and the need for large spatial coverage.

Spatial extent of the camera grid depends somewhat on jaguar density. Areas with high jaguar density (>3 per 100 km^2) might only need to be as large as half to 1 jaguar home-range size, while areas with low jaguar density (< 1 per 100 km^2), as in the NRU, will need to cover more than 1 jaguar home-range size to produce accurate and precise estimates (Tobler and Powell 2013). We suggest using a minimum of 60 camera-trapping stations, which is in line with suggestions by Tobler and Powell (2013) to use 60-100. This number will be necessary due to the low jaguar density and large home ranges for males in the NRU. Using 60 camera stations at 4-km intervals will result in a camera grid size of ~960 km^2, or about 2 of the largest jaguar home ranges noted for males. This size also is equivalent to nearly 2 hexagons from the Occupancy Protocol and is in line with Tobler and Powell's (2013) recommendation to cover 500-1,000 km^2.

Genetic Sampling for Abundance and Density

We suggest conducting genetic sampling within the same ~960 km^2 areas delineated by the camera trapping grid as this will enable comparison of the effectiveness of the 2 different methods, allow for combination of the 2 methods to improve density estimates (Gopalaswamy et al. 2012*b*), and give detailed genetic information from the focal areas of the NRU. Additionally, efficiency can be increased by placing at least 1 hexagon from the Occupancy Protocol within each of these 4 focal areas and using the scat data collected for both occupancy and abundance/density.

We suggest using temporal replicates, rather than spatial replicates, in order to increase sample sizes of captures and, especially, recaptures needed for CR analyses. For flexibility in searching, a 4 km x 4 km grid (16-km^2 grid cells) can be superimposed across each study site and each 16-km^2 grid cell opportunistically searched for approximately 8-10 linear km along established roads, trails, game trails, and other likely travel paths, following the techniques described in Wultsch (2013). In this type of opportunistic searching, the researcher should use these likely carnivore paths in order to increase detections of scat samples, as carnivores are known to mark on paths and at prominent locations including road junctions, for example. A distance of 8-10 km searched per grid cell enables researchers to standardize effort across grid cells, but allows flexibility in choosing the search paths through the grid cells. The 8-10 km searched should be along paths within each grid cell. Completion of all cells in the survey will constitute 1 sampling occasion. The survey will then start over searching all cells again, until 4 to 5 repetitions have been completed. It should be noted that the same trails can be surveyed, or different trails can be searched with each repeat survey to cover more spatial area within each grid cell.

Sampling Duration

Camera trapping—With rare and elusive species, researchers usually need to compromise between sampling long enough to collect enough data, but short enough so that the parameter under investigation is biologically and ecologically meaningful. Closed-capture models require that no individuals in the study population die or emigrate, and that no new individuals are recruited, over the course of the survey. Approximating this assumption is usually done by keeping surveys relatively short. The amount of time depends on the biology of target species and, for big cats, a study duration of 2 to 3 months is generally adequate (Henschel and Ray 2003, Silver 2004). This usually enables enough captures and recaptures to run CR analyses while meeting the demographic closure assumption. Demographic closure also can be evaluated through closure tests (Otis 1978, Stanley and Burnham 1999). In practice, it can be difficult to distinguish between lack of population closure and heterogeneity in detection. Jaguars not recaptured may have emigrated, or died, or may have simply eluded re-detection as the study progressed. New animals might be immigrants, or their movements may not have initially coincided with the location of camera trap stations. Using simulations, Tobler and Powell (2013) found that short periods reduced precision and confidence intervals. They recommended minimum periods of 60 days, and even sampling durations of 90 of 120 days, stating that in most situations the data gained by extending the survey period should outweigh the risk of violating closure. Geographic closure (i.e., no immigration or emigration) is a harder assumption to meet over a 3-month trapping period, because some sampled individuals may permanently move, or may have home ranges that extend beyond the edges of the sampling grid, thus temporally emigrating from the grid. Geographic closure can be assessed using the Pradel model (Pradel 1996) implemented in program MARK. Every month of an extremely large camera-trapping survey is expensive. Thus, the minimum number of days required to level out density estimates and coefficients of variation becomes as important for the budget as it is for the science. For example, simulations predicted the need for a sampling duration of over 90 days in a jaguar camera-trapping study in Guatemala. However, preliminary results from this study show a steep curve of new individuals lasting up to approximately 70 days, with no appreciable changes in density estimates after 60 days. Additionally, steep declines in the coefficients of variation with increasing study duration level out at approximately 60 days and become gradual thereafter. The preliminary results of the large scale test of the simulations in Tobler and Powell (2013) suggest that 60 days were adequate for accurate results, and that extra time yielded diminishing returns despite added expenses (Rony Garcia, Wildlife Conservation Society, personal communication).

Unlike the Occupancy Protocol, where surveying such a large number of 500 km^2 hexagons will take many months, setting up camera for the intensive abundance surveys should each take about

2 weeks and then run continuously for 3 months. This is reasonable considering that camera stations are spread continuously in relatively close proximity across the grid.

We also suggest sampling during the dry season to avoid camera trap malfunctions due to high moisture and logistical complications in reaching the field sites during the wet season. In Jalisco, the dry season lasts from October to May, in Sonora from November to June. This also may be more appropriate for the closed-capture models if jaguars change their ranging behavior as seasons change, potentially violating geographic closure.

Genetic sampling—Genetic sampling can take place entirely within the 3-month sampling period when cameras are functional. The amount of time it will take for each repeated scat survey (i.e., each encounter occasion) across the entire study site will depend on how many, and what type of, searches are used. To increase efficiency of finding scat samples, we recommend using scat-detection dogs rather than people searching for scat visually. Scat-detection dogs have been shown to be highly efficient in finding jaguar scats in other studies (Vynne et al. 2011, Wultsch 2013, Wultsch et al. 2014). We suggest using 2 scat-detection dog teams to complete surveying such large areas repeatedly in 3 months. Each dog team could search nearly 2 of the 16-km^2 superimposed grid cells per day. With 60 grid cells, that would take about 15 days per occasion plus several days rest for approximately 20 days per occasion. With this schedule it would be possible to complete 4 (possibly 5) repetitions in 90 days. It is likely that 10-12 scats per 15-day occasion could be collected, and up to 50 scats after 4-5 repetitions.

Setting and Checking Cameras

The main difference between camera sets for occupancy versus abundance is the requirement of having 2 cameras per station for abundance estimation, rather than 1 (see Figure 17-8). Cameras are set on opposing sides of the target area to photograph both flanks of the jaguar for individual identification based on unique spot patterns. Cameras should be at least slightly offset to prevent mutual flash interference; however, some researchers prefer to have the opposing cameras within each camera's viewshed to record interesting behaviors, such as when animals investigate the opposing camera. This can also lead to multiple photos of individuals, aiding in individual identification. Additionally, cameras should be set to take multiple photos (at least 3) with each triggering event to improve identification success. Wait time between triggering events should be short (15-30 seconds), because some studies have noted cats following each other in either family groups or male/female pairs (Marcella Kelly, Virginia Polytechnic Institute and State University, personal communication).

Camera station locations can be decided based on past experience of jaguar researchers in the target areas and through GIS mapping of locations based on spacing requirements suggested above. In the field, however, cameras should always be placed to maximize capture probability by using established trails, dirt roads, canyons, ridgelines, water holes, river edges, or other features that jaguars are known to use and which funnel animals in front of the cameras

(Harmsen et al. 2010, Sollmann et al. 2011). Randomly placed cameras usually have very low jaguar detection and will not generate enough data for CR modeling. More detailed and specific information regarding camera placement can be found in the Setting Cameras subsection of the Occupancy Protocol and we refer to this subsection for suggestions on camera setting in the field.

We suggest having a "camera setup data sheet" that includes documentation of local conditions at the site such as: trail or road type (e.g., game trail versus human trail, or logging road versus 2-track), trail or road width, canopy cover, habitat type, presence of water, land use category, etc. (Appendix 6). These data may clarify variables important to study animals. Apps et al. (2006) used data from 30 independent variables in a 5,496 km^2 systematic DNA hair-trap survey to describe interspecific landscape partitioning between grizzly and black bears according to terrain, vegetation, and land cover variables at 2 separate scales. We also suggest checking cameras periodically to troubleshoot malfunctions, and change batteries and memory cards as necessary (Appendix 7).. The amount of time between camera checks depends on local weather conditions and logistics. In wetter areas, more frequent checks will be needed, as humidity is known to negatively affect camera functionality. Some tropical studies check cameras every ten days (Marcella Kelly, Virginia Polytechnic Institute and State University, personal communication), while in dryer areas this could be lengthened. We suggest triggering each camera at setup, at each camera check, and at retrieval, with a trigger card displaying the date, station code, camera number, and time, as this information can not only aid in data organization, but also in correcting photo data if the camera's date/time stamp malfunctions. We suggest using a "camera checking data sheet" to record all relevant information (e.g., battery levels, camera condition, number of triggers) at each camera check. Example data sheets can be found in Sunarto et al. (2013) and an example is provided in Appendix 8.

Setting and checking of camera traps also provide for opportunistic collection of jaguar scats (see Opportunistic Searches and Scat Collection). Scat and other opportunistically-collected data (e.g., tracks, skins) should be recorded in the jaguar observation database (see Data Capture and Curation).

Surveying with Scat-Detection Dogs

Details and specific information regarding training and survey with scat-detection dogs can be found in the Sampling Using Scat-Detection Dogs subsection of the Population Genetics discussion, below.

Data Recording

Photographic records—As with occupancy analysis, all photographic records should be entered into a comprehensive database with a single record for every independent photographic event, including humans and domestic animals. A single photographic event is often recorded as any distinctly different individual within a 30-minute time period regardless of the number of photographs of that individual (Davis et al. 2011). From there, it is relatively easy to manipulate the raw data in order to calculate trapping rates for all species, to create detection/non-detection matrices for all species, and to create capture histories for individual jaguars. Similar to occupancy, information associated with each record should include, at minimum: species common and scientific names, individual ID for jaguars, sex and age if possible, number of individuals in the picture, total number of photographs of each event, time of day, date, camera-trap station identifier and/or coordinates, camera(s) that triggered, study site, and survey identifier (if multiple surveys are run in a study site).

The main difference between occupancy and abundance in camera-trap data entry is that for abundance there are 2 cameras per station instead of 1. This complicates data entry because 2 cameras can photograph the same animal and these should not be double-counted as 2 separate photographic events – they are the same event, but with 2 photographs. Therefore, researchers must simultaneously examine data from both opposing cameras and determine if the events are the same or different. The camera's date and time stamp aids tremendously, unless it malfunctions, in which case deciphering independent events can be a somewhat onerous task. Attaching a laptop or desktop computer to a separate monitor (or 2) can ease data entry by keeping separate cameras at the same station each on a different monitor while conducting data entry. More details on data entry from camera traps can be found in Sunarto et al. (2013). Examples of jaguar capture histories are provided in Appendix 9.

As with occupancy, it is essential to store photographs in a manner that makes locating a specific record easy, e.g., in a folder structure that identifies the survey site, camera trap site, the camera number, and date range. Because abundance studies have 2 cameras per station, it will be necessary to uniquely label each of the 2 cameras at each station. It is helpful if this identifier includes the camera model such as RX01 (for Reconyx 01), or some similar naming pattern. This is especially helpful when using more than one camera brand and model. Specific software is available to store camera-trap data and link spreadsheet records to photographs and we refer to the Occupancy Protocol for a description of platforms such as Camera Base, DeskTEAM, and ExifPro.

Regardless of the chosen platform to manage and archive data, we provide a standardized spreadsheet for jaguar detections in Figure 19. This spreadsheet is designed for compatibility with the Jaguar Event-Record Database (http://jaguardata.info/) developed by WCS. The necessary user interface for easy batch import of jaguar observations from camera-trap data (and other data sources) using this standard spreadsheet could be developed to increase the time and efficiency with which large datasets from camera trapping or telemetry could be incorporated with the existing database. Importing jaguar observations into this overall presence database will help centralize information on jaguar occurrence and allow researchers to find out about jaguar studies throughout the species' range.

Scat collection and recording—See Population Genetics section for details regarding how to handle and collect scat samples for genetic analysis. In addition, a data sheet will be needed that records date, time, GPS location of each scat sample, local conditions (e.g., trail type, weather, scat condition). Additionally, it will be necessary to record all paths traveled, preferably downloaded from the recorded tracks of a hand held GPS unit. These will be needed later to assess effort in each grid cell, and can aid in determining how to assign scat locations to stationary detectors for spatially explicit capture-recapture modeling (see Types of Abundance/Density Models).

Survey information—It is important to keep track of survey related information, such as camera-trap location (X and Y coordinates), date of installation, date(s) of checking, date of final retrieval, and local characteristics of camera setup (see Setting and Checking Cameras for suggestions on "camera setup data sheet" and "camera checking data sheet"). If upon checking or retrieving, a camera unit is not working (because it is malfunctioning, out of battery, or out of storage space), this should be recorded. Extra cameras should always be brought into the field to immediately replace ones that are not functioning. It is very helpful to take test pictures using a trigger card that has the station code, date, time, and the camera unit (especially when you have 2 cameras per stations). This aids in keeping track of camera functioning and in organizing and labeling large numbers of folders of camera trap data. This also allows for easy calculations of survey effort, such as number of functioning trap-nights at each station and across all stations for the entire survey. Writing the time and date on trigger cards enables researchers to back-calculate correct dates and times of photographs when/if the camera displays incorrect dates/times due to malfunctions.

Data also should be entered with a single line for each camera station (regardless of if there are 1 or 2 cameras) and a column for each day of the survey, from the day the first camera was set up to the day the last camera was removed, with entries of "0" or "1," depending on whether a given camera trap was installed and functioning on any given day (1) or not (0). These data are necessary for spatially-explicit density estimation, which requires information on whether a particular station was available for trapping animals. When using 2 cameras per station, the station is generally still considered as functioning as long as 1 of the 2 cameras is operational.

For genetic sampling, it is important to make sure that scats collected in the field are easily matched to data sheets and later genetic samples. Refer to Population Genetics section for more information.

Covariates—Detection can be modeled as a function of covariates, and most modeling platforms already include the common influences on detectability: time effects, behavior effects, individual heterogeneity, and combinations of these effects. Other covariates that have been shown to improve abundance/density estimates are sex of the animal (males usually have higher detectability than females) and camera or scat sample location (road stations usually have higher detection rates than off road stations) (Sollmann et al. 2011, Wultsch 2013). Unlike occupancy, where landscape covariates can be extracted from a GIS database from multiple survey cells (n=133 in our Occupancy Protocol) and used to predict occupancy in cells not surveyed (see also Sunarto et al. 2012), this is not usually done in an abundance context because the scale of abundance surveys is much smaller and the outcome is a single abundance/density estimate for only a single area. We do propose, however, to survey 4 areas for abundance, and this may give us some insight into how abundance or density varies across the landscape. Detection also can be modeled as a function of location-specific covariates, such as habitat variables collected surrounding each camera trap or scat sample, but modeling from here would be only within-grid modeling of either trapping rates (Davis et al. 2011) or within-grid occupancy analyses (Sunarto et al. 2012), which would be equivalent to modeling animal activity or habitat use within a grid, rather than true occupancy. See Setting and Checking Cameras for examples of site specific covariates for camera traps, or review Davis et al. (2011) and Sunarto et al. (2012) for micro-habitat features to measure surrounding camera traps. Micro-habitat sampling surrounding scat samples can follow similar protocols as surrounding camera traps, but other variables related to scat condition could be useful (e.g., substrate, scat color, moisture content, presence of mold), especially because these can also be linked to DNA amplification success.

Abundance/Density model input and data format—Structure of the input files varies depending on the software used for implementing abundance/density models, but all software programs require an individual-by-occasion, detection/non-detection matrix, and this may allow the covariate of sex depending on software. Other input files include a list of station identifiers and their GPS locations, a site-by-individual matrix (list of locations where individuals were captured), a site-by-occasion matrix depicting when (and where) cameras were operational or the site was searched for scats, and a file depicting the locations of hypothetical home-range centers. These hypothetical home-range centers should be spaced at regular intervals across the landscape, the closer the better, with an understanding that computing time will be longer with more home-range centers. Input may include site-specific habitat covariates.

Data Analysis

Many platforms exist for abundance/density analyses. We have divided these up into: 1) traditional approaches, and 2) SCR approaches for clarity. We strongly recommend the use of SCR approaches, because these represent a major improvement over traditional approaches, especially for species like the jaguar that occurs at low densities and moves over large areas.

Traditional model platforms include Programs CAPTURE (frequentist approach; Otis et al. 1978, Rexstad and Burnham 1991) and MARK (information theoretic approach; White and Burnham 1999), both of which estimate abundance only and the user must determine the area surveyed in a separate analysis to use in converting to density. Spatially explicit modelling platforms include Program DENSITY or the equivalent R package secr (information theoretic approach, Efford 2004, 2011, Borchers and Efford 2008), and program SPACECAP implemented in R (Bayesian approach; Singh et al. 2010, Gopalaswamy et al. 2011), which incorporate the spatial locations of the camera traps or scats detected directly into the modeling process and estimate density directly. Implementing density models in a Bayesian framework also is fairly straightforward using programs such as WinBUGS (Gilks et al. 1994) or JAGS (Plummer 2003) and offers more flexibility in model building or incorporating covariates. For a discussion of abundance/density models, see Capture-Recapture Modelling for Abundance and Density.

Equipment and Costs

Personnel—Field work should always be conducted in teams of at least 2 people. A field assistant will cost approximately 750 USD per month in salary. As a frame of reference, in a 300-km^2 survey of Mexican wolves and their prey, 3 teams spent 3 days in the field to set up 30 camera trap stations (Carlos López-González, Northern Rockies Conservation Cooperative, personal communication). This translates to 1 team-day (i.e., 1 team working 1 day) per 3.3 camera traps. Scaled up to the suggested design of double the number of camera stations at 60 stations, each abundance survey would require 18 team-days per survey to set up stations and could be done in 6 days using 3 teams (assuming similar camera spacing).

The costs estimated here do not include time spent determining field locations, including obtaining landowner permissions to access land (if needed), time for programming cameras, field team housing, vehicle purchase or rental, or vehicle running costs. Also, there will likely be substantial person-hours needed for data entry and analysis, which include identifying species and individuals on photographs, transferring photo records into a database, creating capture histories and other files needed for modeling, and modeling itself.

Scat collection personnel —Two dogs and 2 handlers are required. Researchers have the option of either contracting or collaborating with commercial conservation scat-detection dog organizations or training their own dogs and handlers. Commercial conservation dogs average 400 USD per day for a team of dogs, handler, and orienteer, which translates into ~8,000 USD per month. Alternatively, the University of Arizona Jaguar Survey and Monitoring Project purchased a dog and trained the dog and handler using U.S. Border Patrol methods (Melanie Culver, University of Arizona, personal communication). The dog handler is paid 13 USD/hour and the team can work 6 hours/day and 30 hours/week, yielding total wages of 1,500 USD per month plus benefits.

Scat collection equipment—Field equipment requirements are fairly minimal for detection dog work and consist of a handheld GPS unit for each orienteer and a small GPS unit carried in the pack of each working dog to document the search track each day. These GPS units run anywhere from 200-500 USD depending on brand and quality. Generally, handheld GPS units should be of high enough quality to record 8-12 hours of data every 20-30 seconds and have the capability to download resulting tracks into associated programs such that search tracks can be imported into GIS programs. Additionally, detection dog teams will need Ziplock® bags for collecting scats in the field and centrifuge tubes to transport detected scats in the appropriate storage agent (i.e., either 95% ethanol or buffer agent) to the lab. The detection dog contractor should provide all goods and services required for the completion of the above sampling tasks, which include, but are not limited to: veterinary care, food, water, rewards, GPS units, and batteries. There may be costs associated with obtaining any necessary permits and/or landowner permission for conducting transect sampling with canines in the areas selected. Finally, vehicle operating and maintenance costs will need to be accounted for as well.

Camera traps—Depending on the model, camera traps cost between 250-500 USD (including memory cards, cables, and locks). For each abundance survey, a full study would require approximately 150 cameras, which includes 2 cameras per station for 60 stations (120 cameras) plus an extra 30 cameras to replace malfunctioning, vandalized, or stolen cameras. If executing more than one abundance survey, we suggest running them sequentially. For example, if there were 2 sites in Sonora, once the abundance survey is completed in Sahuaripa-Huasabas, cameras could be moved immediately to Alamos, for a total of 6 months of surveying (3 months in each location). The same schedule could be followed simultaneously in the Jalisco Core Area by moving cameras sequentially between 2 sites. In this way, 150 cameras would be needed for each area (northern and southern) for a total of 300 camera traps total for the 4 survey areas. Depending on the camera model, this would range from 37,500-75,000 USD.

See Occupancy Protocol for a description of various types and features of remote cameras. However, because abundance estimation requires individual identification, cameras with high resolution are essential for clear images of coat patterns needed for individual identification. This is different from occupancy, which only requires species identification. White flash may also be necessary for clear images at night, but this feature must be balanced with the potential increased risk of theft due to increased conspicuousness. Scent devices can be installed to slow cats down in front of the camera to increase the chance of a high quality, non-blurry pictures. We also suggest setting cameras to take multiple photos at each triggering event to improve success of individual identification (see Setting and Checking Cameras).

Genetic costs—If we assume that a 15-day session with the scat dog produces 10-12 scat samples, and those sessions are repeated 4 (possibly 5) times, then a total of 40-50 jaguar scat samples will be collected. These samples will need to be genetically analyzed to confirm species ID, then, if identified as a jaguar, a gender identification will need to be performed, followed by individual identification. The cost of species, gender, and individual ID is 100 USD per sample, which includes labor, materials, supplies, and analysis of data. For 50 scat samples per 90 days of searching, the cost is 5,000 USD. Also, if desired and funding is available, diet analysis can be performed on bone and cartilage found inside the scat. Diet involves decalcification of the bone prior to DNA extraction, which is labor intensive, but only species ID on the molecular end is needed, so the cost is 40 USD per bone sample, or a total of 2,000 USD if all the samples were genetically identified as jaguar. Chances are that there would be some dropout for samples that did not work or are not jaguar, so this cost is more likely to be around 1,000 USD for the 90 day period. This includes 1 bone sample per scat.

Other—The initial investment that 16-GB memory cards represent will pay for itself in the guarantee of no lost data, and potentially less labor to check units. Theft-proof metal boxes that can be bolted and/or locked to a tree or post are available for many camera brands and these should be considered in areas with theft potential. Posts may need to be purchased for areas where there are no trees or other features on which to mount cameras. Costs for camera batteries can be substantial and many camera models now require expensive lithium batteries. However, these lithium batteries will likely last an entire survey period or longer. Other equipment includes GPS units, tools to remove vegetation, and miscellaneous field gear including backpacks, clipboards, maps, compasses, etc. A large-scale study such as this will incur additional miscellaneous cost items that will need to be budgeted for.

Logistical Challenges

Implementing any ambitious camera-trapping effort overlapping private land requires contacting landowners, and possibly an arrangement for modest payment at the study's end if the units have received no vandalism or theft. This approach has been tried in Guatemala and Nicaragua with very good results. This kind of engagement is also helpful in developing an understanding of the area in general, and possibly identifying some interested local field assistants. Ideally, this kind of outreach to seek permissions to access land is done before camera installation such that cameras can be set up quickly and efficiently. Engagement while installing units may also be useful. The time required for this should be planned into the survey schedule (see Occupancy Protocol for more detail).

Capture-Recapture Modeling for Abundance and Density Estimation

Types of Abundance/Density Models

Camera trapping was first used in conjunction with capture-recapture models to estimate abundance and density for tigers (Karanth 1995, Karanth and Nichols 1998) and then modified later for jaguars (Kelly 2003, Wallace et al. 2003, Silver et al. 2004). These studies used the simplest type of abundance model, the closed-capture model, which is equivalent to the single-season occupancy model. Following similar analyses, genetic CR models for jaguars have only recently been used (Vynne et al. 2011, Wultsch 2013). Closed-capture models can be extended to multiple seasons in an open population framework following the "robust-design" capture-recapture approach (Pollock 1982). Additionally, Royle and Nichols (2003) linked heterogeneity in abundance to heterogeneity in detection to estimate local abundance of unmarked target species. Recently, Rich et al. (2014) used mark-resight models to estimate abundance of target species when only a portion of the population can be identified by natural marks. There are many more types of CR models with extensive available literature, but we deem the ones described and discussed in more detail below the most useful for monitoring jaguars, sympatric predators, and prey for the NRU.

Closed-capture models—Above we describe the basic closed-capture model for abundance, which allows detection to vary by time, behavior, heterogeneity, or combinations of those factors (White et al. 1982). However, comparing abundances from one area or time period to another is not possible when sites have been surveyed with different numbers of camera traps using differently sized grids. In this case is it necessary to estimate density rather than abundance, usually described in numbers of jaguar per 100 km^2.

The "traditional approach" to density estimation entails using a closed-capture model implemented in either program CAPTURE or MARK and then dividing the resulting abundance estimate by an effective survey area. Program CAPTURE is not very flexible, but it does test for time, behavior, heterogeneity, combination effects, and closure violations, ultimately using a discriminant function analysis to rank models. Program MARK uses a maximum likelihood approach (i.e., to incorporate heterogeneity as a mixture model) and Akaike's information criterion (AIC) model selection regime to rank the aforementioned models (Burnham and Anderson 2002). MARK is more flexible and allows use of covariates for individuals, such as sex or groupings by age or other factors.

Although CR models provide a statistically sound means of estimating abundance, estimating the effective survey area is problematic. Traditionally, researchers calculated half of the mean maximum distance moved (½MMDM) between camera locations among all individuals re-captured at least once (Wilson and Anderson 1985, Karanth and Nichols 1998), as a proxy for home-range radius, and applied this buffer around the camera-trapping grid. Wultsch (2013) used this same technique but from scat sampling. Unfortunately, this buffer size is highly influenced by trap spacing and trapping grid size (Dillon and Kelly 2007, Maffei and Noss 2008). Additionally, for studies with both telemetry/GPS and camera-trap data, the ½MMDM has been shown to be a poor proxy for home-range radius (Soisalo and Cavalcanti 2006 - jaguars, Dillon and Kelly 2008 - ocelots, Sharma et al. 2010 - tigers). These traditional methods have been shown to produce biased density estimates that tend to overestimate jaguar density (Tobler and Powell 2013).

The SCR approach, on the other hand, makes use of the spatial information of individual captures to model individual movement and account for differential exposure of individuals to the trapping grid, thereby addressing a major source of individual heterogeneity in detection probability. The spatial location of captures is used to estimate activity centers (i.e., home-range centers) and the number of these centers is considered as the number of individuals in the study site. SCR models treat the trapping grid as embedded in a larger area, thus circumventing the problem of estimating an effective sampled area (Efford 2004, Royle and Young 2008). SCR models make some additional assumptions to the closed CR models, including that: 1) home ranges are stable during the survey, 2) activity centers are distributed randomly (Poisson process), 3) home ranges are approximately circular, and 4) capture rate declines with distance away from the activity center following a predefined detection function, such as the half normal or hazard rate functions. SCR approaches provide a flexible framework where both trap-station-specific and individual covariates can be included in the models (Gardner et al. 2010*b*, Kéry et al. 2010). The SCR approach can be implemented using either maximum likelihood estimation techniques in Program DENSITY (Efford 2004) or the equivalent R package secr (Efford 2011), or in a Bayesian framework (Royle and Gardner 2011) in Program WinBUGS (Gilks et al. 1994) or JAGS (Plummer 2003), or the R package SPACECAP (Gopalaswamy et al. 2012*c*).

Because of these issues associated with using traditional density estimation techniques, we recommend using the SCR approach for jaguar density in this protocol. However, the data generated from this study can be analyzed by both traditional and SCR methods, allowing us to compare estimates to past studies that only used traditional methods. However, because we plan to cover large areas, the traditional and SCR methods may converge and our results may not be comparable to results from other studies using tradition methods if those studies used smaller survey areas. We expect our expanded number of camera stations and large spatial extent to result in accurate and unbiased jaguar density estimates.

Both traditional and SCR methods can be used on camera and genetic CR data. However, SCR methods were originally designed for surveys where detectors were stationary (e.g., camera traps), whereas for genetic data, there are no stationary detectors, as scat samples are collected anywhere they are found within the survey area. This issue can be resolved by placing a grid over the study area, such as a 2 km by 2 km grid, and assigning scat collected within that 2 km by 2 km area to the center of that grid – as if that was the stationary detector (Russell et al. 2012, Wultsch 2013). For animals such as jaguars, with large home ranges, this method is adequate for running SCR models on genetic data, as long as the size of the grid cells is smaller than individual movements. More recently, Royle et al. (2011) developed an SCR model for search-encounter data.

Robust-design, open population models—These models are an extension of the closed-capture models and are equivalent to multi-season models in the Occupancy Protocol. They use capture history data on individual animals from surveys occurring over multiple years, following the “robust-design” CR approach (Pollock 1982, Pollock et al. 1990, Kendall and Nichols 1995, Kendall et al. 1997), which can be implemented in Program MARK. For the SCR framework, open models can readily be formulated in the WinBUGS language (e.g., Gardner et al. 2010*a*). We discuss these models more in the section on Measuring Trends in Abundance/Density, below.

Mark-resight models—A limitation of photographic CR techniques above is that the species must be individually identifiable using natural markings, thus restricting sampling to species with unique coat patterns. Mark-resight models (Arnason et al. 1991, White and Shenk 2001, McClintock et al. 2009), on the other hand, provide a viable alternative to CR and SCR techniques when only a portion of the photographed population is uniquely identifiable, usually by subtle, natural marks such as scars, ear nicks, tail kinks, and color patterns on legs (or botflies in Belize; Kelly et al. 2008). Photographic mark-resight techniques estimate abundance by incorporating photographs of marked (i.e., uniquely identifiable individuals), unmarked (i.e., individuals only identifiable to the species level), and marked but not identifiable individuals (McClintock et al. 2009, McClintock 2012 - http://www.phidot.org/software/mark/docs/book). The last classification occurs when an investigator determines that a photo is of a marked individual but cannot unambiguously identify the individual, usually due to a partial photo or blurry image. Mark-resight techniques assume the marked individuals are representative of the entire population in terms of detectability (McClintock et al. 2009, McClintock 2012). This is usually a reasonable assumption for naturally marked animals. Converting abundance estimates from mark-resight models into density follows the same ad hoc estimation (and suffers from the same disadvantages) of density using MMDM techniques in CR models. But recently, spatial mark-resight (SMR) models, similar to SECR models, were developed (Chandler and Royle 2013, Sollmann et al. 2013*a*, *b*) to address these limitations, and they have been successfully used for estimation of puma densities (Rich et al. 2014). We suggest using spatial mark-resight models on puma data that will be obtained from camera trapping to give us additional insight into how jaguars and pumas (competitors for similar food resources) co-vary across study sites.

Abundance-induced heterogeneity (Royle-Nichols) models—The Royle-Nichols model (Royle and Nichols 2003) makes use of the link between abundance and detection probability to estimate local abundance of target species. These models are based on the idea that heterogeneity in abundance generates heterogeneity in detection probability (i.e., the more locally abundant a species, the easier it is to detect at least 1 individual of that species during a survey). Based on this concept, this model uses the detection/non-detection data to estimate point abundance of the target species. This model is of particular interest to model prey abundance, because most prey species cannot be identified to the individual level. Jaguar prey is one of the most important limiting factors to jaguar presence and abundance, hence information on prey status is essential.

Pilot Data

Camera-trapping pilot-study data from parts of the NRU are currently available (see Jaguar Status and Habitats in the Mexico Portion of the NRU). However, it should be noted that our protocol calls for much larger trapping grids following recommendations of Tobler and Powell (2013) to obtain unbiased and precise estimates of jaguar density. The pilot study data that does exist should be used to guide the placement of additional camera traps in our proposed expanded abundance grids.

Measuring Trends in Abundance/Density

A major component in determining the status of a population is to determine trends in abundance or density over time. This gives us much more useful information than a single point estimate at

1 time period, and will enable us to determine if jaguar populations are increasing, decreasing, or remaining stable. We can also calculate population growth rates from multi-year abundance estimates, further enhancing our understanding of jaguar population dynamics. Robust-design, open population models (similar to multi-season occupancy models) provide the opportunity to model changes in abundance through time and determine population growth rates. They use capture history data on individual animals from surveys occurring over multiple years. With this approach, each year is considered a primary period with several secondary sampling periods (days or weeks) within each primary. Within each primary period, the population must be closed and hence follow CR assumptions. But from one primary period to another, the population is open such that individuals can enter or leave. This allows estimates of time-specific abundance, annual survival, and number of new recruits. Additionally, this approach explicitly models the effect of capture probability on capture history data and then can use reduced parameter models where certain parameters can be held constant over time (Lebreton et al. 1982), increasing the precision of survival estimates for any particular year (MacKenzie et al. 2005). This is important because some researchers have noted the relative imprecision of single-year abundance estimations from camera traps. For example, Karanth et al. (2006) were able to obtain more precise estimates and confirm that the tiger population in Nagarahole, India, was demographically viable with positive growth rate ($\lambda = 1.03$), high survival ($s = 0.77$), and high number of recruits.

We highly recommend using this multi-year camera trapping approach for jaguars in the NRU in order to obtain this demographic information. Surveys could be conducted annually for 3-month time periods as described above. Alternatively, we could also use multi-year scat surveys to do the same analyses if initial results reveal that scat collection obtains better information on jaguar abundance. However, because cameras will have already been purchased, it is likely that using camera trapping only may be more cost effective, especially if the 2 techniques give us similar results for closed-capture CR modeling.

Open population SCR models are not (yet) available in any of the user friendly software platforms (DENSITY, secr, SPACECAP), but can readily be formulated in WinBUGS (e.g., Gardner et al. 2010*a*). Robust-design kind of models, which estimate not only density in each primary period, but also survival and recruitment, are still in the process of being developed (Royle et al. 2014).

Conclusion

Surveying target areas via simultaneous large-scale camera trapping and scat-detection/molecular scatology surveys will give us a solid understand of baseline jaguar abundances and/or density across 4 distinctly different areas of the NRU. Extension of these capture-recapture surveys over multiple years also will enable determination of survival, recruitment, and population growth rates across the sites, information particularly useful for assessing trends through time. The background information and techniques described in this abundance and density protocol can be used as a guide for planning such a project.

In addition to determining population abundance and density, jaguar status should also be assessed though population genetics. The scat samples collected through this protocol for genetic mark-recapture also can be used towards the goal of assessing genetic diversity, population structure, and genetic connectivity across the landscape (see Population Genetics). The in-depth, intensive surveys proposed here will give us some information on ranging behavior for individuals, but ranging information such home-range size and habitat use patterns is best achieved through GPS collaring of individuals jaguars (see Demographic Parameters and Spatial Ecology). The abundance surveys can aid in the process of GPS collaring by revealing where individuals repeatedly occur, and therefore the areas that can be targeted for trapping, thus increasing efficiency. The outlined abundance and density protocol is based on sound, up-to-date methods and analyses, will provide a substantial knowledge base on its own, and will feed into various other aspects of the overall monitoring plan, supplying needed information that will enhance jaguar conservation and management.

POPULATION GENETICS

Investigations into the genetic diversity, population structure, and demographic history of jaguars across most of their geographic range have revealed an absence of deep geographical subdivision and no evidence of bottlenecks, inferring historically high levels of gene flow (Eizirik et al. 2001, 2008, Ruiz-García et al. 2009, Culver and Hein 2013). In the context of gene flow into recent times and scant evidence for major historic-geographic differentiation, a range-wide connectivity analysis and interview-based occupancy modeling were used to identify and validate potential corridors connecting known populations and predicting travel routes between them (Rabinowitz and Zeller 2010, Zeller et al. 2011). Natural and anthropogenic boundaries (such as those encountered in the NRU) have been shown to affect population dynamics and structure for species with movements at the landscape level (e.g., Andreasen et al. 2012). Genetic population monitoring, including estimates of heterozygosity within and among populations, deviations from Hardy-Weinberg equilibrium, inbreeding within populations (F_{IS}), and subdivision among populations (F_{ST}), can contribute significantly to understanding population structure and movement of jaguars across large landscapes.

Noninvasive genetic methods provide researchers with new approaches to use landscape genetics to elucidate conservation challenges. These methods are used to document the presence, distribution, and abundance of rare, cryptic, and difficult to observe or handle species, including jaguars (Piggott and Taylor 2003). The most common sources of noninvasively-collected genetic material for studies of carnivores include museum samples (Johnson et al. 1998), hair (Kendall et al. 2009, Gardner et al. 2010*b*), scat (Kohn et al. 1995, Ernest et al. 2000, Farrell et al. 2001), and occasionally bone and connective tissue (King et al. 2008). The choice of which source is preferable depends on the question being asked and the species and population being studied.

Questions of an evolutionary nature can often be answered using museum samples if samples are available and if DNA is obtainable from the samples. Questions regarding current population structure, connectivity, gene flow, levels of inbreeding, or other population genetic parameters usually require contemporary samples such as hair or scat. Hair samples have been widely used for noninvasive research on many canids (dogs), ursids (bears), and mustelids (e.g., weasels) (Woods et al. 1999, Mowat and Strobeck 2000, Mowat and Paetkau 2002, Kendall and McKelvey 2008, Kendall et al. 2009, Gardner et al. 2010*b*). In felids, scat is preferable to hair as studies have yielded a higher success rate with scat. This could be due to the lower amount of DNA in felid hairs as quantified by the Federal Bureau of Investigation, who determined a ten-fold lower yield of DNA from felid hairs compared to primate hairs (Bruce Budowle, University of North Texas Health Science Center, personal communication). The collection of jaguar hair using hair-snare sampling techniques in the wild has not been successful, attributed to the nature of felid hair, which are very short and fine compared to the coarser hair found in many canids, ursids, and mustelids (García-Alaníz et al. 2010, Portella et al. 2013). Additionally, compared to primate hair, felid hairs contain ten-fold less DNA per hair root (Victor David, National Cancer Institute, personal communication). Other sources of noninvasive samples include bone and connective tissues. These samples can be obtained opportunistically from carcasses found in the environment, but also from predator scat as sample source for obtaining diet information (King et al. 2008).

Measuring jaguar occupancy and abundance provides a foundation for more intensive, noninvasive survey efforts to monitor jaguar population genetics. Recent advances in molecular genetics and the use of detection dogs to locate the scat of target species make fecal DNA analysis a promising and viable option for genetic monitoring. Population genetic monitoring has several objectives, including: 1) adding new detection locations for individuals detected on camera traps – this is important because camera traps are stationary, whereas surveys for scat samples cover a large area more completely, therefore the additional detections will give a better insight into jaguar distribution across the landscape; 2) detecting additional individuals to those known from cameras – this could be from detecting more individuals from scat than from photos or detecting different genders from scat than from photos; 3) investigating the basic genetic character of populations monitored (e.g., heterozygosity within and among populations, overall genetic diversity within and among populations, level of inbreeding within populations, comparing genetic diversity and inbreeding from populations monitored here with other published studies, differentiation of populations relative to other nearby populations); and 4) determining jaguar diet items found in scat using genetics, providing insight into preferred prey and/or livestock depredation – an important component in human-jaguar conflict.

Jaguar Scat Collection

Jaguar scat collection should be conducted: 1) opportunistically during setting and checking of remotely-triggered cameras as part of an occupancy or abundance survey; and 2) with the use of scat-detection dogs following a block design centered on locations of camera stations detecting jaguars.

<u>Opportunistic Searches</u>

Scats should be searched for opportunistically during the process of setting up and checking remotely-triggered camera stations, as cameras are set in locations that scat and other sign are usually found (e.g., canyon bottoms, natural funnel zones, along ridge lines, water holes, lesser used dirt roads). When time and logistics permit, opportunistic searches can be expanded to a wider area around the camera station (e.g., walking out a different travel route than the one used on the way in).

