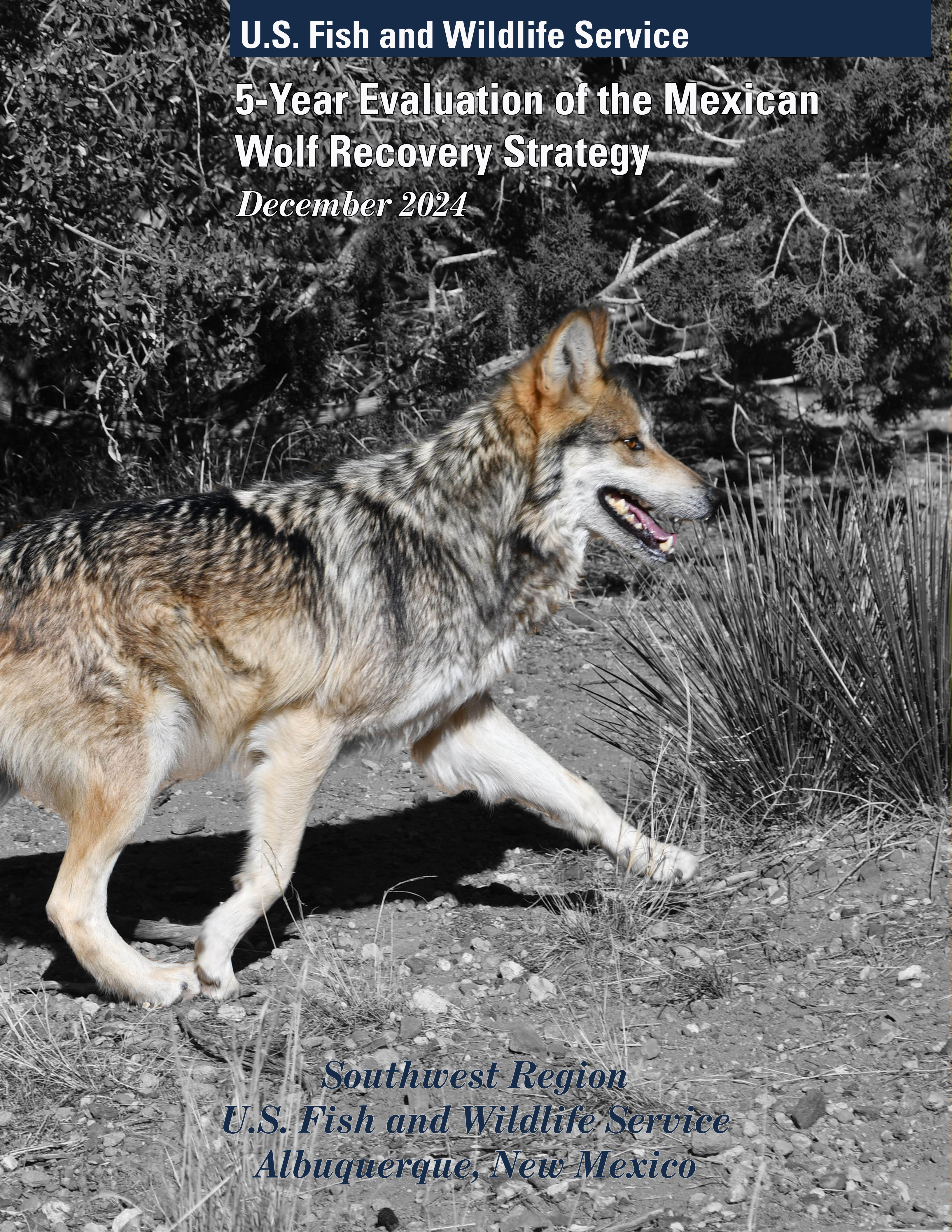
U.S. Fish and Wildlife Service

5-Year Evaluation of the Mexican Wolf Recovery Strategy

December 2024



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

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DISCLAIMER

This 5-year evaluation assesses efficacy and progress of programmatic efforts for Mexican wolf recovery 5 years after signing the Mexican Wolf Recovery Plan, First Revision, in 2017 (USFWS 2017b). In response to a court-ordered remand of the Mexican Wolf Recovery Plan, First Revision, we developed the Mexican Wolf Recovery Plan, Second Revision in 2022 (USFWS 2022a). This version of the recovery plan is the current guiding document for our recovery strategy and includes additional site-specific management actions to address the threat of human-caused mortality, including illegal killing, that the previous version of the recovery plan did not include. While the 2022 plan guides recovery, we are evaluating our progress 5 years after signing the 2017 plan as we retained the 2017 interim targets and evaluation period in the 2022 recovery plan.

The addition of the site-specific management actions was responsive to the District Court of Arizona's October 14, 2021, ruling that the Mexican Wolf Recovery Plan, First Revision, did not contain site-specific management actions to address the recognized threat of illegal killing of Mexican wolves or explain why it would be impracticable or unnecessary to do so (*Center for Biological Diversity, et al., v. Haaland, et al.,* (Case No. 4:18-CV-00047-TUC-JGZ) (lead) and *WildEarth Guardians, et al., v. Haaland, et al.,* (Case No. 4:18-CV-00048-TUC-JGZ) (member). The Plaintiffs appealed to the Ninth Circuit Court of Appeals as the district court had ruled in favor of the United States on most of the points raised in the Complaint; the United States did not appeal. After the final revised recovery plan was published in September 2022, the United States filed a motion to dismiss this case. The motion to dismiss was denied without prejudice to allow the Ninth Circuit panel to address it when the panel addressed the full case. On December 12, 2023, the Ninth Circuit held that the lawsuit was moot because it was superseded by the 2022 plan. Plaintiffs subsequently filed a motion to vacate the original ruling and a petition for rehearing. Both the motion to vacate and petition for rehearing were denied on April 18, 2024, which finalized all ongoing litigation on the recovery plan.

The recovery plan and this 5-year evaluation do not commit any entity to implement the recommended strategies or actions contained within it, but rather provide guidance for ameliorating threats and implementing proactive conservation measures, as well as providing context for implementation of other sections of the Endangered Species Act. Nothing in this evaluation 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. Additionally and as indicated above, here we are assessing programmatic efforts for Mexican wolf recovery, and while responsible parties may not be listed for each element of this evaluation, it is intended to be a holistic assessment of our progress, inclusive of collaborative and partner led efforts. Lastly, this evaluation does not necessarily represent the views or the official positions or approval of any individuals or agencies involved in the evaluation formulation, other than the United States Fish and Wildlife Service.

LITERATURE CITATION AND AVAILABILITY

Literature citation should read as follows:

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Copies are also available online at:
https://www.fws.gov/program/conserving-mexican-wolf

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Mexican wolf (*Canis lupus baileyi*) has been protected as an endangered subspecies of gray wolf since 1976 under the Endangered Species Act (ESA) of 1973, as amended (80 FR 2488). Following the near extinction of the Mexican wolf due to predator eradication efforts from the mid to late 1800s to mid-1900s, the United States Fish and Wildlife Service (Service), Mexico, and partner agencies initiated a binational captive breeding program descended from 7 founder wolves and began efforts to re-establish Mexican wolves in the wild in the United States in 1998 and Mexico in 2011.

Our current recovery strategy for the Mexican wolf is to establish and maintain a minimum of two resilient, genetically diverse Mexican wolf populations distributed across ecologically and geographically diverse areas in the subspecies' historical range in the United States and Mexico, as outlined in the first and second revision of the Mexican Wolf Recovery Plan (Recovery Plan, USFWS 2017b, 2022a). The Mexican Wolf Recovery Plan included evaluations to ensure we are making timely progress toward recovery 5 and 10 years after implementation of the Recovery Plan and subsequently adjust our management as needed. The timing of the 5- and 10-year evaluation is based on calendar years following the signing of the Mexican Wolf Recovery Plan, First Revision, in 2017. Thus, we used the data collected at least through the end of 2022 to conduct this evaluation in 2023 and 2024 and used data from 2023 when available.

The evaluation considers progress on the recovery objectives for the Mexican wolf, assessment of each population's progress towards interim abundance and release targets, comparisons between observed metrics and those predicted in 2017 modeling efforts (Appendix A), and next steps for furthering progress towards Mexican wolf recovery.

Over the course of the 5-year evaluation period, the Mexican wolf population in the United States has surpassed interim abundance and release targets as well as 2017 model predictions for gene diversity and population growth (Tables 1 and 2). We have now seen eight consecutive years of population growth, indicating our recovery strategy is proving effective at maintaining mortality rates below critical thresholds and enabling the population in the U.S. to make progress towards recovery. As of 2023, a minimum of 20 different litters have been produced by fostered wolves, and gene diversity in the U.S. population relative to the captive population continued to exceed 90% retention in 2023.

Conversely, while gene diversity metrics in the Mexico population are better than predicted and the wild population retained 97% of the captive population's gene diversity in 2022, the population has not grown at the rate anticipated in the 2017 population viability analysis nor is the population reaching interim abundance targets nor interim release and translocation targets (Table 1 and 2). High mortality rates and too few releases and translocations have resulted in population growth below projections in Mexico. Efforts, however, have increased to reduce human-caused mortality through outreach and community engagement. Additionally, the Mexican government is working towards establishing compensation programs for livestock producers impacted by wolf-livestock conflict and have endorsed exploring additional release sites in Durango and southern portions of Chihuahua, Mexico.

Table 1. Summary of observed metrics at the 5-year evaluation mark (2022) compared to interim abundance and release or release and translocation targets in the United States and Mexico.

	United States		Mexico	
	Target	Observed	Target	Observed
Abundance[1]	145	242	100	35
Release and Translocation[2]	9	13	25	9

[1] Abundance metrics are minimum population counts.
[2]Release and translocation targets are the number of released wolves surviving to breeding age in the United States and the number of released and translocated wolves surviving to breeding age in Mexico.

Table 2. Summary of predicted versus observed metrics from wild populations compared to PVA model predictions (Miller 2017). Dates for the analysis for the United States population are from 2015 through 2023 and for the Mexico population from 2015 through 2022.

	United States		Mexico	
	Prediction	Observation	Prediction	Observation
Population size[1]	229±85	257	124±39	35
Mean annual growth rate	11%	13%	33%	11%
Gene diversity retained	74.99%	76.09%	79.8%	79.74%
Mean inbreeding coefficient	0.234	0.211	0.181	0.166
Adult mortality	18.9%	15.8%	18.9%	39.0%
Pup mortality	28.2%	32.3%	28.2%	N/A[2]

[1]Predictions for population size were total abundance and observations are minimum counts.
[2]The sample of wild pups with radio collars was too low to estimate a survival rate.

We recommend continuing to implement the recovery strategy and recovery actions identified in the Recovery Plan to further progress on our recovery objectives for the U.S. population. To improve population performance in Mexico, we have highlighted recovery actions, previously identified with our partners in Mexico, to improve progress on recovery objectives for the population, focusing on increasing social tolerance, reducing mortality rates, improving monitoring efforts, pursuing additional release sites, and increasing releases and translocations of Mexican wolves. These efforts are reliant on binational collaborative partnerships, and we remain committed to those as well as closely monitoring recovery progress. Further, we intend to conduct additional analyses to evaluate modified release strategies that will best facilitate Mexican wolf recovery in Mexico while maintaining source population viability.

I. INTRODUCTION AND BACKGROUND

The Mexican wolf is the smallest, rarest, southernmost occurring, and most genetically distinct subspecies of the North American gray wolf (*Canis lupus*). The Mexican wolf is a top predator native to the southwestern United States and Mexico that lives in packs and requires large expanses of forested terrain with adequate prey base to support the pack. Predator eradication programs in the mid to late 1800s to mid-1900s resulted in the near extinction of the Mexican wolf. Extinction was averted with the initiation of a binational captive breeding population descended from 7 Mexican wolf founders.

The Mexican wolf is currently listed as endangered under the Endangered Species Act (ESA, 80 FR 24885) and has been protected under the ESA since first being listed as endangered in 1976 (41 FR 17740). The Service designated a Mexican wolf nonessential experimental population under section 10(j) of the ESA in 1998, which was revised in 2015 (80 FR 2512) and 2022 (87 FR 39348). The current binational recovery strategy is defined by the 2022 Mexican Wolf Recovery Plan, Second Revision (Recovery Plan, USFWS 2022a).

Within the context of the Recovery Plan, we consider current threats to the Mexican wolf to be excessive human-caused mortality, demographic stochasticity associated with small population size, and loss of gene diversity. To address the identified threats and craft a strategy for Mexican wolf recovery, we developed the Recovery Plan using Mexican wolf monitoring data from the wild and captivity, data from other gray wolf populations when relevant, and other relevant scientific information. We also utilized two computer modeling analyses to develop the recovery strategy and criteria in the Recovery Plan, including the Mexican wolf population viability analysis or PVA (Miller 2017) and a habitat suitability analysis (Martínez-Meyer et al. 2021).

Current recovery efforts focus on the reestablishment of two Mexican wolf populations in the wild, one in the United States and one in Mexico, and on maintenance of the captive breeding population. See the Recovery Plan for further discussion on the history of Mexican wolf recovery efforts, threats to the Mexican wolf, recovery actions identified to alleviate threats, details on data and analyses used to craft our recovery strategy, and recovery criteria for the Mexican wolf (USFWS 2022a).

Recognizing the challenges inherent in Mexican wolf recovery, the Recovery Plan recommended progress evaluations 5 and 10 years into plan implementation to ensure the recovery strategy is effective at reaching interim targets (USFWS 2022a, pp. 27-28). Specifically, we committed to assessing the status of each population contributing to recovery and each population's progress toward recovery criteria. We define 5 years to be through 2022 or 5 years after signing of the Mexican Wolf Recovery Plan, First Revision (USFWS 2017a). While the period of evaluation goes through 2022, we also consider data through 2023 when available.

This report constitutes the 5-year evaluation to assess progress towards demographic and genetic benchmarks since plan implementation. We evaluate the effectiveness of our recovery strategy in achieving progress toward recovery goals, including comparing predicted versus observed metrics from the 2017 PVA used to define our quantitative recovery criteria (Appendix A). Based on this information, we identify aspects of population performance needing improvement and determine what actions are necessary to address identified needs.

II. EVALUATION OF THE RECOVERY STRATEGY AND PROGRESS TOWARD RECOVERY OBJECTIVES

Our recovery strategy uses the principles of resiliency, redundancy, and representation to increase the Mexican wolf's viability. Resiliency is the ability of a species to withstand environmental and demographic stochasticity; it is improved by having large, connected populations. Redundancy is the ability to withstand catastrophic events; it is improved by having multiple, widely distributed populations. Representation is the ability to adapt to changing environmental conditions; it is fostered by maintaining genetic variability and the use of diverse habitats.