<u>Scat Collection</u>

All scats with large felid characteristics should be collected for genetic analysis because of the difficulty in visually differentiating jaguar and puma scat based on morphology (Foster et al. 2010). Specific data for each scat sample should be carefully documented and each sample should be labeled with a unique and obvious identifier (e.g., MacKay et al. 2008:221). As in the

Occupancy Protocol and the Setting Cameras section, a standardized protocol should be developed beforehand by people familiar with the study area, including clear descriptions of the data to be recorded. This will ensure that data are collected systematically and avoid confusion between field and laboratory personnel. Data for each scat should include, but are not limited to, date of collection, GPS coordinates, elevation, description of the substrate and habitat, scat length and diameter, a measure of vegetation density (e.g., can animals move around freely or are they likely to stay to defined paths), canopy cover, presence of a road or trail, presence of another kind of habitat edge (e.g., grassland/scrubland), presence of a stream/river, mountain ridge, gully, etc. The surrounding area should be photographed to document the scat morphology and vegetative community.

Each scat should be handled with unused latex gloves for surveyor safety and to prevent contamination of the sample. A variety of methods exist for preserving samples until genetic analyses are conducted. These include air drying at room temperature, freezing at -20° C, saturating and storing in a buffer solution, drying in a lyophilizer (i.e., a freeze dryer), storing in 70-100% ethanol or DETs buffer, drying and storing in silica or Drierite-based desiccant, or drying with an oven or ethanol then storing with silica desiccant. Each preservation method has its own advantages. The laboratory conducting the genetic analyses should be consulted to discuss options prior to sampling.

Portions of each scat should be collected in the field for preservation and transport for DNA isolation following Wultsch et al. (In review) or recommendations of the collaborating laboratory. The remaining scat material should be collected and dried or frozen for diet analyses (Scognamillo et al. 2003). Wultsch et al. (In review) evaluated the performance of 2 DNA storage techniques (DETs buffer [20% DMSO, 0.25M EDTA, 100mM Tris, pH 7.5, and NaCl to saturation (Seutin et al. 1991)] and 95% ethanol) for fecal DNA samples of jaguars and co-occurring Neotropical felids collected in Belize. For each fecal sample, approximately 0.5 mL fecal material was collected and stored at ambient temperature in 2 sterile 2-mL screw-top tubes filled with either DETs buffer or 95% ethanol at 1:≥4 volume scat-to-solution ratio. For each intact scat located, approximately 0.5 mL of fecal material was collected from 4 different locations (top, side, bottom, and inside) of the scat. Scat vials were stored for up to 8 months at room temperature until extraction. The authors reported DETs buffer was the superior fecal DNA preservation method with 44% higher (PCR) amplification success and 17% higher genotyping accuracy compared to 95% ethanol-stored samples.

Alternatively, the University of Arizona Jaguar Survey and Monitoring Project is drying and storing collected scat samples in Ziploc® bags with a 4:1 silica to scat weight ratio or freezing scat samples within 24-48 hours (Melanie Culver, University of Arizona, personal communication). In the laboratory, epithelial cells are obtained from the surface of the scat using a swabbing technique (see Rutledge et al. 2009, Wasser et al. 2011). Cotton applicators are saturated with PBS buffer and used to swab the surface of the individual scat sample. The swab stick is then cut and placed in a labeled 2 ml tube containing 300 microliters (µl) of ATL buffer (QIAGEN, Inc.).

<u>Sampling Using Scat-Detection Dogs</u>

We can increase scat collection rates over large, remote areas by using scent-detecting or scat-detection dogs (Smith et al. 2003, 2005, Wasser et al. 2004, Long et al. 2007, MacKay et al. 2008). Detection dogs commonly are trained and handled following protocols applied for scent-detecting and search-and-rescue dogs (MacKay et al. 2008). Detection dogs (breed generally does not matter as much as ball drive [motivation to play with a ball as a reward for a task that is performed] and trainability) can be trained to detect scat of target species using the techniques described in Smith et al. (2003) and MacKay et al. (2008). Briefly, a scat-detection dog is trained to find scats from target species and to alert the dog handler to the specific location of each scat. Scat-detection dogs are trained to detect scats only from target species and to ignore scats from non-target species. A detection dog team typically consists of the dog, the handler, and an orienteer, all of whom require extensive training to function successfully as a team. Some researchers choose to train their own scat-detection teams while others choose to partner with one of several research laboratories or conservation organizations with experienced scat dog detection teams to conduct scat surveys.

Detections of jaguars by remotely triggered cameras can aid in focusing on target areas for scat surveys in order to increase the probability of locating jaguar scats. Scat-detection dogs, trained to locate jaguar and puma scat, can be deployed to find scat within those hexagons with jaguar detections. We recommend the use of scat dog(s) trained on jaguar and puma scats to avoid potential scat dog performance problems and additional opportunities afforded from collecting sympatric puma scats. Given the morphological similarities of jaguar and puma scats, a handler can erroneously reinforce, effectively training, a scat dog on scats from a non-target species (particularly puma). To avoid this potential challenge, we recommend training the scat dog(s) on both species. Additionally, diet information collected from both jaguar and puma scats would provide further insights into human-felid conflict involving livestock predation. An alternative method to avoid reinforcing non-target detections is to reward the scat dog on only known jaguar scats planted in the field by the handler. This approach would avoid the additional costs of genetically analyzing a large sample of puma scats, and precludes addressing questions related to sympatric jaguars and pumas, but may be advantageous if pumas greatly outnumber jaguars. Generally, the researcher will select and train dogs for the detection of scats. Training should consist of sufficient repetitions and complexity such that canines will be field ready, as determined by the researcher, prior to beginning field work.

For scat collection via scat-detection dog(s), we recommend targeting hexagons that have had detections of jaguars on remotely operated cameras and opportunistic encounters. Because this protocol does not attempt to estimate abundance in each hexagon, it is not constrained by obtaining enough captures and recaptures of individuals to conduct capture-recapture modeling.

Rather, this protocol attempts to obtain as many genetic samples as possible (preferably from different individuals) to better estimate genetic diversity and population genetic structure. Therefore, we suggest a flexible survey design where effort is standardized, but hexagons are searched opportunistically. We suggest conducting scat dog surveys using the established roads and trails, including the ones where cameras are placed, and other areas that jaguars are likely to use such as waterholes, rivers sides, canyons, and ridgelines. We suggest large spatial coverage, such as traversing the hexagon 5 to 6 times roughly from north to south or east to west, and ensuring that no 25-km^2 area that is accessible is totally missed, as this size is the smallest home range recorded for a female. If the hexagon is roughly 22 km across, this equates to 110-132 km of opportunistic searching per hexagon. Conservatively, scat dogs can cover 10 km per day, so this would equate to 10-13 days per hexagon. This protocol can be modified by lengthening or shortening surveys based on initial scat collection results. As a guide, at 2 relatively low density sites in Belize (i.e., 1-2 jaguars per 100 km^2), Wultsch (2013) used a similar opportunistic searching regime and found a scat sample on average every 1.3-3.0 km of searching, but this did include both puma and jaguar samples. We suggest using GPS units to mark tracks searched and track distances traveled for ease in modifying search design following preliminary results.

Equipment and Costs

Refer to the Equipment and Costs section of the Abundance and Density section.

Laboratory Genetic Methods

Analyses of genetic samples are conducted by a DNA or conservation genetics laboratory selected at the beginning of the survey. Several factors should be considered in selecting a laboratory, including the lab's: 1) experience with jaguar or other felid scat samples collected in areas with similar conditions; 2) availability and ability to conduct or assist with post-genotyping statistical analyses (e.g., tests for genetic structuring); 3) ability to store samples over time; 4) protocols for evaluating contamination and errors; and 5) policies on data ownership and dissemination (Schwartz and Monfort 2008:251). The laboratory should be consulted on sample storage methods, labeling, tracking, and shipping genetic samples throughout the study design, sample collection, and genetic and data analyses phases of the research.

The DNA or conservation genetics laboratory selected will apply particular molecular genetic techniques depending on the expertise of laboratory to isolate DNA from scat samples; identify species, individuals, and gender; and conduct post-genotyping statistical analyses. The following are the suite of molecular genetic techniques used by the University of Arizona Jaguar Survey and Monitoring Project (Melanie Culver, University of Arizona, personal communication).

DNA Isolation From Scat

DNA is extracted using a QIAGEN stool kit following manufacturer's protocol (Qiagen, Valencia, CA). Extractions are (and should be) carried out in a room dedicated to low quantity

DNA sources to minimize contamination risk. Negative controls (no scat added) are (and should be) included in all DNA extractions and PCRs to test for contamination. The DNA extraction procedure is as follows: 33 µl of proteinase K (QIAGEN, Inc.) is added to the 2 ml tube and incubated at 70°C overnight. The swab is removed and 366 µl of AL buffer (QIAGEN, Inc.) is added, vortexed, and incubated at 70°C for 1 hour. Then 266 µl of ethanol is added and mixed by inverting. The DNeasy tissue kit (QIAGEN, Inc.) is used, following manufacturer's protocol for the remainder of the DNA purification.

Species Identification

The molecular genetic markers available for species identification in mammals almost exclusively include utilization of genes of the mitochondrial DNA. These are amplified using PCR and a DNA sequence is obtained and compared to known sequences to find a match to the species of origin. The ATP-6 region has been used to distinguish between jaguar and puma (Haag et al. 2009) and the mtDNA cytochrome b gene has been widely used to distinguish among all carnivores and mammals (Naidu et al. 2011). Pumas are the most widely distributed mammal in the western hemisphere and are abundant throughout the range of the NRU, and will be a common non-target species for scat collected, so either molecular marker strategy is appropriate for the purposes of species identification. However, the mtDNA cytochrome b strategy provides complete information on all samples, for example samples that are ocelot or canid, which also might be of interest. Also, because mtDNA cytochrome b amplifies all mammals, it can distinguish samples that contained some preserved DNA, even if it happens to be DNA of the prey species rather than the predator, which occasionally occurs.

Sequencing should be attempted with mtDNA cytochrome B primers (Farrell et al. 2000 or Verma and Singh 2003) using protocols described in Onorato et al. (2006) for the Farrell primers, or Naidu et al. (2011) for the Verma and Singh primers. Species identification of sequenced scats should be conducted by comparing DNA sequences obtained with known sequences of target species and with entries in GenBank using the BLAST program (National Center for Biotechnology Information).

The PCRs should be performed in a 20 µl final volume with a final concentration of: 12.3 µl of H_20; 2.0 µl of 10x PCR Buffer (QIAGEN, Inc.); 0.8 µl of $MgCl_2$ (QIAGEN, Inc.); 0.4 µl dNTPs (QIAGEN, Inc.); 1.0 µl 0.05 % BSA (Sigma-Aldrich, St. Louis, MO, USA); 0.1 µl of Taq DNA Polymerase (QIAGEN, Inc.); 0.5 µl each of forward and reverse primers; and 4 µl of template DNA. The PCR conditions should consist of initial denaturation at 95°C for 10 minutes, followed by 35 cycles of denaturation at 95°C for 45 seconds, annealing at 51°C for 1 minute, extension at 72°C for 2 minutes, and a final extension step at 72°C for 10 minutes. All resulting PCR products should be cleaned with ExoSAP-IT (USB Corporation, Cleveland, OH, USA) and sequenced on an Automated DNA Analyzer.

Individual Identification

Felid microsatellite loci shown to be polymorphic in jaguars using PCR should be amplified to positively identify jaguar samples. The ten loci selected are shown to perform well in scat samples (FCA026, FCA075, FCA077, FCA090, FCA126, FCA139, FCA193, FCA211, FCA224, and FCA310; Menotti-Raymond et al. 1999) using the same PCR conditions as in Eizirik et al. (2001).

Costs

Refer to Genetic Costs section.

Analysis of Jaguar Scat Genetic Data

Species Identification

Sequence data should be edited using the program SEQUENCHER (version 3.0, Gene Codes Corp, Ann Arbor, Michigan) and compared to an existing database of mammal sequences to determine the species of origin for each sample. This analysis is used to identify jaguar versus other carnivore scat.

Individual Identification and Population Genetics

Microsatellite data should be scored and analyzed using the program GENOTYPER (version 1.1) (Applied Biosystems Inc.,) to precisely calculate the sizes of the fragments and discard ambiguous or low-quality amplified genotypes. Once a composite genotype across all loci is compiled for each sample, for up to ten felid microsatellite DNA loci, pairwise genetic distances should be calculated among scat samples using the program MICROSAT (Minch et al. 1995). All pairs of samples with a distance of zero (i.e., complete sharing of microsatellite allelic data) should be presumed to have originated from the same individual, allowing an estimate of the number of unique individuals, which serves as a minimum number of jaguars for this study area. Estimates of heterozygosity within and among populations, deviations from Hardy-Weinberg equilibrium, inbreeding within populations (F_{IS}), and subdivision among populations (F_{ST}) should be made using the program ARLEQUIN (Excoffier and Lischer 2010).

DEMOGRAPHIC PARAMETERS AND SPATIAL ECOLOGY

While the broad brush of occupancy can provide a high quality sketch of where jaguars are and their relationship to resources, other questions relevant to jaguar recovery across the NRU can only be addressed through more intensive methods. A sound understanding of jaguar demographic characteristics and dispersal patterns will support landscape planning and management. Knowledge of how jaguars are organized in time and space, interact with each other and sympatric species, and obtain the resources on which they depend are all useful for developing finely-tuned conservation measures (Ceballos et al. 2005, Azevedo and Murray 2007*a*, Ripple et al. 2014), including the design of conservation practices that reduce the frequency of negative impacts caused by human-carnivore interactions (Treves and Karanth 2003)

Dispersal and Long-Distance Movements

Dispersal is usually a one-time behavior, often during adolescence but sometimes during adulthood, when an individual leaves its natal home range or its established home range, to establish its own, new home range (Turchin 1998). For example, using telemetry, Ausband and Moehrenschlager (2009) studied swift fox (*Vulpes velox*) dispersal on the Blackfeet Reservation of Montana and documented straight-line distances moved of 43.1 to 190.9 km. Beier (1995) tracked dispersing juvenile pumas in fragmented habitat in California, elucidating the details of their use of habitat corridors and peninsulas.

Elbroch et al. (2009) documented a straight-line dispersal of 167 km by a male puma along the Chile-Argentina border. Atheyra et al. (2014) tracked the movements of a tigress through a human dominated landscape in India, obtaining extremely detailed information and a straight-line movement distance of 40 km. Fattebert et al. (2013) documented a male leopard (*Panthera pardus*) traversing 3 countries in Africa covering a minimum distance of 352.8 km. In northern Europe, Kojola et al. (2009) fitted 82 wolves with radio-collars, of which 15 carried a transmitter with a GPS and a mobile phone component (GSM; Televilt, Sweden, and Vectronic Aerospace, Germany) which provided 6 radio-locations daily. Dispersal distances, calculated as the straight-line distance between the middle of the capture territory and the middle of the wolves' new territories, exceeded 800 km for half the wolves with GPS collars.

Genetic tools can reveal patterns of abundance and dispersal as well. Gour et al. (2013) used non-invasive genetic data (from fecal samples) to establish the presence of 28 tigers in total, composed of 22 females and 6 males within the core area of the Pench tiger reserve. Through genetics from the scats, the authors examined patterns of male-biased dispersal and female philopatry, documenting female dispersal up to 26 km. It should be noted that non-invasive genetic methods (from fecal samples) have been used to estimate tiger abundance in India (Mondol et al. 2009, Gopalaswamy et al. 2012*b*) and clearly can be expanded for more detailed population ecology studies.

Using invasive methods, Forbes and Boyd (1996) unraveled the origins of naturally colonizing wolves (*Canis lupus*) along the edges of Glacier National Park in Montana. Using tissue samples and hair samples, Proctor et al. (2004) used invasive methods in a study of gender-specific dispersal of grizzly bears (*Ursus arctos*) over a range of 100,000 km^2 straddling the rocky mountains of British Columbia, Alberta, Montana, and Idaho. They found that, on average, females and males dispersed 14.3 and 41.9 km from the center of their natal home range, respectively.

Telemetry and genetic studies requiring the capture and handling of jaguars are not recommended for NRU areas where rare individual animals are precariously reestablishing territories in historical but recently unoccupied jaguar range, like in secondary areas or portions of them. However, in areas where jaguars are more abundant and secure, such as the Sonora and Jalisco Core Areas of the NRU, capture-handling-telemetry based studies, which also yield genetic samples, may generate extremely useful ecological information for large landscape-level conservation planning and management.

Demography

Obtaining demographic data for jaguars is far more challenging than, for example, for African lions (*Panthera leo*), which inhabit relatively open habitats with good visibility that facilitates observations and data-collection to estimate survivorship and recruitment (Funston 2011, Mogensen et al. 2011, Brink et al. 2012, Ferreira et al. 2012). Through decades of hard work, Ruth et al. (2011) established an unprecedented understanding of puma survival and source-sink structure in Yellowstone's Northern Range, but also benefitted from the relatively open habitats, occasional roads, seasonal snow cover for tracking, and, in general, developed infrastructure and utilities the United States provides. Even the rugged Northern Rockies might provide some easier logistics than some of the larger jaguar habitats in the wild American tropics. Nonetheless, the wealth of studies on pumas suggest useful methods for jaguars (e.g., Hornocker 1970, Seidensticker et al. 1973, Lindzey et al. 1992, Ross and Jalkotzy 1992, Logan and Sweanor 2001, Robinson et al. 2008).

Calvalcanti and Gese (2009) conducted one of the most intensive jaguar telemetry studies (ten jaguars, 3 years) in the Pantanal of Brazil. The authors reported that home ranges were very unstable for both sexes, varying among seasons as well as individuals. In addition, site fidelity was also reported to vary considerably. These results emphasize that jaguars, once in a productive landscape, may be more social than previously thought for this species. Moreover, in such productive landscapes, spatial patterns of jaguars may be determined through territoriality rather than food limitation (Azevedo and Murray 2007*a*). These studies in the Pantanal region of Brazil may be relevant for understanding the spatial organization of jaguars and how spacing patterns may be affected by the availability of food resources in NRU recovery areas.

The vegetative density and extremely undeveloped areas without basic services that cover much of jaguar conservation range may find their logistical equivalent in the rugged mountain refuges that snow leopards (*Uncia uncia*) occupy, and are a partial reason for the lack of in-depth studies. However, the most relevant parallels for study design in much of the jaguar's range are likely found in tiger studies in tropical Asia (Karanth and Nichols 2002) and the furtive habits of jaguars may approximate those of leopards (Balme et al. 2009, Du Preez et al. 2014).

Logistical challenges notwithstanding, the methods for assessing demographic parameters, population ecology, spatial ecology, and dispersal are similar across all the above-mentioned species. Only long-term intensive research can reveal recruitment, mortality, emigration and immigration, and dispersal patterns. This requires correspondingly long funding commitments, and studies of this kind are recommended for the core areas of the NRU and for other significant core sites across the jaguar range.

In the context of jaguars returning to and residing in the southwestern United States, adaptive management and monitoring in the Sonora Core Area is particularly important. The configuration of the NRU, however, with Core Areas separated by Secondary Areas where jaguar status is less certain and secure, is a management and monitoring scenario echoed throughout jaguar range.

The collection of remotely triggered camera data to estimate occupancy or abundance can, in many cases, be extended to estimate key demographic parameters. In areas of high jaguar densities, biotelemetry (including very-high frequency [VHF] and GPS) provides opportunities to examine detailed demographic, spatial, and population ecology-related questions by enabling the estimation of survival, reproduction, dispersal, home range, and habitat selection (White and Garrott 1990, Millspaugh and Marzluff 2001, Miller et al. 2010). Methods used to capture and handle jaguars to deploy telemetry devices are presented in Polisar et al. (2014) and additional guidance on handling captured animals is provided in Proulx et al. (2012) and Foresman et al. (2012). Telemetry provides the ability to remotely monitor elusive, wide-ranging carnivores while they conduct their normal movements and activities, and, through active, near-continuous tracking, can reveal details that spatially stationary camera-trap stations will not. Genetic methods can be a powerful tool, too, to understand population characteristics, such as parent-offspring and dispersal movements, and, thus far, may have undeveloped potentials for even in-depth population data, such as survival and recruitment, logistics depending.

Survival and Recruitment

Camera-trap data in conjunction with open population capture-recapture models are used to estimate key demographic parameters in cases where camera-trap surveys can be repeated and individuals are identifiable over extended time periods, such as multiple seasons or years (Pollock 1982, Karanth et al. 2006, 2011*b*, Pollock et al. 2012). Open population models are used in long-term studies where, in addition to population sizes, the goal is to estimate population losses (mortality and emigration) and gains (recruitment and immigration). The robust-design framework (Pollock 1982) combines sampling at 2 time scales where several short-term pulses of sampling ("secondary periods" that usually assume closure) are nested within long periods ("primary periods" during which the population is open). Analysis of capture-recapture data can be done using program MARK (White and Burnham 1999) and employing the "Recaptures Only" model to estimate apparent survival. Additionally, Gardner et al. (2010*a*) and Royle and Gardner (2011) provide details of how to formulate and run a series of hierarchical spatial capture-recapture models, and to extend them to demographically open populations, using WinBUGS.

Karanth et al. (2011*b*) used the Cormack-Jolly-Seber model (Cormack 1964, Jolly 1965, Seber 1965) and Pollock's (1982) robust-design model to estimate apparent survival, the latter of which nests 2 sampling scales: the primary being open and long-term, the secondary being the separate discrete closed sampling, which supports the primary. In this scenario, recruitment was estimated combining survival estimates and time-specific abundance. The details of distinguishing residents from transients, as well as distinguishing immigrants and emigrants, will not be handled here, but suffice to say the effort of Karanth et al. (2011*b*) covered ten consecutive years of sampling using a robust-design capture-recapture study to estimate time-specific abundance, survival, transience, recruitment, and trends. A long-term commitment in a core site is needed to estimate these parameters. Based on their experience, Karanth et al. (2011*b*) recommend increasing the number of camera traps, as well as the area sampled, to improve precision of the estimates. Quoting the authors "*in studies where a demographic monitoring program is really needed to address management or scientific questions, we believe that intermediate to long-term camera trap studies can be an effective approach.*" We recommend a combination of long-term capture-recapture studies in areas consistently occupied by jaguars throughout their range to assess population trends and basic vital rates, combined with an occupancy framework that examines jaguar distribution in the surrounding matrix.

Telemetry enables researchers to remotely locate and monitor marked individuals. These technologies provide opportunities to determine mortality rates, relate covariates to rates of survival (e.g., age-class, sex, resource availability), and identify sources of mortality. In survival studies, radio-marked animals are followed closely to determine whether they live or die between sampling periods, detecting each individual during each sampling period in which it is alive. Recent advances in tracking and telemetry technology have seen traditional VHF technologies eclipsed by the widespread use of GPS-enabled devices (Hebblewhite and Haydon 2010). GPS devices can collect fine-scale spatio-temporal location data systematically throughout the day and night. GPS telemetry can reduce the time investments needed to obtain animal locations and eliminate potential biases involved when collecting ground based telemetry locations. The technology has particular potential where road systems are absent, when animal movements are likely to surpass VHF tracking limitations, and where aerial and terrestrial access is limited due to security concerns.

Despite the advantages of GPS telemetry, Hebblewhite and Haydon (2010) issued several cautions. Because upfront costs, battery limitations, and failure rates are significantly higher for GPS devices, researchers may decide to deploy a smaller of GPS units to obtain more in-depth data sets on individuals at the risk of sacrificing the sample sizes needed to make population level inferences. These decisions may result in weaker study design, reduced sample sizes, and poorer statistical inference, relative to a study deploying VHF transmitters (Hebblewhite and Haydon 2010, Fieberg and Börger 2012).

As an example, studies of animal survival with known-fate collar data require more than 50-100 animals (Murray 2006, Hebblewhite and Haydon 2010). Schwartz et al. (2010) used data from 362 grizzly bears spanning 21 years to examine hazards affecting grizzly bear survival in the Greater Yellowstone Ecosystem. Smith et al. (2010) monitored survival of 711 radio-collared wolves between 1982 and 2004. Ruth et al. (2011) used data from 104 pumas to assess survival in Yellowstone's northern range before wolf reintroduction (1987-1994) and after wolf reintroductions (1998-2005). Goodrich et al. (2008) used data from 42 radio-collared Amur tigers between 1992-2005 to assess survival rates. Several of these data rich studies combine VHF and GPS technologies because they date back decades, but the cost of obtaining similar samples for equally meaningful survival estimates using GPS units is considerable.

Thus, estimates of population-level parameters may still be more precise when using VHF data, particularly if among-animal variability is substantial. Most top-end collars now provide both capabilities, allowing vast data collection via satellites while retaining the option for researchers to get close to the location and confirm habitat selection, kill characteristics, and mortality and its sources.

The 2 most common analytical frameworks, Kaplan-Meier and Cox proportional hazard models, have been used to estimate survival rates and assess the influence of covariates on survival for select populations of large felids. The staggered entry Kaplan-Meier method (referred to as the "known fates" option in program MARK) is widely used to estimate survival of radio-marked populations and investigate the influence of covariates on survival probabilities (Pollock et al. 1989*a*, *b*). This method allows animals to be added to the study while it is in progress and to be censored if animals leave the study area or lose their radio tags. The standard model assumes that censoring is independent of animal fate; that is, disappearance of an animal is not associated with death. The Cox proportional hazard model (Cox 1972, Venables and Ripley 1994) is a regression-based alternative to calculating survival rates and relating survival to covariates. This method is often preferred over Kaplan-Meier when: 1) there are several explanatory variables, particularly when some of these are continuous; 2) fates of individuals are not known for various reasons; 3) the study is stopped before collars are lost; and 4) all individuals have died. Riggs and Pollock (1992) provide a detailed application of the model.

The 18-year-long study on pumas in Northern Yellowstone, initiated by M. Hornocker and K. Murphy, and summarized by Ruth et al. (2011), is instructive of the dedication and detail needed to determine vital rates. Using a combination of track surveys in snow; captures of adults, subadults, and kittens; radio telemetry; ear tags; age estimates; VHF and GPS telemetry with mortality sensors; carcass inspections; necropsies; and on-ground close proximity locations complemented by GPS capabilities, adequate data were available to assess patterns of female and male survivorship and sources and sinks within a 3,779-km^2 mountain landscape, which, while focused largely in the intermediate elevations where prey was abundant, also contained some of the most rugged terrain in North America. This depth may not be possible in the Sonora and Jalisco Core Areas of the NRU, or in other areas across the jaguar's range, but the general recommendations derived for the survival parameters are as follows:

- Study areas can be defined by adult home ranges;
- Program MARK should be used to evaluate survivorship;
- Kitten, sub-adult, and male and female adult survivorship should be analyzed independently;
- Temporal covariates (e.g., drought months in semi-arid environments, flood months in others) should be examined;

Landscape/habitat characteristics should be examined, such as elevation, topographic roughness, predominant forest type, real or validated proxy measures of prey abundance, distance to communities and roads, and other relevant indices of wilderness, either aggregated or through specific parameters.

Hornocker (1970) and Seidensticker et al. (1973) pioneered puma studies in wild rugged terrain in Idaho, which likely matches the Sierra Madre in Mexico and therefore could be used as a model for collecting these data within some areas in the NRU. Data like these are obtained in increments, with a long-term commitment.

Home Range

The concept of a home range is one of the core concepts of modern spatial ecology. GPS telemetry technologies have allowed the collection of location data at an ever-increasing rate and accuracy, ushering in the development of new methods of data analysis for portraying space use, home ranges, and utilization distributions. Vendors of telemetry equipment include Lotek (Knopff et al. 2009, Chadwick et al. 2010, Inman et al. 2012), Telonics (Schwartz et al. 2006, Kojola et al. 2009, McCarthy et al. 2010, Ruth et al. 2010, Smith et al. 2010, Hojnowski et al. 2012, Inman et al. 2012, Coleman et al. 2013), Televilt, acquired by Followit (Kojola et al. 2009, Smith et al. 2010, Elbroch and Wittmer 2012, Inman et al. 2012), and African Wildlife Tracking (Tambling et al. 2010), but also see Advanced Telemetry Systems, Vectronics-Aerospace and NorthStar. Fuller and Fuller (2012) present the fundamentals of satellite telemetry. Selecting appropriate units involves tradeoffs between weight, data storage download characteristics, unit lifespan, cost, and research objectives.

With an ever-increasing number of techniques available, research questions must be designed to test theoretical predictions and avoid *post hoc* analyses with little power (Kie et al. 2010). Although intensive, large-scale camera-trap studies can and will obtain information which can be interpreted as home ranges and spatially explicit capture-recapture models may generate home-range estimates and related parameters as output, these studies are confined both by the stationary camera traps, and also the boundaries of the sampled area. The unbounded continuous space and series of points obtained through telemetry are far more appropriate for home-range estimates and understanding how individuals overlap, avoid each other, and spend time together. Camera-trap studies will provide similar data, but are confined to each and all the sampling stations, while telemetry tracking is continuous across space, providing more detail.

Minimum convex polygons (MCP), although widely used, provide little more than crude outlines of where an animal has been located (Hayne 1949, Powell 2000, 2012). Although conceptually simple and allowing for comparisons to earlier studies using MCPs, problems with the method are many, including discarding 90% of location data collected within the outer boundaries, thus emphasizing the often unstable outer boundary of a home range, and ignoring the internal structure of a home range.

Most modern home-range estimators produce a “utilization distribution” from location data describing the intensity of use of different areas by an animal. A utilization distribution is calculated as a probability density function, which describes the probability that an animal has been in any part of its home range (Hayne 1949, White and Garrott 1990). Kernel density estimators are now widely used to estimate home ranges (Laver and Kelly 2005). Band width selection is a critical, yet a difficult, aspect of developing a kernel estimator for animal home ranges (Silverman 1986). Band width can be chosen using location error, the radius of an animal’s perception, and other pertinent information, but must be chosen to fit the hypothesis being tested, the datasets, and other research goals (Powell 2012).

Alternatively, local convex-hull estimators are an important alternative to the widely used kernel estimators, especially when use of space has sharp boundaries (Getz and Wilmers 2004, Getz et al. 2007). Brownian bridges can be used to estimate the probability of an animal being at a specific location in between fixes by incorporating time-sequence information that is available with most data on animal locations (Horne et al. 2007, Kie et al. 2010, Powell 2012). Additionally, biased random bridges offer another approach to movement modeling that is not based on the assumption of constant, diffusive movements, and creates movement based kernel density estimates rather than locational-based kernel estimates (Benhamou 2011). Finally, model-supervised kernel smoothing (Matthiopoulos 2003) and mechanistic (Moorcroft and Lewis 2006) approaches to home ranges evaluate the underlying importance of habitats or landscape characteristics when the amount of time an animal spends in a location may not coincide with the importance of that location.

As with the selection of band width, selection of a home-range estimator must be chosen to fit the hypothesis being tested, the datasets, and other research goals. Traditional kernel home-range estimators can still be used to advance our knowledge of why animals have evolved the behaviors and use of space documented (Kie et al. 2010). The adehabitatHR package (Calenge 2011) for the R statistical environment (R Core Team 2014) is one of many software packages used to estimate MCPs, kernels, local-convex hulls, and Brownian bridges.

GPS telemetry yields large data sets with less sampling limitations and bias than ground-tracking. In many cases, the understanding of time-specific resource availability has not kept pace with this enhanced resolution. This is particularly an issue if remotely accessible data means research biologists have no field sense of their study area, or if the resources important to study animals remain understood only at far coarser level than the telemetry data. Hebblewhite and Haydon (2010) advocate using the time saved on radio-tracking triangulations and flights for a better resolution picture of the habitat and resources important to the study animals, stating that "ecologists should become better in matching temporally varying estimates of resource availability at the same time scale as animal movements."

Habitat Selection

The concept of "habitat" is based on the classic notion of the ecological niche, whereby animals select the resources and conditions that increase fitness (Hall et al. 1997, Morrison 2001, Sinclair et al. 2005, Mitchell and Hebblewhite 2012). The niche is a property of a species, includes abiotic and biotic components, is related to fitness, and includes long temporal and large spatial scales. Several studies have examined habitat use of jaguars, including, but not limited to: Crawshaw and Quigley (1991), Núñez et al. (2002), Cavalcanti (2008), and Conde et al. (2010). These studies provide some insight into *where* jaguars live, but knowing *why* animals live where they do can lead to robust understanding, effective management, and long-term conservation (Gavin 1991). The best understanding of jaguar habitat will explicitly relate resources to the survival and reproduction of jaguars (Mitchell and Hebblewhite 2012).

Johnson (1980) proposed a hierarchy of selection processes in which first-order selection is the physical or geographical range of the species. Within that range, second-order selection is the home-range of an individual or social group (e.g. an individual jaguar or a wolf pack). Third order selection is the use of habitat components within a home range. Fourth order selection could be the specific procurement of food items within a habitat sub-component (e.g. capybara in a stream edge, or peccary in adjacent gallery forest). The boundaries of these orders are less important than recognizing that there is a hierarchical continuum of scales. Proctor et al. (2012) used genetic analyses from 3,134 bears and radio-telemetry data from 792 bears to examine grizzly bear population fragmentation across 1,000,000 km^2 of western Canada, the northern

United States and southern Alaska. This approximates a first-order selection scale. Studies examining grizzly and black bear seasonal habitat preferences (Carter et al. 2010, Graham et al. 2010, Nielsen et al. 2010, Milakovic et al. 2012) or seasonal shifts in jaguar home ranges (Cavalcanti and Gese 2009) could be viewed as third order selection on an annual or lifetime perspective and second order selection on a seasonal time frame. Zeller et al. (2014) proposed the use of continuum of scales when examining habitat selection, and used data from 8 collared pumas and gradients of criteria to differentiate habitats selected during movements versus during relatively stationary resource use.

Roads may be a component of jaguar habitat and can be characterized by year built, construction class (width of road surface and width of cleared land) and traffic volume data (Graham et al. 2010). Where anthropogenic factors are significant, human density, types of roads, and distance to roads and/or communities should be factored into habitat selection models.

Sampling Designs

Almost all habitat-selection studies follow one of two sampling protocols: 1) comparing used resources with unused resources, or 2) comparing used resources with available resources (Manley et al. 2002). Used-unused (presence-absence) designs are perhaps the most straight forward for habitat-selection studies. Logistic regression is a common statistical framework for comparison, whereby a binary response variable represents used and unused resources (Hosmer and Lemeshow 2000). Data relevant to investigating jaguar habitat selection using this design include remote-camera trapping (animals are either photographed or not-photographed) or mark-recapture trapping through photographing and DNA sampling. Using aerial track surveys in snow for large-scale (3,851 hexagonal 100 km^2 sampling units) occupancy sampling in northern Ontario, Bowman et al. (2010) found wolf occupancy higher in sample units with high caribou (*Rangifer tara*ndus) and moose (*Alces am*ericanus) occupancy. In a similar fashion, prey occupancy may interact with other environmental characteristics to influence jaguar distribution. Sunarto et al. (2012, 2013) made recommendations on data to collect at camera trap stations to characterize those micro-sites. We make these available in Appendix 6. Details on modeling environmental covariates are provided in the Covariates subsection in Presence-Absence and Occupancy and Abundance and Density.

Use-available (presence-only) designs are among the most common method used for analysis of habitat selection (Mitchell and Hebblewhite 2012). The design only includes information about where animals used habitats (Pearce and Boyce 2006). Radio-telemetry data are perhaps the most common for the use-available design. DNA sampling has been used for use-availability resource selection (Vynne et al. 2011), but scat locations may have biases the constrain their utility as an indication of the continuum of microsites important for carnivore fitness. They may be best handled in a presence-absence framework. Abundant repeated locations of radio-marked animals identify areas used, and a random sample or census of resources within an animal's home range identify available resources (Manley et al. 2002).

Availability Data

Inferences from habitat-selection modeling with the use-availability design are contingent on how availability is defined (Beyer et al. 2010, Mitchell and Hebblewhite 2012). No completely objective means of calculating availability exist; however, recommendations exist in the habitat-selection literature.

The concept of availability depends on the spatial scale at which selection is investigated. Fundamental to an understanding of how and why jaguars use particular areas is mapping of availability at a scale relevant to jaguars. Many studies have sampled availability with a set of random locations within an animal's home range (i.e., 3rd order selection; Johnson 1980). The implicit assumption that animals can move anywhere within their home ranges at any time between successive locations may not hold in all circumstances. Thus, movements and habitat selection are intrinsically linked. Compton et al. (2002) defined availability as the area each individual could have reached from each location based on its history of movements. Used and available locations were compared using a conditional logistic model (Hosmer and Lemeshow 2000). Although Compton et al. (2002) studied wood turtles, the technique has applicability to jaguars.

Covariates

Many studies of the habitat ecology of carnivores describe habitat simply as the places or prevailing conditions where animals are found (Mitchell and Hebblewhite 2012). This descriptive approach relates occurrence, use, or selection by carnivores to vegetation communities, digital elevation models, remote sensing variables, and other types of spatial variables easily obtained in a GIS framework. These variables are used as surrogates for measures of resources, such as specific food types, which contribute directly to fitness. The use of surrogates relies on assumptions about their relationship to what they represent and, in many circumstances, could be violated. The assumption that variables reflecting vegetation communities are surrogates for availability of plant forage for omnivores or of prey for carnivores are often unwarranted and infrequently tested (Mitchell and Hebblewhite 2012). The inability of these habitat models to explain carnivore behavior argues strongly for considering prey resources explicitly.

Relating prey abundance and distribution to vegetation types and physical characteristics allows a better understanding of why felids use space the way that they do (Karanth and Sunquist 1992, Karanth 1993, Polisar et al. 2003, Scognamillo et al. 2003, Karanth et al. 2004, Azevedo and Murray 2007*a*, Hojnowski et al. 2012). We suggest that habitat definitions for jaguars include abundance and distribution of prey. Because rigorous estimates of prey abundance and biomass are labor intensive, defining the scale of sampling is an important consideration in quantifying prey biomass and relating it to habitat characteristics and anthropogenic factors. Methods for occupancy-based estimations of prey density using field sign are provided in Gopalaswamy et al.

(2012*a*). Sampling and analysis considerations for distance sampling methods based on direct observations are provided in Buckland et al. (2001, 2008). Physical characteristics, such as proximity to publically-accessible roads or human settlements, still may be important predictors of jaguar survival, and therefore also should be included when defining jaguar habitat.

Data Analysis

Resource selection functions (RSFs) have gained prominence in habitat-selection studies (Boyce and McDonald 1999, Manley et al. 2002). Manley et al. (2002) defined RSFs as any function that is proportional to the probability of an animal's use. RSFs are commonly used to develop posteriori statistical models to describe habitat, but they also lend themselves to hypothesis testing. Hypotheses about the relative importance of specific habitat features and combinations of those features can be tested by evaluating competing multivariate RSF models using AIC (Burnham and Anderson 2002).

However, Mitchell and Hebblewhite (2012) offer:

> *…the uncritical use of surrogates, particularly given the rapid growth of remotely sensed land-cover data, computing power, and the use of sophisticated analytical techniques, has produced a large number of studies whose definition of habitat would seem to be "throw a bunch of conveniently available environmental variables into the statistical hopper and see what pops out."*

Alternatively, Mitchell and Hebblewhite (2012) recommend testing meaningful, *a priori* hypotheses linked to fitness parameters that provide stronger inferences on the cause-and-effect relationships that underlie habitat selection.

Cross-validation, both with internal and external data, is necessary to test the predictive accuracy and utility of a habitat model (Roloff et al. 2001, Boyce et al. 2002, Johnson and Gillingham 2005, Johnson et al. 2006). Cross-validation also provides insights into how robust a habitat model is to aspects of study design, such as autocorrelation, non-independence, multicollinearity, and sample size (Manley et al. 2002, Johnson and Gillingham 2005). Internal cross-validation uses data used to generate the model to test different "versions" of the model in a k-fold procedure. Briefly, a researcher divides data into k-partitions and cross-validates the predictive capacity between observed frequency of use and predictive frequency of use across the partitions of the data. A superior alternative to internal cross-validation is external validation, whereby a comparison of model predictions to independent data (collected in different years and study areas) are used to test model generality, accuracy, and precision.

Examples

In order to clarify second order habitat selection, in a 4,900 km^2 study area in North Carolina, Dellinger et al. (2013) used adaptive nearest neighbor convex hull methods to construct 95%

home ranges for 20 red wolves (*Canis rufus*) carrying Lotek GPS 4400S radio collars. Using rarefaction curves the authors determined that home range estimates had stabilized if size increased < 5% with each additional week for at least twelve weeks. The authors used RSFs that assumed habitat selection was indicated by comparing known points (GPS locations) to random available locations across the landscape. The number of randomly selected locations equaled the number of used locations. All used or available locations were combined across individuals (conceptually a pack of red wolves would approximate an individual jaguar). The authors categorized six types of land cover types, three natural, and three human-altered habitats, as well as biologically meaningful interactions (land-cover type by distance to roads, land-cover type by human density, and distance to roads by human density). One of the conclusions of this second order examination of habitat selection was that, in the absence of high human density (threats), red wolves selected for human-altered habitats, such as agricultural fields and regenerating logged forests that were potentially rich in prey such as white-tailed deer. Low volume dirt and gravel roads in the study area were not avoided. However, where human densities and hence potential threats increased, the use of natural habitats including old growth forest, also increased.

In an effort to understand the impacts of major road work on gray wolves (*Canis lupus*) in 12,907 km^2 area in Quebec, Canada, Lesmerises et al. (2013) tracked 22 wolves belonging to three packs along three major roads using GPS collars (Lotek 3300SW and Telonics GPS-4580), acquiring fixes every four hours year round. For habitat availability, maps at the 1:20,000 scale were classified into ten categories of forest type. Roads were described as before, during (active/inactive), and after. RSFs were used to estimate the relative probability of use of each habitat feature. Home ranges were calculated as 95% minimum convex polygons (MCPs) and for each wolf as many random points as GPS locations were distributed within the MCP to obtain an assessment of habitat suitability and determine the habitat category where the GPS location and the random point were found. The distance to nearest paved road was calculated for both points within a 5-km threshold. The RSF was developed to integrate the interaction between the shortest distances to paved road with the state of the road at that nearest point. “Before” was used as a reference. Mixed-effects models were used with crossing rate as the dependent variable and road state, annual period, daily period, and their interactions among the fixed effects. Wolf responses were primarily driven by the level of human activity, but crossing rate also decreased as road enlargement increased. Wolves still crossed enlarged highway, but at reduced rates, and were likely to use forested areas as hiding cover, crossing the road at night.

In a very remote, relatively natural 7,400 km^2 study area in Northern British Columbia, Milakovic et al. (2011) monitored 26 wolves from five packs using GPS collars (Simplex-Televilt). GPS locations were compared to randomly selected locations within the 95% MCP of each wolf pack (equivalent of an individual jaguar) across five seasons based on biological criteria for wolves. Habitat values were based on readily available biophysical characteristics (land cover, elevation, and aspect) that were reduced to 10 cover types and 4 aspect categories, as well as a categorical fragmentation index. Concurrently, GPS data were collected on moose, elk (*Cervus elaphus*), Stone's sheep (*Ovis dalli stonei*), and caribou, and logistic regression models for these species incorporated locations, land cover class, elevation, aspect, fragmentation, vegetation biomass and quality and an index of predation risk. The prey selection surfaces were incorporated into wolf selection models, competing with those based solely on biophysical parameters, running the wolf selection models for each prey item separately and then all four pooled. On a global level, wolves selected for shrub-communities and high fragmentation across all the seasons, although each pack demonstrated individual habitat selection characteristics. Wolves did not select the same areas that the four prey species did (the latter also selecting areas to avoid predation risks), but may have selected opportunistic travel routes between land cover classes that maximized encounters with diverse prey.

In the same study area as above, Milakovic et al. (2012) used data from 27 grizzly bears fitted with GPS collars (Simplex, Televilt), using RSFs (Manley et al. 2002) to model habitat selection. The authors defined habitat availability within 95% MCP home ranges, and identified three seasons based on plant phenology, pooling seasonal data for each bear across years, using 50 points as a minimum to satisfy sample size and aid model differentiation. Land cover and topographical variables were 25 m resolution raster data, and included 10 land cover classes, three categories of fragmentation. Analyses included selection models developed for ungulate prey in global seasonal selection models across all bears and for each individual bear. Across seasons, grizzly bears as a group avoided conifer stands and low fragmentation areas and selected for burned vegetation classes and high fragmentation areas, with the interpretation being that these areas provided high quality forage and potential encounters with ungulate prey.

Jaguars differ from wolves in being solitary, stealth hunters rather than coursing hunters. Unlike grizzly bears, they are not linked to plant phenology due to an omnivorous diet. However, their mammalian prey may be linked with plant phenology patterns. The above studies demonstrate that selection may be positive for habitats where the risks of being killed by humans are lowest. Nielsen et al. (2010) recommended more attention be given to food resources affecting bottom-up regulation of populations, while top-down limitations be integrated into habitat models through mortality risk. Their recommendations were based on 42,853 GPS telemetry locations from 44 grizzly bears used to assess predictive habitat quality models that were developed from 642 land cover stratified random field plots for plant food quality, 51 field-visited ungulate kill locations, 1,032 field visits to GPS fix locations, and complemented by data from a hair-snag mark-recapture study.

Conde et al. (2010) reduced 5,246 GPS locations from three adult females and three adult males in the Selva Maya of Mexico just north of Guatemala by filtered points through 72 hour intervals to reduce autocorrelation, resulting in 218 independent female locations and 226 independent male locations. A random sample of 10,000 pesudo-absences were selected from each individual's home range. Habitat variables used in generalized linear models included those drawn from geo-spatial data (five general land cover types, density of paved and unpaved roads, distance to roads) and sex of study animals. Distance to population centers and human population densities were not included due to strong correlations with road proximity. The model that included interactions between sex and road distance and between gender and land cover had lowest AIC values, runner up models included sex and landcover interactions, and the model that excluded gender performed poorly. Both male and female jaguars showed a preference for tall forest (which in the Selva Maya has a higher diversity of mast producing trees as well as less seasonal flooding than short forest). Females avoided two disturbed land cover types, cattle ranching and secondary vegetation. Males showed a tendency to use agricultural land and cattle ranching in proportion to availability. The probability of female occurrence increased away from roads, while roads had a negligible effect on male occurrence. To assess predictive capabilities of the model, the authors used 149 telemetry locations from five jaguars not included in model development. Cross validation showed reasonable discrimination by the selected model, with results indicating substantial agreement between observed and predicted values, and the percentage of points correctly placed ranging from 85.5 to 96.4, testimony to intra-specific differences in habitat selection.

Kertson et al. (2011) used data from GPS and VHF collars on 27 pumas in a 3,500 km^2 study area in western Washington in the United States to evaluate use of space and movements in the wildland-urban interface. In a RUF, use is a continuous variable represented by a utilization distribution, which is related to landscape features using a multivariate resource utilization function (RUF). This identifies the individual animal as the experimental unit, measures use continuously instead of discretely, and accounts for variable intensity of use. The landscape characteristics used in modeling were hypothesized as good predictors of presence of prey and cover, and measures of anthropogenic land change. However no direct measures of prey or stalking cover were part of the six variables used. The relative importance of landscape features differed between all pumas and years, with no two pumas using the landscape the same way. Despite significant variation in resource use at the individual level, when cross-validated, the population wide RUF accurately predicted puma and human interactions. The population level conclusions aligned with the author’s local knowledge of puma natural history, but they speculated that the large variability among individual pumas may have been a result of some landscape features being poor surrogates, and suggested that an ideal model of puma space use would include direct measures of cover and prey availability.

In a 4,089 km^2 study area in the Santa Monica Mountains of California, Zeller et al. (2014) used data from eight pumas fitted with GPS collars (Lotek 4400) programmed to acquire locational fixes every five minutes. The authors used a range of threshold distances moved between these fixes to determine behavioral state and thus examine potential differences between resource use and movement locations and thus, differences in habitat selection in behavioral states.

Wells et al. (2014) used GPS collars (GPS plus collar v6 Vetronic-Aerospace) on mountain goats (*Oreamnas americanus*) fitted with accelerometers that recorded count data at five-minute intervals based on movement of the GPS collar in X and Y axes to identify behaviors of interest. This impressive hardware was used in conjunction with Brownian Bridge Synoptic Models

(BBSM) to delineate and evaluate mountain conservation and management planning. The step-wise BBSM approach uses the serial nature of telemetry data to establish independence, rather than applying arbitrary thresholds. At each step along a movement path, the BBSM defines an underlying distribution of availability. The probabilities of availabilities are higher in the direction of persistent movement. This reduces the error of pairing random points with use points when in fact telemetry data may indicate a persistent movement in one direction. The BBSM is a fine-scaled approach that joins the analytical tools of RSFs that can help researchers and managers effectively use GPS collar location data to obtain maximize insights into the details of habitat selection at the individual and population levels.

Conclusion

Thoughtful, *a priori* questions are paramount in designing habitat selection studies and guiding the scale of the mapping and sampling needed to address questions. Jaguars use large areas, but may concentrate their activity in specific parts of enormous home ranges. What are the characteristics and significance of those areas? A jaguar's use of space relates to patterns of prey distribution and abundance. What environmental factors are driving the spatial patterns of secondary productivity? Risk and high mortality might also result in apparent habitat selection patterns. What physical characteristics are the most relevant for survival and recruitment? These questions will help define the biological and physical parameters to include when examining habitat selection in a meaningful way. Developing hypotheses *a priori* will clarify what supporting data are needed.

Well-chosen environmental covariates in occupancy modeling will provide insights on the parameters important to confront threats for existing jaguar populations and facilitate range expansion. Collecting environmental data at each station during camera-trapping CR studies can identify habitat characteristics associated with increased capture rates. However, camera trap studies of any type have the inherent limitation that they are sampling specific points that animals pass by, rather than along the continuum of their movements. Intensive telemetry studies provide the best movement data, and GPS collars provide abundant, unbiased location data for high-definition habitat selection studies.

Zeller et al. (2014) noted that animals usually select habitats and resources along a continuum of scales and that selection may change depending on behavioral states. The random selection of availability points employed in RSFs can satisfy questions about third order selection. RUFs and BBSM can track individual animal selection patterns, employing directional selection rather than a cloud of points in a home range that, in all likelihood have linear relationships along gradients of use intensity. Technological advances have increased our ability to examine jaguar habitat use at multiple higher-definition scales, yet, across vast stretches of jaguar habitat protected area enforcement and wildlife law enforcement remain weak. On the large scale of jaguar range and landscapes, effecting conservation may require that considerable conservation resources and efforts are directed at the multiple social and administrative levels needed to accomplish on-the-ground advancements. The continuum of habitat selection information obtained through 1) environmental covariates in occupancy surveys, 2) covariates in CRC studies, and/or 3) high resolution telemetry based RSF, RUF, and BBSM habitat selection studies can inform these efforts.

DATA CAPTURE AND CURATION

Collection and export

Jaguars may be detected using a wide variety of techniques, such as those described in this document. Each technique generates particular types and formats of data, which can vary depending on the software used to capture and manage them. These data can then be used in particular types of analyses, such as:

- camera trap monitoring;
- radio/GPS collar or other telemetry techniques;
- scat dog detection;
- transect surveys;
- historical and museum specimen records;
- layperson or citizen-science reports.

As a general principle, it is both advisable and realistic to collect and maintain these raw data using the methods commonly associated with each technique, rather than shoehorn them early into one-size-fits-all schema inappropriate to the data or the intended analyses. For example, camera trap data are often produced with the help of software that ships with particular camera models (e.g., BuckView with Reconyx cameras: http://images.reconyx.com/file/BuckViewUserGuide.pdf) or open-source applications such as OpenDeskTEAM (an offshoot of http://www.teamnetwork.org/help-deskteam) and CameraBase (http://www.atrium-biodiversity.org/tools/camerabase/). Other techniques commonly employ spreadsheets in formats comfortable to individual researchers for particular applications.

Each technique should use the most efficient and tested method and format, *as long as it is capable of being easily exported or converted*. The ideal is to collect and manage data for a particular study in the easiest and most cost-effective manner possible, and then with equal ease be able to export it to a format capable of being compared with or integrated into other datasets.

Important considerations are that raw data (photos) be backed up prior to being sorted and analyzed, and that the analyzed photos be subsequently backed up for long term/permanent storage.

Converting data to a common standard is important for any higher-level analysis that involves synthesizing and analyzing data collected using different techniques across large areas and swaths of time. Estimating jaguar populations in NRU Core and Secondary Areas based on habitat-correlated densities depends on being able to establish a common set of accepted point observations to correlate with various habitat variables.

Standardization and aggregation

The Wildlife Conservation Society, with funding and collaboration from USFWS, has created an online jaguar observation database, available at http://jaguardata.info/, as a repository for all jaguar observation data, collected using any technique (Figure 20). The database:

- maintains a central authoritative version of standardized data, with integrated geographic information, providing anybody with web access maps and downloadable data they can be sure are the latest comprehensive versions and cite in publications;
- provides quick and easy access to customized sets of observations that match whatever criteria are important to particular users;
- allows multiple editors access to add, edit, or delete data and track change history, using a robust account and security system;
- uses an event-record structure (Sanderson and Fisher, 2011) that preserves *all* records of a given jaguar detection, not just the records considered authoritative;
- is capable of incorporating detections with all levels of geographic specificity: specific lat/long coordinates, polygons for detections attributable to an area but not a specific point, and even no geographic data.

Ingestion and Editing

Manual Editing

For accessibility by citizen scientists and/or laypersons, a web-accessible platform for sorting and analyzing data collected has great advantages. The online database provides a system of user accounts that allows an administrator to create, edit access rights for, and delete accounts to be used by designated editors. Editors can then add, edit, and delete events (i.e., observations or detections), the records that provide the evidence for the events, bibliographic information for those records (using the Zotero online bibliographic software: https://www.zotero.org/groups/jaguars_in_the_southwest/items), and geographic and attribute information about the records. See Figure 21-25 for screenshots of how the application functions.

Automated Ingestion

For relatively small amounts of data, such as those from historical records, individual layperson reports, and studies involving small numbers of events, the existing observation editing interface performs well. For ingesting larger datasets, tools will be added (contingent upon funding) to the database administrative interface that will allow an editor to:

1. *Upload and process simple tabular data*. A standard template for the table in either csv or xlsx format is in the process of being specified, provisionally with the columns outlined in Figure 19.

   In order to ingest data, data will need to be converted from the system used to collect it into the standard, either via simple spreadsheet manipulation or via an export operation from collection software (e.g., CameraBase, OpenDeskTEAM). Values for identity_type, lifestage_type, and sex_type will be drawn from authoritative tables reflecting the latest types in the central database.

2. *Specify spatial and temporal distinction*. Larger datasets collected via modern scientific techniques such as camera trap and telemetry surveys often include multiple raw data points representing a single observation. Several images might be fired by a single camera trap trigger, for example, that a researcher wants to consider a single observation; similarly, many GPS-collar records of a jaguar might be collected from the same geographic point. The interface will provide a way to aggregate records into observation events according to a temporal threshold (e.g., camera trap records with timestamps <= 60 minutes apart) and/or a spatial threshold (e.g., radio-collar records with locations >= 3 km apart).

3. *Attach raw data attachments*. The interface will allow an editor to upload or link to the raw data that served as the basis for a set of observations, to preserve in a central location a copy of the original data that was converted or exported for inclusion in the standardized database structure. For example, an editor might attach a MySQL dump exported from OpenDeskTEAM for a season's camera trap survey.

Recommendations and Guidelines for Northwestern Recovery Unit and Beyond

Because jaguars occur across approximately 50% of their historical range, they may appear secure. The species' adaptability to semi-arid scrub, humid forests, and flooded swamps with forest islands imparts some insurance. Some jaguar conservation units are vast and contain hundreds of jaguars. Some contain thousands of jaguars. However, the fragility of jaguar status becomes clear every time the passive protection provided by poor access and low human population density rapidly melts as pastures and towns replace wild areas and jaguars. On the edge of human and jaguar contact, mortality rates can be stunning. In the matrix of effective conservation areas and areas experiencing rapid decreases, common measures are needed. How are jaguars doing range wide? Are they decreasing, increasing, or remaining stable?

Assessing the status of jaguars that occupy huge 10,000-100,000 km^2 source areas requires cost-effective designs and metrics. As a result, the monitoring protocol that we present for the extreme northern edge of jaguar range is designed to address a range of situations. Although designed for the Mexico-USA NRU, the protocol combines the experience of researchers who have worked on jaguars in Guatemala, Belize, Honduras, Nicaragua, Costa Rica, Panama, Venezuela, Ecuador, Bolivia, Paraguay, Argentina, and Brazil. The intent is versatile guidance to assess jaguars in the NRU and beyond.

At the core of recommendations for extremely large areas like the NRU is monitoring occupancy. Occupancy surveys can be used to evaluate the spatial distribution or estimate the proportion of a given area occupied by jaguars and jaguar prey. This tool can provide a low-cost, effective evaluation of where jaguars are across large landscapes and trends across time and space. It provides indirect measures of jaguar abundance and opportunities to test, on a grand scale, the influence of covariates of biological and management importance (such as vegetation types, altitudes, topographical relief, prey abundance, livestock frequency, and human influences (proximity to open-access roads and towns)). Through occupancy sampling, we will begin to understand exactly where jaguars are, and why they are there, while establishing a baseline for long-term monitoring.

Guidance for occupancy field sampling and analyses, including how to measure trends, is outlined in the section titled Presence-Absence and Occupancy. We recommend sample units of $500km^2$, based on estimated male home ranges in the NRU to reduce auto-correlation and assess occupancy in a biologically meaningful way. We recommend assessing 50% of an area of interest to ensure adequate data are collected for reliable occupancy modeling. However, this could be reduced to 30% in subsequent surveys based on experience and objectives. Doing this right will require pilot studies to evaluate and refine methods. Evaluating occupancy can be done with either camera traps or using sign. Based on our knowledge of the NRU we have recommended camera traps. Elsewhere in jaguar range, sign-based surveys might provide quicker, more efficient results. We provide guidance for both.

Constraining surveys to the dry season potentially reduces variation due to jaguars making seasonal movements. It also reduces camera trap malfunctions due to moisture. Sign surveys may benefit from moist substrates, and thus, best be done in a wet season. Either way, constraining surveys to a single climatic season will help approximate constant occupancy states. Repeated single-season occupancy surveys can be assessed using a multi-season model for trends, and/or multiple surveys can be combined and a time effect included in the predictor for occupancy. We provide guidance on study duration, camera placement, data to collect at each station, data processing and storage, analysis, costs, and how to conduct power analyses on the suggested pilot studies. Large scale occupancy surveys are recommended to assess the status of jaguars range wide.

While occupancy provides a broad brush assessment of trends in time, our understanding of jaguar conservation status in the NRU, and other significant, large areas across the jaguar's range, will be better when the results of occupancy monitoring are complemented by a more complete understanding of population parameters that require individual identification. We can accomplish this through select, long-term research sites set in the larger conservation landscape matrix.

Large occupancy surveys provide unbiased guidance in where to conduct long-term monitoring of trends in abundance that tells us if populations are increasing, decreasing, or remaining stable. In these focal areas, trends in the density of jaguars can be rigorously measured through photographic and genetic capture-recapture methods, following the detailed guidance provided in our Abundance and Density section. Across jaguar range, when using camera traps for density estimates we specifically recommend numerous units, ample spacing of stations, and large sample areas. For the NRU we recommend a minimum of 60 camera trap stations, all spaced approximately 4 km from each other, to sample approximately 960 km^2. Our recommendations include procedures for data collection at each station to examine covariates, data storage and analyses. Data should be analyzed using spatially explicit capture-recapture (SCR) models, but we also recommend conventional non-SCR models when assessing trends. Repeated non-SCR surveys assessed as single season closed population estimates, and again across multiple years, will provide estimates of time specific abundance, annual survival, and number of new recruits. Methods for assessing trends using SCR methods should be advanced and tested. Multi-year scat surveys for genetic CR are an alternative and/or complementary method of capture-recapture sampling. We recommend using scat dogs for efficient sampling in large sections of the NRU, and provide guidance on how to sample large areas to allow all resident females an equal probability of being captured through scats. These recommendations on how to conduct genetic capture-recapture sampling in the NRU have application anywhere in jaguar range.

Population Genetics methods are powerful tools to reveal otherwise elusive large scale and long-term details of movements, relatedness, and population status. Occupancy sampling can ensure productive searches with scat dogs that are guided by confidence of where jaguars are most likely to be. We recommend using the mtDNA cytochrome b gene for its versality; it can be used to separate jaguars and pumas, and also identify other carnivores.

Occupancy surveys can locate the best areas for long-term in depth research, but those sites should also be selected because of their potential to be defended through time, and their potential role as population sources. Detailed studies require secure study areas where trends and individual animals can be followed for years.

In these focal areas telemetry, genetic studies, and camera trapping can clarify Demographic Parameters and Spatial Ecology. We need to know more about jaguar movements across complex landscapes, and we need a better understanding of the characteristics of dispersal and long range movements. Population losses and gains can be tracked using camera traps and/or telemetry. However, for either method, only a long-term commitment will result in enough data to generate meaningful results. Survival studies, in particular, require abundant data, across many years.

GPS telemetry has expanded our ability to understand how jaguars use space, but the technological advances need to be matched by well-designed hypotheses and ancillary data that provides context for jaguar movements. We recommend the use of home-range estimators based on utilization distributions and present options for defining jaguar habitat. When designing habitat selection studies, assessments of resources should be on the same temporal-spatial scale as radio-location data, and attempt similar resolution for meaningful analyses.

All the above approaches function in complementary ways to build a deep understanding of jaguar population ecology, and clarify the threats, trends, and the biological factors that determine the status of a jaguar population and increases its connectivity with neighboring areas.

Jaguar conservation across the NRU and range wide will benefit from better coordination and curation of data. Building on the experience gained in the NRU and collectively in study areas across the jaguar's range we offer a system of Data Curation, which will allow efficient assessments of the jaguar's status throughout the NRU, with the potential to be expanded range wide.

Carnivore conservation is accomplished by mitigating a suite of threats. As examples, the factors reducing wolf survival in the Northern Rockies are human caused mortality, but this can be related to the percent of home ranges including agricultural land/livestock versus core protected areas with natural prey (Smith et al. 2010). Grizzly bear survival is best explained by degree of human development and road density (Schwartz et al. 2010). Amur tiger home ranges focus on the location of their ungulate prey (Hojnowski et al. 2012). Jaguars can survive in area dominated by ranchlands, but only if large areas of habitat for jaguars and prey are set aside, apart from the cattle operations (Polisar et al. 2003, Azevedo and Murray 2007*a*, *b*, Cavalcanti and Gese 2009, 2010, Hoogesteijn and Hoogesteijn 2011). As large jaguar source areas become increasingly disjunct from each other, indirect and direct threats require concrete conservation mechanisms – whether they are incentives or enforcement or their complementary combination – for corridors to function.

In northern Mexico and the United States, jaguars are on the edge, of their range. Between every large jaguar conservation unit, jaguars are on the edge. As time passes and pressures mount across the jaguar's range (e.g., hydrocarbon extraction, roads, reservoirs, agricultural crops, urban expansion, and direct killing of jaguars), jaguars are increasingly on the edge. What is the status of jaguars range wide? Are they increasing, decreasing, or stable? This protocol proposes cost-effective sampling methods for an extremely large area (>200,000km^2) as an example of what can be used for a rigorous, field-sampling-based range-wide assessment. It presents guidance for more detailed studies on demographic patterns, and studies that elucidate how jaguars move across the landscape and select habitats. Knowing where your study animal is paramount. Understanding its status is critical. Comprehending how jaguars make a living, knowing which environmental parameters lead to their survival and increase, and providing those factors in abundance is essential to effect jaguar conservation range wide.

> *Humans still need expansive wild places with big scary mammals that challenge us. By conserving those life forms in their wild environments, we benefit our own survival. If we accomplish that, then we will prove that we have earned our self-given name – sapiens – the wise.*

We agree with that statement made by Logan and Sweanor (2001). It is our hope that this monitoring document helps hold ground for jaguars, and provides additional kindling for the jaguar's wild spirit to repopulate places where the fire has temporarily been extinguished.

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Table 5. The Northwestern Recovery Unit (NRU) by components.

NRU Components	Total Area[a] km^2	Suitable Habitat[b] km^2	Core Habitat[c] km^2
Borderlands Secondary Area – US Portion	29,021	6,682	0.0
Borderlands Secondary Area – Mexico Portion	33,955	22,915	431
Sonora Core Area	77,710	67,889	28,294
Sinaloa Secondary Area	31,191	28,753	18,847
Jalisco Core Area/Sinaloa sub-population	59,949	44,404	26,315

[a] Total areal estimates extracted from Sanderson and Fisher (2013).

[b] "Suitable Habitat" estimates represent the area with a suitability index greater than zero, based on tree cover, terrain roughness, distance to water, human influence, and ecoregions (Sanderson and Fisher 2013).

[c] "Core Habitat" estimates represent all suitable habitat that has a modeled jaguar density (based on the relationship of habitat suitability model with observed densities across the NRU) greater than or equal to 1 jaguar per 100 km^2 that has contiguous blocks of area capable of supporting 3 or more females (Sanderson and Fisher 2013).

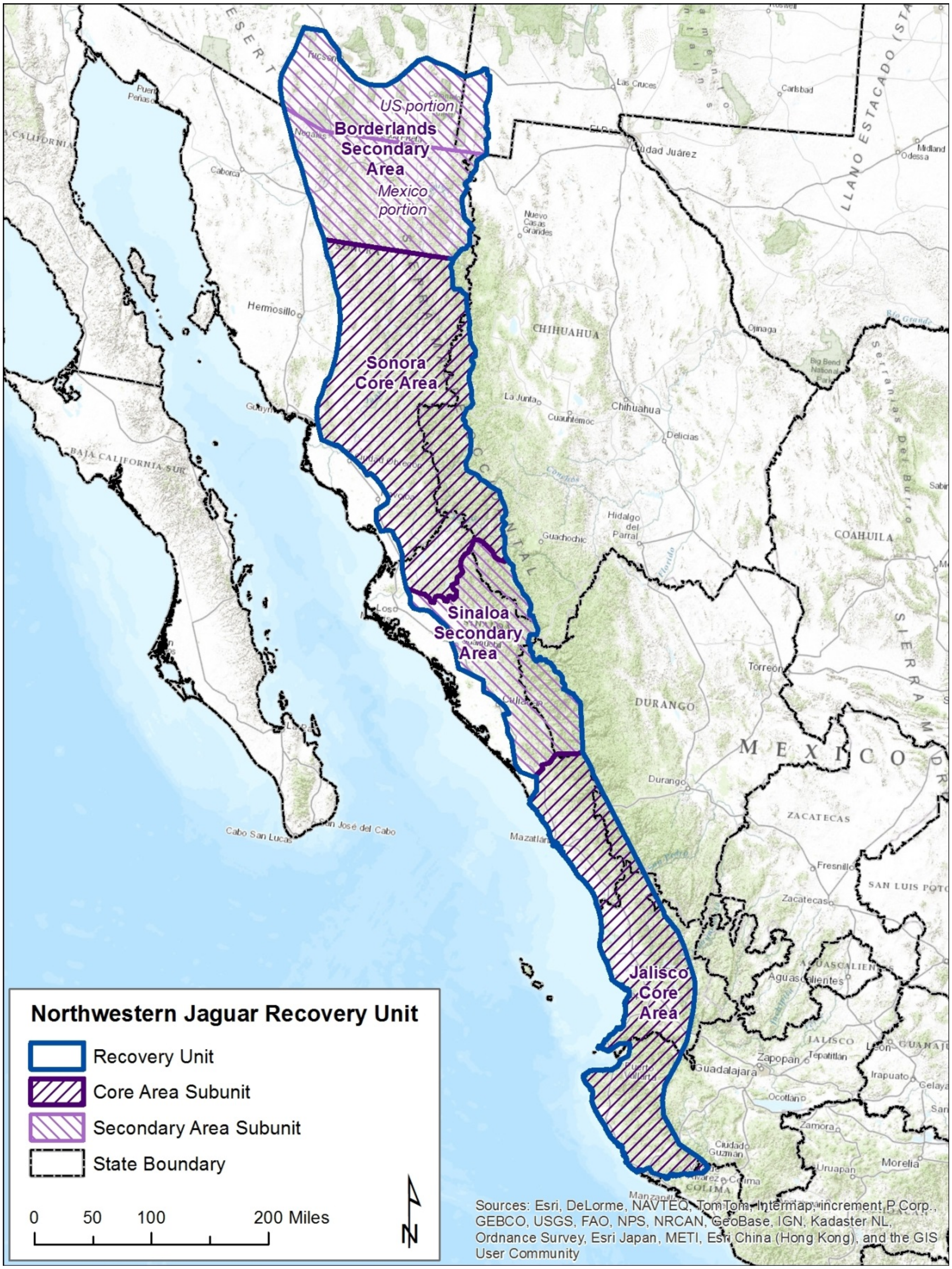

Figure 11. The 226,826 km^2 Northwestern Jaguar Recovery Unit (NRU) straddles the United States-Mexico border with approximately 29,021 km^2 in the United States and 197,805 km^2 in Mexico.

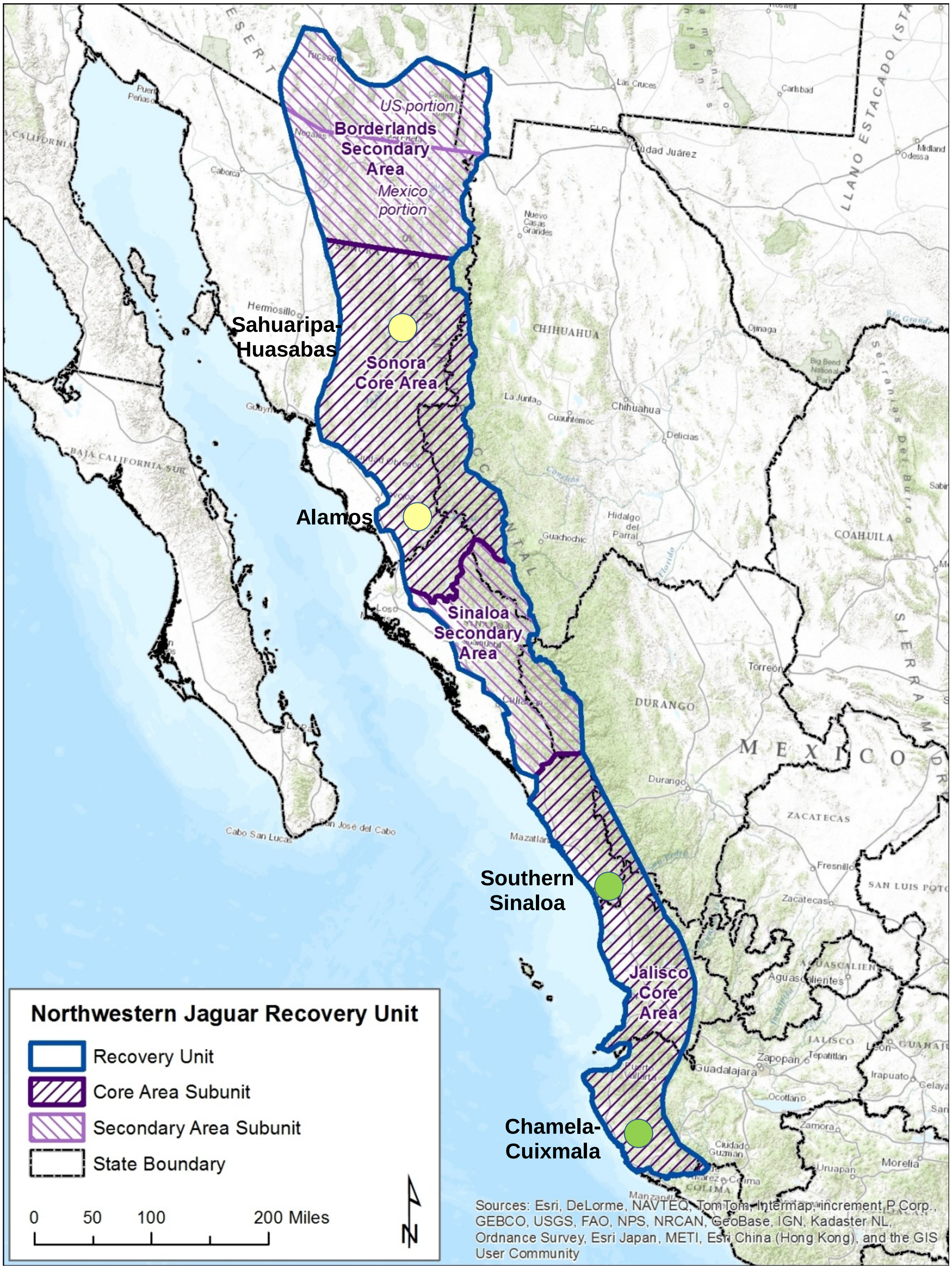

Figure 12. Known breeding populations in the Sonora Core Area occur in Sahuaripa-Huasabas and Alamos (yellow dots), and in the Jalisco Core Area occur in southern Sinaloa and Chamela-Cuixmala (green dots).

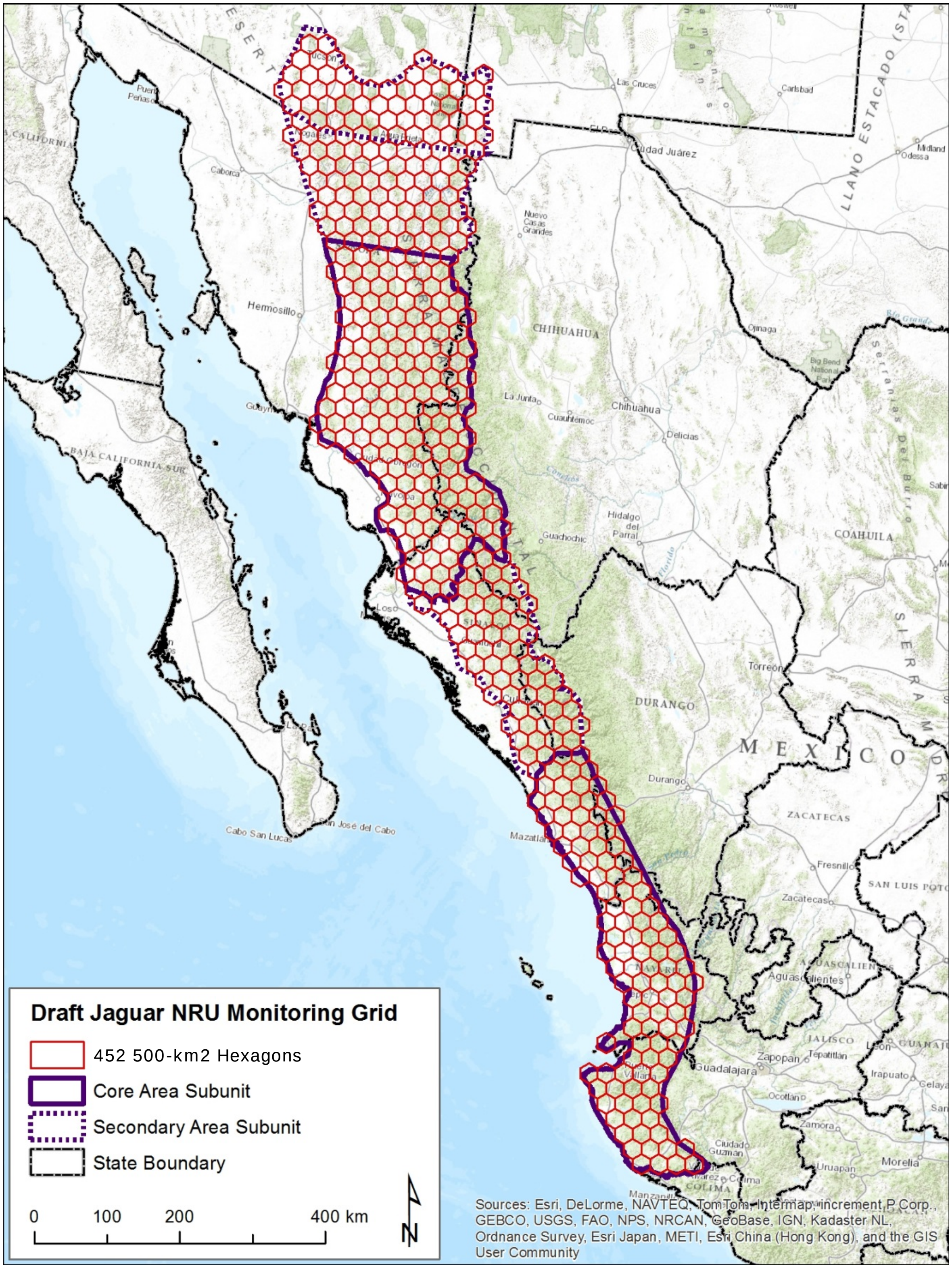

Figure 13. A grid of 452 500-km^2 hexagons across the 226,826 km^2 Northwestern Jaguar Recovery Unit (NRU).

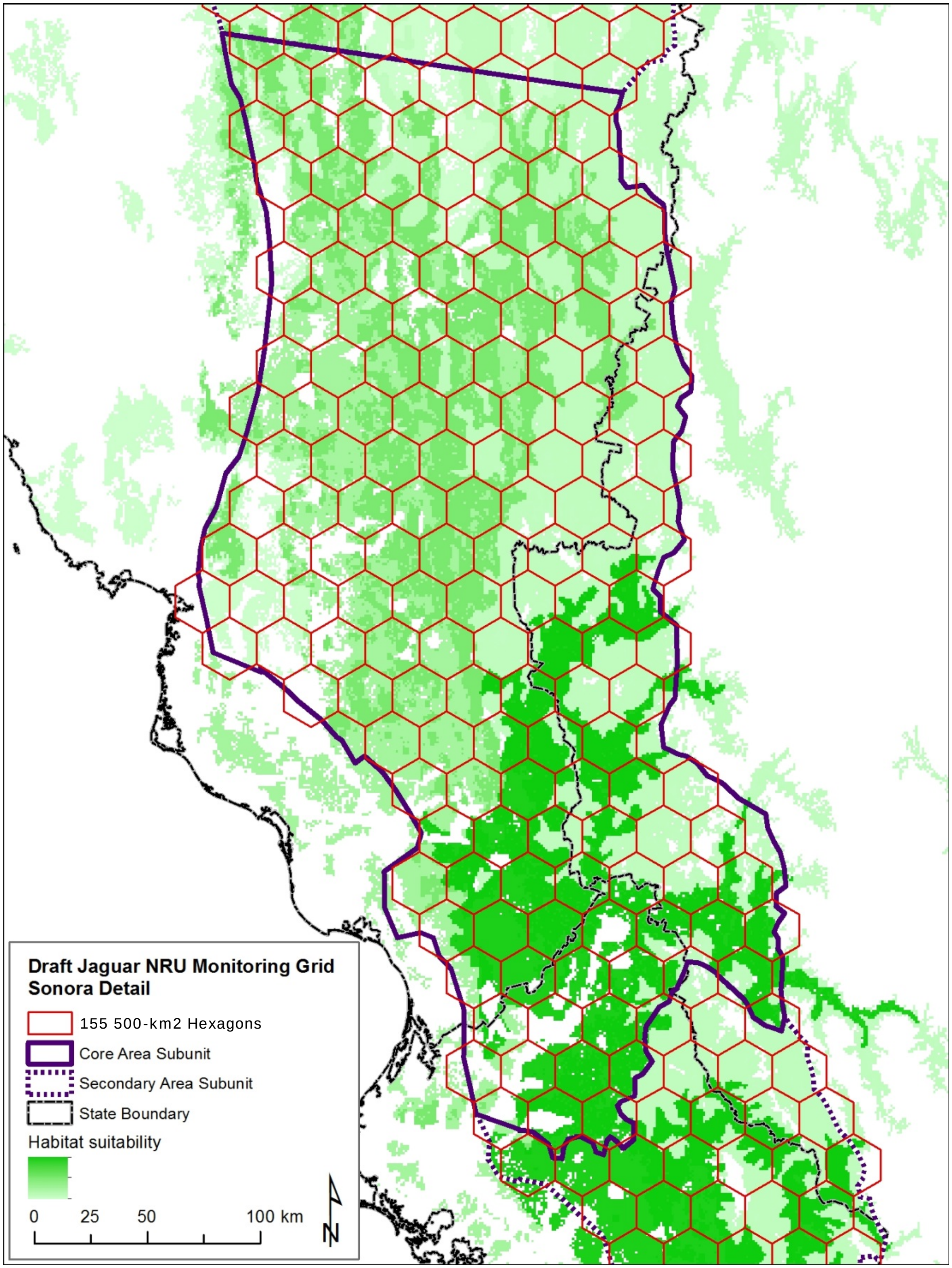

Figure 14. A grid of 155 500-km^2 hexagons across the 77,710 km^2 Sonora Core Area in northern Mexico. Habitat suitability index at 1-km^2 resolution, darker shades of green indicating higher suitability (Sanderson and Fisher 2013).