To reduce extinction risk and increase Mexican wolf resiliency, redundancy, and representation we, in collaboration with partners, focus our recovery strategy on expanding the geographic distribution of the Mexican wolf in historical range, increasing population abundance, improving gene diversity in the wild, monitoring wild populations and implementing adaptive management, and addressing social and economic concerns related to Mexican wolf recovery. See the Recovery Plan for full details on our strategy and rationale (USFWS 2022a).

Our recovery goal is to conserve and protect the Mexican wolf and its habitat so that its long-term survival is secured, populations are capable of enduring threats, and it can be removed from the list of threatened and endangered species. Recovery objectives identify outcomes that will lead to achieving the goal of recovery and delisting. Recovery objectives for the Mexican wolf are:

1. Increase the size of two Mexican wolf populations;
2. Improve gene diversity and maintain the health of Mexican wolves;
3. Ensure adequate habitat availability to support viable Mexican wolf populations;
4. Maintain the Mexican Wolf Species Survival Plan (SSP, now called Saving Animals from Extinction [SAFE]) captive breeding program to improve the status of wild populations;
5. Promote Mexican wolf conservation through education and outreach programs; and
6. Ensure recovery success.

To meet the identified objectives and goal, we define recovery actions and site-specific recovery activities in our Recovery Plan and Recovery Implementation Strategy (RIS, USFWS 2022a, USFWS 2022b). We provide detailed reports on the implementation of our Recovery Plan in our annual progress reports (USFWS 2019, USFWS 2020, USFWS 2021, USFWS 2022c, USFWS 2023, USFWS 2024). Here we evaluate the 5-year interim success of our recovery strategy by assessing progress on recovery objectives.

Increase the size of two Mexican wolf populations

Our recovery strategy aims to increase the size of Mexican wolf populations in the United States and Mexico to an abundance that confers a low probability of extinction. As population abundance increases, the threat of demographic stochasticity decreases, and population resiliency increases (Goodman 1987; Pimm et al. 1988; and see discussion in USFWS 2022a). To achieve the objective of increasing the size of Mexican wolf populations, we have been working on implementing identified recovery actions and activities that address the threats of extinction risk, demographic stochasticity, and exceeding threshold mortality rates. Our focus aims at surveying, monitoring, and implementing adaptive management of Mexican wolf populations as well as reducing human-caused mortality, increasing awareness and tolerance of wolves, and reducing Mexican wolf-livestock conflicts. Full reports on annual implementation of these recovery efforts are outlined in our progress reports (USFWS 2019, USFWS 2020, USFWS 2021, USFWS 2022c, USFWS 2023, USFWS 2024).

United States

In the United States, population growth has and will likely continue to be driven primarily by natural reproduction. The minimum population count of the U.S. Mexican wolf population in 2017, at the onset of our Recovery Plan implementation and start of this evaluation, was 114 wolves. In 2022, at the 5-year mark for this evaluation, there were a minimum of 242 wolves in the U.S. As of 2023, the wild population has grown to 257 wolves, well over doubling the population since implementation of the Mexican Wolf Recovery Plan, First Revision. Annual growth rates were 12% in 2018, 24% in 2019, 13% in 2020, 5% in 2021, 23% in 2022, and 6% in 2023. The sustained growth of the population for the evaluation period indicates our recovery strategy is proving effective at increasing the size of the United States' population of Mexican wolves, and we consider how this growth compares to what we predicted in the 2017 PVA below (See Evaluation of Progress Towards Recovery and Actions Needed).

Our Recovery Plan outlines numerous actions to increase the population of Mexican wolves in the U.S., including surveying and monitoring the population, documenting population parameters, and determining whether annual mortality rates are consistent with meeting demographic criteria (see below and USFWS 2022a for all recovery actions). We provide annual updates in our progress reports, and here we utilized the mortality data by age class from those reports to compare with levels of mortality predicted in the population viability model (Miller 2017, USFWS 2019, USFWS 2020, USFWS 2021, USFWS 2022c, USFWS 2023, USFWS 2024). The mortality rates in the annual progress reports were based on radio collar data only, as such, these comparisons were only based on the mortality rates of pups after September, when pups are able to wear collars based on weight constraints, or phase 2 of pup mortality as described in Miller (2017). We had to generate mortality rates based on 183-day survival rates rather than 365-day rates that appear in the annual reports to compare with rates reported in Miller (2017). Mortality rates from most age classes during most years were below or within the values predicted in the U.S. population (Figure 1).

Adult mortality rates have been identified in previous analyses as a major factor driving population dynamics (Carroll et al. 2014, Miller 2017). Lower adult mortality rates (an average of 15.8% for 2017-2023) relative to those simulated (18.9%) likely contributed to the higher growth in the U.S. population than predicted (Figure 1, Appendix A). Conversely, pup mortality for collared animals (18.5%; i.e. phase 2 of pup mortality) was higher than predicted (13.5%), but highly variable (Figure 1). Given the overall growth rates observed, the results continue to demonstrate the importance of adult mortality rates while pup mortality appears to have little influence on growth rate. Sustained population growth in the United States suggests implementation of our recovery strategy is proving effective in maintaining mortality below critical thresholds (See actions to reduce human-caused mortality section below and annual progress reports).

Food caches influence the number of pups recruited (Clement et al. 2024) and it is worth noting that a smaller proportion of wolf packs were provided with food caches than simulated in the PVA (Figure 8, Appendix A). The metric of survival based on radio-collar data, however, is unlikely to be impacted by food caches. Mexican wolf pups are not usually collared before September and food caches are typically discontinued or ineffective after September because of the abundance of food available associated with hunting and broader ranged movements of the pups (Clement et al. 2024).

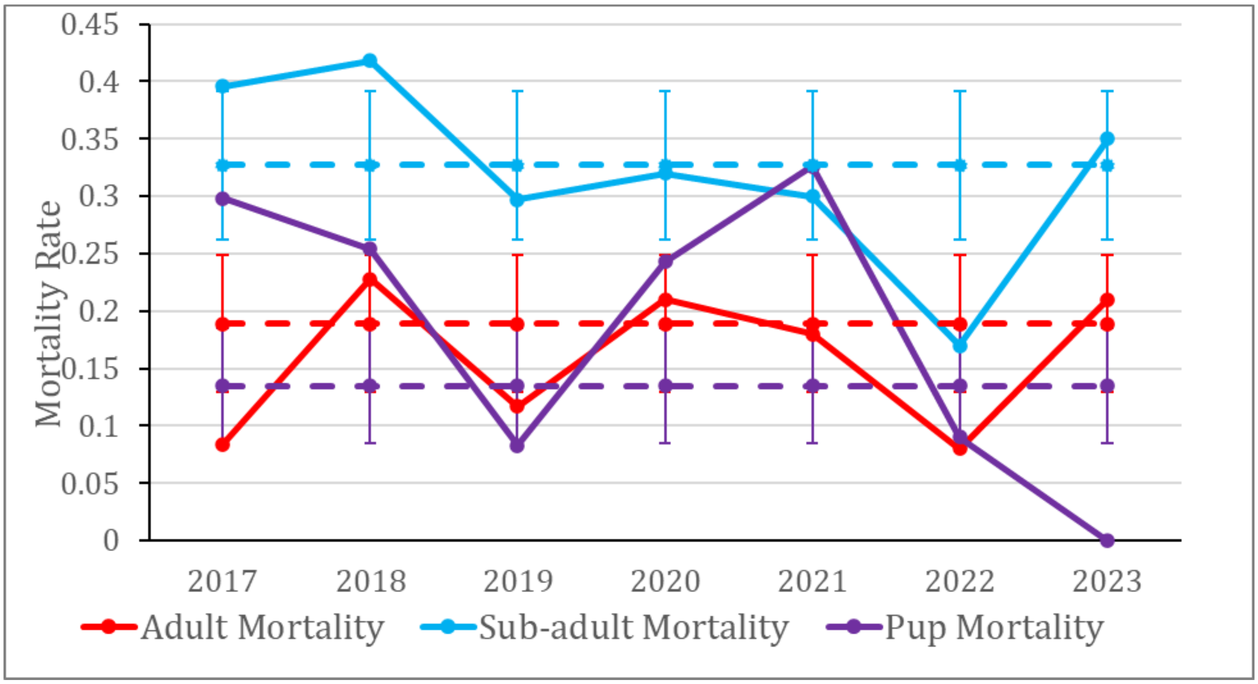

Figure 1. Observed (solid lines, based on radio-collared animals) and predicted (hashed lines in same color with confidence intervals) mortality of Mexican wolves in the New Mexico and Arizona, USA. Predicted values were based on Miller (2017). Adult mortality levels fell within or below (outside of confidence intervals) predicted values. Sub-adult values were generally within predicted values with the exception of 2018 (above) and 2022 (below), while pup mortality (phase 2 or greater than ~6 months of age when collars were able to be placed on pups based on Miller 2017) was highly variable with 2017, 2018, 2020 and 2021 well above predicted values and 2023 well below predicted values.

While we provide further details on implementation of our recovery strategy, actions, and activities to increase the size of the U.S. Population of Mexican wolves in annual progress reports, here we provide additional discussion and evaluation on the effectiveness of select recovery actions at meeting the objective of increasing the size of the Mexican wolf population in the United States.

Actions to reduce human-caused mortality

Most documented mortalities in the United States are human-caused (USFWS 2017a); therefore, reducing mortalities from human-caused sources such as shooting and vehicle collision may provide our best opportunity to improve population performance and speed the time to recovery.

Illegal mortality is the highest source of Mexican wolf mortality. Primary efforts to address this source of mortality include education, outreach, and law enforcement. In addition to ongoing education and outreach discussed below (See Promote Mexican wolf conservation through education and outreach programs), an extensive outreach program referred to as “Know the Difference” was developed by AZGFD to reduce inadvertent illegal shooting of Mexican wolves by educating hunters and the public to better differentiate Mexican wolves from coyotes. The Know the Difference Program has been in effect since 2019 and includes mailing flyers to hunters participating in relevant elk and deer hunts, posting flyers on social media, hand-delivering flyers to businesses frequented by hunters and others who recreate in wolf-occupied areas, displaying posters at ranger stations, individual flier distribution by the Mexican wolf Interagency Field Team, incorporating the content in online state hunting regulation packages, and distributing the flier through sportsman groups.

In addition to education and outreach, law enforcement is an important element of our recovery strategy for addressing illegal mortality. All documented mortalities of Mexican wolves in the United States are investigated by the Service's Office of Law Enforcement Special Agents. The Service has a designated special agent to coordinate law enforcement activities related to Mexican wolves, and both AZGFD and NMDGF have a law enforcement field force that assist Service personnel. Specific actions to reduce illegal take include the ability to restrict human activities within a 1-mi (1.6-km) radius of release pens, active dens, and rendezvous sites; proactive removal of road kills to reduce the potential of wolves scavenging, which may result in vehicular collision or illegal take of a Mexican wolf; and monetary rewards for information that leads to a conviction for unlawful take of the subspecies. Currently, the Service’s monetary award for information is $50,000; the AZGFD Operation Game Thief and the NMGFD are each offering a reward of up to $1,000, and conservation organizations pledged an additional $51,500 award for information leading to the conviction of individual(s) responsible for the deaths of Mexican wolves. Of the 61 wolf mortalities classified as suspected illegal take between 2017 and 2022, two individuals have been federally prosecuted and three individuals have paid a civil penalty.

Highway collision is the third highest source of mortalities for Mexican wolves (USFWS 2022c), and efforts are underway to reduce risk of Mexican wolf vehicle collisions. For example, four high risk areas have been identified in Arizona for deploying mobile, flashing signs to alert motorists of increased risk of wildlife collisions. AZGFD is coordinating with the Arizona Department of Transportation for deploying mobile signage in the identified high-risk areas.

To understand trends in human-caused mortality since implementing the Recovery Plan in 2017, we utilized human caused mortality data from the Mexican wolf annual progress reports which generated rates across all age classes by cause of death for 2017 to 2023 (USFWS 2019, USFWS 2020, USFWS 2021, USFWS 2022c, USFWS 2023, USFWS 2024). The mortality rates in the annual progress reports were based on radio collar data only. Human-caused mortality and overall mortality rates across all age classes appear stable to slightly declining from 2017 to 2023 with yearly fluctuations (Figure 2).

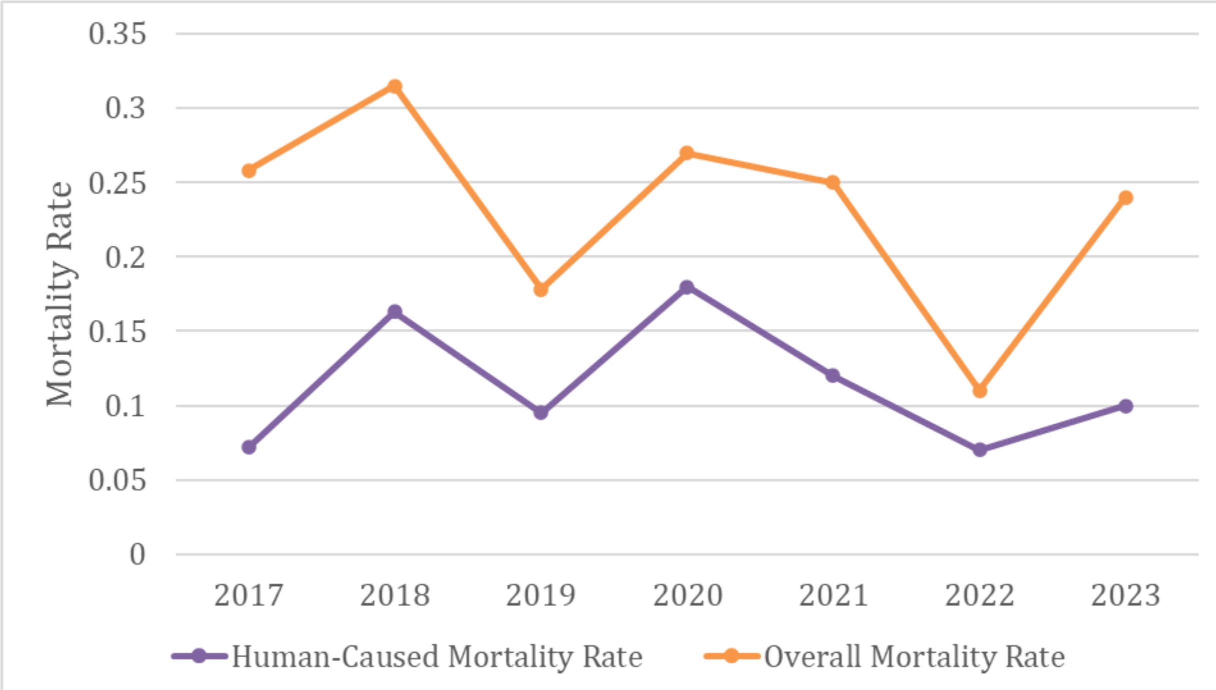

Figure 2. Human-caused and overall mortality rates across all age classes of Mexican wolves in the New Mexico and Arizona, USA.