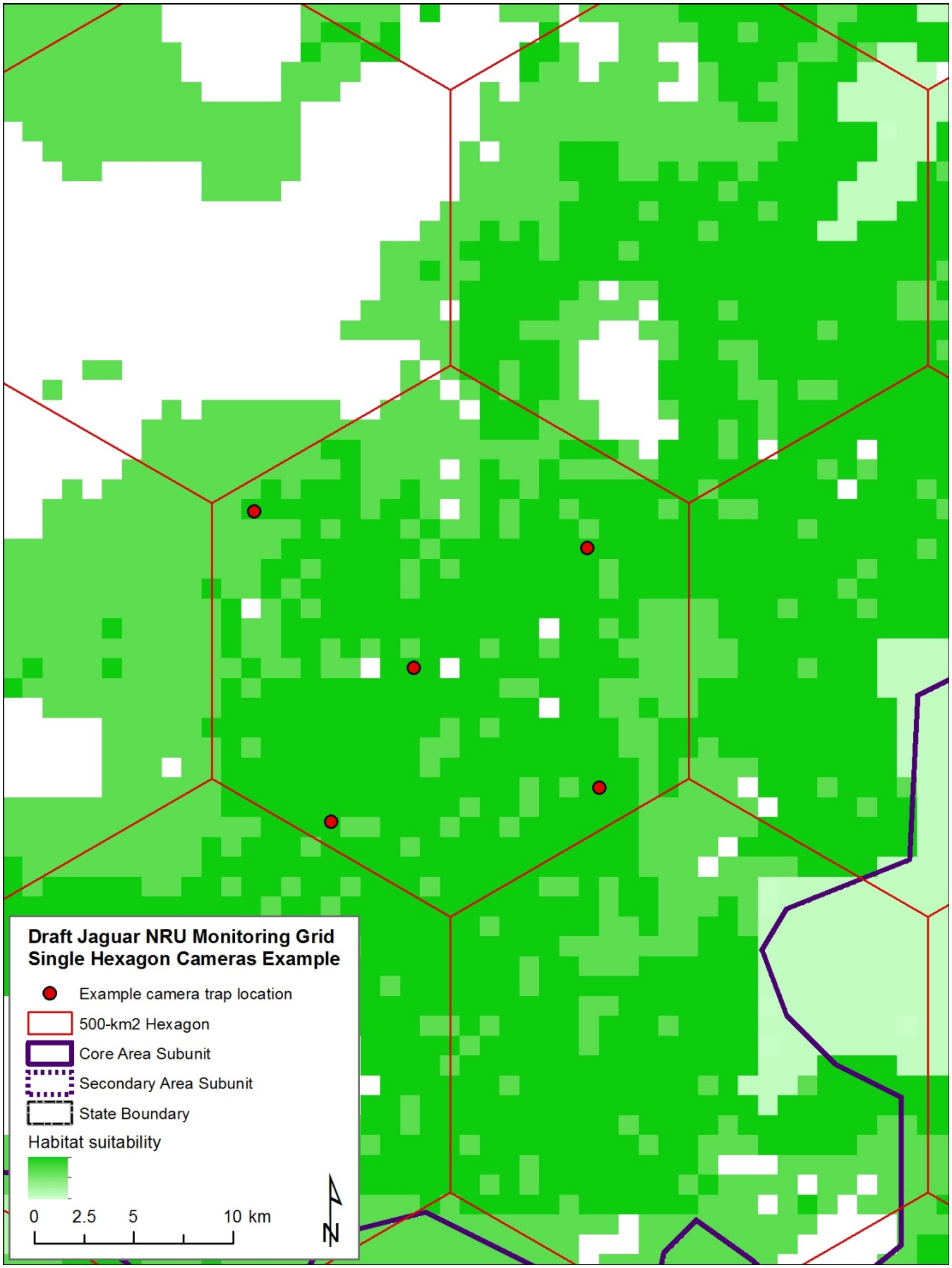

Figure 15. Individual camera-trap locations within a 500-km^2 hexagon in the 77,710 km^2 Sonora Core Area in northern Mexico. Habitat suitability index at 1-km^2 resolution, darker shades of green indicating higher suitability (Sanderson and Fisher 2013).

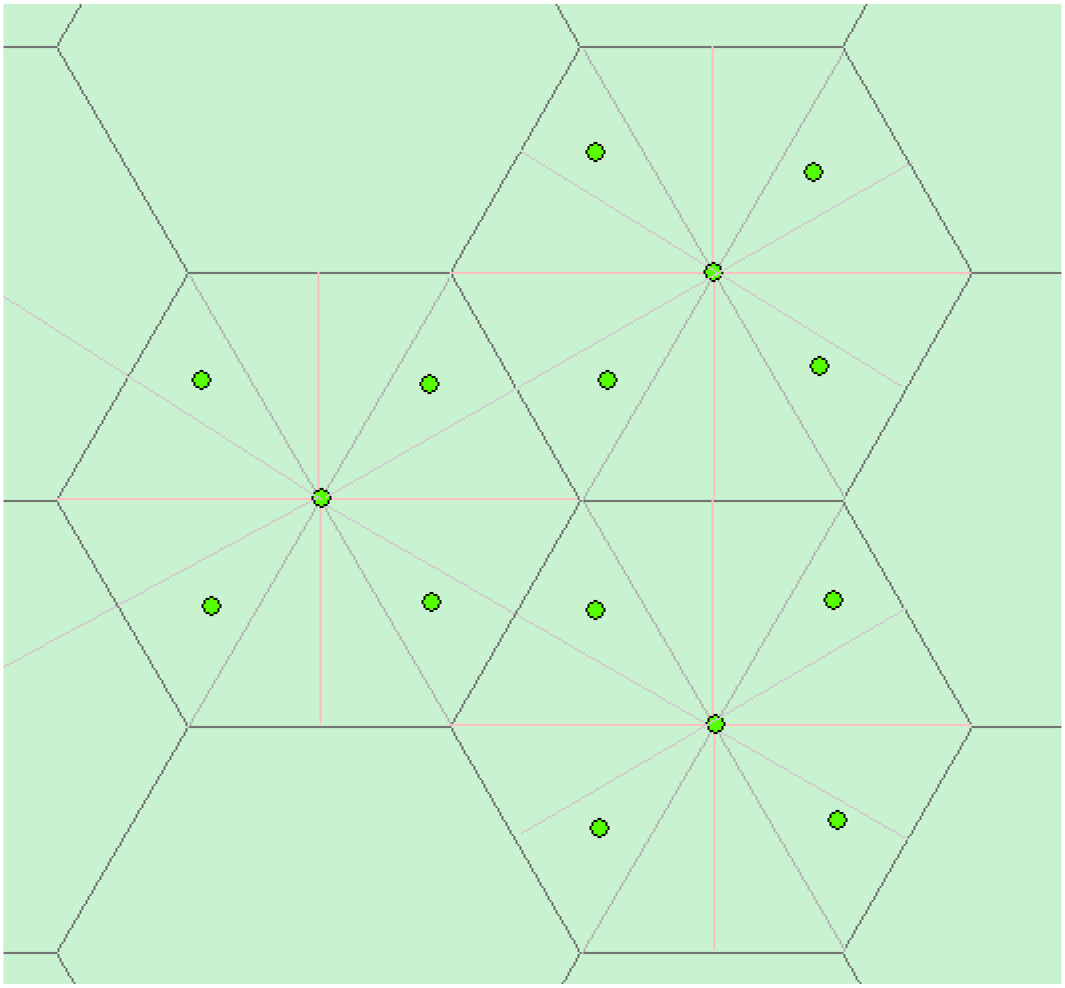

Figure 16. Possible within-hexagon camera-trap setup maximizing spatial coverage.

Figure 17. Guido Ayala and Maria Vizcarra testing 2 camera traps set on opposite sides of a trail in Bolivia. Photo by Julie Maher.

Figure 18. Camera trap sampling using paired cameras in the Upper Caura watershed, Guianan Shield Forests,Venezuela. Photo by Lucy Perera.

record_id	lat	long	date_year	date_month	date_day	date_time	identity_type	lifestage_type	sex_type

Figure 19. A standard template for the table in either csv or xlsx format is in the process of being specified, provisionally with the columns above.

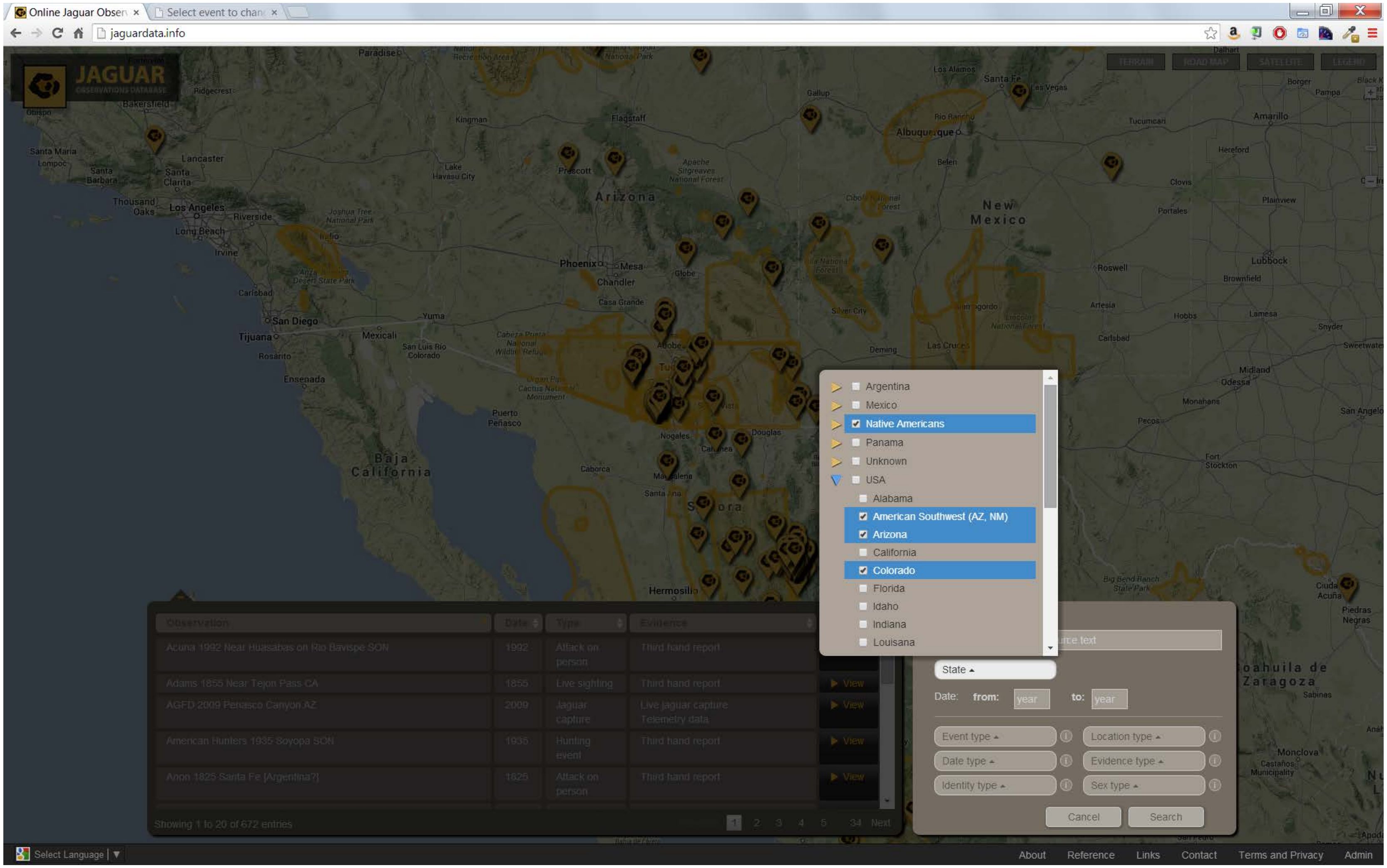

Figure 20. Public interface to jaguar observation database (http://jaguardata.info/) developed by the Wildlife Conservation Society, showing controls that allow the user to filter by text, geographic location, year, event type, specificity of location and date, evidence type, and individual identity and sex.

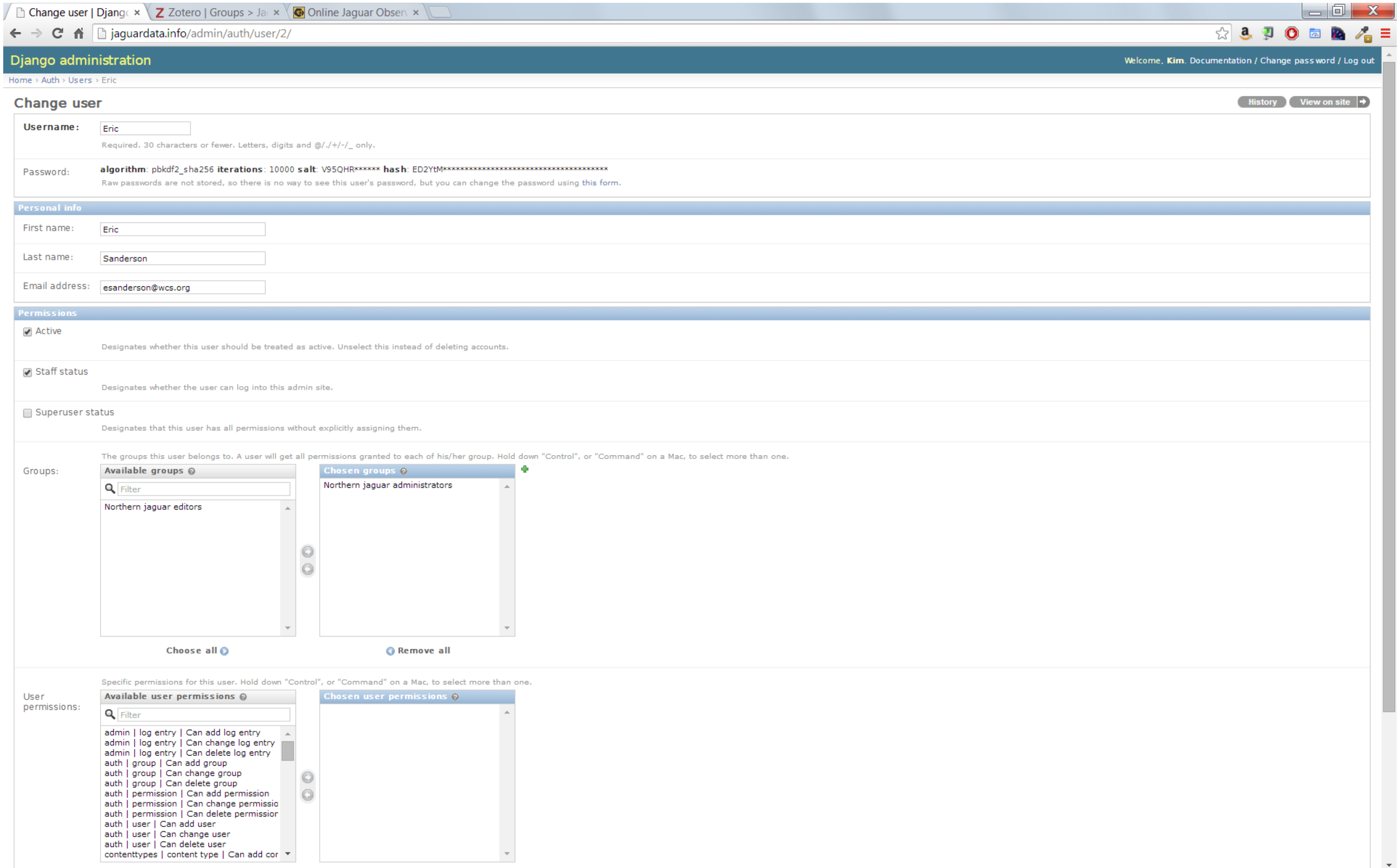

Figure 21. User administration interface of the jaguar observation database (http://jaguardata.info/) developed by the Wildlife Conservation Society.

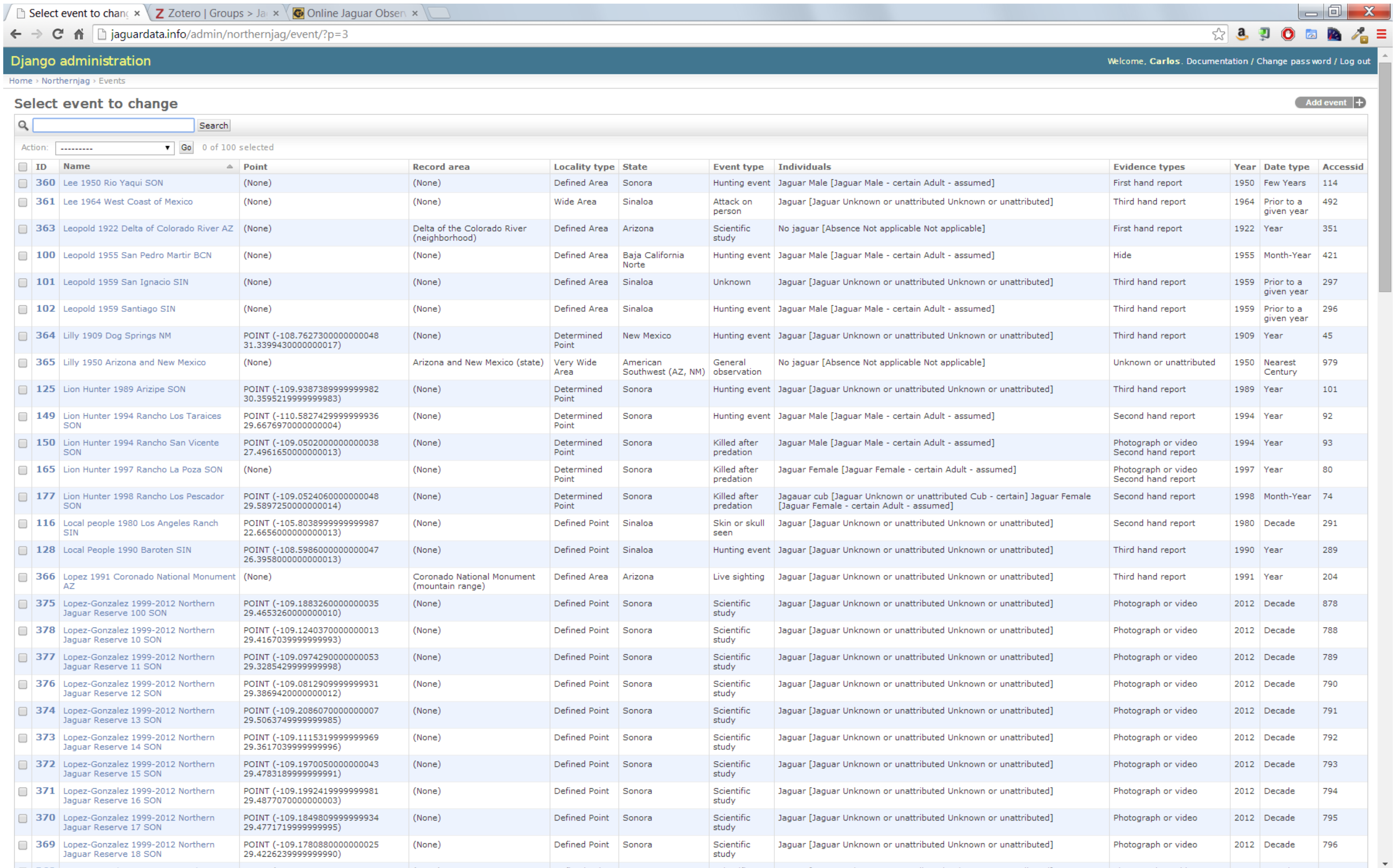

Figure 22. Jaguar event listing of the jaguar observation database (http://jaguardata.info/) developed by the Wildlife Conservation Society.

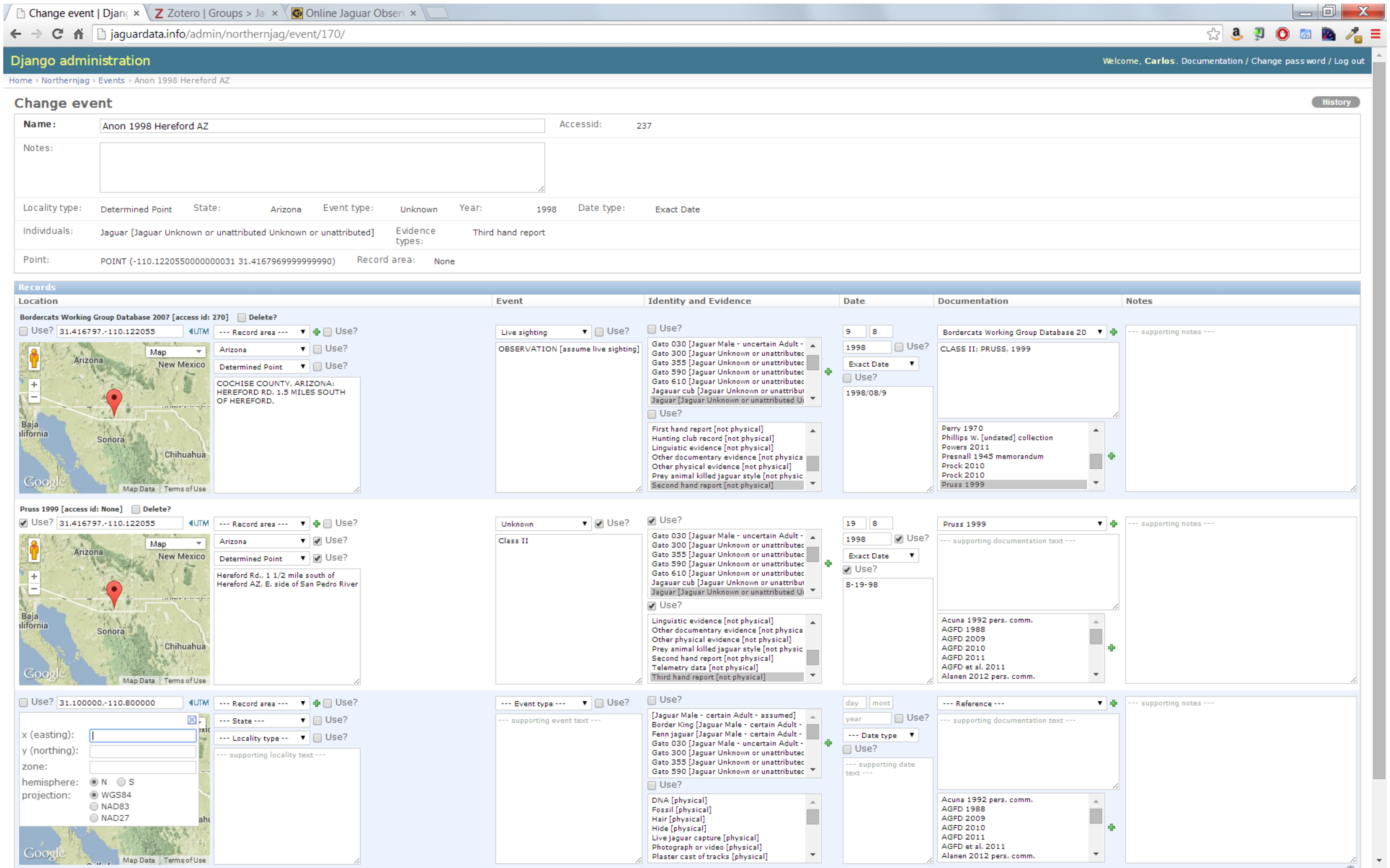

Figure 23. Event editing interface of the jaguar observation database (http://jaguardata.info/) developed by the Wildlife Conservation Society.

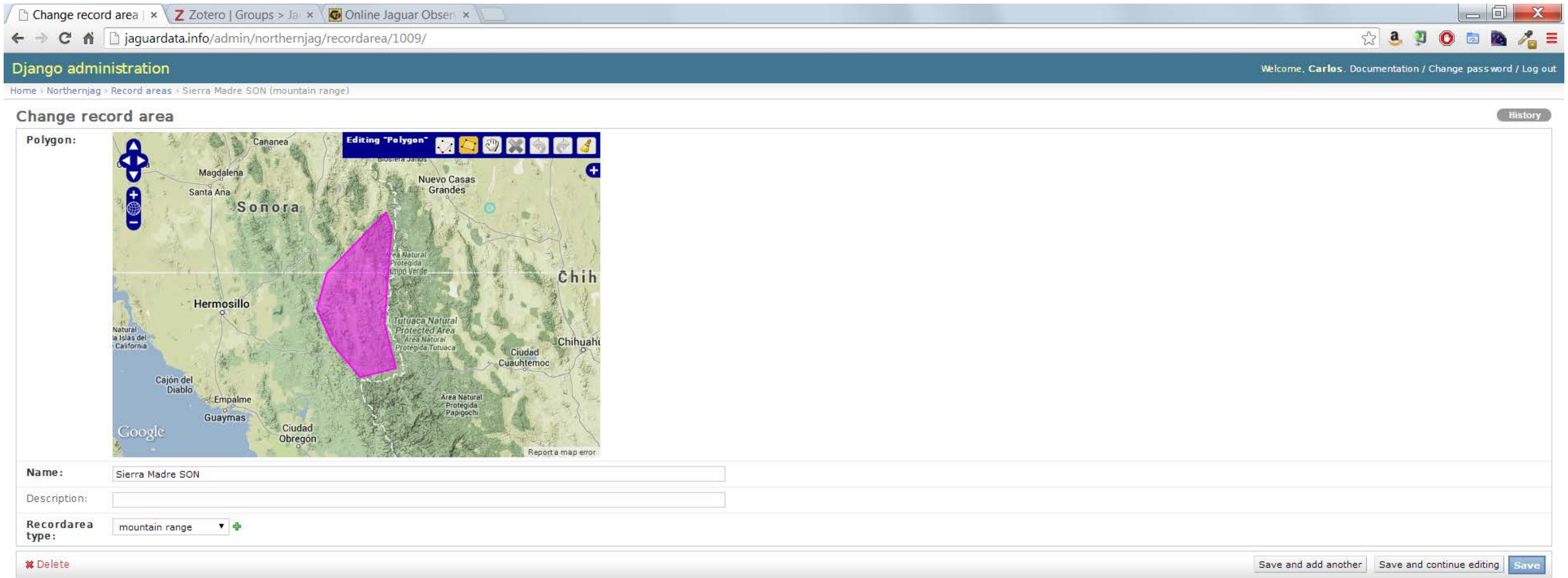

Figure 24. Editing a polygonal record area for association with non-point jaguar events of the jaguar observation database (http://jaguardata.info/) developed by the Wildlife Conservation Society.

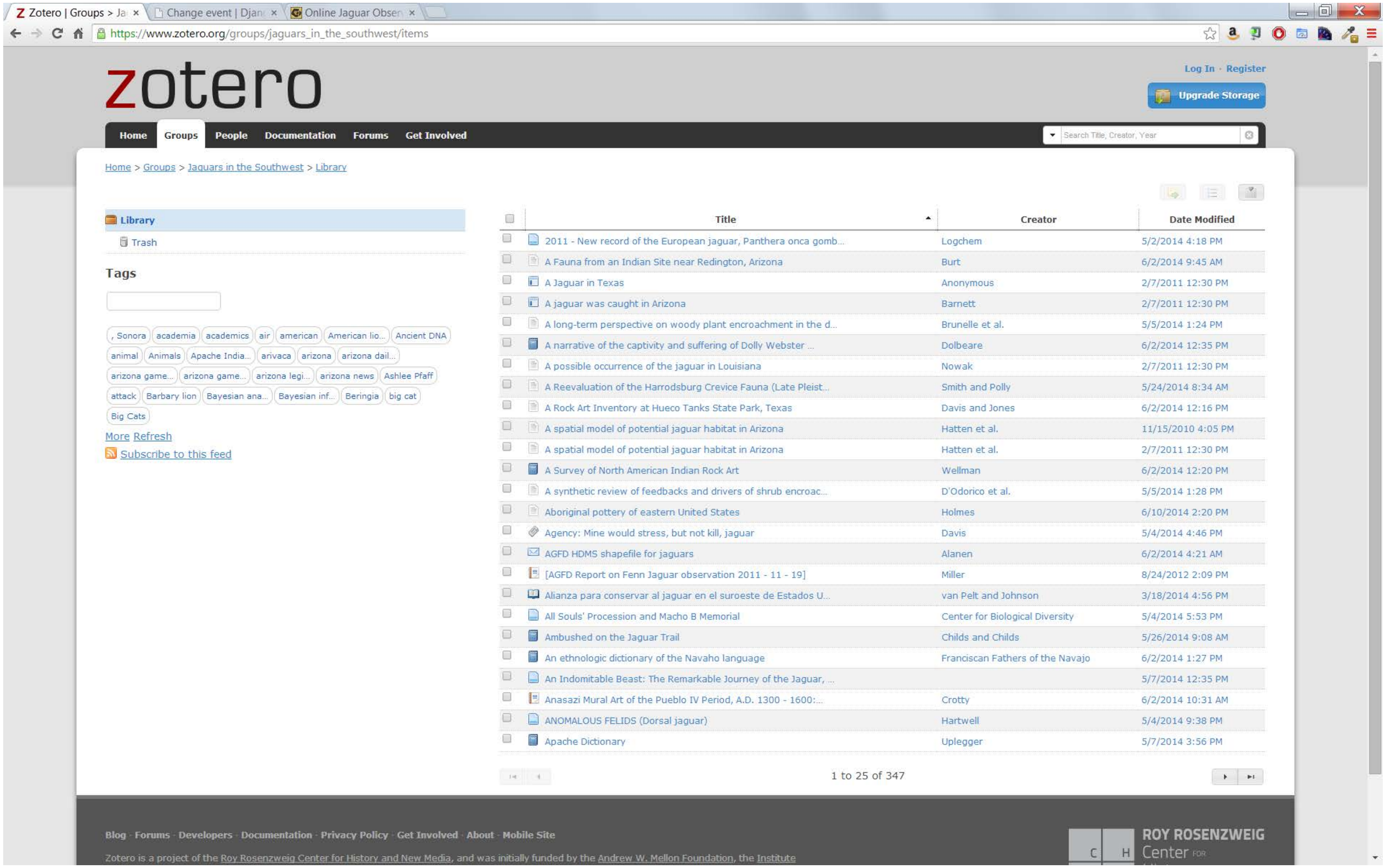

Figure 25. Zotero jaguar bibliography linked to the jaguar observation database (http://jaguardata.info/) developed by the Wildlife Conservation Society.

Appendix 1:
Glossary

Área de Protección de Flora y Fauna Silvestre (APFF): areas of Mexico established in accordance with the general provisions of the Ecology Law and other applicable laws in areas containing habitats whose existence depend preservation, transformation and development of species of wild flora and fauna. In October 2013 there were 37 areas, protecting 66,872 km^2, representing 3.4% of the national territory.

Área de Protección de Recursos Naturales (APRN): areas of Mexico designated for preservation and protection of the soil , watersheds , water and natural resources generally located on forest land suitability for forestry.

Àreas Naturales Protegidas (ANP): areas of Mexico over which the nation exercises sovereignty and jurisdiction where the original environments have not been significantly altered by human activity or require to be preserved and restored. They are created by presidential decree and activities that can be performed on them are established in accordance with the General Law of Ecological Balance and Environmental Protection, Regulations, program management and ecological management programs. They are subject to special protection, conservation, restoration and development, according to categories established by the Act. The National Commission of Natural Protected Areas currently manages 176 natural areas of federal character representing more than 253,948 km^2. ANPs may contain some federally owned lands, but generally land-ownership within ANPs is either private or ejido lands. See http://www.conanp.gob.mx/regionales/

Bayesian Statistical Methods: seek to provide a probabilistic characterization of uncertainty about parameters based on the specific data. Both data and parameters are viewed as random variables according to the calculation known as Bayes' Rule and a probability distribution is generated based on the data, which is referred to as the posterior distribution. Bayes' theorem expresses conditional probability (or "posterior probability") of an event A when B is observed, in terms of the "prior probability" of A, and the "conditional probability" of B, given A.

These methods, which require considerable iterations, have become more popular in recent years due to faster computers and more efficient methods for solving complex Bayesian inference problems. In the Bayesian view, data are realizations of random variables, and the parameters of the model are also random variables.

The prior distribution, when combined with information about the conditional probability distribution of new data through specified functions, yields the posterior distribution, which in turn can be used for future inferences. A uniform prior distribution is a symmetrical probability distribution in which all intervals (values), continuous or discrete, are equally probable. A discrete uniform distribution is a symmetric probability distribution in which a finite number of values all are equally likely.

Expert opinions can inform "priors" resulting in strong prior distributions, leading to less uncertainty in posterior distributions. The sequential collection of data to specify transitions from prior probabilities to posterior probabilities is an iterative process that can be time consuming, with posterior probabilities resulting from data collection in one period becoming the prior probabilities for the next period.

Bias: systematic deviation of the estimate from the true parameter of interest.

Biosphere Reserve (UNESCO): Biosphere reserves are sites established by countries and recognized under UNESCO's Man and the Biosphere (MAB) Programme to promote sustainable development based on local community efforts and sound science. As places that seek to reconcile conservation of biological and cultural diversity and economic and social development through partnerships between people and nature, they are ideal to test and demonstrate innovative approaches to sustainable development from local to international scales. See http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/

Biosphere Reserve (Sonora): The geologically unique El Pinacate y Gran Desierto de Altar Biosphere Reserve in Sonora is adjacent to the Cabieza Prieta National Wildlife Refuge and the Organ Pipe Cactus National Monument/Biosphere Reserve in the United States, thus forming an extensive, even if primarily arid land, protected area complex spanning the international Mexico-USA border.

Convergence: a condition in statistical modeling when the iterative process used to estimate model coefficients was unable to find appropriate solutions, indicating that the coefficients are not meaningful.

Core areas (U.S. Fish and Wildlife Service 2012): are the areas within a recovery unit for the jaguar with the strongest long-term evidence of jaguar population persistence. Core areas have both persistent, verified records of jaguar occurrence over time and recent evidence of reproduction.

Criteria for core areas:

1) Reliable evidence of long-term historical and current presence of jaguar populations.

2) Recent (within the last 10 years) evidence of reproduction.

3) Contains habitat of the quality and quantity that is known to support jaguar populations and is of sufficient size to contain at least 50 adult jaguars.

Core habitat (Sanderson and Fisher 2013): is all suitable habitat that has a modeled jaguar density (based on the relationship of the habitat suitability model with observed densities across the NRU) greater than or equal to 1 per 100 km^2, and has contiguous blocks of area capable of supporting 3 or more females.

Corridor: area connecting protected areas/source sites.

Critical habitat: is a specific geographic area(s) that contains features essential for the conservation of a threatened or endangered species and that may require special management and protection. Critical habitat may include an area that is not currently occupied by the species but that will be needed for its recovery.

Ejido: is an area of communal land used for agriculture, on which community members individually possess and farm a specific parcel. Ejidos are registered with Mexico's National Agrarian Registry (Registro Agrario Nacional).

Northwestern Jaguar Recovery Unit (NRU) (U.S. Fish and Wildlife Service 2012, Sanderson and Fisher 2013): The 226,826-km^2Northwestern Jaguar Recovery Unit (NRU) straddles the United States-Mexico Border with approximately 29,021 km^2 in the United States and 197,805 km^2 in Mexico.

Nuisance parameter: any parameter or variable which is not of immediate interest but which must be accounted for in the analysis of those parameters which are of interest. The classic example of a nuisance parameter is the variance, σ^2, of a normal distribution, when the mean, μ, is of primary interest.

Peripheral areas (U.S. Fish and Wildlife Service 2012): are those areas included in general range maps that are inhospitable to jaguars, rarely having jaguar presence, and almost never supporting jaguars in recent times (last 100 years).

Criteria for peripheral areas:

1) Few verified historical or recent records of jaguars.

2) Habitat quality and quantity is marginal for supporting jaguar populations. Habitat may be in small patches and not well-connected to larger patches of high-quality habitat.

3) May sustain short-term survival of dispersing jaguars and temporary residents.

Precision: the amount of scatter, or repeatability, of the estimate when made many times. An estimate can be precise, yet, due to bias, off-target (compared to true population value), generating inaccurate estimates.

Primary occasion: a duration of sampling, usually seasons or years, and subdivided into repeat visits to sample sites – so-called secondary occasions.

Primero Conservation: non-profit organization created to work with counterparts in Sonora to mitigate killing of carnivores and monitor fauna on cattle ranches near the confluence of the Aros and Bavispe Rivers (Moreno et al. 2013).

Prior distribution: is a key part of Bayesian statistical methods and represents the information about an uncertain parameter that is combined with the probability distribution of new data to yield the posterior distribution.

Ramsar Site: a wetland of international importance under The Convention on Wetlands (Ramsar, Iran, 1971), called the "Ramsar Convention". The Convention is an intergovernmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance and to plan for the "wise use", or sustainable use, of all of the wetlands in their territories. See http://www.ramsar.org/cda/en/ramsar-cop12-logo-homeindex/main/ramsar/1%5E26530_4000_0__ and http://www.ramsar.org/cda/en/ramsar-news-2rs-mexico/main/ramsar/1-26%5E25013_4000_0__

Recovery Units (National Marine Fisheries Service 2010): are subunits of a listed species that are geographically or otherwise identifiable and essential to the recovery of the species.

Secondary areas (U.S. Fish and Wildlife Service 2012): contain jaguar habitat with historical and/or recent records of jaguar presence with no recent record or very few records of reproduction. These areas are of particular interest when they occur between core areas and can be used as transit areas through which dispersing individuals can move, reach adjacent areas, and potentially breed. Jaguars may be at lower densities in secondary areas because of past control efforts, and, if future surveys document reproduction in a secondary area, the area could be considered for elevation to a core area.

Criteria for secondary areas:

1) Compared to core areas, secondary areas are generally smaller, likely contain fewer jaguars, maintain jaguars at lower densities, and contain more sporadic historical and current records. Evidence of occupancy may be weak or low because the area is not well surveyed, resulting in an unknown status of jaguars in these areas.

2) There is little or no evidence of recent (within 10 year) reproduction.

3) Habitat quality and quantity is lower compared to core areas.

State variables: variables that are used to quantify the current status of a community or population, including species richness (number of species), occupancy (proportion of an area occupied by a species or fraction of landscape units where the species is present), and density (number of individuals per unit area).

Suitable habitat: the area with a suitability index greater than 0, based on tree cover, terrain roughness, distance to water, human influence, and ecoregions (Sanderson and Fisher 2013).

Terrestrial conservation priority area: the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (National Commission for the Knowledge and Use of Biodiversity; CONABIO) has conducted gap analyses to identify priority areas for conservation. In the most recent review, experts combined high resolution species distribution modeling and maps, with weighted threats to biodiversity to generate maps of ranked terrestrial priority sites for conservation. There are a substantial number and area of high and extreme priority sites for conservation in the Mexico portion of the NRU (Urquiza-Hass et al. 2009).

Unidad de Manejo para la Conservación de Vida Silvestre (UMA): Management units under any ownership (private, ejido, communal, federal, etc.) established to help harmonize and mutually strengthen biodiversity conservation with the needs of production and socio-economic development in rural areas of Mexico. See http://www.semarnat.gob.mx/temas/gestion-ambiental/vida-silvestre/sistema-de-unidades-de-manejo and http://app1.semarnat.gob.mx/dgeia/informe_04/05_aprovechamiento/recuadros/c_rec1_05.htm

Uniform prior distribution: in Bayesian statistical methods, a prior distribution where all intervals of the same length on the distribution's support are equally probable.

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Appendix 2:
April 2014 Workshop Participants

Jaguar quantitative sampling and monitoring scientists and agency personnel contributing to the development of a jaguar survey and monitoring protocol at a workshop hosted by the Wildlife Conservation Society (WCS) in April, 2014, at the Ladder Ranch in Caballo, New Mexico.

Name	Title, Institution, and Location	Area of Expertise
Marit Alanen	Fish and Wildlife Biologist, U.S. Fish and Wildlife Service (USFWS), Tucson, Arizona	USFWS Project Manager
Carlos De Angelo	National Research Council, Instituto de Biología Subtropical, Universidad Nacional de Misiones, Puerto Iguazu, Argentina	Jaguars in Argentina, ecology and conservation, methods for large scale public monitoring of jaguars
Fernando C.C. Azevedo	Professor, Departamento de Ciências Naturais, Universidade Federal de São João del Rei, Brazil/Pantanal/Iguaçu	Jaguars in Brazil, ecology and conservation, human-jaguar coexistence
Jon Beckmann	Conservation Scientist/North America Connectivity Coordinator, Wildlife Conservation Society, Bozeman, Montana	Large carnivore ecology and connectivity, genetic and telemetry field sampling for population analyses
Melanie Culver	Assistant Professor, Wildlife and Fisheries Science, University of Arizona, Arizona Cooperative Wildlife Research Unit, Tucson	Jaguars in the southwestern U.S., application of population genetics to field programs
Kim Fisher	GIS Programmer, Wildlife Conservation Society, Bronx, New York	Jaguar habitat modeling throughout the NRU
Carlos López-González	Co-leader Jaguar Recovery Team/University of Querétaro, Mexico/Sonora	Jaguars in Sonora and Mexico, ecology and history of borderlands jaguars

Bart Harmsen	Fellow Wildlife Chair, Environmental Research Institute, University of Belize, Belmopan, Belize/Panthera/Belize/Mesoamerica	Jaguars in Belize, population estimation methods
Marcella Kelly	Associate Professor, Department of Fish and Wildlife Conservation, Virginia Tech University, Blacksburg/Belize	Jaguars in Belize, population survey methods, global carnivore ecology, genetic capture-recapture
Sean Matthews	Conservation Scientist, Wildlife Conservation Society, Bozeman, Montana	Carnivore ecology, population estimation and spatial ecology, human-carnivore coexistence
Rodrigo Núñez	Projecto Jaguar, Puerto Vallarta, Mexico/Jalisco	Jaguars in Jalisco and Mexico
Tim O'Brien	Senior Conservation Scientist and Biostatistician, Wildlife Conservation Society, Bronx, New York	Quantitative wildlife population survey design and modeling
John Polisar	Jaguar Conservation Program Coordinator, Wildlife Conservation Society, Bronx, New York	Jaguars throughout their range, monitoring, human-jaguar coexistence, protected area management
Octavio Rosas-Rosas	Professor, Programa de Manejo y Conservacion de Fauna Silvestre, Colegio de Postgraduados, San Luis Potosi, Mexico	Jaguars in Sonora, , human-jaguar coexistence
Eric Sanderson	Senior Conservation Ecologist, Wildlife Conservation Society, Bronx, New York	Jaguar habitat modeling throughout the NRU, jaguar database construction
Rahel Sollmann	Post-doctoral Associate, North Carolina State University, Raleigh/Brazil	Jaguars in Brazil, quantitative wildlife population survey design and modeling

APPENDIX 3:
SUMMARY OF THE APPLICATION OF TECHNIQUES

How are jaguars distributed across a study area? What are the extremely coarse patterns of their abundance?

- *Use single-season occupancy models using program Presence (McKenzie et al. 2002, 2006; see Presence-Absence and Occupancy)*

What proportion of an area is occupied by jaguars and their prey?

- *Use single-season occupancy models using program Presence (McKenzie et al. 2002, 2006; see Presence-Absence and Occupancy)*

What are the environmental and management factors that influence jaguar distribution and abundance in an area?

- *This requires the inclusion of potential covariates in occupancy analyses.*
    - *Use survey sign frequency and recorded environmental and management parameters in transect segments when using foot-travelled and sign-based surveys – by transect within grid cell (using models developed in Hines et al. 2010, and deployed by Karanth et al. 2011a, Sunarto et al. 2012; see Sign-based Occupancy Sampling for Jaguars)*
    - *Use remote-sensing-based parameters when using camera traps for occupancy (see Covariates subsection of Presence-Absence and Occupancy)*
    - *The abundance-induced heterogeneity (Royle-Nichols) models can be used for crude estimates of jaguar abundance (see Abundance-induced heterogeneity (Royle-Nichols) models subsection of Presence-Absence and Occupancy), but can also be used for crude estimates of prey abundance (see Occupancy Modeling for Prey Species) – which also then serve as a template to understand jaguar distribution and abundance (see Abundance and Density)*

What are the methods used to design and conduct adequate studies to measure trends in occupancy?

- *Use multi-season occupancy models using program Presence (McKenzie et al. 2003, 2006) to assess trends (see Measuring Trends in Occupancy), using single season pilot studies as input for power analyses, and conducting power analyses to evaluate effort needed to reach desired levels of confidence (see Power Analysis)*

What are the methods used to measure numerical jaguar abundance and density with confidence?

- *See Abundance and Density*
- *Use stationary camera-trap stations, following guidance in the text, and analyze using closed-population capture-recapture modeling: spatially explicit capture-recapture models (Gopalaswamy et al. 2012c, Royle et al. 2014)*
- *Use individually identified scats, following guidance in the text, then analyze using closed-population capture-recapture modeling via non-spatially explicit models, or spatially explicit capture-recapture models assigning scats located by search encounter into a grid system, thus transforming them into spatially stationary units, or via new models in development (Royle et al. 2011)*
- *Combine camera trap and genetic individual identifications (e.g, Gopalaswamy et al. 2012b)*

What are the methods for measuring trends in abundance and density over time?

- *See Measuring Trends in Abundance/Density*
- *Use non-spatially explicit robust-design open population capture-recapture modeling (Pollock 1982, Pollock et al. 1990, Kendall and Nichols 1995, Kendall et al. 1997) implemented in the program MARK (White and Burnham 1999)*
- *Use open SECR capture-recapture models formulated in the WINBUGS language (in development in 2014 – e.g. Gardner et al. 2010, Royle et al. 2014)*

What are the methods for managing camera trap data?

- *We provide guidance on the options for data recording for occupancy studies (see Data Recording subsection in Presence-Absence and Occupancy), and abundance and density studies (see Data Recording subsection in Abundance and Density), including recommendations on how to structure templates and design systems for efficient entry and retrieval/uptake for occupancy and density analyses*

What are the methods for assessing jaguar demography, the patterns of survival and recruitment in my study area?

- *See Demographic Parameters and Spatial Ecology*
- *Design and commit to long-term research sites*
    - *Use multi-year camera-trap data in conjunction with non-spatially explicit open population modeling repeated over years (Pollock 1982, Pollock et al. 1990, Karanth et al. 2006, 2011b, Pollock et al. 2012)*

        - *Analyze capture-recapture data using program MARK (White and Burnham 1999)*
        - *Follow Karanth et al. (2011b) using the Cormack-Jolly-Seber model (Cormack 1964, Jolly 1965, Seber 1965) and Pollock's robust-design model (1982) to nest discrete closed population samples in an open long-term analysis to estimate survival and recruitment*
        - *Use hierarchical spatial capture-recapture models using WINBUGS (Gardner et al. 2010)*
    - *Use long-term known-fate collar data from at least 50-100 animals for survival analyses using the following models*
        - *Staggered entry Kaplan-Meier "known fates" option in MARK*
        - *Cox proportional hazard model (Cox 1972, Venables 1994, Riggs and Pollock 1992)*

What are the methods to use radio-telemetry to understand demographic parameters, dispersal, home range, and general spatial ecology of jaguars in a study area?

    - *See Home Range and Spatial Ecology*
    - *Frame research questions, study size and duration, and budget, then evaluate which vendors offer telemetry equipment adequate to address the questions. High initial investments lead to lower costs overall because failures are less frequent and study objectives are met. Demographic parameters will require large samples and multiple years to be meaningful, and any aspect of animal ecology requires time, so be prepared for years of research and plan accordingly*
    - *Use home-range estimators that produce a utilization distribution describing the intensity of use of different areas*

- What are the methods used to obtain information about dispersal and long-distance movements?
    - *See Dispersal and Long-Distance Movements*
    - *This requires reliable telemetry equipment and a plan for a very large-scale study (Elbroch et el. 2009, Fattebert et el. 2013; see Home Range)*
    - *Genetic tools can also be used to evaluate dispersal and long-distance movements (Gour et al. 2013, Forbes and Boyd 1996). See our section Population Genetics for technical advice and recommendations on collecting and processing samples*

- What are the methods used to evaluate patterns of habitat selection by jaguars in a study area?
    - *See Habitat Selection*
    - *In large-scale camera-trap-based occupancy sampling, remote sensing covariates provide abundant information about factors which may influence jaguar distribution (see Covariates subsection in Presence-Absence and Occupancy)*
    - *When environmental characteristics are recorded along segments of transects used for sign-based occupancy surveys for jaguars, the data can be used to model jaguar habitat selection (Sunarto et al. 2012; see Sign-Based Occupancy Sampling for Jaguars)*
    - *When environmental parameters are recorded at each camera station in a capture-recapture study for jaguars, that data can be used for an analyses of habitat selection (Apps et al. 2006)*
    - *In large-scale telemetry studies, remote sensing can provide useful covariates to test as crude environmental characteristics influencing how jaguars use space (see Covariates subsection in Habitat Selection); however, there are ways to improve these analyses – the "habitat" data should be collected on the same time frame and on a similar level of resolution as the jaguar location data*
        - *Sign-based prey occupancy sampling described in Gopalaswamy et al. (2012a) can be used to model the fine-grained patterns of prey distribution and abundance across the study area*
        - *Distance sampling (Buckland et al. 2008) can be conducted along linear foot transects distributed across vegetation types in the study area for a high-resolution assessment of total prey abundance and biomass, and also to provide a foundation for comparative value of habitats in terms of prey resources*
    - *We recommend that the fine grained real-time data obtained through telemetry be matched with vegetation and prey distribution data of similar resolution to maximize understanding of the habitats and resources selected by study animals (see Conclusion subsection in Habitat Selection)*
- What information is available in population genetics data and how are samples collected and processed?
    - *Population genetics reveals patterns of gene flow within and among landscapes that cannot be discerned by any other method (Andreasen et al. 2012). Beyond*

invisibly tracking relatedness inside individual jaguar conservation units, or across huge sections of jaguar range, population genetics analyses also provide estimates of heterozygosity, potential inbreeding, sub-division among populations, and increase our understanding of the evolution of the species on a range-wide scale (Eizirik et al. 2001, 2008, Ruiz-Garcia et al. 2009)

  - *We provide technical advice on Jaguar Scat Collection, sampling using scat-detection dogs, laboratory genetic methods, and analysis of jaguar scat genetic data*

- How are jaguar data recorded, stored, and processed on a large scale, e.g., the NRU, or range wide?

  - *Based on experience gained developing testing a platform for the entire NRU, we offer general and global recommendations on data capture and curation, offering recommendations on data collection and export, standardization and aggregation, and editing and ingestion*

- How can we monitor the status of jaguars in the NRU and range wide?

  - *We summarize the recommendations generated by our team in the section Recommendations and Guidelines for Northwestern Recovery Unit and Beyond*

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APPENDIX 4:
DIRECT JAGUAR AND PUMA OBSERVATIONS

Nº: ______ **DIRECT JAGUAR AND PUMA OBSERVATIONS**

TO DESCRIBE THE ANIMAL/S	***Jaguar*** ❐		***Puma*** ❐	**TO DESCRIBE DE PLACE**
	Other: ____________________			**Location**
Color				
Size				**GPS:** _______________/_______________
Other characteristics				**Place characteristics**
Number of	*Male*	*Female*	*Unknown*	
Adults				
Juvenile				**Weather conditions**
Cubs				

TO DESCRIBE THE OBSERVATION	**Date**	**Time**	**Term**	**Distance to the animal**	**Comments of the observer**
Other information collected	*Tracks*	*Feces*	*Other*		

Direct observer	**Complete name**	**Post address / e-mail**	**Phone**

Person that complete the sheet	**Complete name**	**Phone / e-mail**	**Comments of the collaborator**	

Nº: _____

DIRECT JAGUAR AND PUMA OBSERVATIONS

TO DESCRIBE THE ANIMAL/S	***Jaguar*** ❐		***Puma*** ❐	**TO DESCRIBE DE PLACE**
	Other: ____________________			**Location**
Color				
Size				**GPS:** _______________/_______________
Other characteristics				**Place characteristics**
Number of	*Male*	*Female*	*Unknown*	
Adults				
Juvenile				**Weather conditions**
Cubs				

TO DESCRIBE THE OBSERVATION	**Date**	**Time**	**Term**	**Distance to the animal**	**Comments of the observer**
Other information collected	*Tracks*	*Feces*	*Other*		

Direct observer	**Complete name**	**Post address / e-mail**	**Phone**

Person that complete the sheet	**Complete name**	**Phone / e-mail**	**Comments of the collaborator**	

Nº: ______

FICHA DE REGISTRO DE AVISTAJES

CARACTERÍSTICAS DEL ANIMAL	***Yaguareté*** ❐	***Puma*** ❐		**CARACTERÍSTICAS DEL LUGAR**
	Otro: ____________________			**Ubicación**
Color				
Tamaño				**Punto GPS:** ______________/______________
Señas particulares				**Características del lugar**
Cantidades	*Macho*	*Hembra*	*Desconocido*	
Adulto				
Juvenil				**Condiciones del tiempo**
Cría				

DESCRIPCIÓN DEL AVISTAJE	**Fecha**	**Hora**	**Duración**	**Distancia del observ.**	**Comentarios**
Anexos al registro	*Huellas*	*Heces*	*Otros*		

Datos del observador directo	**Nombre completo**	**Dirección postal / e-mail**	**Teléfono**

Datos del tomador del registro	**Nombre**	**Teléfono / e-mail**	**Comentarios del tomador del registro**	

Nº: _____

FICHA DE REGISTRO DE AVISTAJES

CARACTERÍSTICAS DEL ANIMAL	***Yaguareté*** ❐	***Puma*** ❐	
	Otro: ____________________		
Color			
Tamaño			
Señas particulares			
Cantidades	*Macho*	*Hembra*	*Desconocido*
Adulto			
Juvenil			
Cría			

CARACTERÍSTICAS DEL LUGAR
Ubicación
Punto GPS: ______________/_____________
Características del lugar
Condiciones del tiempo

DESCRIPCIÓN DEL AVISTAJE	**Fecha**	**Hora**	**Duración**	**Distancia del observ.**	**Comentarios**
Anexos al registro	*Huellas*	*Heces*	*Otros*		

Datos del observador directo	**Nombre completo**	**Dirección postal / e-mail**	**Teléfono**

Datos del tomador del registro	**Nombre**	**Teléfono / e-mail**	**Comentarios del tomador del registro**	

APPENDIX 5: COLLECTING DATA ON TRACKS AND SCATS

Sheet to photograph next to the footprints

JAGUAR AND PUMA TRACKS

Track Num.: ___ ***Date:*** _____/_____/______

Place: ____

GPS: ____________________/____________________

Collector: _____________________________________

Notes: ____

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**

Label to stick on paper bags to collect feces

FECES OF JAGUARS AND PUMAS

Sample N°: ___. ***Date:*** / / .

Place: .

GPS: / .

Collector: ____.

To describe the place: **river/stream – marsh**

near a house or building – forest – shrubs

pastures – crops – road – trail

Notes: _.

____.

____.

____.

Keep in a dry, ventilated place until process the sample

Ficha para fotografiar junto a las huellas

HUELLAS DE JAGUAR Y PUMA

Nro. Huella:Fecha: _____/_____/____

Lugar: ____________________________________

Punto GPS: ________________/_______________

Colector: _________________________________

Observaciones: ___________________________

1	2	3	4	5	6	7	8	9

Etiqueta para pegar en las bolsas de papel para colectar heces

COLECTA DE HECES DE JAGUAR Y PUMA

Nro. Muestra: __ . ***Fecha:*** // .

Lugar: _ .

Punto GPS:_____/___.

Colector:____ .

Tipo de Ambiente: **río/arroyo – bañado**

cerca de vivienda – bosque/selva – arbustal

potrero – cultivo – camino – sendero

Notas: _.

____.

____.

____.

Mantener en un lugar seco y aireado hasta procesar la muestra

APPENDIX 6:
EXAMPLE CAMERA SETUP DATA SHEET

SITE: HILL BANK-Rio Bravo Conservation & Management Area
May-August 2012 - CODE 4RBHB2012 - Jaguar Survey

Station	Camera #s	Physical location	Date (m/d/y)	GPS location Easting (UTM X)	GPS location Northing (UTM Y)	Road (R), Trail (T), New Trail (NT), Game Trail (G), Skid Road	Width of road or trail (m)	Distance from Camera to middle of road or trail (m)	Canopy cover (%) at station **	Land use ***	Habitat type ****	Notes
4RBHB 01												
4RBHB 02												
4RBHB 03												
4RBHB 04												
4RBHB 05												
4RBHB 06												

* Human use: very high = >1 per day, high = 4-7/week, med= 1-3/week, low = < 1/week, zero = only camera work. ** Canopy cover: 0 = 0-10 %, 10 = 10-20%, 20 = 20-30%, 30 = 30-40%, 40 = 40-50%, 50 = 50-60%, 60 = 60-70%, 70 = 70-80%, 80 = 80-90%, 90 = 90-100%. ***Land use: P pasture, C crops, PL plantation, PA protected area, PR Private Land, R roads, BA built up area. ****Habitat: FB broadleaf forest, FP palm forest, G grassland, B brushland, WG wooded grassland, M mangrove, FS Fresh water swamp, SS saline swamp, R riverine, P Playa (beach) (/transition between types)

APPENDIX 7:
EXAMPLE CAMERA CHECKING DATA SHEET

Site: Rio Bravo Conservation and Management Area - Hill Bank: 4RBHB - May 2012 - August 2012 - Jaguar survey

Survey Name: Check mark for things checked, Y or N for answers, dash for things not needing checking

Station Code RBHB = Hill Bank RBLM = La Milpa	Camera type & number BSS = BLK Moultrie MTD = Camo Moultrie RM = Reconyx RM45 HC = Reconyx HC500	Init camera checkers	Today's Date (m/d/y)	Trigger with station #, camera #, and date on display card	# Pics taken	Open camera, press off button, remove card	Battery level % for digital cameras	Change Batteries? Yes (Y) NO (N)	Which batteries changed? AAs, Cs, Ds	Card swapped out? Yes (Y) or No (N)	Digitals on still picture mode (S) or video mode (V)	Image Quality? High (H), Med (M), Low (L)	Event Delay in minutes	# pictures per event	Check date/time stamp on camera- is it correct?	Clean O-rings (camera seal) with cloth or alcohol prep pad	Clean lens cover, flash cover, and sensor cover	Set, lock, and reposition	Make sure camera is on (AUTO for MTs or switch for REs)	Trigger with station #, camera #, and date on display card	Notes - include anything out of the ordinary, damage to cameras by animals, suspected malfunctions, physical location if you change a camera location etc.
4RBHB																					
4RBHB																					
4RBHB																					

Appendix 8:
Example Camera Test Card

Date: ________________________________

Camera
Station: ________________________________

Camera ID: ____________________________

APPENDIX 9:
EXAMPLE PHOTO-CAPTURED JAGUARS DATA SHEET

Jaguars: Firbeburn Reserve, Belize

J90 **Male** **J91** **male**




date	time	x-location	y-location	place	date	time	x-location	y-location	place
08/07/07	14:56	0377210	2009269	C6	08/03/07	9:49	0375193	2007569	C10
08/09/07	21:03	0375193	2007569	C10	08/03/07	9:10	0375027	2005851	C16
07/31/07	22:35	0375193	2007569	C10	09/02/07	14:49	0374202	2004163	C22
08/04/07	6:59	0375193	2007569	C10	07/31/07	21:13	0374202	2004163	C22
08/28/07	7:29	0369451	2000916	C11					
08/01/07	9:05	0370319	2003233	C14					
08/04/07	7:41	0375027	2005851	C16					
08/09/08	20:23	0375027	2005851	C16					
08/15/07	14:31	0375027	2005851	C16					
08/31/07	21:56	0375027	2005851	C16					
08/04/07	8:26	0374202	2004163	C22					
08/08/07	15:12	0374202	2004163	C22					
08/09/08	19:42	0374202	2004163	C22					
09/13/07	14:36	0374202	2004163	C22					
08/28/07	14:39	0374202	2004163	C22					
06/30/07	8:13	0375043	2012516	N5					
05/22/07	22:54	0374354	2013205	N13					

APPENDIX D: Genetic monitoring of jaguar populations for downlisting or delisting

As stated in the recovery plan, two of the criteria for downlisting [delisting] include that "over 15 [30] years (about 3 [6] jaguar generations),

(1) genetic distance between the Sonora and Jalisco Core Areas does not significantly increase,
(2) genetic distance between the Jalisco Core Areas and the nearest population in central Mexico does not significantly increase, <u>and</u>
(3) inbreeding coefficients (F_{IS}, G_{IS}, or another appropriate measure of population inbreeding) within each of the Sonora and Jalisco Core Areas do not significantly increase."

This appendix describes procedures for the genetic monitoring needed to meet these two criteria. The procedures described below provide a description of a highly thorough genetic sampling of the NRU region. However, the key sampling and analyses in response to downlisting and delisting criteria are provided in #6 and #7. The procedures used to generate genetic data and make inferences from them are continually evolving. Therefore, the procedures described herein are subject to revision as more powerful approaches to understanding population genetics become available.

All raw data from these monitoring efforts should be made publicly available in a timely fashion so that independent scientists can also evaluate the data and make inference from them.

Protocol to monitor genetic distances and inbreeding coefficients

1. Within each Core Area, collect DNA-bearing tissue from individual jaguars within a sampling period of five years (one generation), attempting to sample evenly across the Core Area.

    - *How many individuals must be sampled?* The sample size will have to be large enough to disprove the hypothesis of "Genetic distance between Core Areas has increased over time." We recommend equivalence testing (#7 below) because it allows managers to sample "just enough" to justify downlisting or delisting, rather than achieving an arbitrary sample size. The first samples can be used to estimate the number needed, keeping in mind that many current genetic analysis algorithms use Bayesian statistics, and with Bayesian genetic analyses, 40 samples are required from each sampled population to achieve statistical significance.
    - *Why sample evenly across the Core Area?* In the presence of isolation by distance, clumped sampling with large gaps in sample distribution can give rise to spurious inferences of population subdivision.
    - If tissue samples are of a type that cannot readily be attributed to individual animals at the time of collection (e.g., fur samples from hair snares or scat), many

samples must be collected to ensure that enough individuals are represented, as some individuals are likely to be represented multiple times. Similarly, if tissues with low-quality DNA (e.g., scats) are used, many samples must also be collected to yield sufficient sample size with usable DNA, as some samples with degraded DNA are unusable.

2. For each sample, determine the individual's genotype across at least 13 variable (frequency of the most common allele < 0.90) and independent felid microsatellite DNA markers, or a large number of single nucleotide polymorphisms (SNPs).

    - *Why microsattelites?* An ideal monitoring program would monitor diversity in genes that affect phenotype and fitness (Sherwin and Moritz 2000). However, it is difficult to identify the portions of the genome most relevant to survival and reproduction. As a more feasible strategy, this protocol monitors microsatellites (molecular markers that are believed to be undergoing neutral evolution). The strategy outlined here relies on an assumption that rates of loss of neutral genes reflect rates of loss of adaptive genes. Thus, our proposal to monitor neutral genetic variation is probably comprehensive and reliable. As an alternative marker choice, SNPs include both neutral and adaptive genetic information, and typically hundreds to thousands of SNPs are available from a single marker development procedure. SNPs may be useful markers for the purposes outlined here if they have been tested and developed for jaguars in the future. Additionally, this monitoring protocol can be replaced by a protocol that monitors changes in adaptive genetic variation, if that becomes practical in the future. Finally, mitochondrial DNA evolves at a slower pace, and thus would be less suitable for this monitoring purpose.
    - *Why a minimum of 13 microsatellite markers?* This number should provide sufficient statistical power to distinguish between individuals and even siblings. Eizirik et al. (2008) and Haag et al. (2010) reported that 13 microsatellite markers were highly variable in jaguars in other portions of the species range. If increased statistical power is needed (see #7), managers can increase the number of microsatellite markers, the number of jaguars sampled, or both.

3. Report expected and observed heterozygosity, number of alleles, number of private alleles, and allelic richness within each Core Area and across Core Areas. Compare these values to those for other jaguar populations. If genetic diversity is much lower than in other jaguar populations, consider whether additional recovery actions to increase genetic diversity may be warranted.

4. Use genetic information to adaptively revise this monitoring protocol, and if necessary, to revise the recovery criteria. The team presumes that there is one core area in Jalisco, one core area in Sonora, and no core areas in the Secondary Area between the Jalisco core and the Sonora core. Genetic sampling and surveys in the Secondary Area may reveal the existence of additional jaguar core areas. Such information should be use to adjust this monitoring protocol, and perhaps the recovery criteria. Specifically, we recommend:

- Use genetic clustering techniques to determine if there are genetically distinct subpopulations within a Core Area.
- Use spatial and non-spatial assignment tests to assign individuals to source populations and infer movement rates between Core Areas or between newly-discovered subpopulations within putative Core Areas.

5. Calculate genetic distance and the standard error of the estimate between each pair of Core Areas using F_{ST}, G_{ST}, or another appropriate measure of genetic distance. Genetic distance ranges from 0 (complete similarity) to 1 (complete difference).

6. Using the same data, calculate an inbreeding coefficient within each Core Area using F_{IS}, G_{IS}, or another appropriate measure of population inbreeding. The inbreeding coefficient ranges from 0 (complete outbreeding) to 1 (completely inbreeding).

7. Repeat these procedures in preparation for proposed downlisting or delisting.

   A. Determine whether inter-core genetic distances have remained stable for at least 15 years (downlisting) or 30 years (delisting). Use equivalence testing (Parkhurst 2001) to reject the one-tailed hypothesis that "Inter-core genetic distances have increased by at least N% (where N% is the minimum important effect size (MIES), or 5-25% (see below))" at $p < 0.05$. Unlike a standard test of a null hypothesis, equivalence testing puts the burden of proof on proponents of delisting (they must prove that connectivity has not been degraded), thus creating an incentive to carry out a statistically powerful sampling effort. In contrast, a less robust sampling effort with low statistical power could be interpreted as supporting the tailed null hypothesis that "connectivity has not changed over time." The program GENETIX (Belkhir et al. 2004; www.genetix.univ-montp2.fr/) uses permutation procedures to calculate exact probability values of departures from a hypothesis. Although normally used to test null hypotheses, these procedures can be adapted to equivalence testing.

   B. Determine whether the inbreeding coefficients within each Core Area have remained stable for at least 15 years (downlisting) or 30 years (delisting). As with genetic distance, use equivalence testing because it requires that the sampling effort will be sufficient to disprove the hypothesis that inbreeding coefficients have increased by more than N% at $p < 0.05$.
      - *What is the minimum important effect size?* Even if there were no barriers to gene flow between the Core Areas, genetic drift and isolation by distance are inevitable, especially given the low population densities of jaguars; thus "no increase in genetic distance or inbreeding coefficients" would not be reasonable criteria. We suggest that the most appropriate minimum important effect size (MIES) should be somewhere between 5% and 25%. For genetic distance, a MIES of N% means that an increase of N% or more in genetic distance is considered "important" to conservation of jaguars, and that an increase of < N% is considered "equivalent" or "acceptable." There is no consensus among conservation geneticists about what absolute levels of genetic distance, or what levels of relative increase in genetic distances, are acceptable. If genetic distances

are small (e.g., $F_{ST} < 0.05$) at the start of the monitoring period, a 25% increase (e.g., from 0.04 to 0.05) might be a reasonable MIES. If genetic distance is large (e.g., $F_{ST} > 0.2$) at the start of monitoring, an increase of 5% (e.g., from 0.50 to 0.525) would be a more appropriate MIES. The same logic applies to inbreeding coefficients. At the time delisting is proposed, the most defensible minimum important effect size (or the most defensible level of maximum genetic distance) should be used, reflecting advances in scientific understanding between now and then.

- *Can downlisting or delisting occur if samples are taken only at two points in time (at least 15 or 30 years apart, respectively)?* Yes. Nonetheless, the recovery team recommends more frequent sampling (ideally every five years) to detect changes in connectivity between, and inbreeding within, Core Areas, or potential genetic erosion, in a more timely fashion.
- *What if statistical power is too low to disprove the hypothesis that genetic distance has increased?* Statistical power can be improved by increasing the number of jaguars sampled or increasing the number of genetic markers used, or both. Because the number of jaguars sampled during the baseline period (approximately now) cannot be increased at the time of proposed downlisting or delisting (about 15 or 30 years from now), it would be wise to collect tissues from a large number of jaguars (well over 30 per Core Area) during the baseline period. The number of genetic markers can be increased at a future time if the tissues from the baseline period are safely stored, and additional genetic markers have been developed by the time these additional genetic tests are needed (at downlisting or delisting).

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APPENDIX E: Jaguar Habitat Modeling and Database Update (Sanderson and Fisher 2013)

Jaguar Habitat Modeling and Database Update[c]

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Summary

All project objectives and outcomes, as outlined below, were accomplished, including revising the jaguar database and habitat model created in 2011 in coordination with the technical subgroup of the Jaguar Recovery Team (JRT). We updated the database with additional observations obtained since July 2011 through July 2012, conducted analyses of how different selections of jaguar "events" (as explained herein) influenced the choice of habitat variables, and produced five revised versions of the habitat model (designated versions 9 – 13 below). For each version, under the advice of the JRT, we selected habitat variables, constructed a simple habitat model, and translated that habitat model into potential carrying capacity in northern Mexico and the southwestern United States (over the area designed as the "Northwestern Recovery Unit" or NRU, described herein). Model versions were revised in each case to match the expert assessments of the JRT regarding the current status of jaguars in the NRU. The final habitat model (version 13) suggests a potential carrying capacity of more than 3,400 jaguars over an area of over 226,000 square kilometers. This capacity can be further broken down into smaller geographic areas or "subunits" of the NRU which, from south to north, may have the potential to contain: ~1,318 jaguars in the Jalisco Core Area, ~929 jaguars in the Sinaloa Secondary Area, ~1,124 jaguars in the Sonora Core Area, and ~42 jaguars in the Borderlands Secondary Area. Note that current populations are substantially below these carrying capacities, but are not zero according to recent observations in all four subunits. Accompanying this report is a data package consisting of a CD containing GIS files and a revised Microsoft Access database described below.

Project Objectives and Outcomes

The overall objective of this project was to assist the U.S. Fish and Wildlife Service (FWS) in digital mapping aspects of recovery planning for the northern jaguar. For this round of database and habitat model updates, the Wildlife Conservation Society (WCS) agreed to:

1. Prior to the technical subgroup meeting: coordinate with the JRT leaders and Arizona Ecological Services Office – Tucson (AESO) prior to the technical subgroup on task items as described in the Performance Work Statement; provide an initial audit of the FWS jaguar location database; input additional jaguar locations provided by FWS; with the JRT and AESO, develop criteria for "Class I" jaguar records and possible selections deemed useful; and create fields in the database for rapid application and extraction of records using criteria from the technical subgroup meeting.

[c] Final report to the USFWS in response to Solicitation F12PS00200, submitted March 12, 2013.

2. At the technical subgroup meeting (April 24 – 26, 2012): attend and advise the technical subgroup meeting; based on input from the technical subgroup, identify potential errors in and revise the jaguar location database; and re-run the habitat modeled developed last year, as described in Sanderson & Fisher (2011).
3. Prior to the full recovery team meeting: coordinate with the JRT and AESO on follow-up from the technical subgroup meeting; input additional locations identified by the technical subgroup; complete the audit of the jaguar database; revise the previous habitat model and prepare presentations for the full recovery team meeting; and make calculations and summaries from the model and database as instructed by the JRT and AESO.
4. At the full recovery team meeting (July 31 – August 2, 2012): attend the full recovery team meeting; present the audited revised database and revision of the habitat model; and lead the recovery team in developing a new habitat model.
5. Following the full recovery team meeting: prepare a final report describing the audited and revised database and the new JRT habitat model; and, with the report, deliver an audited and revised database and JRT habitat model by DVD to AESO office within 15 days of receiving comments.

Objective 1: Preliminary database audit and additions and criteria

Eric Sanderson and Kim Fisher had a conference call with Erin Fernandez, Marit Alanen, Howard Quigley, and Carlos López González on April 13, 2012 to discuss the Performance Work Statement.

In prior work WCS created a jaguar "event-record" database based on input from the JRT (Sanderson and Fisher 2011). An event refers to the experience of a person observing a jaguar. Events happen at a given place, at a given time, and vary in kind. Kinds of events include mortalities (when a person kills a jaguar), sightings (when a person observes a jaguar), observations of scat or sign attributed to a jaguar, or no observations (when a qualified person looks for a jaguar but does not see one). Events result in a memory on behalf of the observer(s) and may also result in physical evidence (like a skull, skin or photograph). Events are also commonly recorded, resulting in a record. A record is a written, graphical or verbal account of a jaguar event. Written records occur in newspapers, books, scientific journals, and ideally can be cited and rest in the public domain. Graphical records include photographs, paintings, or other human created representations of a jaguar (like a figurine of a jaguar). Verbal records are accounts of the event, either by someone with firsthand experience, or someone who heard the story from someone else.

In the event-record database, each record is described according to a standard set of fields (see Sanderson and Fisher 2011), and then assigned to an event. The same event can have multiple records, derived from different bibliographic references, and often with slightly different versions of the event, different levels of precision, and so forth. At the level of the event, the best available scientific information is summarized with a pre-defined classification system to describe the most precise locality, date, identity, and evidence associated with that event (described in Appendix 1 and explained below). Collecting the data in this structure enabled the JRT to have a fine level of control over which events (and via the event, which records) were admitted into the habitat analysis described below.

Based on feedback from the FWS and JRT, we audited the previous jaguar event-record database, correcting a number of typographical errors and two locations related to the 1996 and 2006 Glenn records.

We added these additional data to the database:

- 186 records of track and camera trap photos of jaguars from the studies reported in McCain & Childs (2007), with data provided to FWS by the Arizona Game and Fish Department
- 1 photograph record from the Ajos Bavispe Reserve in Sonora forwarded by Carlos López González

Objective 2: Revise database and habitat model at technical subgroup meeting

Kim Fisher attended the technical subgroup meeting on April 24 – 26, 2012, in Tucson, Arizona. Eric Sanderson participated by phone for portions of the meeting. Fisher presented a review of the database and habitat model developed by WCS and the JRT in 2011, as described in Sanderson and Fisher (2011).

<u>Further revisions of the jaguar event-record database</u>

The technical subgroup did not identify any errors in the database. However they did reveal additional sources of records from camera traps and telemetry to be included in the analysis, and they requested a different treatment of camera trap and radiotelemetry observations in the event-record framework. Camera trap and radiotelemetry studies often have many locations of the same animal in close proximity in time and in space. It was recognized that to include each camera trap record or each radiotelemetry record as a separate event could create pseudo-replication and bias the resulting habitat model. To avoid this problem, the technical subgroup advised us to apply the following rules:

- For camera trap studies, to create a single record for each individual camera trap location that assimilates all observations made over time at that location (i.e., to generate only one event per camera trap location).
- For radiotelemetry studies, to create a single event for all telemetry locations for a single animal more than 3 km from other observations.

<u>Application of the revised event-record database to the habitat model</u>

At this meeting, the subgroup discussed how to select jaguar events for use in the habitat model. In terms of scientific analysis and recovery planning, it is desirable to have high confidence in the event locations used for habitat modeling. It is also important to understand how different selections of events lead to different habitat maps. To deal with the issue of confidence in a systematic way, previous work by the Arizona Game and Fish Department, the New Mexico Department of Game and Fish and the Arizona-New Mexico Jaguar Conservation Team adapted a system developed by Tewes and Everett (1986) for ocelot and jaguarundi for the jaguar. For example, in the Jaguar Recovery Outline (FWS 2012), these classes are defined as:

- Class I records include those records [note that “record” in this context is analogous to the term “event” as used in this report] with physical evidence for verification. Class I reports are considered “verified” or “highly probable” as evidence for a jaguar occurrence.

- Class II records have detailed information of the observation but do not include any physical evidence of a jaguar. Class II observations are considered “probable” or “possible” as evidence for a jaguar occurrence.

- Class III reports are considered unreliable as account details are vague, observer reliability is questionable and/or the animal described is something other than an ocelot, jaguar or jaguarundi.

The technical subgroup recognized and discussed some difficulties in applying these particular definitions across the entire NRU (see Figure 1) and over the full length of the data record in a consistent manner. For example, many jaguar events, especially pre-1970 observations in the United States and nearly all the observations in Mexico, do not have physical evidence that can be verified by a third party. Typically such verification requires a photograph, DNA evidence, or museum voucher specimens (e.g., a skull or skin). Using only events with a verifiable voucher specimen or photograph would strongly bias the observations set to those made since 1970.

There are also problems with establishing a precise geographic location and a precise date associated with each event from the available records. Although most recent records may have modern global positioning system (GPS) locations, prior to 1990 such locational accuracy is rare. For older records, and therefore events, locations are assigned based on locality name (e.g., Santa Rita Mountains, Pima County, etc.). Exacerbating the problem from the perspective of database quality and analysis, some record locations and dates may be obscured by government agencies and/or data compilers who fear that releasing precise locations may lead to harm to the animal. For example, state agencies often report to the public observations only within the nearest mountain range or county. Also, historical observations may have more generalized locality descriptions according to the conventions of geographic naming at the time the observation was made or use names that are no longer recognized.

There may be questions related to what kind of animal is actually observed (as suggested in the definition of Class III above). Observations of “large black cats” are relatively common, but probably rarely represent jaguars, especially in recent times. Other wild animals, including mountain lions, coyotes, and bears, even large domestic dogs may be mistaken for jaguars in poor light. Without corroborating evidence it is difficult to verify that what was seen was actually a jaguar, especially for records of jaguars from the historical record.