Quantifying the effectiveness of individual efforts to reduce human-caused mortality on the population of Mexican wolves in the United States is difficult, but consistent population growth over the last eight years indicates efforts to reduce human caused mortality and removal have helped maintain mortality rates below critical thresholds and furthered our objective to increase the size of the Mexican wolf population in the United States.

Actions to reduce Mexican wolf-livestock conflicts

While mortality of Mexican wolves continues to be primarily human-caused (i.e., illegal mortalities or vehicle related; USFWS 2024) with relatively few management actions resulting in removal of wolves from the population, addressing wolf-livestock conflicts through collaborative management of Mexican wolves remains important for increasing the size of the Mexican wolf population in the United States. During the period of this evaluation, and prior, we have focused on preventive measures and compensation programs to address wolf-livestock conflicts, which is similar to management patterns observed from 2008 to 2019 (phase 2 in Breck et al. 2023) that resulted in Mexican wolves resuming population growth after a period of stagnation of the population.

Our annual progress reports provide detailed summaries of activities to reduce wolf-livestock conflicts including altering wolf livestock grazing rotations, carcass removals, diversionary food caches, the use of hay and supplements, hazing, livestock producer engagement, radio telemetry, radio activated guard boxes, wolf removals, trapping, turbo fladry, fox lights, and range riders. Over the first 4 years of our evaluation period (2018-2021), confirmed killed cattle rates (depredations per 100 wolves) were higher than the previous 10-year average, but rates began to drop after a peak in 2019. Then in 2022 confirmed killed cattle rates were lower than the previous 10-year average, and the 2023 rate of cattle confirmed to have been killed by Mexican wolves was notably lower than the previous 10-year recovery program mean and 15 percent lower than in 2022. While the many variables involved makes it difficult to quantify the impact of the various wolf-livestock conflict avoidance tools, the 2020 decrease in confirmed depredation rates coincides with increased dedicated range rider effort, which suggests the range rider program, in concert with other management tools, may be contributing to a reduction in wolf-livestock conflict.

Compensation programs for losses due to wolf depredations and for proactive conflict-avoidance measures are additional tools to reduce wolf-livestock conflict. There are two programs from which livestock producers can seek compensation for confirmed livestock losses due to predation by Mexican wolves and the latter option also provides financial assistance for proactive, non-lethal activities to address wolf-livestock conflict, 1) the Livestock Indemnity Program authorized by the 2018 Farm Bill and administered by the U.S. Department of Agriculture's Farm Service Agency, and 2) the Wolf Livestock Loss Demonstration Grants (WLDG) authorized by the Omnibus Public Lands Management Act of 2009 (P.L. 111-11) and awarded by the Service through a competitive process to qualifying States and Tribes. Tables of annual WLDG amounts and disbursement of funds by state are provided in our annual progress reports (USFWS 2019, p. 12; USFWS 2020, p.14; USFWS 2021, p. 14; USFWS 2022, p. 14; USFWS 2023, p. 13; USFWS 2024, p.13).

The Mexican Wolf-Livestock Council, who administered the WLDG funds received by AZGFD and New Mexico Department of Agriculture, was established in 2011 to reduce the economic impact of Mexican wolf recovery. The Arizona Livestock Loss Board and the County Livestock Loss Authority were subsequently established in 2019 and 2022 respectively and took over the role of administering compensation and conflict avoidance funds in each state. These programs were established to increase the efficiency of compensation, conflict avoidance, and pay for presence programs. In this five-year evaluation period (2018-2022), these entities have reviewed and approved compensation for Mexican wolf depredation in the total of $950,994.83 and reviewed and approved requests for conflict avoidance grants in the total of $734,921.

Balancing management removals with population growth and focusing on conflict prevention are critical to addressing conflict while the population is progressing towards recovery (Breck et al. 2023), and consistent population growth of Mexican wolves in the U.S. suggests our strategy to reduce wolf-livestock conflicts along with other programmatic efforts are helping to progress on our objective to increase the population of Mexican wolves in the United States.

Mexico

The Mexican wolves that occupy northern Sierra Madre Occidental can be characterized as an extremely small, establishing population. In this smaller Mexican wolf population, population growth can be stimulated by the continued release of a substantial number of Mexican wolves from captivity to the wild, translocations, and population growth from natural reproduction increasing over time as more wolves become established in the wild.

At the onset of implementation of our Recovery Plan, First Revision, in 2017 the Mexican wolf population in Mexico had a minimum of 35 wolves. Between 2017 and 2022, 35 wolves were released or translocated into Mexico, which is far fewer than the 72 release or translocations modeled in the 2017 PVA (Figure 4 and 6, Appendix A). The small population has experienced fluctuations with both growth and declines. As of 2022, the minimum count remained at 35 wolves in the wild. While there have been Mexican wolf sightings reported in Mexico, we do not have an estimated minimum count for 2023, and Mexico reported zero collared wolves alive in the wild in 2023, mostly due to illegal poisoning. Monitoring wolves in Mexico proves much more challenging than in the United States due to limited resources and inability to access much of the habitat occupied by wolves. While these challenges suggest the true abundance may differ from the minimum counts, the population has not grown sufficiently to reduce the threat of small population size nor reach the desired growth for the identified recovery objective for the population.

We worked with the biologists who conducted the reintroduction in Mexico to gather data and develop mortality rates via the methodology described in Miller (2017). These mortality rates include mortalities, removals, and cryptic mortality as failure events to develop a failure rate that was applied to wolves within one year of initial release, one year of translocation, and wolves that were wild born or lived greater than a year following release or translocation (Miller 2017). We used survival data from 2011 to 2023 because the data are limited (e.g., all collared data are important information) and we had previously used population data from the United States to parameterize Mexico survival patterns due to a lack of Mexico specific data (Miller 2017).

Mexican wolf mortality in Mexico was almost exclusively known or likely human-caused (39 out 40 mortalities) with relatively few removals (four) and only one cryptic mortality from 2011 to 2023. Poisoning of wolves (16 mortalities) was the most frequent cause of death followed by unknown deaths that were considered likely human-caused (13 mortalities). Survival rates were remarkably similar to those estimated from the U.S. population that were used for model development (Table 3), with the exception of adult survival for wild wolves (wolves that were either born in the wild or lived greater than one year following release or translocation).

Table 3. Summary of survival rates of Mexican wolves in Mexico from 2011 to 2023. Pup survival is calculated using a 183-day survival rate, while adult and sub-adult survival rates are calculated using 365-day survival. Numbers in parenthesis represent the 95% CI surrounding the estimate. Bolded numbers represent the model predicted survival rate (see Miller 2017 for confidence intervals).

Class	Initial Release Wolves Survival Rate	Translocated Wolves Survival Rate	Wild Wolves Survival Rate
Adult	0.267, 0.284 (0.224, 0.302)	0.528, 0.527 (0.359, 0.691)	0.610, 0.811 (0.455, 0.745)
Sub-adult	0.086, **0.388** (0.072, 0.102)	0.492, **0.378** (0.020, 0.979)	0.627, 0.673 (0.108, 0.959)
Pup	0.786, **0.496** (0.036, 0.997)	0.377, **0.555** (0.111, 0.744)	N/A[a], **0.865** (N/A)

[a]Only one wild pup was captured and collared, which resulted in 138 radio-days of monitoring without a mortality.

Establishing a wild population of wolves can be challenging in the initial years of recovery implementation and releases. For example, in the history of Mexican wolf recovery in the United States, between 2002 and 2009 there were also periods of growth and decline where the population fluctuated around 40 wolves. While there are challenges inherent in growing a small population, there needs to be greater progress towards the recovery objective of increasing the Mexico population of Mexican wolves to achieve recovery. Below, we discuss further how our predicted metrics from the PVA compare to observed metrics in the wild population and possible explanations for discrepancies as well as actions to address needed improvements (See Evaluation of progress toward recovery criteria and actions needed below).

Improve gene diversity and maintain the health of Mexican wolves

To increase Mexican wolf viability through greater (genetic) representation we are working to improve gene diversity of Mexican wolf populations in the wild by releasing wolves from captivity to the wild and translocating wolves between populations to ensure wild populations benefit from the gene diversity available in the captive population. The release of Mexican wolves from captivity to the wild can result in a substantial amount of the gene diversity available in captivity being represented in the wild. Release strategies from captivity include the release of individual or paired adult wolves, a pack of wolves, or fostering pups into wild dens. Released wolves (including both releases from captivity and translocated wolves) contribute their gene diversity to the recipient population when they breed and produce offspring. We consider genetic management such as releases from captivity (including fostering pups) and translocations to serve as an effective tool during the recovery process to achieve appropriate representation (Miller 2017).

United States

Pup fostering has been the primary release method and tool for incorporating gene diversity from the captive population into the wild U.S. population. Using this technique, we place captive-born pups into wild dens to be raised with the wild litter. This strategy enables us to release pups from multiple diverse family groups in a single year to be raised in the wild by experienced wild wolves. This further reduces the controversy and nuisance behavior commonly observed following releases of adult captive-reared wolves. Our transition to focusing primarily on pup-fostering is a product of adaptive management and the evolution of our recovery strategy to build on successes while also recognizing the importance of social tolerance to Mexican wolf recovery.

For the 2017-2022 period of this evaluation, we have released 77 pups into the Mexican Wolf Experimental Population Area (MWEPA) through fostering and fostered an additional 16 pups in 2023. From 2016 to the end of 2023, 10 fostered wolves had been documented producing pups and a minimum of 20 different litters had been produced by foster wolves. In our Recovery Plan, we recognize the need for release and translocation of wolves into the wild for genetic management and outline various release strategies from captivity, including pup-fostering. While we include pup-fostering as a strategy for genetic management, our on-the-ground release strategy for the period of the evaluation diverged from the modeled release strategy used to craft our recovery criteria, which from 2016-2022 only included the release of two pairs with pups (four adults and six pups) in calendar years 2017 and 2021 (model years two and six). We have seen success and benefits of this strategy both for incorporating gene diversity and acknowledging the necessity of social tolerance, and later in our evaluation, we analyze how this strategy is making progress toward our genetic criteria and compare our efforts to modeling predictions that we used to craft our recovery criteria (See Evaluation of progress toward recovery criteria and actions needed and Appendix A below).

Supplemental Feeding

Supplemental food caches are used as a management tool where road-killed native prey carcasses or carnivore logs are provided to wolves to assist a pack or remnant of a pack when extenuating circumstances reduce their own ability to do so. We supplementally feed packs where foster events occur to assist the pack with the nutritional demand of additional pups. Clement et al. (2024) found that packs provided with food caches produced 25% more pup recruits to 9 months of age.

Inbreeding Depression

The high relatedness of Mexican wolves and ongoing loss of gene diversity increases concerns over the potential for inbreeding depression to have negative impacts on future population growth in the United States and requires genetic considerations and active management to improve genetic representation to the degree possible. Early analyses detected inbreeding depression for some metrics of Mexican wolf fitness, including sperm motility (Asa et al. 2007) and pup production numbers (Fredrickson et al. 2007). Miller (2017), however, found less severe, but still demonstrable impact on pup production through the probability of detecting live pups. Due to these concerns, the recovery plan focuses on inserting gene diversity into the United States population through the release of wolves from the captive population. Previously, we had documented that inbreeding depression is impacting the probability of a breeding pair producing a litter, but not to a degree that is hindering annual population growth in the United States population (USFWS 2017a, Miller 2017). More recent studies based on larger sample sizes (Oakleaf 2022, Clement et al. 2024) have found minimal evidence for inbreeding depression causing a demographic effect on pup production or recruitment and the rapid population growth in the United States clearly supports these conclusions. Nevertheless, the high inbreeding coefficients in the United States population and the principal of representation necessitate continued monitoring and efforts to mitigate inbreeding through management actions described in the Recovery Plan (USFWS 2022a).

Mexico

Since the onset of implementation of our recovery strategy in 2017, a total of 35 Mexican wolves have been released or translocated into Mexico to both grow the population and increase gene diversity. Nineteen of the released wolves came from the captive population and 16 were translocated from the MWEPA. Releases and translocations in Mexico have been conducted as pairs or packs of wolves with the majority being released as packs. As we noted above, 35 released or translocated wolves is well below our anticipated release and translocation strategy modeled in the 2017 PVA, and later in this report we analyze how we have made progress toward our genetic criteria and compare our efforts to the modeling predictions that we used to craft our recovery criteria (See Evaluation of progress toward recovery criteria and actions needed and Appendix A below).

Ensure adequate habitat availability to support viable Mexican wolf populations

Our strategy is to establish two populations over a large geographical area of the Mexican wolf's historical range to increase Mexican wolf redundancy and representation (both ecological and geographical). To achieve this objective, we have been working on implementing identified recovery actions and activities that reduce the threats of extinction risk/demographic stochasticity, loss of gene diversity, and exceeding threshold mortality rate.

United States

Recovery in the United States has focused on one large population of Mexican wolves in the MWEPA, and management of Mexican wolves in this area is governed by the regulations for the nonessential experimental population of the Mexican wolf (87 FR 39348). This area contains a large expanse of contiguous high-quality habitat along the Mogollon Rim in central Arizona into west central New Mexico, as well as other patches of high-and low-quality habitat (Martínez-Meyer et al. 2021). Martinez-Meyer et al. (2021) estimated 33,020 km^2 of high-quality habitat occurred in the MWEPA, with a total of 60,732 km^2 of suitable habitat that includes intermediate and high-quality habitat. In 2023, 55 packs utilized a total home range area of 28,068 km^2 (outer boundary of non-overlapping home ranges). The home range area encompassed approximately 18,142 km^2 of high-quality habitat, indicating there is still sufficient available high-quality habitat in the MWEPA for the population to continue growing.

Mexico

In Mexico, there are two large blocks of high-quality habitat in the Sierra Madre Occidental that are connected by areas of lower quality habitat and small interstitial patches of high-quality habitat (Martínez-Meyer et al. 2021); we refer to these two areas as the northern Sierra Madre Occidental and southern Sierra Madre Occidental. Based on habitat modeling, we expected that either of these areas will be able to support a viable population of Mexican wolves (Martínez-Meyer et al. 2021). To date, reintroduction efforts have focused on the northern Sierra Madre Occidental. Of the 18,922 km^2 of suitable habitat available in the northern Sierra Madre Occidental described by Martínez-Meyer et al. (2021), Mexican wolves occupied only a small portion of that area in 2022, indicating there is still sufficient available habitat for the population to continue growing. While release and recovery areas have thus far focused in the northern portions of the states of Chihuahua and Sonora, if Mexican wolves disperse to southern Sierra Madre Occidental or federal agencies in Mexico decide to release Mexican wolves into this area as part of their reintroduction effort, the recovery strategy can be adapted to include wolves in either or both areas. The southern Madre Occidental region contains 25,196 km^2 of suitable habitat (Martínez -Meyer et al. 2021, Miller 2017). Mexico's National Commission of Natural Protected Areas (CONANP) has recently endorsed an effort to evaluate Durango as an additional area for Mexican wolf releases, and there is also consideration for additional release sites in southern portions of Chihuahua.