The technical subgroup recognized the value of treating these different kinds of information systematically, so that intelligent and consistent selections can be made of jaguar events for use in habitat modeling. In the event-record database framework, every event (based on compilation of one or more records) is attributed a code reflecting the precision of that event’s:

- Geographic precision (e.g., point location with geographic coordinates, a named place, a named county, etc.)
- Date precision (e.g., an exact date, a month within a year, a season within a year, within a decade, etc.)
- Identification accuracy (e.g., did the observe describe it as a jaguar, or a large cat, or some other animal)
- Evidence type (e.g., was there any physical evidence? If so, what kind was it?)

Appendix 1 describes this system of attribution for these database fields.

After extensive discussion, the technical subgroup decided to define a subset of events for inclusion in the NRU habitat model for which they had confidence reflected reliable jaguar records. These events had to meet all of the following criteria (the full set of codes is provided in Appendix 1):

- Have localities that are defined by geographic coordinates (e.g., from a GPS) or come from a determined area, with locality descriptions sufficient to place the location with certainty within 10 km of its actual location. [Locality type code < 3]
- Have a date, at least to the nearest century. [Date type code < 11]
- Have been attributed specifically to a jaguar. [Identity code = 1]
- Some evidence. The technical subgroup considered three different filters by evidence type:
    - Evidence Filter 1: "Physical evidence only": use events with evidence types 4, 6 and 7 and 8 only (physical evidence other than fossils).
    - Evidence Filter 2: "Physical and sign evidence": use events add evidence types 13, 14, and 98 (tracks and kills) to the above.
    - Evidence Filter 3: "All evidence types" scenario: include every evidence type from 0-99 (see Table 1.4 in Appendix 1 for full list).

Application of the new filters yielded 102 events for Filter 1, 128 events for Filter 2, and 203 events for Filter 3. The other criteria were all the same.

At the technical subgroup's direction, the WCS team analyzed these three different filtered subsets of the event localities with respect to geographic data on tree cover, terrain ruggedness, human influence, and distance from water (Table 1; described below). These factors were determined by the JRT to be important factors in jaguar habitat during the previous year's work (Sanderson and Fisher 2011; also see below).

We produced histograms showing the frequency distributions of these variables for each filtered set of events, as shown in Appendix 2. The goal was to discover if varying the selection resulted in a different selection of habitat variables to be included in the habitat model. In all three filtered subsets, the overall patterns in frequencies of observation relative to habitat factors were similar, i.e., the selection of event localities did not produce qualitatively different selection of habitat variables (Appendix 2). The technical subgroup hypothesized that this result accords with their expert opinion because jaguars are habitat generalists – in general, the definition of jaguar habitat is cover, prey, and limited human persecution within the NRU. For the habitat modeling it was decided to use all the criteria above and evidence filter 3, because that resulted in the largest number of events for inclusion in the model. Having made this determination, the technical subgroup moved to considering revisions to the jaguar habitat model within the NRU.

<u>Habitat Model</u>

The purpose of the habitat model is to determine potential areas of jaguar habitat and make an estimate of the potential carrying capacity of various subunits of the NRU (Figure 1).

The jaguar habitat modeling approach for the NRU follows a variant of the Hatten et al. (2005) method as described in Sanderson and Fisher (2011). Previously, the JRT determined a set of habitat factors to characterize potential jaguar habitat. They include: percentage of tree cover, ruggedness index, human influence, ecoregion, elevation (some model versions only, see below) and distance from water. Sources of geographic data describing these habitat factors are listed in Table 1.

Table 1. Data sources for habitat factors for the recovery team potential jaguar habitat model.

Habitat Variables	**Recovery Team Potential Jaguar Habitat Model**
Vegetation (Tree cover)	MODIS Tree cover (continuous field data) (https://lpdaac.usgs.gov)
Terrain Roughness (or Ruggedness)	ASTER DEM (https://wist.echo.nasa.gov)
Distance to Water	Derived from HydroSHEDS (http://gisdata.usgs.gov/)
Human Influence (to exclude cities, agricultural and developed rural areas)	Human Influence Index (http://sedac.ciesin.columbia.edu/wildareas/)
Ecoregions	WWF Ecoregions (http://www.worldwildlife.org/science/data/item6373.html)

Thirteen iterations of the habitat model were run using different input variables since the establishment of the recovery team. The first models are described separately in Sanderson and Fisher (2011); the final models from last year's work were designated versions 8 (draft report)/8.1 (final report). This report covers development of version 8 (for reference) through version 13. In each model version, the following basic steps were followed. Appendix 3 contains the details of each model version, including maps showing the results.

(1) Subunit definition: Define the spatial extent of the subunits over which calculations will be made (see Figure 1 for NRU map and small changes in Appendix 3 for subunit areas for each iteration).

(2) Habitat factors: Compare selected jaguar event locations to potential habitat factors to determine which classes or ranges of each habitat factor to include within the model and which to exclude from the model (see Appendix 2).

(3) Habitat weights: Determine weights for habitat types representing how quality of habitat for jaguars varies by ecosystem type (e.g., tropical dry forest, thorn-scrub, pine-oak forest, etc.). In version 8, these weights were arrived at via consensus among JRT technical subgroup experts; starting in version 9, habitat weights were calculated from the average density estimates available for each habitat (see Appendix 3).

(4) Habitat equation: Formulate an equation to combine the selected habitat factors (from step 2) and the weights (step 3) into a habitat score for every 1-sq-km area within the NRU.

(5) Mask: Mask out areas considered unsuitable. Unsuitable factors considered include human influence, elevation, and patch size. In model versions 8/8.1, no habitat factors were used as masks; in later models, a variety of different masks were applied, as described in Appendix 3.

(6) Translation to density: Available studies conducted within the NRU that measure jaguar density were used to translate habitat suitability scores into density. The polygonal boundaries of each study area (in the few cases where boundaries were not explicitly identified, they were estimated by JRT experts or study authors) were used to average the values of the habitat scores within that area. These average habitat scores were then plotted against the respective

density estimates to produce a regression equation that was applied to arrive at jaguar density across the entire NRU.

(7) Sum: Sum the potential number of jaguars (i.e., determine the carrying capacity) based on step 6 over the areas of each subunit and for the recovery unit in total. These data were provided to the population viability analysis described elsewhere.

In general, the net effect of the versions of the habitat model was to bring the results into closer alignment with the expert opinions of the JRT and recent studies of jaguars across the NRU, which reflect low densities of jaguars across the entire region and a general trend of diminishing numbers from south to north, particularly north of the US-Mexico border within the NRU.

Objective 3: Complete database and habitat model revisions based on technical subgroup feedback and meeting output

Database

After the meeting, we received and entered additional jaguar records into the database:

- 95 camera trap photos and telemetry observations from Rodrigo Núñez
- 174 camera trap photos and telemetry observations from Carlos López González
- 67 observations (18 tracks, 1 photo, 1 unknown, and the others predation events) from Octavio Rosas-Rosas
- 27 various records from the team, forwarded from Erin Fernandez, or documented by Sanderson from primary sources (for example, press reports of the 2011 observation in the Whetstone Mountains, Arizona)

We applied the radiotelemetry and camera trap rule sets as described above to generate records and events.

Habitat Model

Kim Fisher and Eric Sanderson met with Marit Alanen, Howard Quigley and Carlos López González at the WCS headquarters in the Bronx, NY, on June 25 – 26, 2012 to further refine the habitat model and discuss density estimates within the study area. Prior to the meeting, a series of emails and phone conversations resulted in revised histograms and a new north/south bifurcation of the model (see Appendix 2). Based on these discussions, several further iterations to the model were made (versions 10-11), to incorporate changes to habitat weights, input variable parameters, subunit definitions, the new north/south bifurcation of the model, and masks (see Appendix 3). Subsequent work after their visit led to version 12.

Objective 4: Present revised database and habitat model to full recovery team meeting

Eric Sanderson and Kim Fisher attended the full JRT meeting July 31 – August 2, 2012, and presented the revised database and habitat model (through version 12). We received feedback from the full team. There were no comments about the form of the habitat model or the data input.

The full team did express concern that the habitat/density trendline used to determine the equation for converting habitat scores to jaguar density (step 6, as described above) should be forced through (0, 0), under the assumption that a zero habitat score translated to zero potential for jaguar density. Not forcing the y-intercept through zero meant that large areas with zero habitat scores still had very low, but non-zero, contributions of jaguars to the carrying capacity estimates for the subunits. The effect can be seen by comparing model versions 12 and 13, particularly for the Borderlands Secondary Area, where habitat is quite patchy and lots of "non-habitat" area is contained within the subunit boundaries. The JRT discussed extensively whether these "non-habitat" areas could still be used by jaguars in some way. For example, it is known that in the Borderlands Secondary Area, jaguars move between mountain ranges, presumably by crossing areas marked as "non-habitat" in the valleys. Eventually the team decided that for purposes of carrying capacity estimation, these areas of "non-habitat" should not be included in the model estimation, and therefore the density regression should be forced to have a zero-intercept.

We revised the approach accordingly to produce the final model, version 13. The general effect of modifications to the model over the course of this year has been to decrease the number of predicted potential jaguars across the study area from versions 8 – 13. These decreases in numbers are in keeping with the expert knowledge, observations, and expectations of the recovery team as to "what is on the ground" today within the NRU (Appendix 3). The JRT discussed the question of whether what is currently the case is an appropriate scientific guide to "carrying capacity", which reflects the potential jaguar population if threats were alleviated. No consensus was reached on this question and so the habitat model stands with version 13 as the "final habitat model" form within the NRU.

New subunit geometry names were decided upon at the July 2012 meeting and are shown on the maps used in this report. Please note that the subunit boundaries were slightly altered between various model versions (see notes under each model version in Appendix 3) and the names are slightly different from previously used terminology (e.g., Sanderson and Fisher 2011). In the tables in Appendix 3, we maintain the old names for purposes of backwards compatibility. The new names are shown on Figure 1. From south to north, they are: Jalisco Core Area, Sinaloa Secondary Area, Sonora Core Area, and Borderlands Secondary Area. Areas outside of the NRU were not analyzed for jaguar carrying capacity in the summary tables.

Note that the Borderlands Secondary Area includes a US portion from the US-Mexico border north to Interstate-10, and a Mexico portion from the US-Mexico border south to the Sonora Core Area. The Borderlands Secondary Area contains the border fence.

Objective 5: Prepare report describing final database and model and provide supporting datasets

This report with attachments (including appendices and DVD with GIS data and database) fulfills this objective. The draft report was submitted on September 17, 2012. Comments on the draft report were received on December 3, 2012. This final report was submitted on March 12, 2013.

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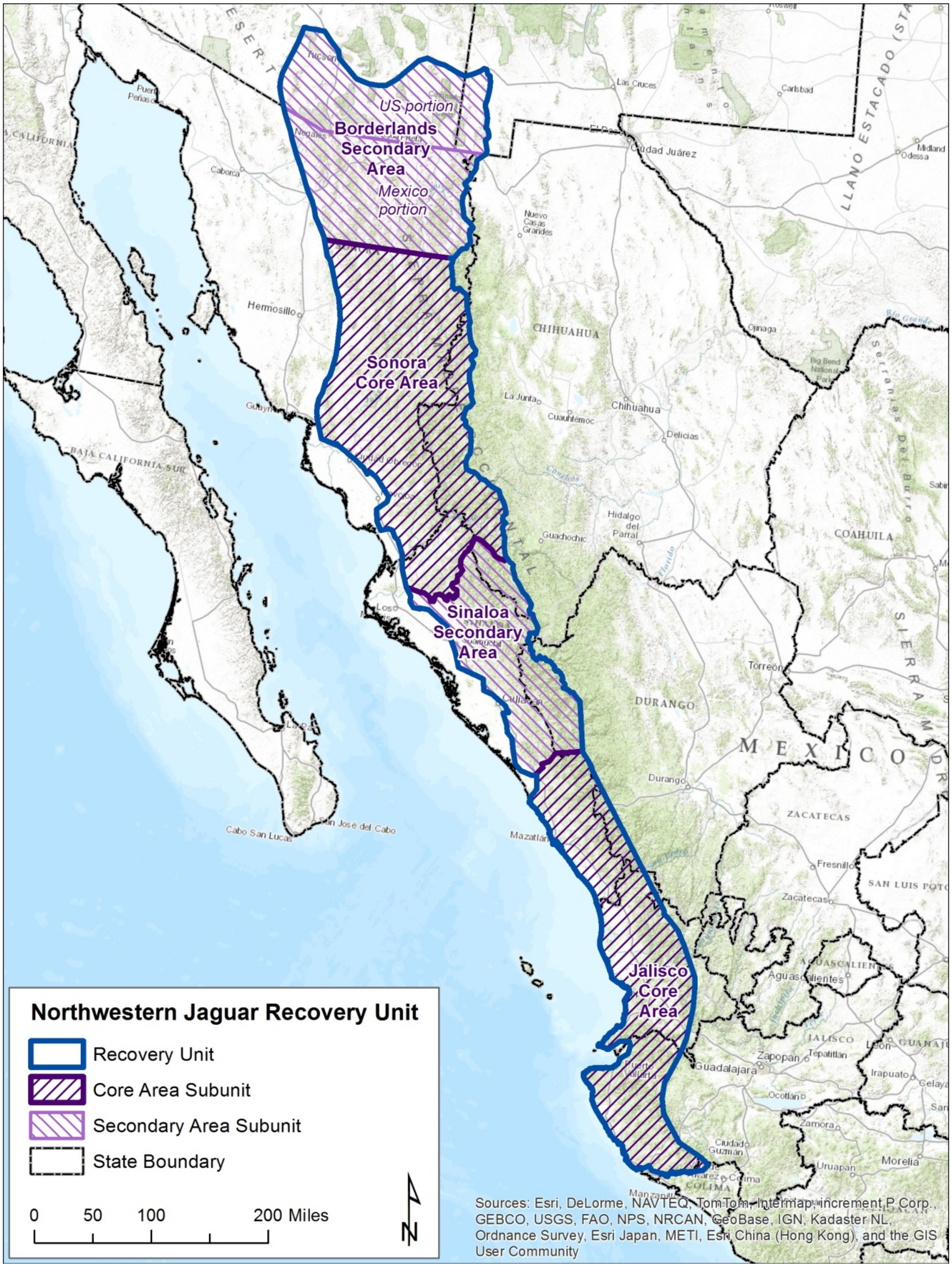
Figure 1: Revised Northwestern Jaguar Recovery Unit



Appendix 1: Systems for identifying precision in the jaguar event-record database

Table 1.1. Locality type codes for the northern jaguar event-record database.

LocalityType Code	LocalityType Text	Description	Examples	Number of Events
1	Defined Point	Geographic coordinates describing locality provided to within 1 km of the location of the event		102
2	Determined Point	Locality description is sufficient to describe locality as point location to within 10 km of the event	Grand Canyon Village, AZ; near the base of Old Baldy, Santa Rita Mountains	121
3	Defined Area	Locality description within 25 km of known place (e.g., mountain range, ranch, town, etc.) or within a named geographic area (e.g., mountain range, county) with an area less than 2000 sq km (~750 sq miles)	Rincon Mountains, near Globe AZ	207
4	Wide Area	Locality description within 100 km of known place (e.g., mountain range, ranch, town, etc.) or within a named geographic area with an area less than 30,000 sq km (~12,000 sq miles)	southeastern Arizona, northern Sonora	58
5	Very Wide Area	Locality description >100 km of known place (e.g., mountain range, ranch, town, county, etc.) or within a large geographic area (e.g., state or states)	Arizona, Sonora, Texas	9
6	Undetermined Area	Locality cannot be determined from description		0

Table 1.2. Date type codes for the northern jaguar event-record database.

DateTypeCode	DateTypeText	Description	Examples	Number of events
0	Unknown			10
1	Exact Date	described to day, month and year	March 9, 1902	138
2	Month-Year	described to month and year	January 1912	47
3	Season within a Year	described to a season within a year or to a few months time	fall of 1910	17
4	Year	described to a year	1946	118
5	Few Years	described to within a three year period; most recent year cited	1904-1907; around 1907; about 1860	44
6	Decade	described to within a ten year period, most recent year cited	1909-1918; 1920s	17
7	Prior to a given year	described at some point in time prior to the year cited, usually used when event time is not given, but record year is known	prior to 1856; until 1900	81
8	Half a Century	described to a 50 year period	early 19th century	2
9	Nearest Century	described to a 100 year period	1800s	2
10	More than a Century but less than a Millennium	described to a period between 100 and 1000 years long (usually multiple centuries)	1540 - 1931, AD 1000 - 1700	8
11	One or more millennia, but less than 10,000 years	described to a period between 1000 and 10,000 years long (to a millenia)	7,000 - 3,800 BP	2
12	Geological Ages	described to a geological age, which vary in length, but are typically more than 10,000 years long	Pleistocene, Miocene	11

Table 1.3. Identity type codes for the northern jaguar event-record database.

IdentityCode	IdentityText	Description	Possible Identity	Number of events
-5	Not culturally significant	Cultural accounts do not claim special significance for the jaguar		3
-4	Wrong country	Record locality has been mistakenly identified within the study area		1
-3	Released	A jaguar was known to have been brought from elsewhere and released for a "canned" hunt		3
-1	Absence	Qualified observer looks for but does not find jaguar or evidence of jaguar		5
0	Unknown or unattributed			1
1	Jaguar	Records claim observation of a jaguar, tigre, el tigre, Panthera onca, Felis onca, or other synonym of jaguar	Jaguar	452
2	Spotted cat	Records claims observation of spotted cat that may be a jaguar	Jaguar, ocelot, bobcat or mountain lion cub	6
3	Cat	Records claims observation of cat of some kind that may be a jaguar	Jaguar, mountain lion, ocelot, bobcat, jaguarundi or domesticated or feral cat	23
4	Large quadruped	Records claims observation of large quadruped that may have been a jaguar	Jaguar, mountain lion, deer, elk, coati, fox, dog, or other similarly sized four legged animal	2
5	Other	Records claim some other creature other than a large quadruped or a cat of some kind and yet which might have been a jaguar		1

Table 1.4. Evidence type codes for the northern jaguar event-record database.

EvidenceCode	EvidenceText	Description	Physical Evidence	Number of events
0	Unknown or unattributed		0	5
1	First hand report	A person who witnessed or participated in the event created the record	0	55
2	Second hand report	A person who witnessed or participated in the event gave an account to someone who recorded it	0	59
3	Third hand report	A person who witnessed or participated in the event gave an account to someone who gave it to someone else who recorded it	0	156
4	Photograph or video		1	102
6	Skull		1	24
7	Hide		1	17
8	Carcass measured		0	1
12	Fossil	Fossilized bone or track found, attributed to jaguar	1	11
13	Tracks seen and/or measured		0	27
14	Prey animal killed jaguar style		0	2
18	Cultural artifact made of jaguar seen		0	7
19	Linguistic evidence		0	5
20	Cultural story or myth		0	5
21	Cultural representation of jaguar		0	12
22	Subfossil	Incompletely fossilized remains	1	1
98	Other physical evidence		0	1
99	Other documentary evidence		0	1

Appendix 2: Frequency histograms of habitat variables based on different selections of jaguar events within the Northwestern Recovery Unit (NRU)

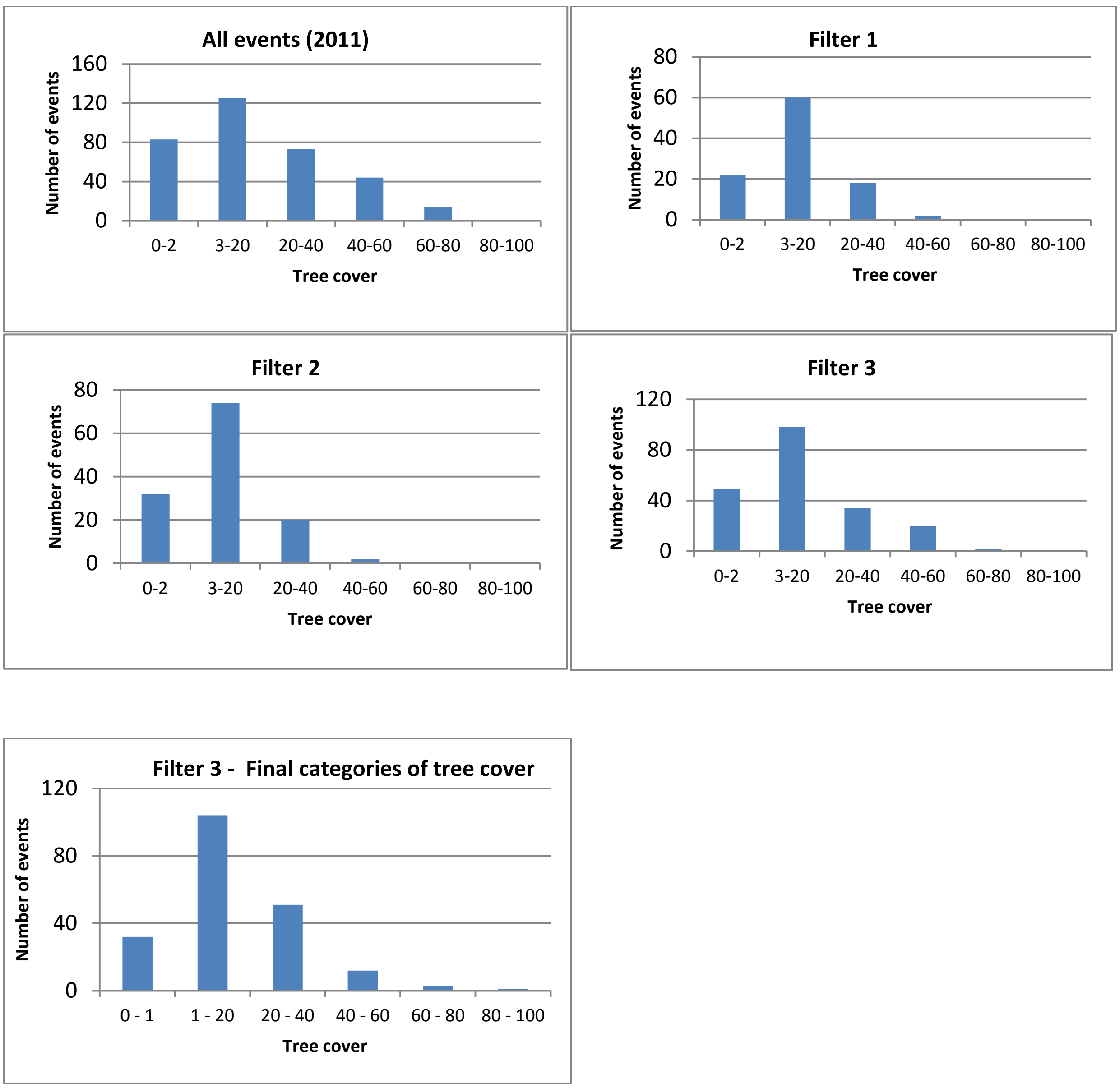
Under the direction of the technical subgroup of the JRT, we examined the consequences of different selections of events on the habitat variables relevant to jaguars: tree cover, terrain ruggedness, human influence and elevation. The technical subgroup also requested analyses of the events in the two southern subunits (Jalisco Core Area and Sinaloa Secondary Area) separate from the two northern subunits (Sonora Core Area and Borderlands Secondary Area). These analyses are presented below without further statistical analysis. Decisions by the technical subgroup about which portions of the habitat variables to include were made based on visual examination of the histograms. In the histograms below, "All events (2011)" refers to the histogram reported in Sanderson and Fisher (2011). The other three histograms refer to event subsets based on filters described in the main report. (Recall that all filters use localities known within 10 km, dates known within a century, observations that were certainly assigned to jaguars, and three different selections of events based on evidence: Filter 1 = physical evidence only, Filter 2 = physical evidence plus tracks and sign, Filter 3 = no filter based on evidence type.)

Tree cover

Visual examination of Figure 2.1 suggests that the selection of events using these different criteria makes little qualitative difference in the shape of the tree cover histogram. Most jaguar events were recorded in areas of moderate tree cover.

Note that, after further discussion, the technical subgroup also decided to create finer categories of tree cover, separating out for 0-1% tree cover and 1-20% tree cover, as shown in the fifth histogram. In the models below, the JRT advised us to use categories of tree cover from 1-40% based on these categories.

Figure 2.1. Comparison of subsets of jaguar events against jaguar habitat variable: tree cover

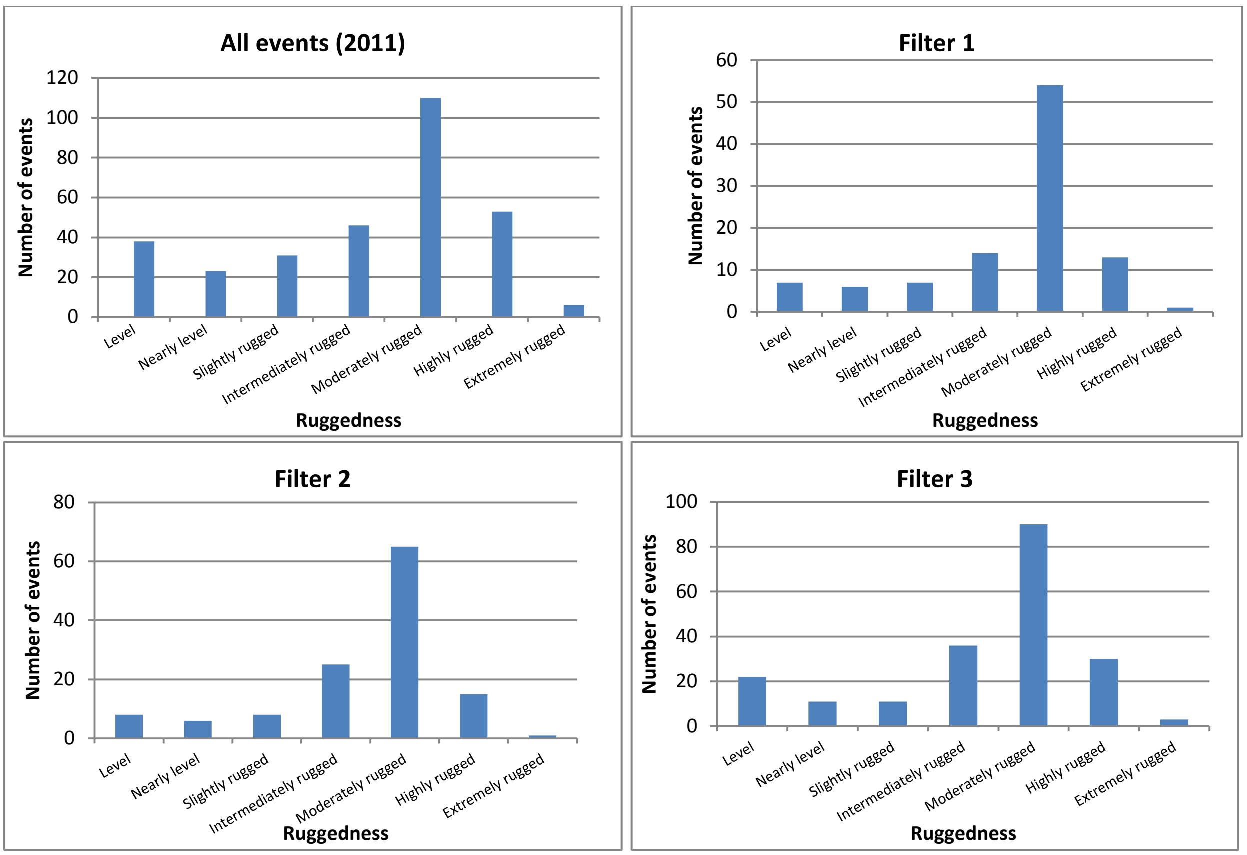


Terrain Ruggedness

Under the advice of the technical subgroup of the JRT, we also examined the frequency distributions of different selections of events for terrain ruggedness. Visual examination of Figure 2.2 suggests that the selection of events using these different criteria makes little qualitative difference in the shape of the terrain ruggedness histogram. Most jaguar events were located in areas of moderate ruggedness, with smaller numbers of events in the intermediately rugged and highly rugged categories.

In the models below, the JRT advised us to use the following categories of ruggedness: intermediate, moderate, and highly rugged categories (no change).

Figure 2.2. Comparison of subsets of jaguar events against jaguar habitat variable: terrain ruggedness

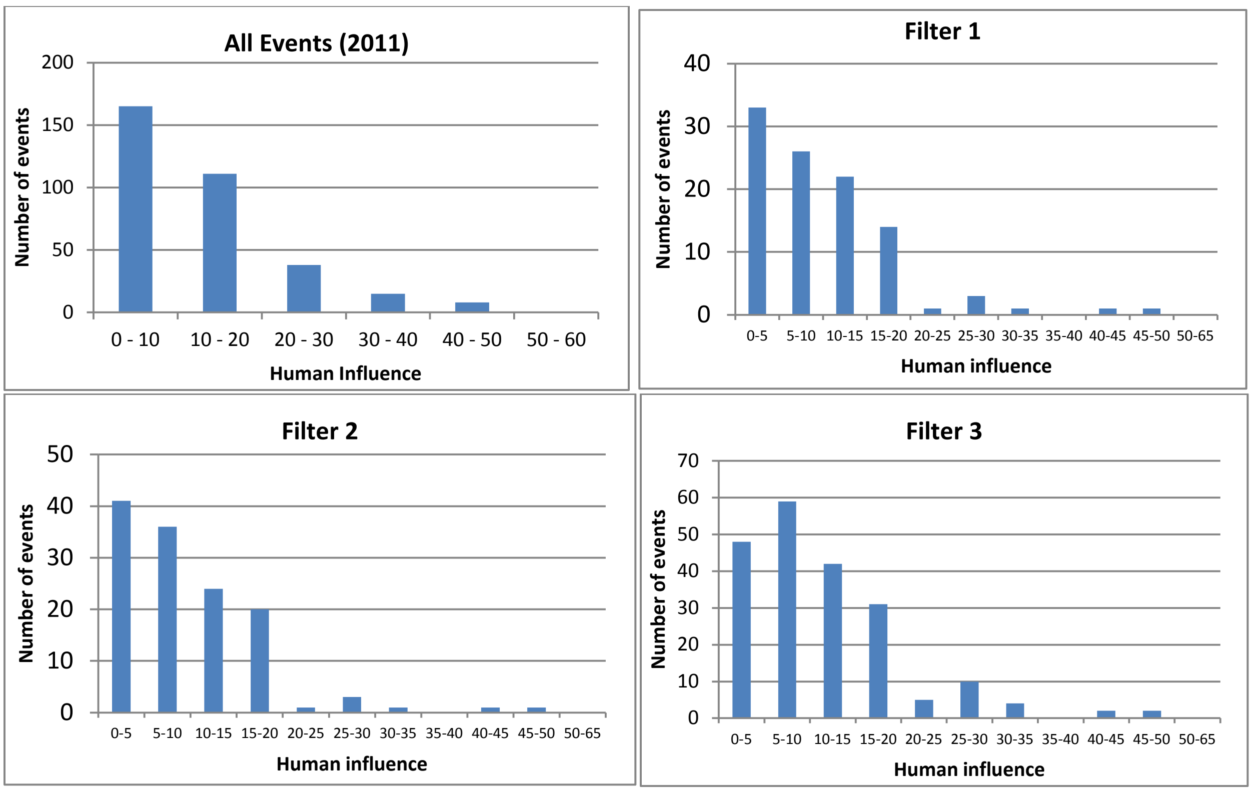


Human Influence

Under the advice of the technical subgroup of the JRT, we also examined the frequency distributions of different selections of events for human influence, based on the human influence index (Sanderson et al. 2002). Visual examination of Figure 2.3 suggests that the selection of events using these different criteria makes little qualitative difference in the shape of the human influence histogram. Most jaguar events were located in areas of low human influence, typically less than a score of 20 on the human influence index.

In the models below, the JRT advised us to mask out areas of human influence greater than 20.

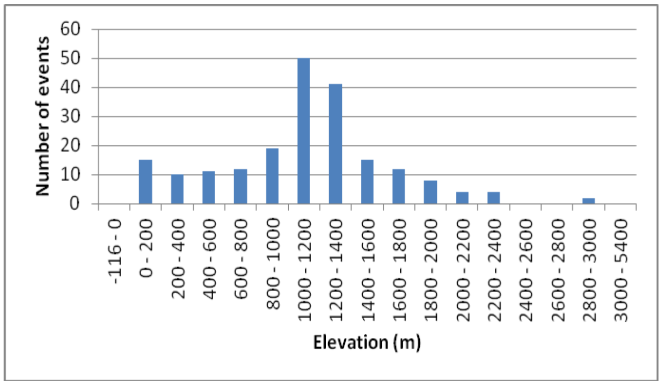
Figure 2.3. Comparison of subsets of jaguar events against jaguar habitat variable: human influence.



Elevation

Figure 2.4 shows the distribution of Filter 3 events by elevation. Because only 20 events occurred above 2000 m, the JRT technical subgroup decided to mask out areas above 2000 m. Because so few events were involved even with the most expansive filter, the technical subgroup decided it was not necessary to examine the other filters for their effect on elevation.

Figure 2.4. Comparison of the Filter 3 subset of jaguar events against elevation



North/South Comparisons
During the development of model versions 10-11, the technical subgroup, via Carlos López González, Howard Quigley, and Marit Alanen, asked us to consider whether separate models for the two northern subunits and the two southern subunits might provide results more in keeping with the technical subgroup's expertise, especially as there is a major habitat shift from the dry tropical forest of Jalisco to the thornscrub vegetation of Sonora. Below we present comparisons of frequency histograms, separating out events from the northern two subunits (shown in blue) and from the southern two subunits (shown in red) for tree cover and human influence. Although there were some differences with respect to these two variables, ultimately the technical subgroup decided that this approach was not useful because it split an already small number of density estimates into two even smaller pools – see notes in Appendix 3 for versions 10-11.

Figure 2.5. Comparison of frequency histograms for jaguar events in the northern and southern parts of the NRU with respect to tree cover.

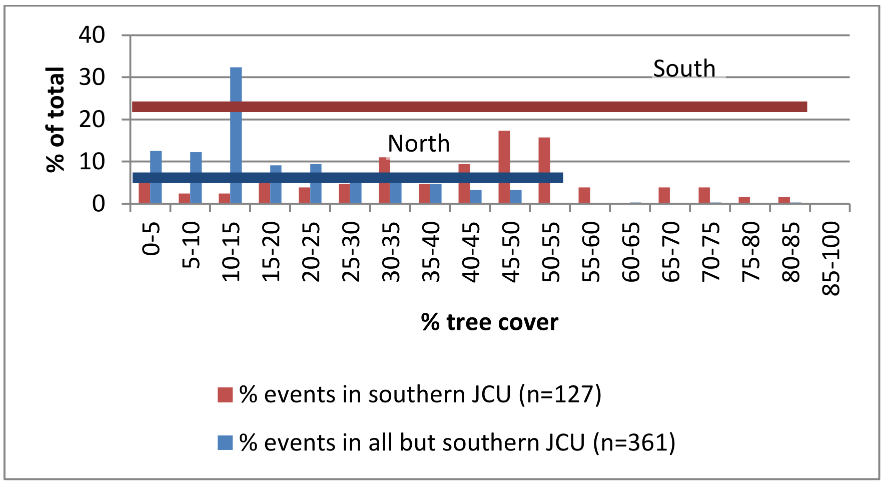
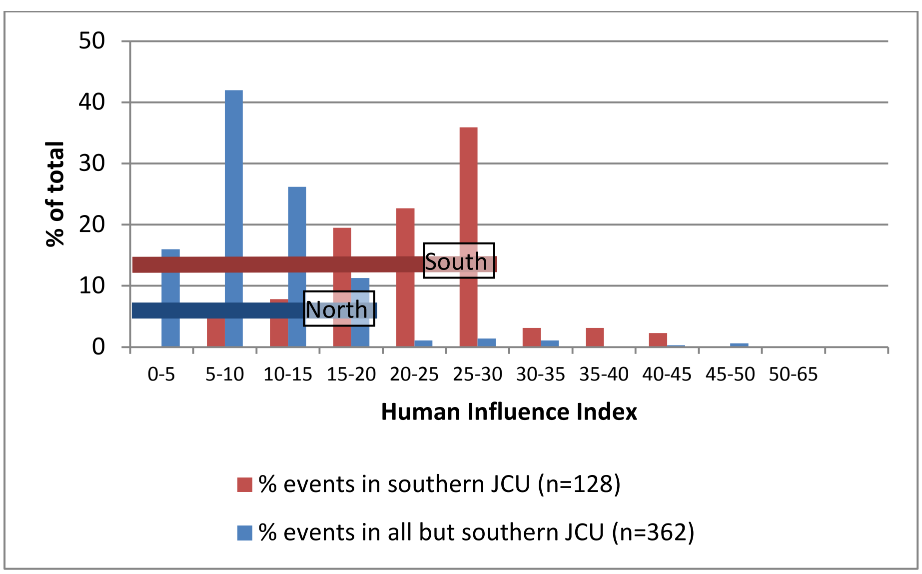


Figure 2.6. Comparison of frequency histograms for jaguar events in the northern and southern parts of the NRU with respect to human influence.



Appendix 3: Habitat model history

The habitat model eventually adopted by the JRT represents an evolution. With a few small noted exceptions, each step was essentially a refinement of the parameters of the same basic conceptual process described in the main text under Objective 2, based on ongoing discussion amongst the technical subgroup of the JRT and the JRT at large. Each description in this appendix begins with a version number, starting from version 8.0 as the starting point for this contract, and specifies:

1. Subunit definition: The geographic extent of each subunit changed slightly from model to model. In some cases names changed as well. Where the subunits changed in area, we produced a summary table of the areas. Former names are listed in a column beside the final names to allow for easy cross-referencing. Where subunit definitions remained the same between model versions, a note to that effect is given rather than providing an additional (duplicative) table.

2. Habitat factors: The model is driven by a simple combinatorial model of habitat factors considered important for jaguars in the NRU. In our descriptions here, we provide a table of each of the environmental factors used, including ranges of values, as necessary. Note the selection of ranges of values is discussed in Appendix 2, based on analysis of the selected jaguar events against the various factors. Where habitat factors remained the same between versions, a note to that effect is given rather than providing an additional (duplicative) table.

3. Habitat weights: In some models, the habitat type is weighted based on the potential ecoregion type. The ways these weights were arrived by the JRT are noted below, and when they did not change between versions, a note to that effect is given rather than providing an additional (duplicative) table.

4. Habitat equation: The formula used to calculate habitat suitability across the NRU given the set of inputs is shown and explained where changes occurred, or a note about lack of change included.

5. Mask: As the model was refined, the JRT determined in a few cases that certain values of individual variables ought to be used to omit areas from consideration during or after calculating habitat suitability. These areas are referred to as “masks” because they exclude associated areas entirely, rather than assign them low or 0 values. These cases, or else a note about the lack of change, are included in this item.

6. Translation to density: For each model version, a table lists each available density study with the average modeled habitat suitability calculated within its extent, along with the source and density value for that study. These values were then correlated as described under Objective 2, producing the regression equation and graph shown under the table in this item (or else lack of change is noted).

7. Sum: Finally, the results of multiplying density by area over each subunit are listed to arrive at jaguar population numbers.

8. Maps: A map of the potential carrying capacity predicted by the model is provided, with an inset map in the upper right corner focused on the northern portions of the Borderlands Secondary

Area in the United States. Note that the definition of the colors on the map indicating potential jaguar carrying capacities vary slightly between model versions.

Potential Jaguar Habitat Model, version 8.0 (March 3, 2011)

(1) Subunit definition:

Population subunit	**Former subunit name**	**Area of subunit (km2)**
Jalisco Core Area	MX Sinaloa Sub-Population	53,446
Sinaloa Secondary Area	MX North Sinaloa Connector Area	41,260
Sonora Core Area	MX Sonora Sub-Population	83,472
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	36,237
Borderlands Secondary Area – US portion	US South of I-10 Highway	29,754
	US North of I-10 Highway	38,073

(2) Habitat factors:

Variable	**1**	**0**
Tree cover	3-60% tree cover	< 3% or > 60% tree cover
Ruggedness	intermediate, moderate, and high ruggedness	Level, nearly level, and extreme ruggedness
Distance from Water	<= 10 km of water	> 10 km from water
Human influence	HII < 30	HII >= 30

(3) Habitat weights: In version 8.0, the relative weight assigned to each habitat type was determined by JRT consensus and was meant to reflect expert opinion about the relative suitability of each kind of environment, independent of the other variables in the model. In later versions this expert opinion was replaced with a quantitative approach.