Maintain the Mexican Wolf Species Survival Plan (SSP, now called Saving Animals from Extinction [SAFE]) captive breeding program to improve the status of wild populations

The Mexican wolf captive breeding program plays a critical role in Mexican wolf conservation by providing genetically valuable wolves for release to the wild. However, the small number of founders of the captive population and the resultant low gene diversity available have been a concern since the beginning of the recovery program (Hedrick et al. 1997) and remain a concern today (Siminski and Spevak 2017 (see USFWS 2022a). Long-term viability or adaptive potential depends on the store of genetic variability. It is desirable to retain as much genetic variability as possible, and it is uncertain when or if the loss of genetic variability might manifest in compromised reproductive function or physical and physiological abnormality (Soulé et al. 1986).

At the onset of implementation of the 2017 recovery strategy, the binational captive program housed 281 wolves in 55 institutions and had retained approximately 83% of the gene diversity of the founders, which is lower than the recommended retention of 90% for most captive breeding programs (Soulé et al. 1986, Siminski and Spevak 2017). It is expected that even with optimal management, gene diversity in the captive population will continue to decline over time as wolves die or reach reproductive senescence, however, careful management of the SAFE population slows the rate of loss of genetic diversity.

As of 2023, the binational captive program housed 356 wolves in 60 institutions and had retained 82.44% of the gene diversity of the founders. While the observed abundance of wolves in the SAFE population is much higher than predicted in 2017, the proportion of gene diversity retained and mean inbreeding coefficient for the SAFE population are nearly identical to those predicted by 2017 modeling efforts (Figure 3, Appendix A). The gene diversity of the captive population remains higher than either wild population in the United States or Mexico. This is expected, as the SAFE program manages wolves which are paired each year for breeding with a priority to breed genetically underrepresented wolves, and the wild populations are established utilizing animals that are genetically well represented within the captive population and subsequent breeding among wild individuals is not managed (Siminski and Spevak 2017). Additionally, the SAFE program maintains a gamete bank to slow the loss of genetic diversity of Mexican wolves by furthering potential genetic contribution of wolves beyond their natural life spans. The Research Department at the Saint Louis Zoo continues work to further refine protocols for use of this gamete bank, including artificial insemination using frozen-thawed semen.

Promote Mexican wolf conservation through education and outreach programs

Education and outreach in local communities within occupied Mexican wolf range and other areas where wolves disperse is critical to improve hunter, trapper, rancher, trade organization, and general public awareness and tolerance of wolves' presence.

United States

Outreach activities were conducted by Service and partner personnel on a regular basis to concerned citizens, government and non-government organizations, media, and other interested stakeholders.

Over the five-year evaluation period of 2017-2022, Mexican wolf program personnel participated in more than 115 presentations, briefings, webinars, and meetings with federal and state agencies, conservation groups, rural communities, schools, wildlife workshops, and various other public, private, and tribal institutions throughout Arizona, New Mexico, and White Mountain Apache Tribal lands.

Over the five-year evaluation period of 2017-2022, we sent more than 40 news releases to local, statewide, and national media. Media were invited to document annual helicopter operations, fostering efforts, and activities at our Sevilleta Wolf Management Facility. Outreach efforts resulted in extensive local, statewide, and national news coverage of Mexican wolf conservation efforts.

We published 53 public reports to provide real-time updates on Mexican wolf packs, mortalities, incidents, proactive management activities, and personnel changes. We also produced 5 annual reports with comprehensive information on recovery, monitoring, and management activities. We maintained a public map showing recent general wolf locations via a GIS web-mapping application.

Every year we contacted campers, hunters, and members of the public engaged in recreational activity in wolf occupied areas to explain legal provisions and provide information on the potential for encountering wolves as well as recommendations for recreating in wolf-occupied areas. Thousands of informational flyers were mailed to deer and elk hunt permit holders and were also distributed at sporting goods dealers, public offices, and businesses in the occupied range to aid hunters in recognizing the differences between wolves and coyotes.

Mexico

Federal agencies in Mexico are working to promote Mexican wolf conservation through collaboration with NGOs, state and federal partners in the United States, the local community, and livestock producers to foster critical discussions on a framework for wolf and carnivore tolerance and conservation. Federal agencies in Mexico have also brought discussions on carnivore conservation and the human dimension to international meetings to enhance strategies for encouraging tolerance in local communities.

Federal agencies in Mexico have been working on engaging with local producers through wolf presence attitude surveys, site visits, and piloting a stakeholder engagement group to further Mexican wolf recovery. As part of this process and in cooperation with the local livestock producers, CONANP is also developing a collaborative livestock loss compensation program.

Field researchers from the University of Queretaro have engaged in a series of site visits with ranchers in the recovery area in Chihuahua, which has resulted in agreements from some ranches in the recovery area to allow for releases on their ranches.

Community outreach is also being conducted in potential Mexican wolf recovery areas in Durango, including in the El Tarahumar community. There, community workshops are being led by collaborators in Mexico in cooperation with the AZGFD to assist the community with biodiversity assessments on their lands as part of the certification process for forestry products. Biodiversity assessments include evaluating prey for Mexican wolves (such as deer, turkey, and lagomorphs), domestic cattle, and other carnivores. These outreach efforts have yielded a letter of support from landowners for future wolf releases in this region of Durango, which has also been endorsed by CONANP.

Ensure recovery success

To ensure recovery success, we must develop adequate regulations, manage the Mexican Wolf Recovery Programs in the United States and Mexico, and coordinate binational Mexican wolf recovery efforts.

The Mexican wolf is federally protected under the ESA as an endangered species except where included in a nonessential experimental population where it is considered threatened (80 FR 2488). Section 9 of the ESA prohibits the take of any federally listed species, and Section 11 provides civil penalties for knowing violations of Section 9. Mexican wolves are also protected by State regulations in Arizona and New Mexico, and by Federal law in Mexico.

Since the implementation of the 2017 Mexican Wolf Recovery Plan, First Revision, we have issued an updated Mexican Wolf Recovery Plan, Second Revision (2022) that includes additional site-specific management actions to address the threat of human-caused mortality, including illegal killing, that the previous version of the recovery plan did not include. We have also issued a revision to the nonessential experimental population of the Mexican Wolf under section 10(j) of the ESA (87 FR 39348) that includes a revised population objective, a new genetic objective, and the temporary restriction of three take provisions until genetic criteria have been met. The nonessential experimental population, managed with these revisions, contributes to the long-term conservation and recovery of the Mexican wolf by alleviating demographic and genetic stressors on this population consistent with our range-wide recovery strategy and goals for the Mexican wolf. We also conducted the statutorily required 5-Year Status Reviews of the Mexican wolf in 2018 and 2023 in accordance with section 4(c)(2) of the ESA to determine whether its status has changed and if it should be classified differently or removed from the list of threatened and endangered wildlife. During both status reviews, we determined that no changes were warranted to the status of the subspecies.

We work with partners to identify and implement effective recovery actions necessary to recover the Mexican wolf and address conflicts related to Mexican wolf recovery in local communities. The recovery of the Mexican wolf has been a collaborative effort since its inception. Effective recovery requires participation by multiple parties within Federal, state, and local governments; non-governmental organizations; academia; Tribal nations, and local communities. Further, Section 6 (a) of the ESA directs the Service to cooperate to the maximum extent practicable with the states (59 FR 34275), and Secretarial Orders 13175 and 3206 and the Service's Native American Policy (2016) require consultation with tribes in the recovery of listed species. We collaborate with Federal, state, county, and Tribal agencies through a Memorandum of Understanding and the establishment of the Mexican Wolf Interagency Field Team, which conducts the reintroduction, management, and monitoring of Mexican wolves in the United States. The Memorandum of Understanding also identifies an Executive Committee to exchange views, information, or advice on decisions and resources necessary for the reintroduction and management of the Mexican wolf consistent with the 10(j) Rule and Recovery Plan. We also have strong partnerships with the SAFE captive breeding facilities in the United States and

Mexico and attend annual SAFE meetings. These partnerships and collaboration have been integral in implementing our recovery strategy.

Successful recovery of the subspecies within historical range requires close coordination and cooperation with recovery partners in Mexico. The Service and its partners have a strong working relationship with the Mexican governmental agencies CONANP and Secretary of Environment and Natural Resources (SEMARNAT), as well as field staff working to reestablish the Mexican wolf in the wild in Mexico. Section 8 (b) of the ESA encourages foreign countries to provide for the conservation of threatened and endangered species, and the Service to enter into agreements with foreign countries to provide for such conservation.

Our relationship with the Mexican government is formalized through a 1996 Memorandum of Understanding establishing the Canada/Mexico/United States Trilateral Committee for Wildlife and Ecosystem Conservation and Management and a Letter of Intent signed in June 2022 on behalf of the Ministry of the Environment and Natural Resources of the United Mexican States, the Service, AZGFD, and NMGFD to further long-term partnerships and strengthen collaboration between Mexico and the United States in recovery of the Mexican wolf. The Service along with partners from state agencies and Mexico participate annually in meetings of the Trilateral Committee for Wildlife and Ecosystem Conservation and Management to further dialogue and collaboration on Mexican wolf recovery. A Transboundary Working Group, co-chaired by AZGFD and CONANP, was also formed through this committee to improve international cooperation, process efficiency, and effectiveness for transporting wildlife, such as Mexican wolves, across North American borders. The Service, state agencies, and Mexico also participate annually in binational meetings with the SAFE program to develop recommendations for the Mexican wolf breeding and transfer plan.

The Service and our partners continue to exchange technology and expertise with Mexico to implement recovery actions and seek funding to assist Mexico in implementing actions necessary to achieve Mexican wolf recovery. The Service and our state partners provide regular financial assistance for Mexican wolf recovery in Mexico, and AZGFD has conducted in-person capacity building workshops with biologists from Mexico and provided a variety of field equipment to biologists in Mexico to assist implementation of biologically sound field programs.

III. EVALUATION OF PROGRESS TOWARD RECOVERY CRITERIA AND ACTIONS NEEDED

As defined in the Recovery Plan, we committed to assessing each population's progress toward recovery criteria and identifying aspects of population performance that may need improvement. In our Recovery Plan, we identified interim abundance and release and translocation targets that we evaluate below. Additionally, the 2017 PVA modeled future growth dynamics and informed specification of quantitative criteria considered necessary for Mexican wolf recovery (Miller 2017, USFWS 2022a). As part of this 5-year evaluation on progress toward our recovery criteria, we contracted Dr. Miller with IUCN's Species Survival Commission Conservation Planning Specialist Group to evaluate how the wild and captive populations of Mexican wolf are performing compared to modeled predictions. The full report can be found below in Appendix A.

United States Population

We are exceeding both the interim abundance and the release targets for the Mexican wolf population in the United States. The U.S. population has experienced a higher mean growth rate over the evaluation period than predicted (Figure 1, Appendix A). We targeted an interim 5-year total abundance of approximately 145 wolves in the United States in 2022, and we observed a minimum count of 242 wolves in 2022 and 257 wolves in 2023. The U.S. population has also surpassed the 5-year release target of 9 released wolves surviving to breeding age with an observed 13 released wolves surviving to breeding age in 2022, and as of 2023 at least 15 released Mexican wolves have survived to breeding age. Exceeding interim abundance targets and interim release targets indicates our recovery strategy is effective at progressing toward recovery goals for the United States population of Mexican wolves.

In the 2017 PVA we modeled release and translocation strategies that focused on releasing packs of wolves into the MWEPA instead of fostering, which has been our primary release strategy in the MWEPA (Figure 5, Appendix A). To evaluate the effectiveness of our recovery strategy, inclusive of fostering, at incorporating gene diversity from the captive population into the U.S. population, we compared observed metrics of gene diversity with those predicted in 2017. We found that genetic measures of variability including proportional gene retention and mean inbreeding level are better than predicted in the 2017 PVA (Figure 1, Appendix A). This indicates that our release methods and recovery strategy are proving effective at incorporating gene diversity from the captive population into the wild population and are exceeding the modeled predictions that we used to craft criteria that would lead to recovery of the Mexican wolf as defined in our Recovery Plan.

Fewer removals from the MWEPA for translocation to Mexico, more fostering releases into the MWEPA from the SAFE population, and reduced adult mortality rates compared to those we predicted likely contribute to observations in the U.S. population surpassing predicted metrics from the 2017 PVA.

Given the successes in exceeding interim abundance and genetic targets as well as the sustained growth of the U.S. population and better performance on genetic metrics than predicted, we recommend continuing with our current recovery strategy to further progress toward our objectives and goals, including the emphasis on fostering to incorporate gene diversity from the captive population into the wild population. At this time, we have not identified any additional activities to work towards recovery goals for the U.S. population other than those already identified in our RIS.

Mexico Population

The population in Mexico is below both interim abundance targets as well as interim release and translocation targets for the 5-year evaluation period. Our interim abundance target for the Mexico population was 100 wolves by 2022, and as of 2022 there were a minimum of 35 wolves in Mexico. The target for interim release and translocation was for approximately 25 released or translocated wolves to have survived to breeding age in Mexico, and as of 2023, 9 released or translocated wolves had survived to breeding age.

In comparing our predictions from the PVA to observed metrics in the Mexico population, percent gene diversity retained, and mean inbreeding coefficient are better than PVA predictions, indicating management selection for the initial founding event and subsequent releases into the population were effective at improving gene diversity in the wild population, even as the population remains small (Figure 2, Appendix A). Minimum counts of the population in the wild are substantially and consistently smaller than predicted abundances over the 5-year evaluation period (Figure 2, Appendix A). Predicted abundance is a total abundance and the observed metric represents a minimum count; thus, the actual abundance may be higher, but the population is still not achieving sufficient growth to meet interim abundance targets. Discrepancies between predicted and observed metrics are likely a result of fewer releases and translocations than predicted as well as higher mortality in the wild compared to what was modeled. Collectively, the survival rate analyses suggest that while the survival rates are adequate to establish populations through initial release and translocation, the adult mortality rate for wild wolves is at a level (0.39) that would result in a high probability that the population would go extinct following the cessation of releases (e.g., see figure 15 in Miller 2017). These results are likely attributable to the impact and lethality of poison on wolves regardless of their knowledge of the landscape or avoidance of humans. Indeed, poison was a key tool in the original eradication of Mexican wolves (Brown 1983).

Demographic performance of the Mexico population must be improved to achieve recovery goals. The population is likely underperforming due to both high mortality in the wild and insufficient releases and translocations to increase the population at expected growth rates. For the period of the evaluation, we anticipated translocating 40 wolves (16 adults, 24 pups) from the MWEPA and releasing 32 wolves (13 adults and 28 pups) from the SAFE population into the Mexico population, but only released a total of 35 wolves from both the U.S. and SAFE populations (Figures 4 and 6, Appendix A). The actions needed to address these concerns are already outlined in our Recovery Plan, indicating a need to reinvigorate and expand these efforts to better meet recovery goals. We elaborate on some of the specifics of these actions here and will continue to work with our partners in the United States and Mexico to further recovery efforts.

The actions needed to address underperformance fall under the following categories: 1. Increase social tolerance and acceptance of wolves and reduce annual mortality rate (Recovery Actions 1.2.2, 1.7, 1.7.1, 1.7.2, 1.9, 1.9.1, 3.3.1, 5.2), 2. Expand monitoring efforts (Recovery Actions 1.2, 1.2.1), 3. Explore new sites for wolf introduction (2.2, 5.2), 4. Increase the number of released and translocated wolves (1.5, 2.2) (USFWS 2022a).

Mexican officials have been working to increase social awareness and tolerance of wolves through community engagement, site visits, Mexican wolf presence attitude surveys, and working with producers and academic institutions to increase monitoring and identify potential additional release site locations, including in Durango and in new areas in Chihuahua. Federal agencies in Mexico are engaging in critical and systematic discussions to develop a framework for wolf and carnivore tolerance and conservation, including creating a pilot program with local stakeholders. They have also recognized that current predation insurance measures are insufficient and are in the planning and preparation phases of implementing a compensation program to address economic impacts of wolf depredation on livestock producers including pay for presence and payment for depredation programs. Mexican agencies are also exploring initiating a predator friendly meat market to further incentivize Mexican wolf recovery partnerships with local producers. By partnering with local communities, the Mexican government also seeks to include local producers in monitoring efforts.

Mexican officials have indicated wolf sightings have occurred outside of areas known to be occupied by wolves, and insufficient monitoring has hindered the program's success and ability to track recovery progress of the population. Officials have been engaged with local producers to work on increased monitoring efforts on private land. Through increased monitoring, Mexican officials hope to better understand habitat use and dispersal of wolves, which may inform future release and translocation strategies. Partners in the United States and Mexico have indicated they are working on identifying additional sites for wolf reintroduction, including developing a risk map for Chihuahua releases as well as engaging with producers and local communities in other potential sites for Mexican wolf releases such as Durango.

For a population in Mexico to reach recovery metrics and goals, the number of releases and translocations into Mexico must be greatly increased and mortality must be reduced to below the 25% threshold. To facilitate understanding of metrics needed to establish a viable population in Mexico, a set of scenarios was developed using the current PVA model to evaluate potential mechanisms to establish a viable Mexican wolf population in Mexico, including the number of individuals to introduce annually into suitable habitat, the demographic composition of each group, and the potential survival of those individuals six months after release (Addendum, Appendix A). This set of scenarios can be used as a guide to better understand conditions needed for successful establishment of Mexican wolves in northern Mexico. While there have been recent sightings of wolves on the landscape in Mexico, we agreed to start the scenarios at zero wolves to be conservative with the understanding that any wolves on the landscape in Mexico would have a positive influence on population dynamics.

Collectively, this set of scenarios (Addendum, Appendix A) indicates that greater than 6 animals need to be released per year preferably with a combination of translocations from the U.S. population and releases from the SAFE population to minimize the impact on both source populations. Adult mortality rates of released and wild animals need to be reduced to successfully establish a population. In addition, the model results suggest that releases with only adults or yearlings were more successful because substituting with younger animals (pups) reduced the number of wolves surviving to breeding age. However, releases in the U.S. population were more successful with young pups likely because of the localizing behavior and corresponding relatively easier management of a pack with young pups relative to large scale dispersal behavior of yearlings or adults absent pups (Oakleaf 2022). We will continue to work with our Partners in Mexico to further progress on our recovery goals and will reassess our progress on our recovery strategy and potential needed changes during our 10-year evaluation.

As stated in the disclaimer, recovery plans and this evaluation of our recovery plan are advisory documents, not regulatory documents. A recovery plan and subsequent evaluations do not commit any entity to implement the recommended strategies or actions contained within it for a particular species, but rather provides guidance for ameliorating threats and implementing proactive conservation measures, as well as providing context for implementation of other sections of the ESA.

IV. CONCLUSION AND NEXT STEPS

Our 5-year evaluation of our recovery strategy indicates the population in the United States is performing better than expected in the 2017 PVA and is exceeding both interim abundance targets and interim release targets. We recommend continuing to implement the recovery strategy and recovery actions and activities identified in our Recovery Plan and RIS to further progress on our recovery goals for the U.S. population.

Our evaluation indicates the population in Mexico is not reaching interim abundance nor interim release and translocation targets for recovery and population growth is much less than predicted. While the population has not grown at the predicted levels, gene diversity metrics in the wild population are better than what we had predicted. To improve population performance in Mexico, we have highlighted recovery actions to improve progress on recovery objectives for the population, focusing on increasing social tolerance, reducing annual mortality rates, improving monitoring efforts, identifying additional release sites, and increasing release and translocations of wolves. These efforts are reliant on binational collaborative partnerships, and we remain committed to those as well as closely monitoring our recovery strategy, including reevaluating again 10 years after implementation of the 2017 Recovery Plan, First Revision.

While we have not identified any additions or amendments to our RIS, we plan to conduct additional modeling to evaluate modified release strategies that will best facilitate Mexican wolf recovery. These efforts will include updating our model to reflect the fostering strategy in the United States, modeling increased and viable release and translocation strategies to improve recovery for the population in Mexico while maintaining source population viability (SAFE and U.S. population), as well as evaluating the best future management strategies for the SAFE population considering these updated release and translocation schedules. These efforts will be informative for our 10-year evaluation of our recovery strategy and to further progress towards Mexican wolf recovery.

We will continue to monitor and document progress on our recovery efforts on an annual basis through our progress reports and will update the RIS as needed. Additionally, we will evaluate our progress again 10 years from the signing of the Recovery Plan, First Revision, to ensure we are making expeditious progress toward recovery. At that time, we will make a determination on whether the recovery strategy is proving effective/feasible or needs to be revised. If we determine the recovery strategy is effective, but some elements of recovery implementation need improvement, we will identify what needs to be improved, including actions to address identified needs and the feasibility of conducting such actions such as timelines and costs. If we determine the recovery strategy is not proving effective and the expected recovery level is not achieved, we will identify the reasons for such finding and, if necessary, revisit the recovery strategy and work with States and others to identify other areas with suitable habitat and adequate prey to achieve recovery; change techniques used to address gene diversity; or implement other substantive changes. Any such revised strategy should include revised time/cost estimates necessary to achieve recovery based on necessary actions. We will revise the Recovery Plan or RIS as necessary.

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VI. APPENDIX A. Population Viability Analysis of the Mexican Wolf (*Canis lupus baileyi*): An Evaluation of Population Demographic Performance in Comarison to Predicted Dynamics (Miller 2024).

Population Viability Analysis of the Mexican Wolf (*Canis lupus baileyi*):

An Evaluation of Population Demographic Performance in Comparison to Predicted Dynamics

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(Includes Addendum)

Introduction

In November 2017, a report was delivered to the U.S. Fish and Wildlife Service (hereafter, Service) that documented a population viability analysis (PVA) of the Mexican wolf, *Canis lupus baileyi* (Miller 2017). This PVA used the best available demographic and genetic data on the two wild (in situ) wolf populations in the United States (occupying the Mexican Wolf Experimental Population Area, or MWEPA) and Mexico (occupying habitat in the northern Sierra Madre Occidental, or SMOCC-N) as well as the captive (ex situ) population (the SSP[1] population, now known as the SAFE[2] population) to assess likely future growth dynamics and to inform the specification of quantitative criteria considered necessary for species recovery. The 2017 PVA document was an important reference for the subsequent recovery plan (USFWS 2017) and its follow-up revision (USFWS 2022).

The Service and its partners are now undertaking an evaluation of recent demographic and genetic characteristics of both in situ and ex situ populations in order to assess "true" population performance in light of the predictions made in the 2017 PVA. In particular, it is instructive to compare recent observed trends of both in situ and ex situ population abundance and genetic diversity with those predicted by the 2017 PVA model and to explore potential causal factors that may explain any differences between them. This report documents the quantitative component of this evaluation.

Methods

The 2017 PVA was conducted using the demographic simulation modeling package Vortex, version 10.2.8 (Lacy and Pollak 2017). New simulations conducted as part of the current evaluation use a newer version of the software (version 10.6.0: Lacy and Pollak 2022) with the same base modeling project used originally. Full details on the structure and function of the PVA model, as well as the data used to create demographic and genetic input values for the model, are not given here but can be found in the original PVA report (Miller 2017). Similarly, details on methods used to generate minimum population abundance counts for in situ populations and to estimate population genetic structure of both in situ and ex situ populations can be found in summary documents published by the appropriate population management authorities (see data source list below).

[1] Species Survival Plan®
[2] Saving Animals from Extinction

The model scenario used for the predicted values of population performance featured the following characteristics, defined in detail in Miller (2017):

- MWEPA population management target: 379 wolves;
- SMOCC-N population management target: 200 wolves;
- Mean expected annual mortality rate of adults: 0.189;
- Anticipated release schedule:
    - SAFE population to MWEPA: Twice the rate reported in the 2014 Environmental Impact Statement (USFWS 2014), which specified the transfer from the SAFE population of two pairs of adults and associated pups (four adults and six pups) scheduled for calendar years 2017 and 2021 (model years two and six);
    - SAFE population to SMOCC-N: Transfer of two pairs of adults and associated pups (four adults and six pups) each year in calendar years 2017 through 2021 (model years two through six); and
- Anticipated translocation schedule (MWEPA to SMOCC-N): Base rate of two pairs of adults and associated pups (four adults and six pups) moved to Mexico every other year between calendar years 2017 and 2023).

In the scenario labeling scheme described in Miller (2017), this scenario was designated "379_200_200_189_[EISx2]20_20". Additional information contained in this scheme refers to a second wolf population to be established in the southern portion of the Sierra Madre Occidental (SMOCC-S), which is not being considered in this evaluation. See Table 2 of Miller (2017) and associated text for a detailed discussion of the scenario labeling methodology. For the current evaluation, a slight revision was made to this scenario by modifying the studbook file used to initialize both in situ and ex situ populations. All living individuals in the studbook (alive as of 31 December 2015) had their age incremented by one year to properly categorize their age just before the pairing/breeding season in the spring of 2016, which is the beginning of Year 1 of the simulation. Testing of this change to initial conditions did not have an appreciable impact on model outcomes.

Data sources for this evaluation include:

- The original PVA report (Miller 2017);
- USFWS Quarterly and Annual Reports and other documents describing population analysis, made available by Service Mexican wolf biologists and also available on the Mexican Wolf Recovery Program website (https://www.fws.gov/program/conserving-mexican-wolf);
- Annual population estimates for the SMOCC-N population provided by Mexican wildlife management authorities (CONANP);
- Breeding & Transfer Plan (BTP) reports for the SSP®/SAFE population provided by the Association of Zoos and Aquariums (AZA); and
- Personal communications with Service and CONANP personnel.

The period for this analysis covers end-of-year wild population counts from 2015 to 2023 (minimum counts reported as of the end of the reporting period). These counts, then, roughly coincide with the estimated abundance reported in the PVA just before the onset of pairing and breeding in the early spring of the following year. However, the predicted abundance estimates reported from the PVA represent total population size and, therefore, is expected to be higher than the observed minimum wild population counts derived from aerial surveys and ground observations. Observed population genetic parameters are reported by the SAFE program as of 1 July each year, based on detailed analysis of the up-to-date studbook including individuals in both the in situ and ex situ populations. This date is chosen to align with the annual meeting of the SAFE program that creates the breeding and transfer recommendations for the following breeding season. The timing of this analysis is approximately 4-6 months out of phase with the timing of reporting from the PVA, where population genetic structure is reported at the same time as total population abundance, i.e., just before the annual pairing/breeding event in the spring of the year. While the timing of their estimation may not precisely coincide, the two genetic metrics are not expected to differ meaningfully within any given year.

For each of the three populations, the evaluation compares observed ("true") vs. predicted estimates of population size, proportion gene diversity (GD, also known as expected heterozygosity) retained, and population mean inbreeding coefficient (F). In addition to reporting the standard gene diversity values that reflect retention relative to the original wild population that served as a source of the founders to the ex situ population, retention of gene diversity in the wild populations is also calculated relative to the source SAFE population per Miller (2017). Predicted values of these metrics represent the mean values across 1000 iterations of the model scenario described above. In addition to these population output metrics, the evaluation compared the actual schedule of translocations from MWEPA to SMOCC-N and of releases from SAFE to MWEPA and SMOCC-N with the schedules encoded in the PVA scenario. Finally, the evaluation compares observed vs. predicted rates of diversionary/supplemental feeding (i.e., providing food caches near packs caring for pups to either help prevent depredations or assist with the raising of pups associated with foster efforts) in the MWEPA, as this tactic was considered to impact the number of surviving pups per litter (see Miller 2017 for a detailed discussion of this model element).

Results

[Note: tabular results for the figures presented in this section can be found in the Appendix.]

MWEPA Population Performance

The abundance of wolves in the MWEPA population predicted by the PVA model was consistently slightly lower than the observed minimum count estimate across the period of comparison (Figure 1A). As of the end-of-year count in 2023, the observed minimum number of wolves in this population was reported as 257 individuals, with the PVA model predicting a total abundance of 229±85 individuals. The mean rate of growth in the population was observed to be just under 13% per year over the period of analysis, while the predicted growth rate was estimated at slightly greater than 11% per year. The observed estimate of proportional gene diversity (GD) retained (Figure 1B) was greater than predicted by the PVA model, most likely resulting from the slightly larger observed estimate of population abundance and differing release schedule (see below). As of the 1 July 2023 date of calculation, the observed GD retained was 76.09%, while the PVA model predicted a retention of 74.99% as of the preceding spring. In a similar fashion, the observed retention of gene diversity in MWEPA relative to the source SAFE population has been consistently above the predicted value, with both measures exceeding 90% retention in the period 2020 – 2023. In keeping with the higher level of GD retention over time, the observed estimate of mean inbreeding coefficient (F) in the MWEPA population was 0.211 in July 2023, with the PVA model predicting mean F = 0.234 in the spring of that same year (Figure 1C). The different values for GD and F at the onset of the evaluation time series in 2016 may reflect the different time point for calculation of these metrics which leads to slight variation in the dataset of living individuals making up the analyses (Figure 1). This interpretation is also valid for the SMOCC-N and SAFE population analyses (Figures 2 and 3).