Habitat type	**Relative weight**
Jalisco dry forest	2.5
Sinaloan dry forest	2
Northern Mesoamerican Pacific mangroves	1.5
Sonoran-Sinaloan transition subtropical dry forest ("thornscrub")	1
Trans-Mexican Volcanic Belt pine-oak forests	0.25
Sierra Madre Occidental pine-oak forests	0.25
Arizona Mountains forests	0.25
Chihuahuan desert	0.1
Sonoran desert	0.1

(4) Habitat equation:

([3-60% tree cover] + [intermediate, moderate, and high ruggedness]) (0-2)

*

[Within 10km of water] (0-1)

*

[HII < 30] (0-1)

*
[Habitat type weight] (0.1-2.5)

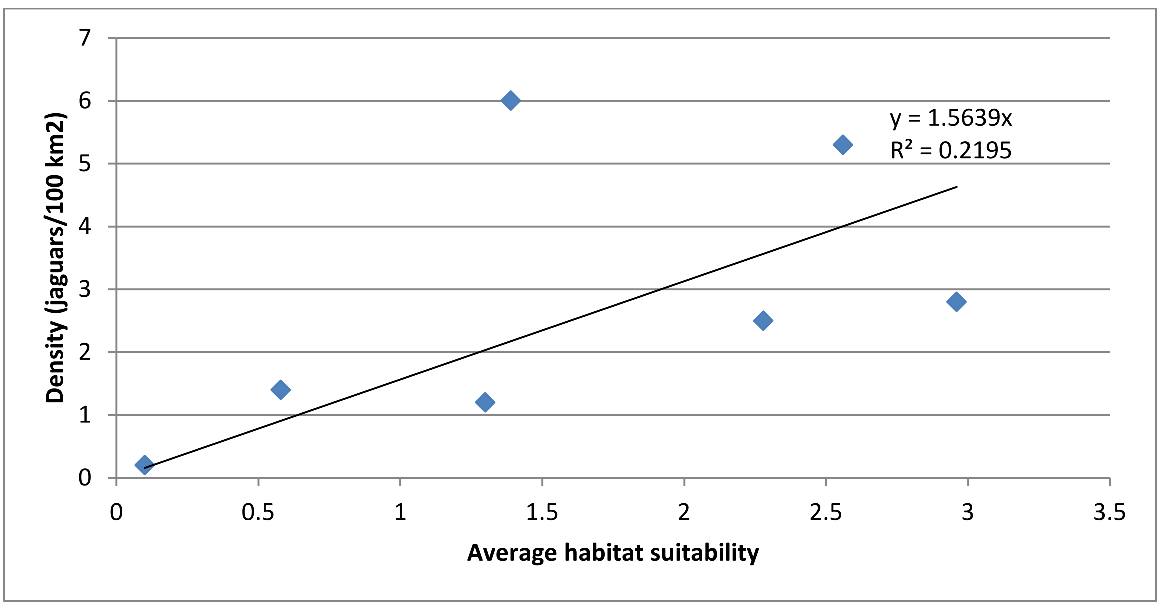
(5) Mask: no additional mask.

(6) Translation to density:

Study ID	Study	Average habitat suitability	Density (jaguars /100 km2)	Source
1	Jalisco-Sinaloa I	3.0	2.8	Núñez-Pérez 2011
2	Jalisco-Sinaloa II	1.4	6.0	R. Núñez (pers. comm.)
3	Jalisco-Sinaloa III	2.6	5.3	R. Núñez (pers. comm.)
4	Jalisco-Sinaloa IV	2.3	2.5	Coronel-Arellano et al., *In press*
5	Sonora I	0.6	1.4	Gutiérrez-González et al., *In press*
6	Sonora II	1.3	1.2	López González and Moreno Arzate 2011
7	Arizona I	0.1	0.2	McCain and Childs 2008

The regression equation: density (jaguars / 100 km2) = (1.5639 * habitat score) / 100.

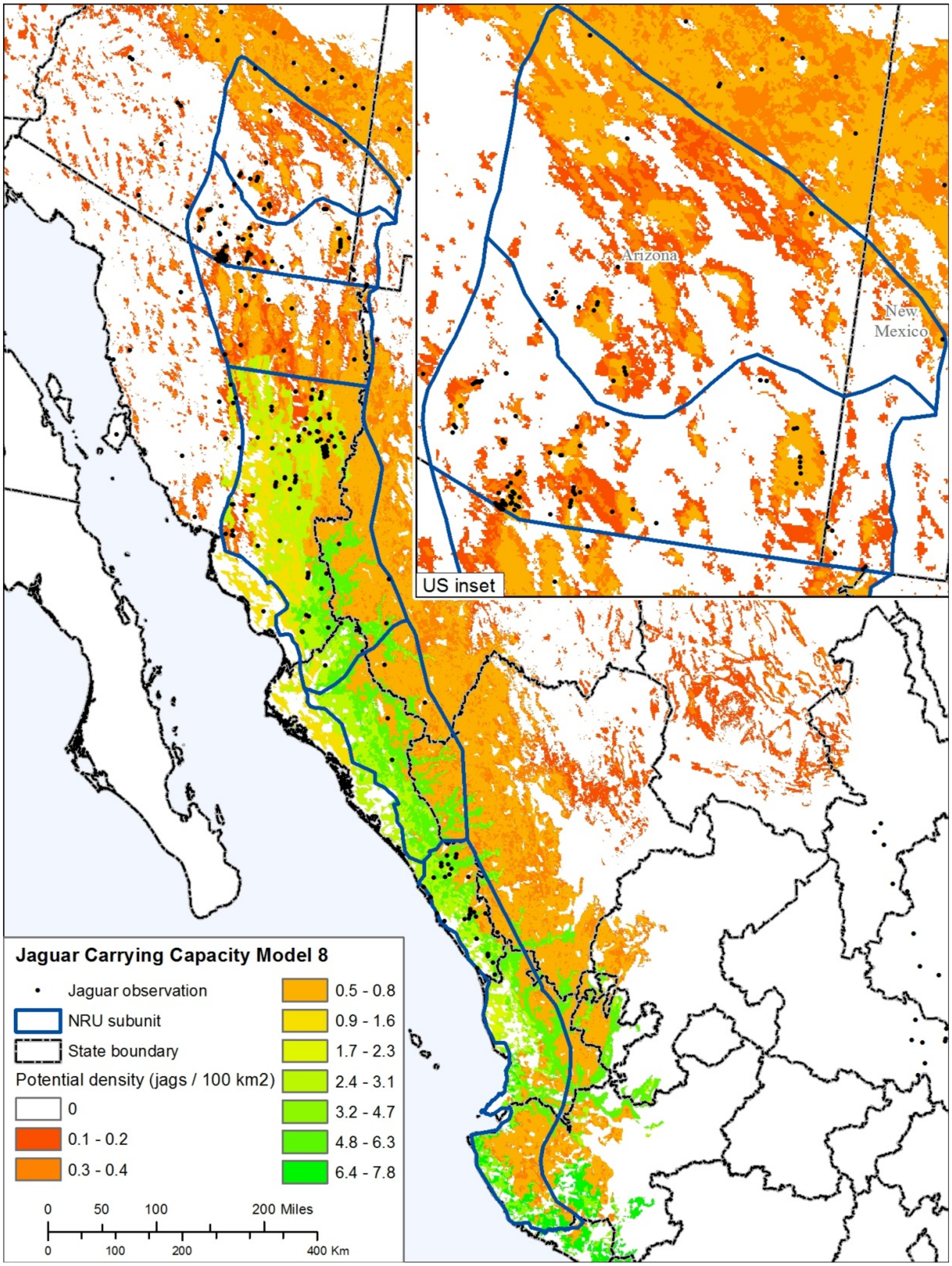
Note that the regression equation forced the y-intercept through zero (see discussion in Objective 4).



(7) Sum: The number of potential jaguars in each subunit and in the NRU (total). Habitat area includes all the areas with non-zero, positive habitat scores within each subunit.

Population subunit	**Former subunit name**	**Estimate of habitat area (km^2)**	**Estimated number of potential jaguars**
Jalisco Core Area	MX Sinaloa Sub-Population	44,510	1,410
Sinaloa Secondary Area	MX North Sinaloa Connector Area	39,501	1,198
Sonora Core Area	MX Sonora Sub-Population	76,271	1,670
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	24,394	135
Borderlands Secondary Area – US portion	US South of I-10 Highway	7,663	27
[this subunit was subsequently deleted from analysis by the JRT]	US North of I-10 Highway	17,269	74
Total		**282,604**	**4,513**

(8) Map of potential carrying capacity.



Potential Jaguar Habitat Model, version 8.1 (August 4, 2011)

Version 8.1 of the model was described in the final report from the WCS to the FWS on August 4, 2011, under agreement F11AC00036 (and modification #0001).

(1) Subunit definition: The area north of Interstate 10 in the United States was removed from the recovery unit definition at the request of the JRT at the meeting March 1 – 3, 2011. Also, a small area (approximately 342 km^2) was removed from the definition of the US South of I-10 Highway subunit in New Mexico.

Population subunit	Former subunit name	Area of subunit (km^2)
Jalisco Core Area	MX Sinaloa Sub-Population	53,446
Sinaloa Secondary Area	MX North Sinaloa Connector Area	41,260
Sonora Core Area	MX Sonora Sub-Population	83,472
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	36,237
Borderlands Secondary Area – US portion	US South of I-10 Highway	29,528

(2) Habitat factors: same as version 8.0.

(3) Habitat weights: same as version 8.0.

(4) Habitat equation: same as version 8.0.

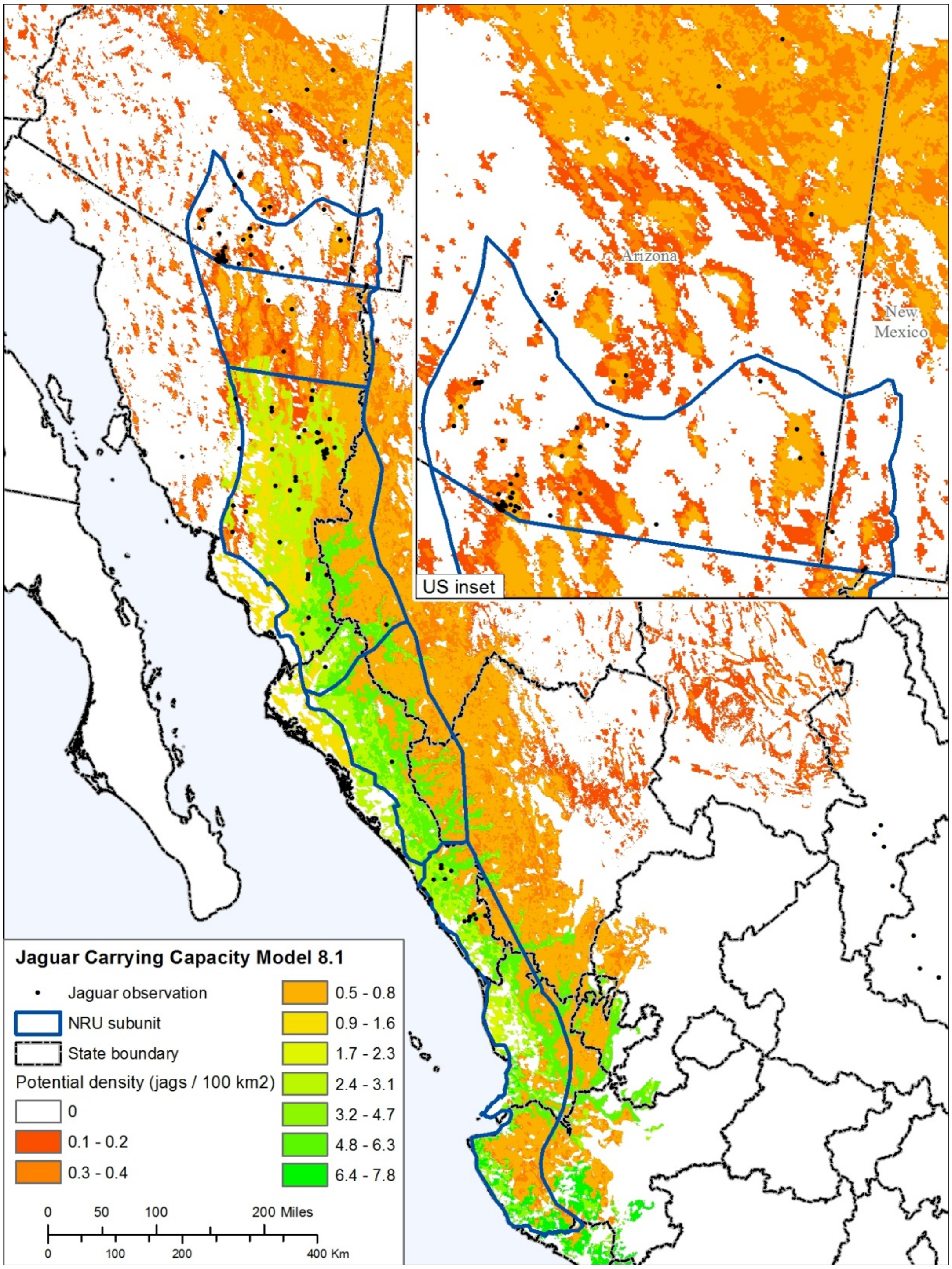
(5) Mask: same as version 8.0.

(6) Translation to density: same as version 8.0.

(7) Sum: same as version 8.0 with the US north of I-10 Highway removed.

Population subunit	Former subunit name	Estimate of habitat area (km2)	Estimated number of potential jaguars
Jalisco Core Area	MX Sinaloa Sub-Population	44,510	1,410
Sinaloa Secondary Area	MX North Sinaloa Connector Area	39,501	1,198
Sonora Core Area	MX Sonora Sub-Population	76,271	1,670
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	24,394	135
Borderlands Secondary Area – US portion	US South of I-10 Highway	7,663	27
Total		**192,339**	**4,440**

(8) Map of potential carrying capacity.



Potential jaguar habitat model, version 9 (April 26, 2012)

(1) Subunit definition: Same as version 8.1.

(2) Habitat factors: At the request of the JRT technical subgroup during the meeting April 24 – 26, 2012, WCS produced a set of three histograms for each habitat factor (see Appendix 2) based on jaguar observations filtered by three sets of criteria. The overall histogram patterns proved very similar across the filtered subsets; while the total in each category was lower in the more restrictive scenarios, the histograms were qualitatively similar, and the thresholds suggested were the same. Therefore, the JRT technical subgroup agreed that the "filter 3" subset of events should be used to revise the thresholds used for the habitat factors based on histogram analysis.

In addition, the JRT technical subgroup requested that a new habitat factor be added for elevation, and that areas above 2000 m be considered unsuitable habitat, since only a limited number of records occurred above that height (see Figure 2.4).

Habitat Factor	**1**	**0**
Tree cover	> 1 and <= 40% tree cover	<= 1 or > 40 and <= 100% tree cover
Ruggedness	intermediate, moderate, and high ruggedness	Level, nearly level, and extreme ruggedness
Distance from Water	<= 10 km of water	> 10 km from water
Human Influence	HII <= 20	HII > 20
Elevation	<= 2000 m	> 2000 m

(3) Habitat weights: At the request of the JRT technical subgroup, WCS added density estimates occurring in the different ecosystem types to the weights table, so that the group could evaluate correlations. In the table produced below, the first column shows the original values, the second column shows existing density estimates falling within each habitat type, and the third column shows the average of the values in the second column. These density estimates were provided from by the technical subgroup or derived from the published literature. The JRT technical subgroup decided to use the values from the third column as new ecosystem weights.

Ecoregion	**Relative weight**	**Density estimates (literature sources and technical subgroup*)**	**Density estimates (expert)**
Jalisco dry forest	2.5	2.8, 5.3, 5.6	4.57
Sinaloan dry forest	2	2.5	2.5
Northern Mesoamerican Pacific mangroves	1.5	6, 2.5	4.25
Sonoran-Sinaloan transition subtropical dry forest ("thornscrub")	1	1.2, 1.1, 1.4	1.23

Trans-Mexican Volcanic Belt pine-oak forests	0.25		0.1
Sierra Madre Occidental pine-oak forests	0.25		0.1
Arizona Mountains forests	0.25		0.1
Chihuahuan desert	0.1	0.2	0.08
Sonoran desert	0.1		0.08

* Data provided by R. Núñez, C. López González, and O. Rosas-Rosas based on studies of jaguar density in Mexico. The only US estimate is drawn from McCain & Childs (2008) by estimating the number of jaguars observed (i.e., two) over the reported sampling area.

(4) Habitat equation:

[Tree cover (> 1 and <= 40%)] +
[intermediate, moderate, and high ruggedness] (0-2)
*
[Within 10km of water] (0-1)
*
[HII < 20] (0-1)
*
[Elevation <= 2000 m] (0-1)
*
[Habitat type weight] (0.08-4.57)

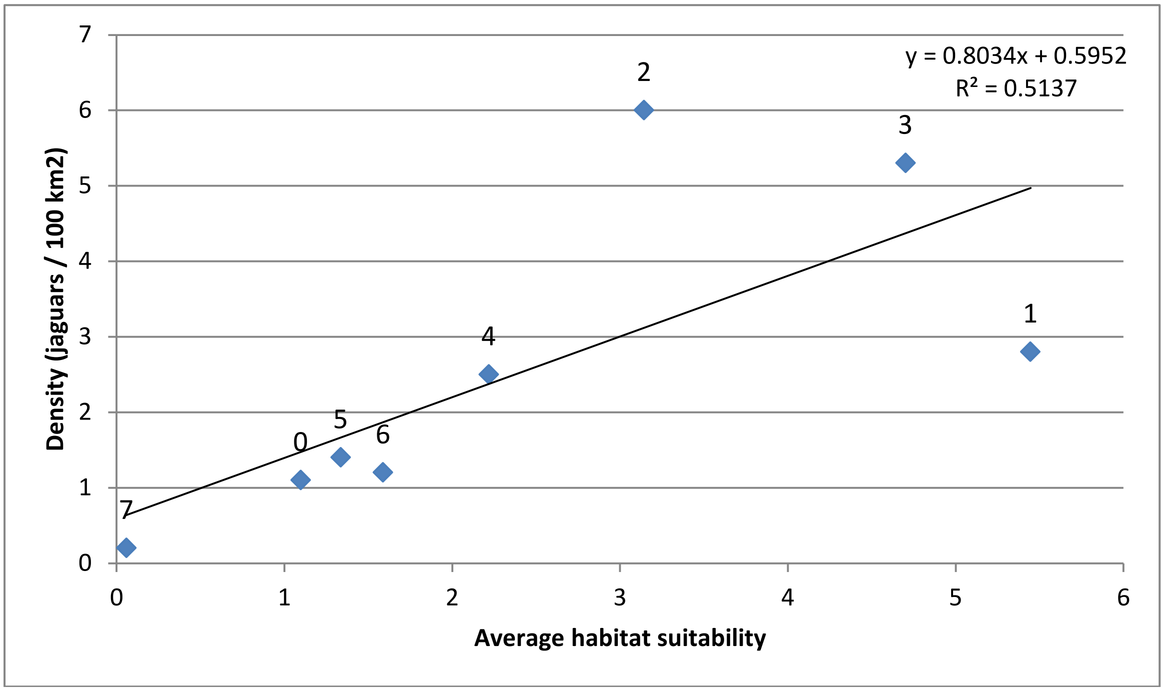
(5) Mask: After habitat suitability was calculated, resulting contiguous areas of less than 100 sq km were removed throughout the northwest jaguar recovery unit, because the JRT technical subgroup consensus was that areas smaller than this are too small to support a jaguar.

(6) Translation to density: One additional density study data point, from Octavio Rosas-Rosas, was added.

Study ID	**Average habitat suitability**	**Density (jaguars /100 km2)**	**Source**
0	1.1	1.1	Rosas-Rosas 2011
1	3.0	2.8	Núñez-Pérez 2011
2	1.4	6.0	R. Núñez (pers. comm.)
3	2.6	5.3	R. Núñez (pers. comm.)
4	2.3	2.5	Coronel-Arellano et al., *In press*
5	0.6	1.4	Gutiérrez-González et al., *In press*
6	1.3	1.2	López González and Moreno Arzate 2011;
7	0.1	0.2	McCain and Childs 2008

The regression equation: density (jaguars / 100 km2) = ((0.8034 * habitat score) + 0.5952) / 100.

Note that the regression equation did not force the y-intercept through zero (see discussion in Objective 4).

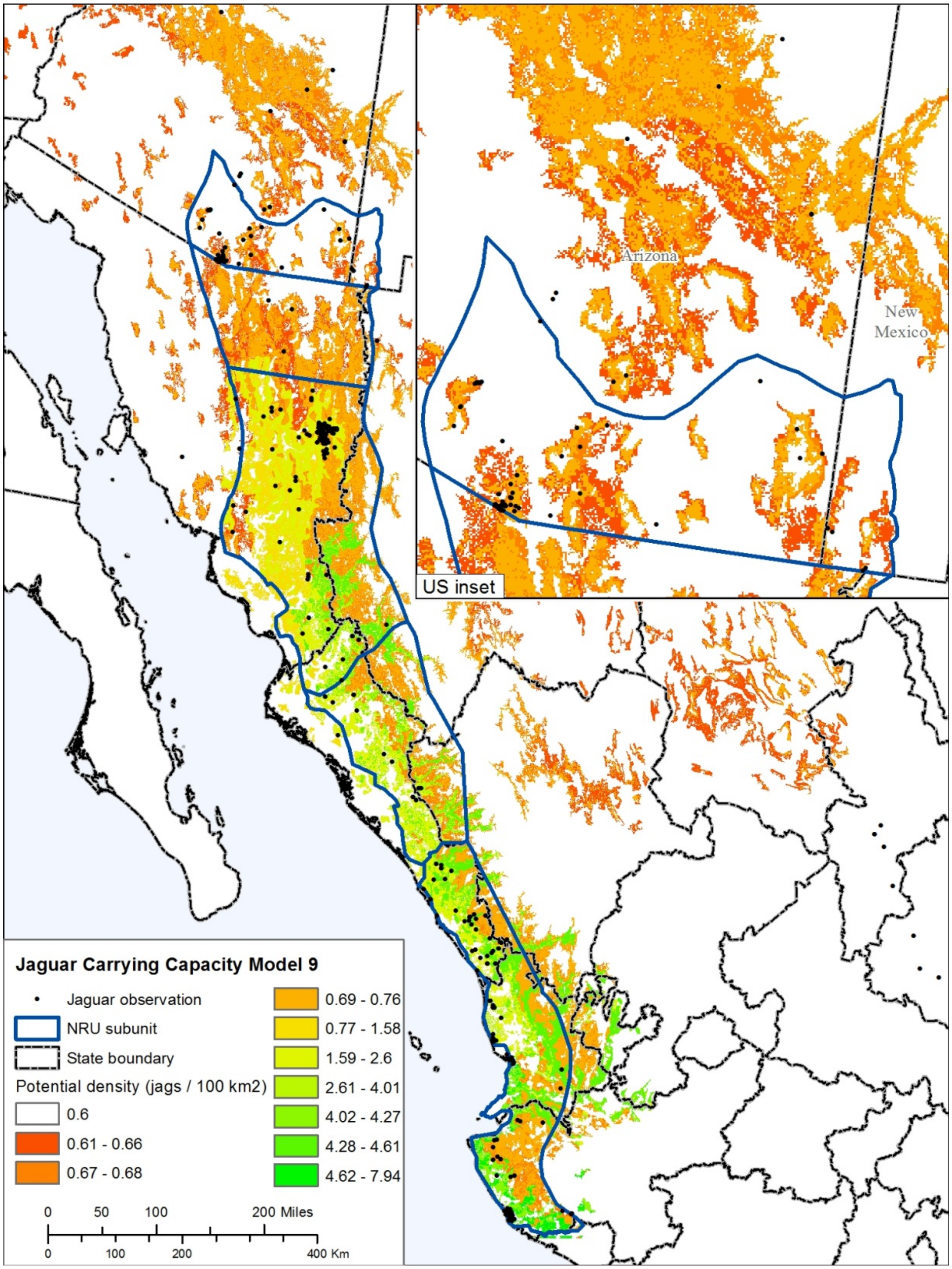


(7) Sum:

Population subunit	**Former subunit name**	**Estimate of habitat area (km2)**	**Estimated number of potential jaguars**
Jalisco Core Area	MX Sinaloa Sub-Population	52,899	1,253
Sinaloa Secondary Area	MX North Sinaloa Connector Area	41,129	675
Sonora Core Area	MX Sonora Sub-Population	82,994	1,316
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	36,200	254
Borderlands Secondary Area – US portion	US South of I-10 Highway	29,534*	182
Total		**242,756**	**3,680**

* Slightly larger than subunit polygon area because of rounding.

(8) Map of potential carrying capacity.



Potential jaguar habitat model, versions 10-11 (June 25-26, 2012)

Versions 10 and 11 are here combined, because version 10 was effectively an intermediate step to 11, produced during a meeting of a subgroup (hereafter the "coleaders") of the JRT technical subgroup (Carlos López González and Howard Quigley, with Marit Alanen acting as the FWS liaison) at the WCS Headquarters in Bronx, NY, during June 25 – 26, 2012.

(1) Subunit definition: The western boundary of the Jalisco Core Area was redefined to fit the area of potential jaguar habitat more closely by making the boundary follow the coast except around Puerto Vallarta.

Population subunit	**Former subunit name**	**Area of subunit (km2)**
Jalisco Core Area	MX Sinaloa Sub-Population	54,949
Sinaloa Secondary Area	MX North Sinaloa Connector Area	41,260
Sonora Core Area	MX Sonora Sub-Population	83,472
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	36,237
Borderlands Secondary Area – US portion	US South of I-10 Highway	29,528

(2) Habitat factors: The coleaders investigated the disparity between results of the model in the northern and southern parts of the NRU. The histogram-based thresholds used to calculate habitat suitability removed large areas from the southern part where jaguar observations occurred. After some discussion, the coleaders decided that a broad north-south ecological divide between and human influence and the types of habitat used by jaguars in the southern two subunits (Sinaloa Secondary Area and Jalisco Core Area) compared to habitat types used by jaguars in the northern three subunits (US and Mexico portions of the Borderlands Secondary Area and Sonora Core Area) was the cause of the poor fit. Jaguars in the southern subunits appear to use areas of higher tree cover compared to jaguars in the northern subunits, and so to improve the model, the tree cover habitat factor was treated differently in the three northern subunits and in the two southern subunits, as elaborated below.

Similarly, human influence thresholds were adjusted, but the coleaders decided to use HII as a post-calculation mask, rather than a habitat factor (see (5) Mask, below).

Habitat Factor	**1**	**0**
Tree cover	> 1 and <= 50% tree cover (north) / > 1 and <= 100% tree cover (south)	<= 1 or > 50 and <= 100% tree cover (north) <= 1% tree cover (south)
Ruggedness	intermediate, moderate, and high ruggedness	Level, nearly level, and extreme ruggedness
Distance from Water	<= 10 km of water	> 10 km from water
Elevation	Elevation <= 2000 m	Elevation > 2000 m

(3) Habitat weights: An additional four density estimates were added to the analysis and one was removed (see (6) Translation to density, below), and these were used to adjust habitat weights based on recalculated density averages. In addition, the two desert habitat types, for which no density studies were available to average, were assigned further reduced weights based on expert opinion about the relative suitability of these environments (i.e., very low) compared to the revised set of density estimates from the other habitat types.

Habitat type	**Density estimates**	**Relative weight**
Jalisco dry forest	2.8, 5.3, 5.6	4.6
Sinaloan dry forest	2.5, 6.7	4.6
Northern Mesoamerican Pacific mangroves	6, 2.5	4.3
Sonoran-Sinaloan transition subtropical dry forest ("thornscrub")	1.2, 1.1, 1.4	1.2
Sierra Madre Occidental pine-oak forests	0.2, 0**, 0**, 0.45**	0.2
Arizona Mountains forests		N/A
Trans-Mexican Volcanic Belt pine-oak forests		0.2
Chihuahuan desert		0.01
Sonoran desert		0.01

** Density estimates provided by C. López González reflecting unpublished estimates from the Chihuahuan pine forests of the Sierra Madre in Mexico.

(4) Habitat equation:

[Tree cover (> 1 and <= 50% north / > 1 and <= 100% south)] +
[intermediate, moderate, and high ruggedness] (0-2)
*
[Within 10km of water] (0-1)
*
[Elevation <= 2000 m] (0-1)
*
[Habitat type weight] (0.08-4.57)

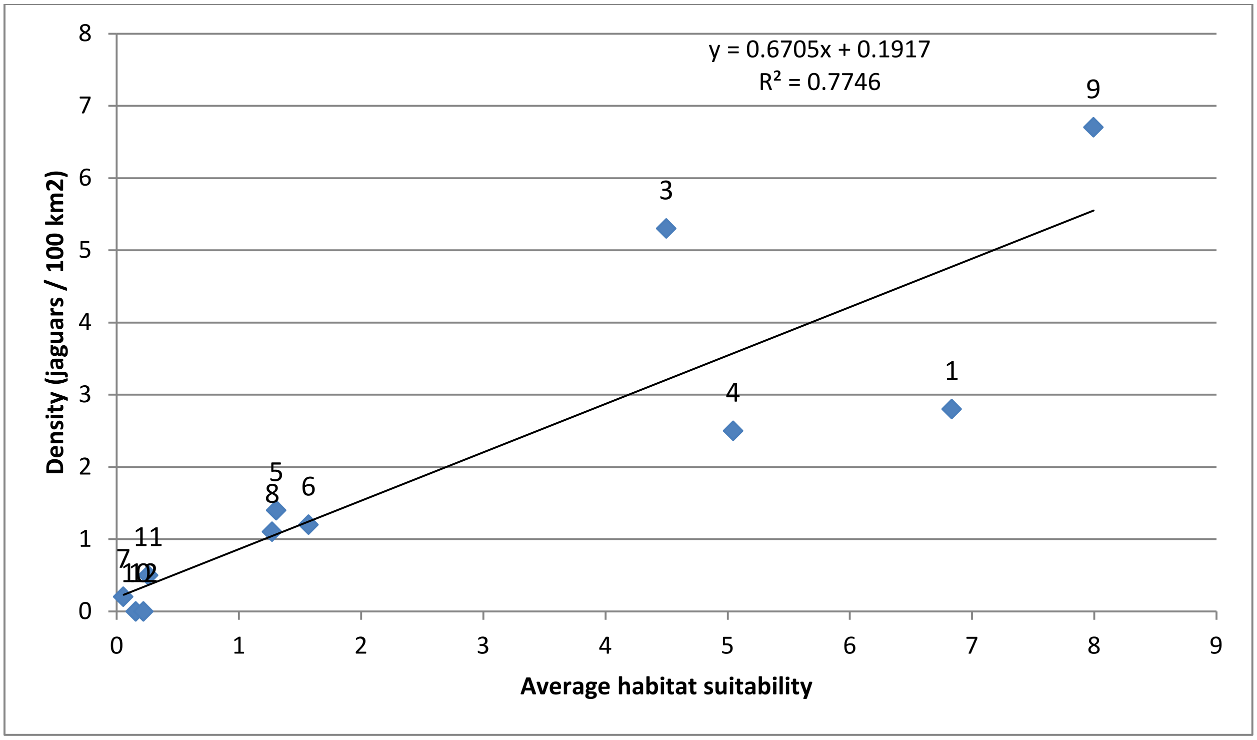
(5) Mask: Application of the thresholds derived from the histograms for jaguar observations against human influence in the previous iteration was removing large areas from the southern end of the NRU where observations had been made; but raising these thresholds was including large areas in the northern portion where observations had not been made and where habitat suitability was clearly poor according to expert opinion. Recognizing that jaguars may respond more tolerantly to human influence in the south than they do in the north, (as defined in (2) Habitat factors, above), the JRT coleaders during their meeting in New York suggested lower thresholds (HII < 20) than in the south (HII < 30) for inclusion in the model. The coleaders further suggested that areas not meeting the HII threshold in each area should be masked out, rather than set to 0 as in previous models. As with the small-fragment mask applied earlier, these masks have the effect of completely removing low-HII areas from consideration.

(6) Translation to density: Four new density studies were added (see table below). Additionally, after examining the habitat models and discussing the outlier results in the southern portion of the NRU in generally and in the Northern Mesoamerican Pacific mangroves specifically, the team coleaders decided to remove density study #2 (see model 10/11) because it occurred in an anomalous mangrove ecological setting, in a protected area surrounded by high human influence, and so was not considered representative of densities elsewhere in the NRU.

Study ID	**Average habitat suitability.**	**Density (jaguars /100 km2)**	**Source**
1	6.8	2.8	Rodrigo Núñez (pers. comm.)
3	4.5	5.3	Rodrigo Núñez (pers. comm.)
4	5.0	2.5	Carlos López González (pers. comm.)
9	8.0	6.7	Rubio 2011
5	1.3	1.4	Carlos López González (pers. comm.)
6	1.6	1.2	Carlos López González (pers. comm.)
7	0.1	0.2	McCain & Childs 2008
8	1.3	1.1	Rosas-Rosas 2011
10	0.2	0	Lara-Díaz 2010 (Master's thesis)
11	0.3	0.5	Lara-Díaz 2010 (Master's thesis)
12	0.2	0	Lara-Díaz 2010 (Master's thesis)

The regression equation: density (jaguars / 100 km2) = ((0.6705 * habitat score) + 0.1917) / 100.

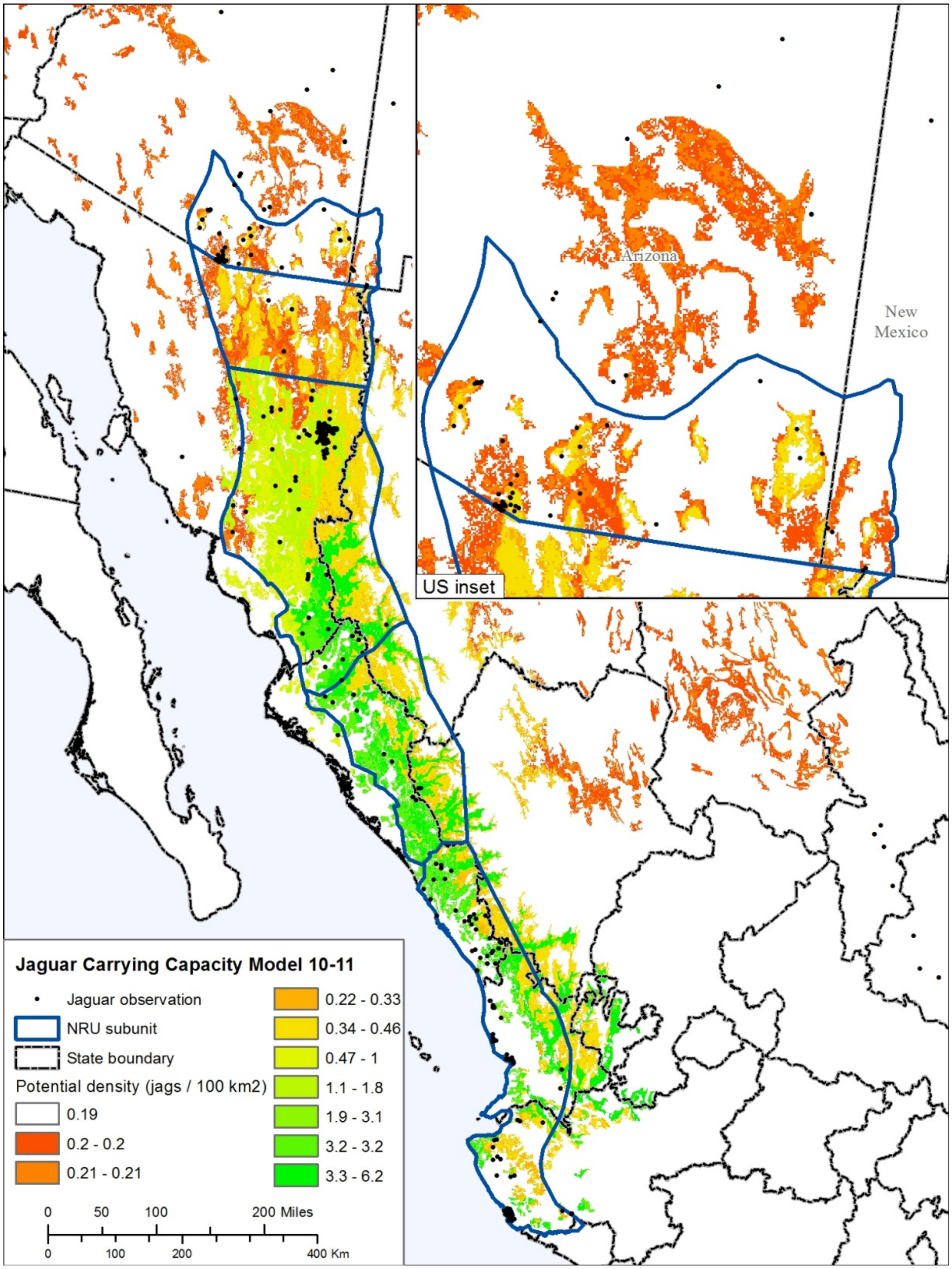
Note that the regression equation did not force the y-intercept through zero (see discussion in Objective 4).



(7) Sum:

Population subunit	**Former subunit name**	**Estimate of habitat area (km2)**	**Estimated number of potential jaguars**
Jalisco Core Area	MX Sinaloa Sub-Population	51,732	1,350
Sinaloa Secondary Area	MX North Sinaloa Connector Area	30,822	982
Sonora Core Area	MX Sonora Sub-Population	76,996	1,277
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	33,286	101
Borderlands Secondary Area – US portion	US South of I-10 Highway	27,737	59
Total		**220,573**	**3,769**

(8) Map of potential carrying capacity.



Potential jaguar habitat model, version 12 (July 31, 2012)

This version of the potential jaguar habitat model was presented at the meeting of the full JRT meeting in Tucson, Arizona on July 31, 2012.

(1) Subunit definition: The eastern boundary of the Mexico portion of the Borderlands Secondary Area, the Sonora Core Area, and the Sinaloa Secondary Area was moved westward to more closely match the western edge of the pine-oak forests and the 2000 m elevation line. In addition, the extreme northwest corner of northernmost unit, which extended into Pinal County, was removed.

Population subunit	**Former subunit name**	**Area of subunit (km2)**
Jalisco Core Area	MX Sinaloa Sub-Population	54,949
Sinaloa Secondary Area	MX North Sinaloa Connector Area	31,191
Sonora Core Area	MX Sonora Sub-Population	77,710
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	33,955
Borderlands Secondary Area – US portion	US South of I-10 Highway	29,021

(2) Habitat factors: same as version 11.

(3) Habitat weights: same as version 11.

(4) Habitat equation: same as version 11.