SMOCC-N Population Performance

The abundance of wolves in the SMOCC-N population predicted by the PVA model was considerably greater than the observed abundance over the period of comparison (Figure 2A). At the end-of-year count in 2022, the observed minimum number of wolves in the population was reported as 35 individuals, with the PVA model predicting a total abundance of 124±39 individuals. The mean rate of growth in the population was observed to be approximately 11% per year, while the predicted growth rate was estimated to be nearly 33% per year. The observed estimate of proportional gene diversity retained was nearly identical to that predicted by the PVA model. As of the 1 July 2022 date of calculation, the observed GD retained was 79.74%, while the PVA model predicted a retention of 79.80% as of the preceding spring (Figure 2B). Gene diversity retention relative to the source SAFE population has increased substantially in this population since 2016, rising to nearly 97% of the SAFE population value by 2022. Before the ending date of this calculation, the observed GD data analysis found that the observed rate of retention was consistently lower than the PVA model prediction, although the general trend in retention over time was generally quite consistent across the two datasets. The observed estimate of mean inbreeding coefficient in the SMOCC-N population was consistently slightly lower than that predicted by the PVA model. The observed estimate of mean F was 0.166 as of the 1 July date of analysis, with the PVA model predicting mean F = 0.181 in the spring of that same year (Figure 2C).

SAFE Population Performance

The observed abundance of wolves in the ex situ SAFE population was considerably larger than that predicted by the PVA model over the full period of comparison (Figure 3A). In 2023, the observed abundance was 356 individuals as of 1 July, while the abundance predicted by the PVA model in the spring of that year (before reproduction) was 251±8 individuals. The mean rate of growth in the population was observed to be approximately 5% per year, while the predicted growth rate was estimated to be just 2% per year. This large discrepancy between observed and predicted abundances is in large part due to a significantly greater number of wolves in the actual SAFE population in recent years (approaching 350 individuals, a value that is currently recognized as exceeding practical management realities) relative to the population carrying capacity used in the 2017 PVA (255 individuals). Despite the differences between observed and expected abundance over time, the proportion of gene diversity retained was nearly identical over the period of observation (Figure 3B). Across both estimates, GD retention remained nearly constant over time with a final estimate in 2023 of 82.44% (observed) or 82.43% (predicted). Mean inbreeding coefficient across the two estimates was also nearly identical across the period of comparison (Figure 3C), with the predicted estimate rising to a very slightly higher value in spring 2023 (F_{Pred} = 0.163) compared to the observed value estimated as of 1 July of that same year (F_{Obs} = 0.151).

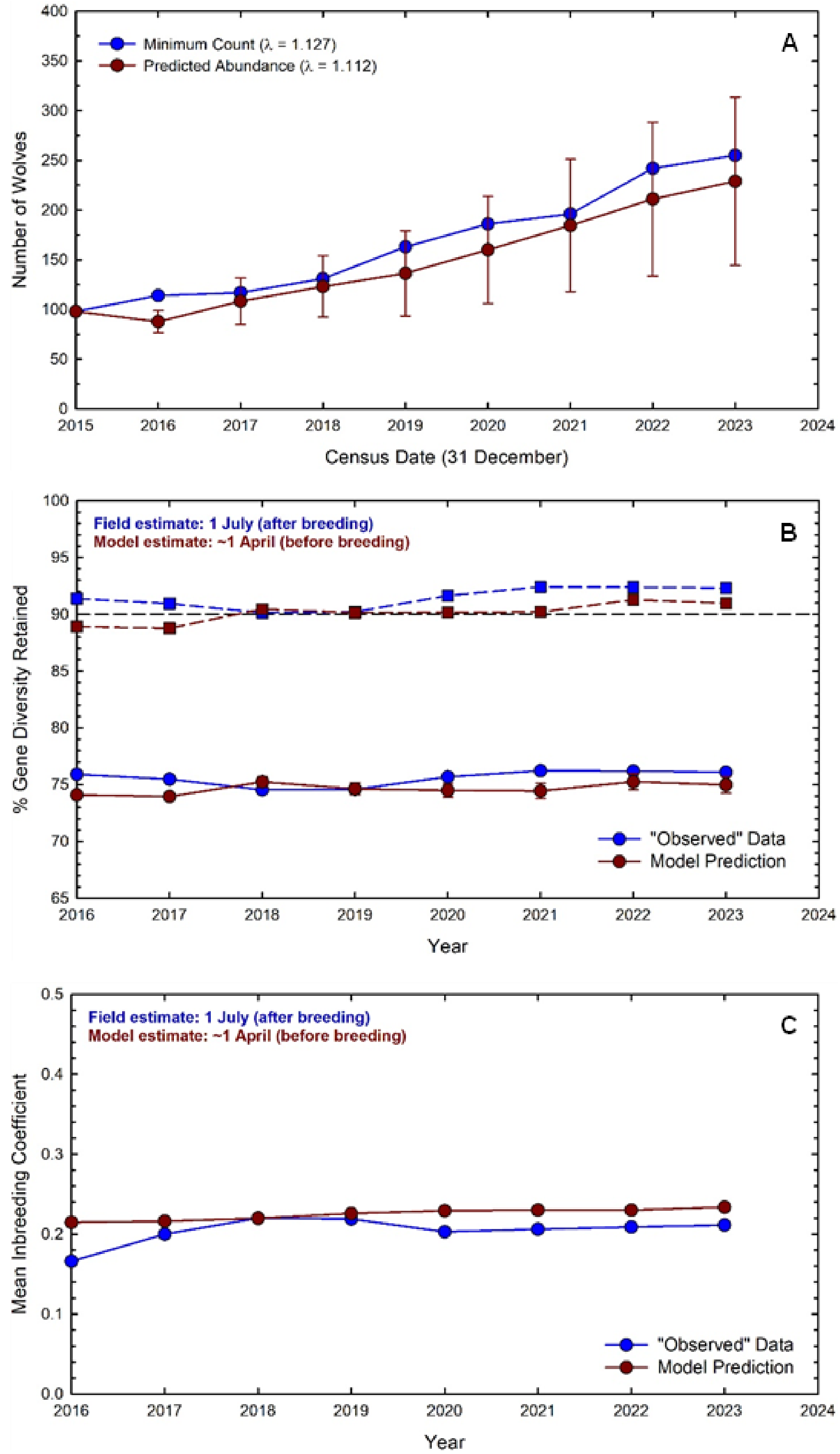

Figure 1. Evaluation of observed vs. predicted performance of the MWEPA population of Mexican wolves. Predicted metrics are reported as (mean±SD) where available. Gene diversity plot (B) includes both base retention values (circles) relative to the original wild population as well as retention relative to the current SAFE population (squares), with the horizontal line denoting a 90% gene diversity retention target. See accompanying text for additional information on definitions of performance metrics and their estimation.

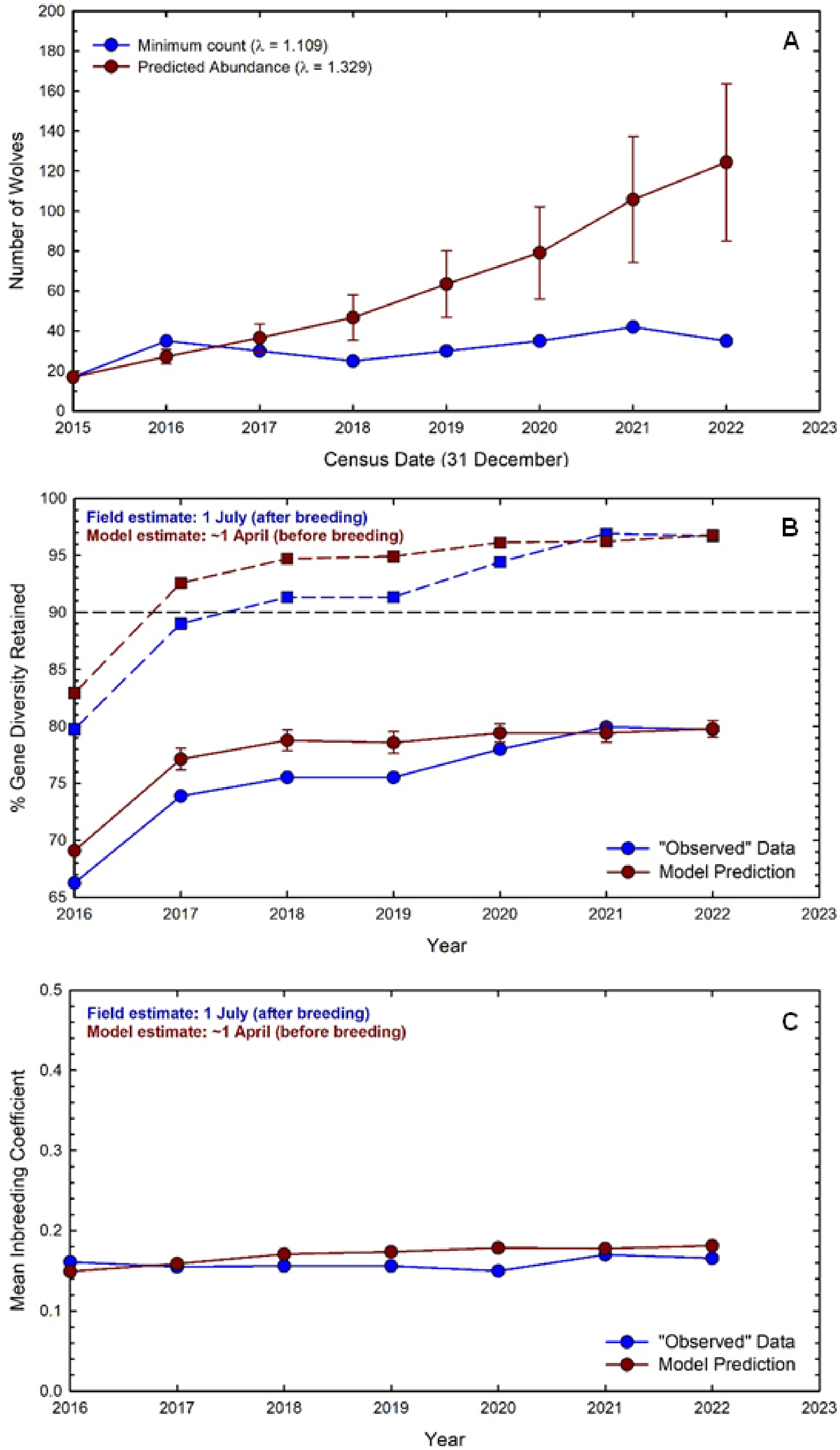

Figure 2. Evaluation of observed vs. predicted performance of the SMOCC-N population of Mexican wolves. Predicted metrics are reported as (mean±SD) where available. Gene diversity plot (B) includes both base retention values (circles) relative to the original wild population as well as retention relative to the current SAFE population (squares), with the horizontal line denoting a 90% gene diversity retention target. See accompanying text for additional information on definitions of performance metrics and their estimation.

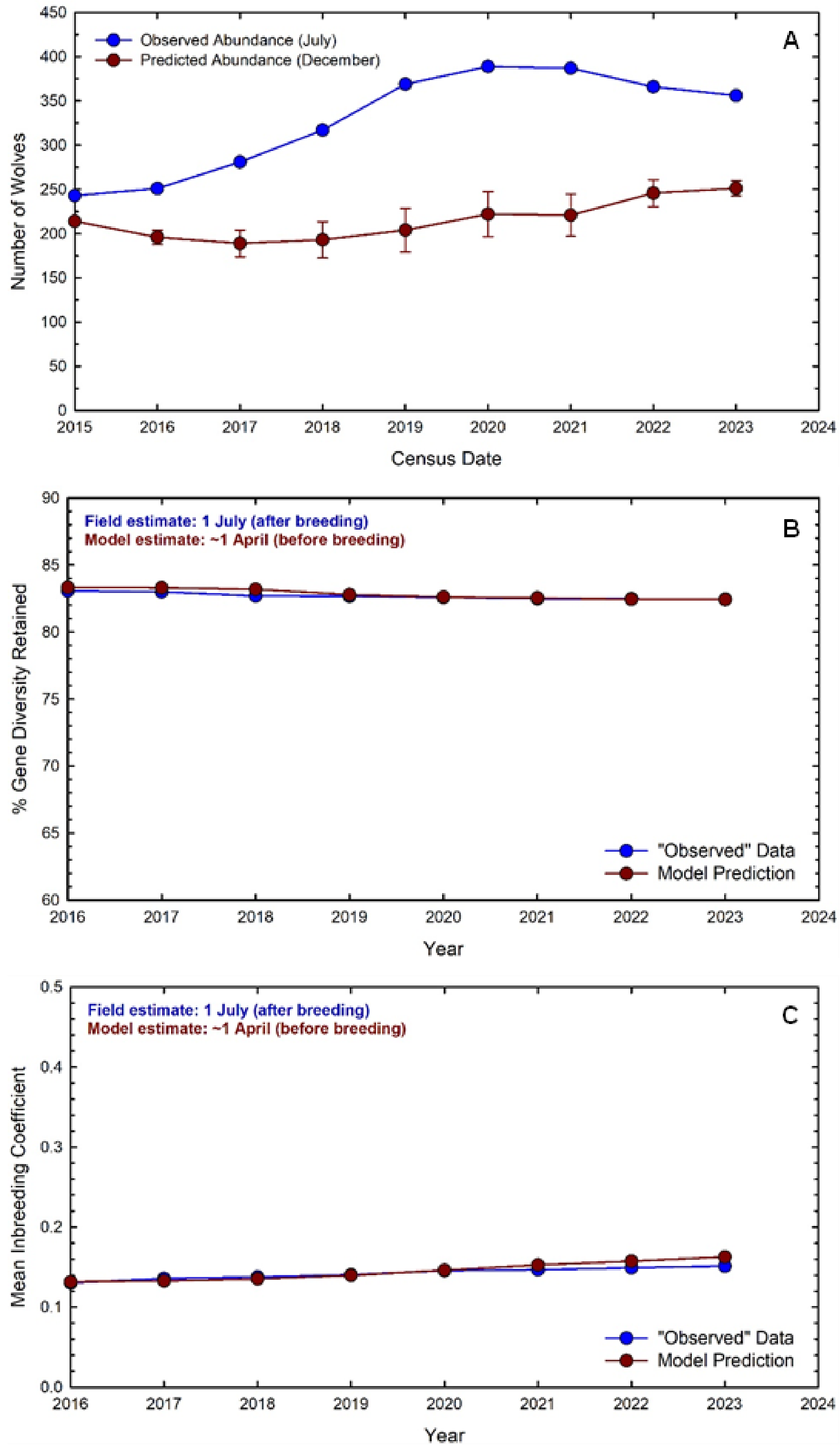

Figure 3. Evaluation of observed vs. predicted performance of the SAFE population of Mexican wolves. Predicted metrics are reported as (mean±SD) where available. See accompanying text for additional information on definitions of performance metrics and their estimation.

Wolf Translocation Dynamics: MWEPA to SMOCC-N

The PVA model featured removal from the MWEPA population of four adults and six pups every other year from 2017 to 2023 for the purpose of translocation to Mexico (i.e., not inclusive of removals for all purposes), leading to a total predicted removal of 16 adults and 24 pups over the period of evaluation. Wolf removals from MWEPA to SMOCC-N occurred less frequently than predicted, with removal events taking place in 2020, 2021 and 2023. During those three years, a total of nine adults, two yearlings (Age-1) and five pups were removed from MWEPA for a total of 16 individuals or 40% of the predicted number (Figure 4).

Thus, the number of wolves translocated to SMOCC-N from the MWEPA population was 40% of the originally predicted number, with the first wild wolves moved to Mexico (2020) three years after the original predicted date (2017). Slightly more than 50% of the intended adult cohort was translocated, but only 21% of the originally predicted pups were translocated during the period of evaluation.

Wolf Release Dynamics: SAFE to MWEPA, SMOCC-N

As predicted in the 2017 PVA simulations, eight adults and twelve pups were to be removed from the ex situ SAFE population and released to MWEPA in each of two years covering the evaluation period (2017 and 2021). The total number of individuals predicted to be released during this period, therefore, was 16 adults and 24 pups. Only pups, however, are recorded to have been released to MWEPA from the SAFE population, and in substantially larger numbers than what was predicted in the 2017 PVA (Figure 5). Over the evaluation period 2016-2023, a total of 99 pups (412% of the predicted number of pups, 247% of the total predicted number of wolves) were released to MWEPA from the ex situ population, with a gradual increase in the annual release rate up to a maximum of 22 pups released in 2021.

The 2017 PVA also predicted a total of 20 adults and 39 pups to be released from the SAFE population to the SMOCC-N population between 2016 and 2021, with four adults and six pups released each year between 2017 and 2021. In reality, a total of eight adults, four yearlings, and seven pups were released between 2018 and 2021 (19 wolves in total, 32% of the predicted value: Figure 6). More recent releases in 2020 and 2021 included only half of the scheduled adults and just 16.7% of the scheduled pups.

Overall, the original prediction in the 2017 PVA included a total of 36 adults and 63 pups to be released into the wild during the period of evaluation (Figure 7). The MWEPA population was to receive 16 adults and 24 pups (40.4% of the total), while SMOCC-N was to receive 20 adults and 39 pups (59.6% of the total). In total, the actual release schedule amounted to 119% of the predicted number but was heavily biased towards pups (106 actual vs. 63 predicted) and to releases into MWEPA (99 actual vs. 40 predicted) with only 19 wolves released to Mexico.

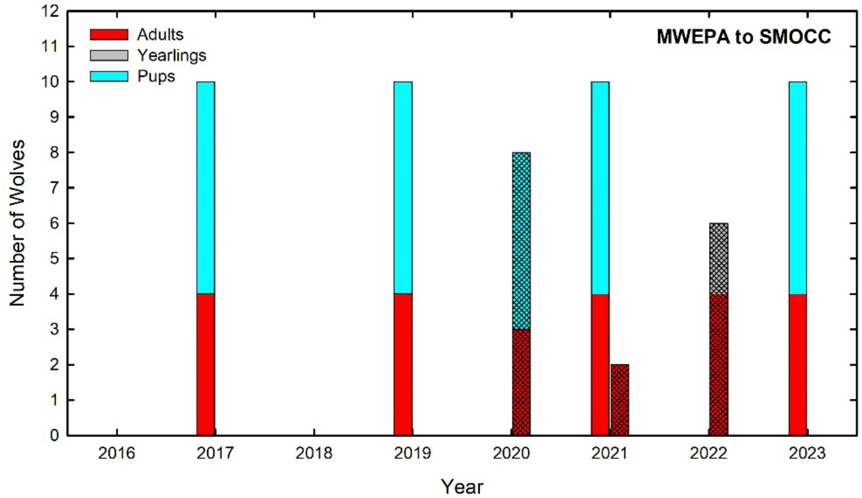

Figure 4. Evaluation of observed vs. predicted events in which wolves were to be removed from the US MWEPA population and translocated to the Mexico SMOCC_N population. In each year of the plot, light-color stacked bars to the left of the year on the x-axis indicate the predicted translocation schedule included in the PVA simulation, while the cross-hatched stacked bars to the right of the year indicate the actual translocation schedule reported by wolf management authorities. See accompanying text and Miller (2017) for additional information on PVA model structure and function.

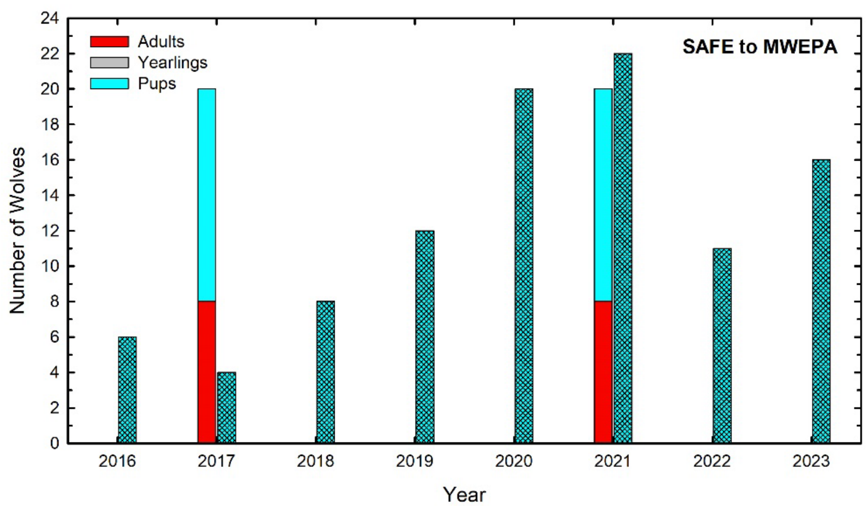

Figure 5. Evaluation of observed vs. predicted events in which wolves were to be released from the ex situ SAFE population to the MWEPA population. In each year of the plot, light-color stacked bars to the left of the year on the x-axis indicate the predicted release schedule included in the PVA simulation, while the cross-hatched stacked bars to the right of the year indicate the actual release schedule reported by wolf management authorities. See accompanying text and Miller (2017) for additional information on PVA model structure and function.

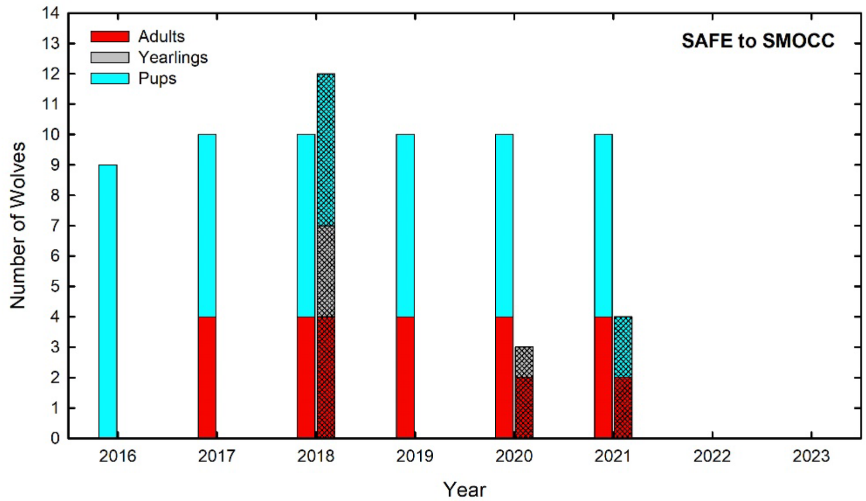

Figure 6. Evaluation of observed vs. predicted events in which wolves were to be released from the ex situ SAFE population to the SMOCC-N population. In each year of the plot, light-color stacked bars to the left of the year on the x-axis indicate the predicted release schedule included in the PVA simulation, while the cross-hatched stacked bars to the right of the year indicate the actual release schedule reported by wolf management authorities. See accompanying text and Miller (2017) for additional information on PVA model structure and function.

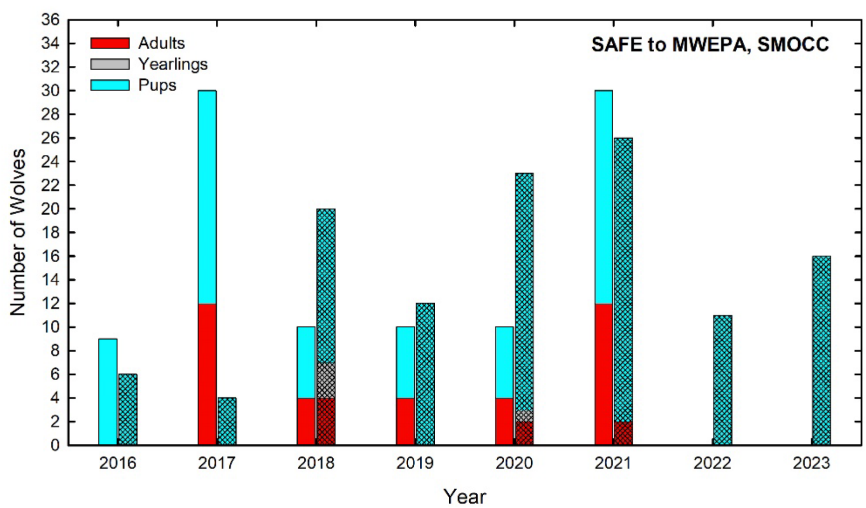

Figure 7. Evaluation of observed vs. predicted levels of removal of wolves from the SAFE population to be released to wild populations in the US (MWEPA) and to Mexico (SMOCC-N). In each year of the plot, light-color stacked bars to the left of the year on the x-axis indicate the predicted removal schedule included in the PVA simulation, while the cross-hatched stacked bars to the right of the year indicate the actual removal schedule reported by wolf management authorities. See accompanying text and Miller (2017) for additional information on PVA model structure and function.

MWEPA Feeding Dynamics

With the exception of 2018, the observed proportion of wolf pairs documented with live pup(s) in the MWEPA population that were provisioned with food caches in the pup-rearing season generally declined over the period of evaluation (Figure 8). In contrast, Figure 8 shows that this proportion was predicted to remain constant over the time period 2016 – 2021, after which time the proportion of pairs documented with live pup(s) with food caches was to begin steadily declining to a much smaller value. The total number of pairs documented with live pup(s) provisioned with caches remained relatively constant over time (Table 1), while the total number of pairs documented with live pup(s) increased 2.5-fold as the MWEPA population grew rapidly during the period of evaluation (see Figure 1).

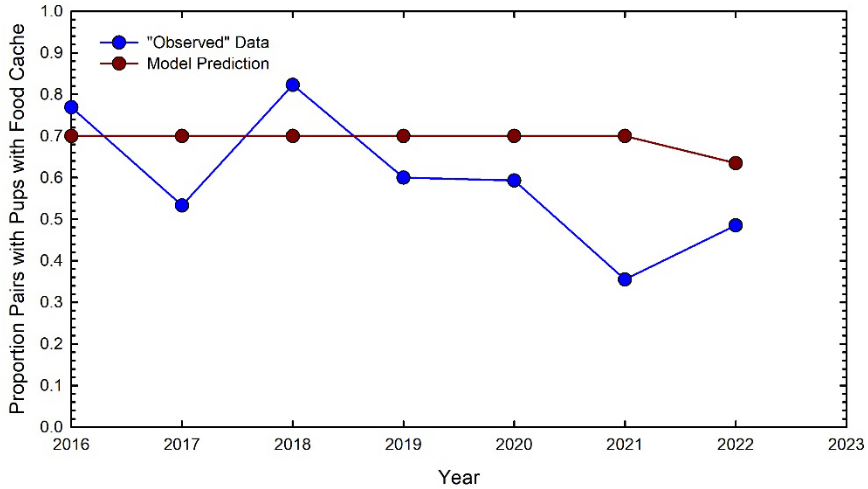

Figure 8. Evaluation of observed vs. predicted levels of supplemental/diversionary feeding among wolf pairs documented with live pup(s) in the MWEPA population. See accompanying text and Miller (2017) for additional information on PVA model structure and function.

Table 1. Total number of wolf pairs documented with live pup(s) in the MWEPA population over the time period 2016-2022, and the subset of those pairs on nearby food caches during the pup-rearing season. Data from USFWS.

Year	Pairs with live pups on food cache (>2 weeks, April – Sept.)	Total pairs
2016	10	13
2017	8	15
2018	14	17
2019	12	20
2020	16	27
2021	11	31
2022	16	33

Conclusion

Overall, the analyses described in this report indicate that the true estimated minimum abundance of the MWEPA population is larger than that predicted by the 2017 PVA model. Additionally, genetic measures of viability – proportional gene diversity retention and mean inbreeding level – are more favorable compared to what was predicted in the PVA. Factors that likely contribute to this observation include:

- Lower adult mortality in the population (15.8%) compared to 18.9% which marked the low end of the range of simulated mortality rates (but also note that the new annual pup mortality rate estimate of 32.4% (based on collared pup mortality rate after six months of 18.5% (new estimate based on the average from 2017 to 2023 of the 183-day pup mortality (phase 2 in Miller 2017), and previous mortality estimate in Miller 2017 prior to collaring pups of 17.0%) since 2015 is slightly higher than the simulated rate of 28.2%;
- A smaller number of wolves removed from the MWEPA for translocation to Mexico; and
- A substantially larger number of wolves (all pups) released into MWEPA from the SAFE population.

It is worth noting that the analysis showed that fewer wolf pairs with documented live pup(s) were provisioned with food caches compared to model predictions. Based on the assumed benefits to pup survival that are to be derived from the presence of these nearby caches, we would expect the reduction in the proportion of packs enjoying this benefit would lead to slightly lower rates of pup survival. Given the high growth rates observed in the MWEPA population – sustained growth since 2009 – this observed increase in pup mortality may be at least partially masked by other management activities that promote observed increases in population abundance.

In contrast to the results for the MWEPA population, the estimated abundance of the SMOCC-N population in Mexico as measured in the field is substantially smaller than that predicted by the 2017 PVA model. Despite the declining rate of growth observed for this population, observed estimates of genetic measures of viability – proportional gene diversity retention and mean inbreeding level – do not diverge to the same extent, suggesting lower levels of sensitivity in these population-wide metrics. Factors that likely contribute to the observed divergence between observed and predicted results include:

- Higher overall mortality of adult wolves (wild born wolves or individuals predicted to survive greater than one year following release or translocation) in the wild (39.0%) compared to what was included in the simulation (note: adult mortality is considered one of the parameters that most impact population performance. Simulations in the 2017 PVA suggested that wolf populations with adult mortality rates above 24.9% have a high probability of extinction). We modeled all future scenarios in Mexico with a 24.9% adult mortality rate (see 5-year evaluation for further discussion);
- A smaller number of wolves with similar survival rates to previous simulations were translocated from MWEPA; and
- A substantially smaller number of wolves with similar survival rates to simulations were released from the SAFE population.