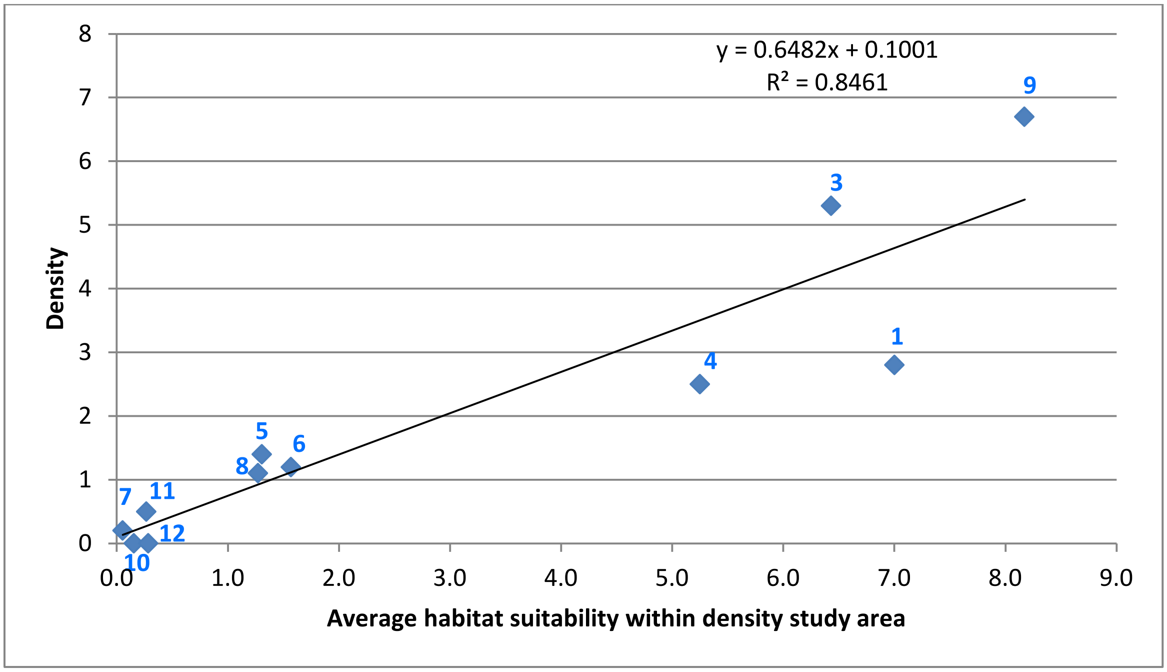
(5) Mask: same as version 11.

(6) Translation to density:

Study ID	**Average habitat suitability**	**Density (jaguars /100 km2)**	**Source**
1	7.0	2.8	Rodrigo Núñez (pers. comm.)
3	6.4	5.3	Rodrigo Núñez (pers. comm.)
4	5.3	2.5	Carlos López González (pers. comm.)
9	8.2	6.7	Rubio 2011
5	1.3	1.4	Carlos López González (pers. comm.)
6	1.6	1.2	Carlos López González (pers. comm).
7	0.1	0.2	McCain & Childs 2008
8	1.3	1.1	Octavio Rosas 2011
10	0.2	0	Lara-Díaz 2010 (Master's thesis)
11	0.3	0.5	Lara-Díaz 2010 (Master's thesis)
12	0.3	0	Lara-Díaz 2010 (Master's thesis)

The regression equation: density (jaguars / 100 km2) = ((0.6482 * habitat score) + 0.1001) / 100.

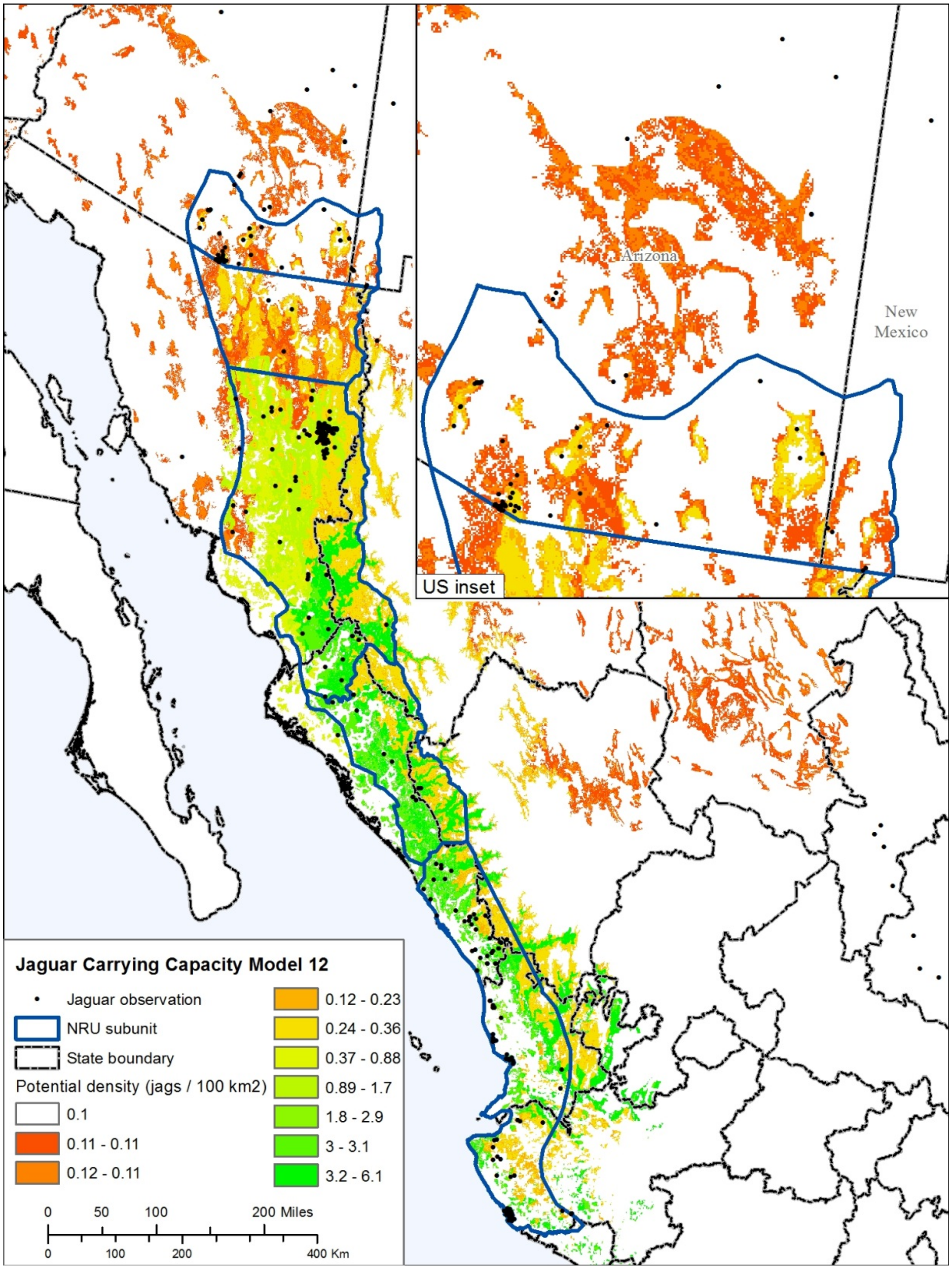
Note that the regression equation again did not force the y-intercept through zero, although the intercept is very small. As a result, this model, as in previous ones with non-zero y-intercepts, predicted a very low jaguar density everywhere in the NRU that had not been masked out, even in areas with "zero" habitat. See Objective 4 for further discussion.



(7) Sum:

Population subunit	**Former subunit name**	**Estimated number of potential jaguars**
Jalisco Core Area	MX Sinaloa Sub-Population	1,342
Sinaloa Secondary Area	MX North Sinaloa Connector Area	949
Sonora Core Area	MX Sonora Sub-Population	1,181
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	66
Borderlands Secondary Area – US portion	US South of I-10 Highway	31
Total		**3,569**

(8) Map of potential carrying capacity.



Potential jaguar habitat model, version 13

(1) Subunit definition: same as version 12.

(2) Habitat factors: same as version 12.

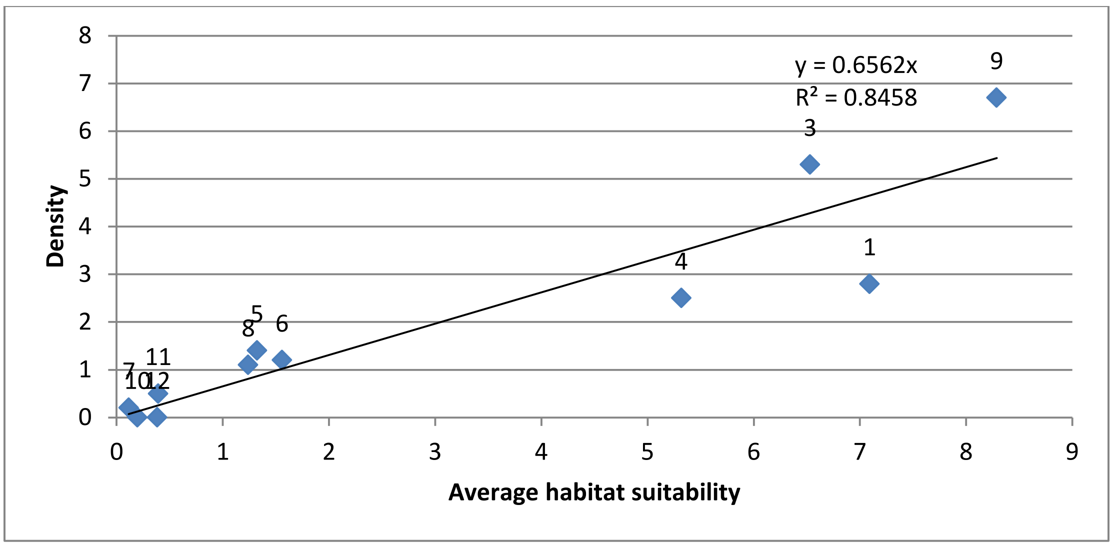
(3) Habitat weights: same as version 12.

(4) Habitat equation: same as version 12.

(5) Mask: same as version 12.

(6) Translation to density: The density studies and habitat values were the same as for version 12, but at the request of the Recovery Team the regression line was forced through 0. Forcing the regression line for zero meant that areas with a zero habitat score would not contribute to jaguar carrying capacity, in effect lowering the total estimated jaguar carrying capacity.

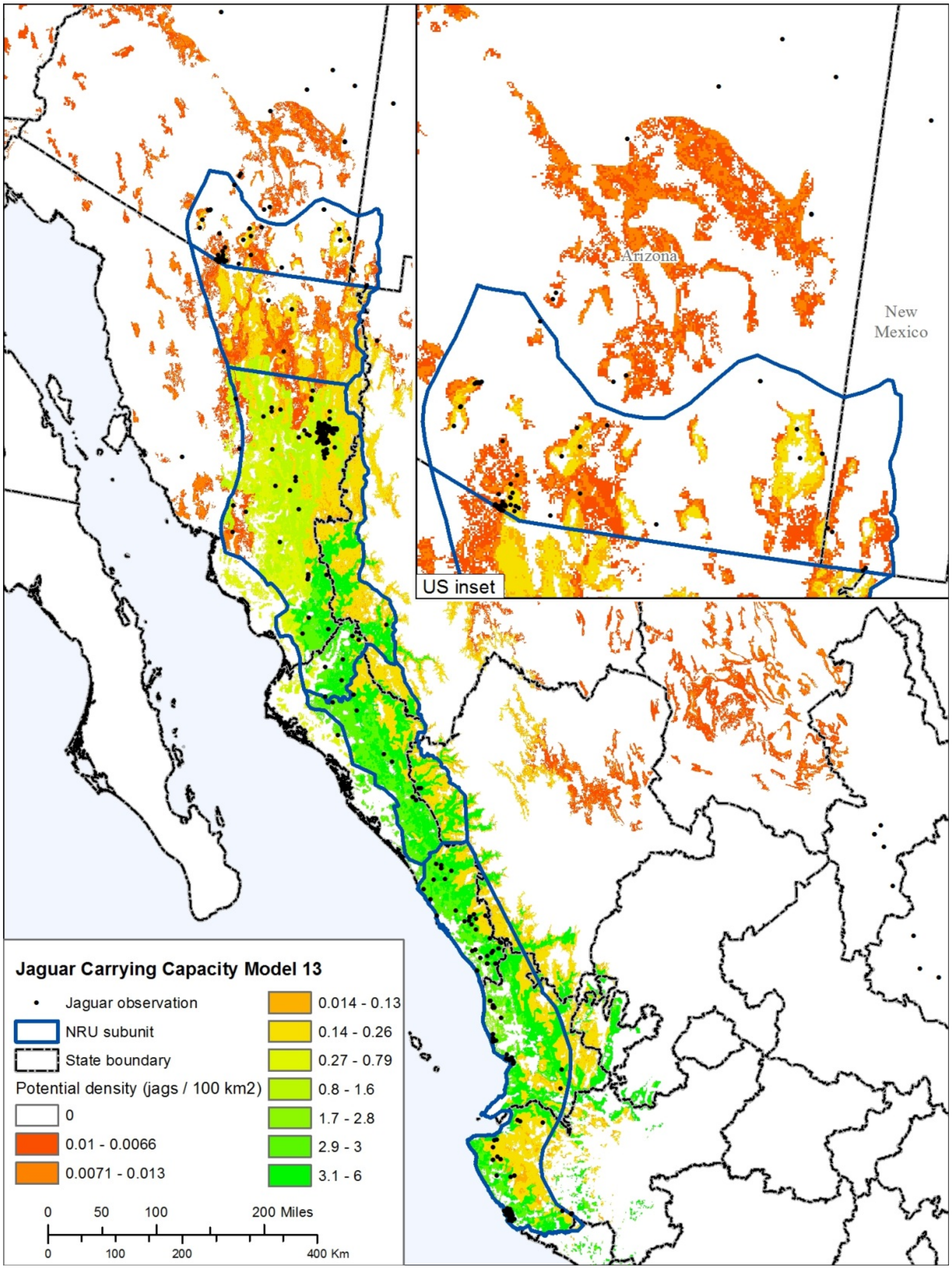
The regression equation: density (jaguars / 100 km2) = (0.6562 * habitat score) / 100.



(7) Sum:

Population subunit	Former subunit name	Estimated number of potential jaguars
Jalisco Core Area	MX Sinaloa Sub-Population	1,318
Sinaloa Secondary Area	MX North Sinaloa Connector Area	929
Sonora Core Area	MX Sonora Sub-Population	1,124
Borderlands Secondary Area – Mexico portion	MX Northern Sonora Connector Area	37
Borderlands Secondary Area – US portion	US South of I-10 Highway	6
Total		**3,414**

(8) Map of potential carrying capacity.



APPENDIX F: Monitoring anthropogenic mortality of jaguars (Foster 2014)

Jaguar Recovery Program

Monitoring anthropogenic mortality of jaguars

Rebecca Foster, 2014
Panthera
Produced for the Arizona Ecological Services Office, U.S. Fish and Wildlife Service

Contents

Causes of anthropogenic mortality in carnivores

A meta-analysis of 69 North American mammal populations across 27 species revealed that 52% of known-cause mortalities were a direct consequence of human activities, with carnivores being significantly more susceptible to anthropogenic mortality than herbivores (Collins and Kays 2011). Causes of anthropogenic mortality in large carnivores may be intentional (e.g., recreational/sport/trophy hunting; harvest for body parts; targeted predator control) or accidental (e.g., non-specific predator control; vehicle collisions). Both sources of anthropogenic mortality should be considered in any management plan (Collins and Kays 2011); however, legal intentional deaths may be easier to monitor than illegal or accidental deaths.

Accidental anthropogenic mortality

Carnivores may be killed accidentally by human activities, for example in road traffic accidents or as by-catch in non-target predator control programs such as indiscriminate trapping and poisoning (e.g., Ferreras et al. 1992, Nielsen and Woolf 2002, Seiler et al. 2004, Fournier-Chambrillon et al. 2004, Haines et al. 2005, Virgos and Travaini 2005, Orlowski and Nowak 2006, Gaydos et al. 2007, Riley et al. 2007). Non-natural accidental deaths may impact the survival of small, endangered populations, particularly if mortality is non-compensatory. For example, a seven-year study of the endangered Iberian lynx revealed that 75% of deaths were accidentally caused by humans (Ferreras et al. 1992). Such high rates of non-natural mortality raised concerns for the survival of the population, estimated to be only 40-50 individuals.

Intentional anthropogenic mortality

Historically, many carnivore populations were heavily exploited for the fur trade. Large-scale commercial hunting declined following the 1973 implementation of the Convention on International Trade in Endangered Species, banning trade in wildlife products derived from endangered species (Johnson et al. 2001); however, illegal hunting ("poaching") and sale of body parts continue on the black market. For example, the international trade in tiger parts for traditional Asian medicine threatens the few remaining tiger populations (Dinerstein et al. 2007). As tiger bones become increasingly rare, traders are switching to other large cat species (e.g., African lions; Hervieu 2013).

Trophy hunting of large charismatic carnivores is popular and lucrative (Frank and Woodroffe 2001). The selective harvesting of specific age or sex classes can disrupt the demography and social system of these populations, although the extent to which this influences population growth is not well known (Milner et al. 2007). Large males are often targeted, and this removal of resident males has been documented to increase acts of infanticide by new male immigrants (Loveridge et al. 2007, Balme et al. 2007, Swenson et al. 1997).

Pro-active or retaliatory lethal control of large carnivores is a common response to real or perceived threats to human life or livestock (Sillero-Zuibiriand and Laurenson 2001, Thirgood et al. 2005). Efforts to protect livestock or game species via lethal control of predators can heavily impact carnivore populations, causing dramatic range contraction or extinction (Woodroffe et al. 2005).

Some carnivore populations, particularly canids, may persist despite intensive persecution because reproduction compensates for harvest mortality (e.g., Knowlton 1972, Harris and Saunders 1993, Knowlton 1999). However, often, populations cannot compensate for sustained exploitation, especially if anthropogenic mortality is additive to natural mortality (e.g., Novaro et al. 2005, Stoner et al. 2006).

Anthropogenic mortality in jaguars

Jaguar populations suffered intense persecution for the commercial skin trade throughout the 20th century; during 1969, approximately 10,000 jaguar skins were imported into the USA (Smith 1976, McMahan 1982, Rabinowitz 2006). Commercial jaguar hunting declined with the ban on international trade in jaguar body parts across all countries within the jaguar range (Sunquist and Sunquist 2002). However, poaching for body parts still occurs within range countries. Pelts, skulls, teeth, and claws are often kept or sold as trophies or adornments. The acquisition or sale of body parts may not necessarily be the primary motivation for killing jaguars, but rather, a profitable by-product of protecting ones' livestock. However, recent anecdotal reports in Belize indicate that illegal traders from the Asian community are offering hunters a premium for jaguar meat and bones (R. Foster pers. obs., Forest Department, pers. comm.). It is not clear how widespread the activity is, or whether demand will increase as access to tiger products for traditional medicine declines. Additionally, the USA has a strong tradition of recreational/sport hunting (e.g., Anderson et al. 2010). As jaguar populations recover, the presence of a charismatic species in the jaguar recovery area (i.e., Northwestern Recovery Unit), and its proximity to the US, might attract the attention of sport/recreational hunters willing to shoot one for a trophy, even if it is illegal. Monitoring jaguar deaths in the recovery area by quantifying poaching and/or illegal trade/ownership of body parts may require covert operations, and the involvement of the relevant law enforcement and border control agencies.

Although commercial hunting of jaguars has declined, direct persecution by livestock owners is a major source of mortality among jaguar populations in human-influenced landscapes (e.g., Foster 2008). National laws governing lethal control of jaguars differ across range countries. For example, in Belize, it is legal to kill a jaguar that threatens life or livelihood, but the body must be handed over to the Government within one month (Belize Wildlife Protection Act 2000). The laws differ in the USA and Mexico, the two countries within the Northwestern Recovery Unit of the jaguar. In the USA, the jaguar is listed as an endangered species, therefore it is illegal to intentionally kill any individual except under extremely rare cases when federal authorities approve or act to remove individuals because of their threat to people or property (U.S. Fish and Wildlife Service 1999; Endangered Species Act, U.S. Congress 1973). In Mexico, it is illegal to kill a jaguar; however, the authorities have the right to grant removal permits in response to attacks on livestock (SEMARNAT 2000). If livestock owners (from hereon, "farmers") tend to take matters into their own hands without involving the authorities, then monitoring lethal control of jaguars will require building good relationships with farmers to encourage their cooperation in reporting jaguar deaths. The specificity of jaguar control strategies varies (Foster 2008), which may further obscure estimates of death rates. Some strategies, such as tracking with dogs from the livestock kill site within 24 hours, are likely to target the correct individual; while other strategies are non-specific (e.g., lacing bait with poison can kill multiple individuals of multiple species, but if the animals move away from the site before the poison takes effect, carcasses may not be found). Therefore, even if the farmers are willing to share information, they may not be able to quantify the jaguar death rate.

As with other carnivores, jaguars suffer accidental anthropogenic mortality. Perhaps most common would be vehicle collision. In a study using telemetry in Belize, Figueroa (2013) found that the highest cause of mortality for jaguars was vehicle collisions. Jaguar-vehicle collisions and road crossing points are associated with environmental factors such as vegetation cover, and these locations may become hot spots for collisions with vehicles (Figueroa 2013, Araya and

Salom 2013). Monitoring jaguar deaths on highways will require identifying hotspots and conducting regular surveys for carcasses of jaguars and other wildlife species.

Few studies have attempted to quantify anthropogenic mortality of jaguars, largely because of the difficulty of collecting data on such a sensitive issue, and those that do make no assessment of the likely impact on the local jaguar population (e.g., Crawshaw 2002, Conforti and Azevedo 2003, Brechin and Buff 2005, Michalski et al. 2006). Individual-based population simulations have been used to investigate the impact of anthropogenic mortality on the population dynamics and long-term persistence of the Belizean jaguar population using field data on abundance and lethal control (Foster 2008). However, such population viability analyses are assumption-heavy and are limited by lack of accurate information on vital rates (e.g., fecundity, age at first reproduction, natural mortality) and on how genetic factors (e.g., inbreeding) and demographic and environmental stochasticity interact and impact population growth rate.

Monitoring anthropogenic mortality in jaguars

Monitoring programs to detect change in a quantity (e.g., population size, mortality) should be designed and conducted at appropriate spatial and temporal scales such that the planned sampling effort is achievable within the logistical and financial constraints of the program, while also ensuring an acceptable level of power (i.e., the probability of detecting change should it occur; Gerrodette 1987, Gibbs 2000). Time and resources will have been wasted if a monitoring program has insufficient power to interpret results that indicate no change. Factors to consider when assessing the power of a monitoring program include the sample size (e.g., number of sites/individuals monitored, number of years of monitoring), the precision of the estimates (if absolute values are not known), and the effect size (i.e., the rate of change per unit time that is considered biologically significant).

Mortality is the proportion of deaths in a population per unit time; therefore, to estimate the mortality of a population for a given year, one must define the study area and estimate both the number of deaths and the population abundance. The most accurate method for monitoring mortality is to tag and track all individuals in the study population, for this enables a count of all individuals and rapid detection and investigation of all deaths (Collins and Kays 2011). Depending on the project resources, and the target population size and distribution, it may be possible to continuously monitor every individual in the population in this way. If so, the absolute values of abundance and deaths, thus mortality, are known exactly. Most likely, it will not be possible to monitor every individual in the target population; however, if a sample of individuals can be monitored, then mortality can be estimated for the sample and it may be possible to draw inferences about mortality at the population level, dependent on sufficient sample size and distribution. If it is not possible to directly monitor individuals, then indirect methods of estimating the death count could be employed, such as surveying the landscape for carcasses or interviewing relevant people (e.g., livestock owners, law enforcement agents, poachers) about the number of death events that they have encountered. Surveys of this sort maybe be biased towards specific causes of death (e.g., lethal control) and are less accurate than monitoring mortality through tagging and tracking, but can allow a conservative estimate of number of deaths per unit time. Formal surveys may be further complemented by informal reports, or “citizen science,” whereby the general public are encouraged to report deaths that they encounter. Verification of death counts from formal interviews and public reporting should be sought whenever possible (e.g., by requesting photographic evidence) to increase confidence in the validity of the interview data or report.

Consider a stratified random sampling strategy to help to ensure that all parts of the population are represented in the sample. This can aid in making inferences at the population level. For example, if animals are being tagged, stratify the sample by gender and age class; if farmers are being interviewed, stratify by factors such as livestock type, farm size, and management strategies; if highways are being surveyed, stratify by factors such as width, speed limit, and traffic volume. For more information about sampling strategies see Särndal et al. (2003).

If individuals are not being monitored continuously, formal surveys to count or sample the number of deaths must be repeated at the same site(s) at a biologically relevant time interval. For a species such as a jaguar, with an inter-birth interval of 22-24 months (Carillo et al. 2009), an appropriate time interval might be two years.

A selection of suggested methods to monitor anthropogenic mortality, death rate or death counts of jaguars is described below. These methods are not exhaustive, and if implemented should be adapted as appropriate so that they are relevant for the local conditions.

Monitoring mortality of jaguars by tagging and tracking

Telemetry/GPS collars have been used successfully to study mortality in a range of cat species including African lions, pumas, Geoffroy's cat, lynx, and jaguars (Woodroffe and Frank 2005, Ruth et al. 2011, Pereira et al. 2010, Figueroa 2013, respectively). Collars could be fitted to all jaguars, or a sample of jaguars, within the area of interest. Details on the appropriate methods for live trapping, immobilizing, collaring, and tracking jaguars can be found in the literature and elsewhere in the Jaguar Recovery Plan. When a mortality signal is detected, the trackers should immediately locate the carcass and determine the cause of death. This should be done as soon as possible; if a jaguar is illegally killed, the perpetrator may remove the collar and take the carcass before the trackers can respond. This method has the benefit of monitoring all forms of mortality, not only those associated with human causes. If resources are only available to tag and track a sample of jaguars, the data could be used to determine which causes of anthropogenic mortality are most common and, therefore, guide decisions about the choice of indirect surveys for jaguar deaths (e.g., monitoring lethal predator control versus monitoring vehicle collisions).

Monitoring lethal control of jaguars

Options for collecting information about pro-active and retaliatory lethal control include standardized interviews with farmers and/or continuous free-reporting by farmers. For those farmers who agree to participate in the program, background information should be collected on livestock species and management, and if possible, whether they employ predator control, and the methods used (e.g., specific versus non-specific methods). In addition, a combination of satellite imagery and ground-truthing can be used to map the farms. These data are useful for guiding study design (e.g. stratified random sampling) if it is not possible to survey every farmer, and for drawing inferences about other farms at the landscape level. Data derived from interviews/reports may be complemented by camera trapping, which would provide a photographic database of jaguars using the farms.

Before beginning the monitoring program, it is important to verify that the farmers can reliably identify jaguars. This can be done by showing them photographs of different local carnivores (jaguars, pumas, coyotes, ocelots, etc.). Data collectors can then conduct interviews with farmers to find out how many jaguars they have killed over a pre-defined time interval. Interviews should be repeated at the pre-defined sampling interval (e.g., every two years) for the duration of the monitoring program. Alternatively, data collectors can request that the farmers report all events of lethal control of jaguars on their farms, in real time. Thus, farmers actively report to the data collectors whenever a jaguar is killed, rather than data collectors visiting the farms intermittently (e.g., once every two years) to conduct interviews.

The reliability of routine interviews or free-reporting depends on farmers being able to correctly identify the species and providing truthful and verifiable information about how many animals, and what species, they have killed. Generally, data collectors cannot verify the answers unless the farmer provides body parts (e.g., skulls, pelts) or photographs of carcasses. In the case of real-time reporting, on receipt of a report, data collectors could visit the site to retrieve or photograph the carcass. If it is not possible to make a site visit, the data collectors should request that the farmer photographs the flanks, teeth, and genitals of the carcass for verification. The reliability of free-reporting also depends on farmers making the effort to report incidents of lethal control to data collectors, whereas the reliability of the interview method depends on farmers remembering how many death events occurred since the previous interview (unless they keep records). Death counts derived from either method that have been verified from photographs or carcasses/body parts should always be considered an underestimate, as other deaths may occur that the farmers choose not to report and/or deaths may result from non-specific predator control (e.g., poison), which cannot be quantified. Given the sensitivity of the information, data collectors should assure the farmers that their anonymity will be protected, and if appropriate, guarantee that they will not be reported to the authorities if they provide information about jaguar deaths.

Whenever possible, the gender and approximate age of the deceased animal should be recorded. If a photographic database of jaguars in the study area exists, then the pelt pattern of the deceased animal should be compared with those in the database to identify whether it is a known or new individual.

Regardless of the number of farms monitored or method employed (interviews or free-reporting), the unit of measure for monitoring deaths due to predator control is the number of deaths per unit time (i.e., death rate). This assumes that every farm in the sample was surveyed at each time interval, or all sample farms were actively reporting during the monitoring period. If the farms participating in the monitoring program change over time, then the death rate can only be calculated at the farm-level rather than at the landscape level. Estimates of the number of jaguars killed per unit area of farmland per year (i.e., death-rate "density") are possible if the size of continuous farmland is larger than the home range of jaguars inhabiting the farmland. Home range estimates can be obtained via GPS or radio telemetry. Note, however, that it may not be appropriate to extrapolate the death rate estimate to other farms because farmers who have agreed to participate in the program may represent non-random sample of farmers in general, and may employ different levels of predator control than farmers who did not agree to join the monitoring program.

If farmers are reluctant or refuse to give information about predator control on their own properties, indirect questioning may be an alternative option. For example, this might be simply asking farmers about rates of lethal control "in general" in the local area; however, this may introduce positive bias if the same incidents are reported by multiple farmers. Alternatively, it may be possible to conduct surveys on farmers' attitudes towards jaguars. In this manner, farmers do not have to report directly whether they have killed any jaguars, but instead they are asked whether they agree, are indifferent, or disagree with various statements such as, "*I like seeing jaguars on my land*," "*I want jaguars on my land*," "*I lose livestock to jaguars*," "*Farmers should be allowed to use lethal control to protect their livestock*," etc. It may then be possible to track changing attitudes toward jaguars through time. While this does not give an index of death rate, it will at least indicate whether tolerance to jaguars, and thus the potential threat of lethal control, is changing.

Monitoring poaching of jaguars

Assuming that hunters are unwilling to share information about poaching jaguars, data could be collected indirectly by monitoring jaguar body parts that have been confiscated by the relevant law enforcements agencies. Options for collecting data on rates of confiscations include routinely accessing the agencies' records of confiscations at pre-defined time intervals, or requesting free-reporting to the data collectors by law agents whenever they confiscate a jaguar body part.

Data collectors can verify records/reports if they are given access to the confiscated body parts or photographs thereof. Skulls, bones, teeth, and claws can be compared with photos/museum specimens to identify species, and, if possible, used to determine gender and estimate age based on size and/or tooth wear. Pelts can be compared with existing camera trap photographs of known jaguars from the area of interest (if available) to identify specific individuals; if it is a known cat, this can be used to verify the gender, approximate age, and the last date and location that it was known to be alive. In the case of uncertainty in identifying species from body parts, tissue samples could be genotyped to confirm species and gender. If data collectors are not given access to the body parts, it is important to verify that the agents who compiled the records, or provided the reports, can reliably identify jaguars from body parts.

The areas of operation/spheres of influence of each agency/agent participating in the program should be defined to aid in making inferences about rates of confiscations at the landscape level. However, it is also important to establish when the animal died and whether it resided in the area of interest to the monitoring program. If it is not possible to confirm that the animal is from the area of interest and/or the approximate date of death, then that record/report should not be included in the poaching count. Confiscation counts based on verified reports should be considered an underestimate, as poaching/illegal trade may have occurred that agents did not detect. However, there is a risk of positive bias if different body parts from the same jaguar are confiscated and recorded/reported independently as separate poaching events. The only way to guard against this is to genotype every confiscated body part to the individual level.

The unit of measure for monitoring poaching is the number of jaguars confiscated per unit time (i.e., confiscation rate). This assumes that all sampled agencies provide records for every monitoring period or were actively reporting throughout the entire monitoring period. It further assumes that the search effort by agents for poaching/illegal trade remains constant through time.

Monitoring vehicle collisions with jaguars

Options for estimating the rate at which jaguars are killed on highways include requesting that existing highway patrol units report incidences of jaguar road-kills to data collectors, and/or data collectors conducting systematic surveys along a sample of highways. Highway patrol units (usually officers in vehicles) could be trained in jaguar identification. On receipt of a report from the highway patrol, data collectors would need to verify the report via an on-site visit or ask the highway patrol to provide photographs. All units that participate in the monitoring program would need to provide daily records of their patrols (such as which highways, speed, and distance travelled), regardless of whether they detect a carcass, so that the data collectors can calculate the search effort and thus the rate of detection of jaguar carcasses per unit distance of highway surveyed. Alternatively, data collectors could conduct systematic surveys of selected highways. Ideally, this would involve driving highways at a constant speed at dawn, with two passengers, one surveying each side of the road. For each survey session, they should record the time spent searching, and map the distance and route travelled. It might also be necessary to repeatedly survey the same stretches throughout the year to estimate seasonal variation in jaguar kills from vehicle collisions. Highway selection could either involve stratified random sampling based on factors such as highway speed limit, width of road, and traffic volume; or, if available, use existing data to identify highways that have carnivore-vehicle collision hotspots, and monitor these. In the latter approach (monitoring "hotspots"), the data will not be representative of all highways, therefore they cannot be used to make generalizations about other highways within the area of interest; however, they can still contribute to an estimate of the total death rate.

Whenever possible, the gender and approximate age of the deceased animal should be recorded. If a photographic database of jaguars in the study area exists, the pelt pattern of the deceased animal should be compared with those in the database to identify whether it is a known or new individual. The detectability of carcasses will vary with factors such as weather conditions, highway width, and roadside vegetation cover; therefore, it may be prudent to keep a record of these extraneous factors associated with carcass sites.

Animals that are hit on the highway but move away from the site of impact before dying of their injuries may not be detected; therefore, road-kill counts should be considered an underestimate. Furthermore, when an animal dies, the window of opportunity for detection of the carcass depends on the decomposition rate. A study could be done on decomposition rate of road-kill mammals that are a similar size as an average jaguar. This will indicate for how long a jaguar carcass is likely to remain detectable under local climatic and biotic conditions (e.g., temperature, precipitation, presence of scavengers). The decomposition rate can be used for designing how often a given stretch of highway should be surveyed, and/or for estimating how many carcasses may not have been detected during the time interval between surveys.

The systematic highway surveys should be repeated at pre-defined intervals throughout the monitoring period. The unit of measure for monitoring deaths due to vehicle collisions via systematic surveys is the number of jaguar carcasses detected per unit search-distance per unit search-time.

Reports from the public

It is worth considering a public awareness campaign requesting that members of the public report any jaguar deaths (e.g., predator control, road kill, poaching/trade/ownership). All reports must be verified via photographs or a site visit conducted by the data collectors. This method depends on the data collectors being able to reliably verify the reports, specifically the species, the cause of death (natural versus anthropogenic), the location of death, and the approximate date of death. Verified reports from members of the public can add to the total count of jaguar deaths within the area of interest; however, they should not be used for monitoring death rate over time as there is no way of estimating or standardizing the effort of this form of data collection.

Interpreting change in anthropogenic mortality of jaguars

Changes in anthropogenic mortality/death counts (intentional or accidental) cannot be used to draw conclusions about changes in population size. For example, farmers may increase their predator control effort in response to: 1) increased awareness of jaguar presence in the study area; this may be unrelated to the number of jaguars in the study area; 2) increased attacks on livestock due to an increase in the contact zone between farms and wilderness as farms expand; this may be unrelated to the number of jaguars in the study area; or 3) a real increase in jaguar numbers associated with increased presence of jaguars and attacks on livestock. Similarly, the rate of poaching and illegal trade may vary independently of population size. Poacher effort and trade may vary with a real or perceived increase in population size, as well as changes in market forces; however, the detection rate of poaching and trade will vary with agent effort, which depends on a suite of factors such as government priorities, funding, and capacity. Finally, changes in accidental deaths may fluctuate independently of population size: vehicle collisions may increase if the volume of traffic increases; accidental poisoning/trapping may increase if the effort or efficiency of non-target predator control programs increases; or, alternatively, if traffic volume and non-target predator control efforts remain constant, an increase in accidental deaths may genuinely reflect an increase in population size. Death rate due to human causes and whether the level is sustainable can only be assessed in conjunction with estimates of abundance and natural mortality within the study area. See Polisar et al. 2014a and 2014b for more information on estimating jaguar abundance and mortality.

Conclusion

Mortality is the proportion of deaths in a population per unit time. Therefore, to estimate the absolute mortality of a population, one must estimate the population abundance and the number of deaths within a defined study area over a defined time period. Anthropogenic mortality of jaguars may be intentional or accidental. Both sources of mortality are considered in the Jaguar Recovery Plan. Direct monitoring is the most reliable way to estimate the number of deaths and identify causes of death. This can be achieved by tagging and tracking all individuals or a sample of individuals, in the study population. If tagging is not possible, then the number of deaths can be monitored indirectly via formal interviews and/or free-reporting with relevant stakeholders; highway surveys for kills in vehicle collisions; and/or informal reports by the public. Verification of the deaths should always be sought (e.g., carcass or photograph of carcass). Care must be taken to consider biases when interpreting data collected through indirect methods. Changes in the number or rate of jaguar deaths caused by people cannot be used to draw conclusions about changes in jaguar population size. The sustainability of anthropogenic mortality of jaguars can only be assessed in conjunction with estimates of jaguar abundance and natural mortality within the study area.

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APPENDIX G: Arizona Game and Fish Department Reported Jaguar/Ocelot/Jaguarundi Observation Form

CLASS[1] ________

Arizona Game and Fish Department
Reported Jaguar/Ocelot/Jaguarundi Observation Form

Interviewer (Name/Job Title): ______________________ Interview Date: ____________

Observer (Name) ______________________ Phone (H / C) ________ (W) ________

Address ______________________ Occupation ______________________

Relevant Biological/Outdoor Experience ____________ Additional Observers ______________
______________________________ Contact Info: ______________

Original report date __________ Reported via: ____ Phone ____ e-mail/letter ____ in person

Report received by: ______________ Agency: ______________________

Observation Details:

Date of Observation: __________

Location (state, county, legal, GPS coordinates with Datum, etc.): ______________________

Description of site (habitat, land use, etc.)
Including visibility (open hillside, brushy, etc.): ______________________

Description of event /
observation: ______________________

Time of day ________ Duration (total time of observation) ________ Photo (Y or N)

Location of the sun to observer: ____ overhead ______ behind animal ______ behind observer

Number of animals seen ______ Distance from observer ______ Optical aids used ________

Description of animal:

Body (color, size, markings, etc) ______________________

Tail (longer/shorter than body) ______________ Head/Face ______________

Legs/Feet ______________ Other: ______________

Behavior of animal: ______________________

Other signs observed (scat, tracks, prey remains, etc.) ______________________

Specific Questions for the Reporting Party:

Observer's first impression: ______________________

Were notes taken during the observation ___ or from memory? ___
Were references used in your decision: ___ Field guide(s) ___ Advice from friends/colleagues ___ Images from Internet
If used, how did this change or influence your decision? ______________
Describe how/why similar species were discounted: ______________

Actions/Follow-up: (for agency personnel only) ______________________

Reasons for acceptance\denial:[2] ______________________
Additional Notes: ______________________

[1]Classification is applied by the Department representative to the Jaguar Conservation Team, usually the Region V Nongame Specialist: I – Confirmed, w/ visual or physical evidence; II – Probable, w/ merit; II – Unsubstantiated, without merit; III – Not Likely

[2](Select one): Visual or physical evidence provided \ confirmed to be jaguar\ocelot\jaguarundi; Inconclusive w\merit – 2 or more separate observations\events within same area\timeframe; Inconclusive w\merit – Observer has worked with or studied jaguars\ocelots\jaguarundis; Inconclusive – Experienced observer familiar with other large cats\mammals; Inconclusive – Inexperienced observer provides detailed description suggesting possible account; Unlikely – Observer provides vague description of animal\account\event; Unlikely- Questionable credibility, Observer exaggerates, reports other rare observations\events