The genetic signature of the initial founding event for this population, along with selection of individuals for translocation and release based on genetic measures of relatedness, are likely to at least partially explain the relatively favorable genetic metrics in the population, even as that population has remained at a small abundance since the beginning of this evaluation period.

Finally, the analyses described here indicate that the true abundance of the SAFE population is now about 40% larger than that simulated in the 2017 PVA. This difference is a result of the expansion in the number of institutions participating in the SAFE program and the number of available spaces within those institutions, which results in a functional increase in the overall size of the ex situ population. SAFE program managers recognize the difficulties that can result from this expansion and are working to avoid overcrowding, etc. where appropriate. Interestingly, even with this expansion of the ex situ population, the genetic metrics of interest to the program show high levels of concordance with 2017 PVA prediction that emerge from simulating a much smaller population through time. This observation is likely a consequence of both the restricted genetic base present at the time of the PVA, as well as the positive benefits of careful genetic management of the ex situ population leading to minimal losses of gene diversity through time.

Taken together, the results of this analysis further reinforce the idea that significant differences between intended and actual schedules of translocation and release efforts play a major role in explaining deviations in predicted vs. actual abundance trajectories for Mexican wolf populations in both the United States and, in particular, Mexico. These results confirm the value of the 2017 PVA model as an effective tool determining the utility of management actions guided by the 2022 Mexican Wolf Recovery Plan, Second Revision and the associated Recovery Implementation Strategy.

References

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Appendix

Table I. Data used for Figure 1, characterizing the MWEPA population of Mexican wolves as evaluated in the field (Observed) and in the PVA model described in this report (Predicted).

	Number of Wolves		% Gene Diversity Retained		% Gene Diversity Retained (SAFE)		Mean Inbreeding Coefficient	
Year	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
2015	98	98	NA	NA	NA	NA	NA	NA
2016	114	87.8 (11.2)	75.91	74.10	91.38	88.92	0.166	0.215
2017	117	108.3 (23.4)	75.48	73.96	90.94	88.78	0.200	0.216
2018	131	123.1 (31.0)	74.54	75.25	90.13	90.46	0.220	0.220
2019	163	136.3 (42.8)	74.59	74.63	90.22	90.14	0.219	0.226
2020	186	160.0 (53.8)	75.69	74.50	91.65	90.17	0.203	0.229
2021	196	184.6 (66.6)	76.23	74.45	92.41	90.20	0.206	0.230
2022	242	211.1 (77.4)	76.20	75.26	92.39	91.28	0.209	0.230
2023	257	229.0 (84.8)	76.09	74.99	92.30	90.97	0.211	0.234

Table II. Data used for Figure 2, characterizing the SMOCC population of Mexican wolves as evaluated in the field (Observed) and in the PVA model described in this report (Predicted).

	Number of Wolves		% Gene Diversity Retained		% Gene Diversity Retained (SAFE)		Mean Inbreeding Coefficient	
Year	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
2015	17	17	NA	NA	NA	NA	NA	NA
2016	35	27.2 (3.6)	66.26	69.10	79.76	82.92	0.161	0.149
2017	30	36.6 (7.0)	73.88	77.13	89.01	92.58	0.155	0.159
2018	25	46.7 (11.4)	75.53	78.78	91.33	94.70	0.156	0.171
2019	30	63.5 (16.6)	75.53	78.58	91.35	94.91	0.156	0.174
2020	35	79.2 (23.1)	77.99	79.43	94.43	96.14	0.150	0.179
2021	42	105.7 (31.6)	79.95	79.43	96.92	96.23	0.170	0.178
2022	35	124.4 (39.3)	79.74	79.80	96.68	96.79	0.166	0.181
2023	NA	NA	NA	NA	NA	NA	NA	NA

Table III. Data used for Figure 3, characterizing the SAFE population of Mexican wolves as evaluated in the field (Observed) and in the PVA model described in this report (Predicted).

	Number of Wolves		% Gene Diversity Retained		% Gene Diversity Retained (SAFE)		Mean Inbreeding Coefficient	
Year	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted
2015	243	214	NA	NA	NA	NA	NA	NA
2016	251	195.9 (7.9)	83.07	83.33	NA	NA	0.130	0.132
2017	281	188.9 (15.0)	83.00	83.31	NA	NA	0.136	0.133
2018	317	193.0 (20.6)	82.70	83.19	NA	NA	0.138	0.135
2019	369	203.9 (24.5)	82.68	82.79	NA	NA	0.141	0.140
2020	389	222.0 (25.3)	82.59	82.62	NA	NA	0.146	0.146
2021	387	220.9 (24.0)	82.49	82.54	NA	NA	0.147	0.153
2022	366	245.8 (15.2)	82.48	82.45	NA	NA	0.149	0.158
2023	356	251.2 (8.4)	82.44	82.43	NA	NA	0.151	0.163

Table IV. Data used for Figure 4, characterizing the release schedule of Mexican wolves from the MWEPA population to the SMOCC population in Mexico as implemented in the field (Observed) and in the PVA model described in this report (Predicted).

	Observed			Predicted		
Year	Adults	Yearlings	Pups	Adults	Yearlings	Pups
2016	0	0	0	0	0	0
2017	0	0	0	4	0	6
2018	0	0	0	0	0	0
2019	0	0	0	4	0	6
2020	3	0	5	0	0	0
2021	2	0	0	4	0	6
2022	4	2	0	0	0	0
2023	0	0	0	4	0	6

Table V. Data used for Figure 5, characterizing the release schedule of Mexican wolves from the SAFE population to the MWEPA population in the United States as implemented in the field (Observed) and in the PVA model described in this report (Predicted).

	Observed			Predicted		
Year	Adults	Yearlings	Pups	Adults	Yearlings	Pups
2016	0	0	6	0	0	0
2017	0	0	4	8	0	12
2018	0	0	8	0	0	0
2019	0	0	12	0	0	0
2020	0	0	20	0	0	0
2021	0	0	22	8	0	12
2022	0	0	11	0	0	0
2023	0	0	16	0	0	0

Table VI. Data used for Figure 6, characterizing the release schedule of Mexican wolves from the SAFE population to the SMOCC population in Mexico.

	Observed			Predicted		
Year	Adults	Yearlings	Pups	Adults	Yearlings	Pups
2016	0	0	0	0	0	9
2017	0	0	0	4	0	6
2018	4	3	5	4	0	6
2019	0	0	0	4	0	6
2020	2	1	0	4	0	6
2021	2	0	2	4	0	6
2022	0	0	0	0	0	0
2023	0	0	0	0	0	0

Table VII. Data used for Figure 7, characterizing the release schedule of Mexican wolves from the SAFE population to the MWEPA population in the United States and to the SMOCC population in Mexico.

	Observed			Predicted		
Year	Adults	Yearlings	Pups	Adults	Yearlings	Pups
2016	0	0	6	0	0	9
2017	0	0	4	12	0	18
2018	4	3	13	4	0	6
2019	0	0	12	4	0	6
2020	2	1	20	4	0	6
2021	2	0	24	12	0	18
2022	0	0	11	0	0	0
2023	0	0	16	0	0	0

Table VIII. Data used for Figure 8, specifying the observed and predicted proportion of Mexican wolf pairs in the MWEPA population with pups with a nearby food cache.

	Proportion of Pairs	
Year	Observed	Predicted
2016	0.769	0.700
2017	0.533	0.700
2018	0.823	0.700
2019	0.600	0.700
2020	0.593	0.700
2021	0.355	0.700
2022	0.485	0.635
2023		

ADDENDUM: Exploring Recommended Conditions for Successful Establishment of Mexican Wolves in northern Mexico

Introduction

In response to the comparatively poor demographic performance of the wolf population in Mexico over the period of this evaluation, the Service and its partners are interested in evaluating alternative methods of transferring wolves from other sources that can help to establish a viable wolf population within historical range in Mexico. In particular, the number of individuals to introduce annually into suitable habitat, the demographic composition of each group, and the survival of those individuals after their release are key parameters that collectively influence the likelihood of successfully establishing a viable population. A set of scenarios was developed using the current simulation model to shed light on these important questions.

PVA Model Characteristics

For this additional analysis, the base model structure was largely unchanged from that described in this report and discussed in detail in Miller (2017), with the following modifications:

- The second population in Mexico, labeled SMOCC-S representing the southern Sierra Madre Occidental habitat area, was removed from the simulation. All simulated wolf transfer efforts target the northern Sierra Madre Occidental habitat, designated SMOCC-N in all models comprising this broad analysis.
- The model featured a start date of early spring 2023, with initial population abundances tallied as of 31 December 2022. This more contemporary start date (the initial PVA published in 2017 featured census data as of 31 December 2015) made it necessary to update the studbook data file with the latest data on living individuals in both in situ and ex situ populations, their ancestry and, where suitable, the identity of their mate. This new information was painstakingly compiled and analyzed by L. Faust (Lincoln Park Zoo, Chicago IL) and C. Gardner (USFWS, Albuquerque NM) to create the updated studbook file. Because of some uncertainty in the exact identity and relationships of some young wolves in the wild MWEPA population, it was necessary to "create" these individuals in the studbook based on the best information on their parentage, etc. More information on this studbook preparation is available from the Service on request.
- Based on the updated studbook, the MWEPA population size as of 31 December 2022 was initialized at 240 individuals, and the SAFE (previously SSP) population at 355 individuals (aged one year and older). Additionally, since no wolves currently in Mexico are wearing radio collars, there is considerable uncertainty in the number of animals alive there as of the start date of this analysis. Therefore, the model development group elected to adopt a conservative approach and set initial population abundance in the SMOCC-N habitat area to zero.
- From analysis of recent wild population mortality data discussed elsewhere in this report, the mean annual adult mortality rate for the MWEPA population was set at 18.9%. This value represents the low end of the range of adult mortality rates previously tested in the 2017 PVA. Adult mortality for the SMOCC-N population was set at 24.9%, representing the high end of acceptable mortality that emerged from analysis of results from the 2017 PVA. A wolf population in the SMOCC-N habitat would be expected to exhibit at least a moderate rate of population growth with this mortality rate, and by extension possess at least a reasonable opportunity for successful establishment following sufficient releases of wolves to that habitat.
- As described elsewhere in this report, the number of wolves recently comprising the SAFE population was and is well above the stated carrying capacity (K = 255: 2017 PVA) of the member

institutions making up the ex situ management program. A reduction in the number of individuals managed within that program is generally considered an essential goal of future population management. Consequently, the added analysis included an initial carrying capacity of 370 individuals – roughly equal to the current abundance – but with a gradual linear reduction in K to 300 individuals over a five-year timespan. This would correspond in reality to calendar year 2027.

- All scenarios were simulated for 15 years, i.e., spring 2023 – spring 2037.

With this general model structure as a guide, the following parameters were systematically varied to create the full set of wolf transfer scenarios:

1. All wolf transfers were conducted annually for ten years, beginning in model year three (calendar year 2025) and ending in model year twelve (calendar year 2034).
2. Four distinct wolf cohorts were included in the analysis:
   a. Adults only;
   b. Yearlings (Age-1 wolves) only;
   c. Adults and yearlings; and
   d. Adults with pups (Age-0 wolves).

   Each distinct model scenario featured the same type of cohort being transferred throughout the ten-year duration of the transfer process.
3. A total of 6, 12 or 18 wolves were transferred each year. When yearlings or pups were transferred with adults, the number of younger wolves was always twice the number of adults; for example, a total of 12 mixed-age wolves would be made up of four adults and eight yearlings or pups.
4. All scenarios featured an equal sex ratio among transferred wolves. When the total number of wolves dictated an odd number of wolves of a given age class to be transferred, the majority of individuals was made to be female (e.g., five females and four males).
5. Transfers were conducted assuming three separate mechanics:
   a. All wolves released to SMOCC-N from the SAFE population;
   b. All wolves translocated to SMOCC-N from the MWEPA population;
   c. A combination of transfer methods, i.e., 50:50 distribution of released wolves from SAFE and translocated wolves from MWEPA.
6. Each unique scenario defined by cohort type and transfer strategy was tested across a range of plausible post-release survival rates. These rates described the probability of a transferred wolf surviving from its introduction to the SMOCC-N population to the time of the next model census just before breeding the following spring. This duration aligns with field data collected by the Service and partners on survival rates of released and translocated wolves in the MWEPA population. It is acknowledged here that ultimate success of a transfer program is measured by the number of transferred wolves that survive to breeding age and successfully reproduce. This process is captured in the PVA model through simulation of continued survival of individuals through time and their successfully pairing and reproduction. The shorter-term six-month survival window is a focus here both because of the explicit data provided by the Service and the explicit methods by which this survival can be best implemented in the model.

   Six-month post-release survival rates chosen for a given scenario ranged from a minimum of 0.1 to a maximum of 0.7 in increments of 0.1. The approximate midpoint of these ranges – 0.5 for pups, 0.4 for yearlings, and 0.3 for adults – generally correspond to the mean post-release survival rates observed in earlier transfer efforts and used in the 2017 PVA (see Table 3 in Miller 2017 for more details).

Data used in the 2017 PVA showed no meaningful difference in post-release survival of pups (and, by extension, yearlings) when either released from the ex situ SAFE population or translocated from the in situ MWEPA population. In contrast, the post-release survival among adults released from the SAFE population was markedly lower compared to those that were translocated from the MWEPA population. This feature was carried over to the present analysis, allowing for an examination of the relative efficacy of each transfer strategy. In the Combination scenario set, half of the transferred adult wolves were given a lower post-release survival compared to those transferred from the MWEPA population to reflect reduced survival of wolves transferred from the SAFE population. For example, a particular scenario may include 50% of a given adult cohort being assigned a post-release survival rate of 0.5, while the remainder would have a survival rate of 0.3. In scenarios featuring just two adults transferred to Mexico, priority was given to assigning them to be transferred from the MWEPA source population. This difference was maintained across the sliding scale of post-release survival rates defining the scenarios in this analysis; in this way, a given transfer scenario would be characterized by broadly poor, mid-range or favorable survival rates among the wolves making up that transfer cohort.

Using the above rules, the various combinations of parameters resulted in a grand total of 250 unique scenarios making up the analysis. Each scenario was run across 1000 iterations. The output from each scenario chosen for analysis included (a) the probability that the SMOCC-N population would exceed 100 individuals (Age-1 and older) at the end of the 15-year simulation; (b) the average size of the SMOCC-N population among those iterations where the population was extant at the end of the simulation; and (c) average population gene diversity (expected heterozygosity) among surviving populations at the end of the 15-year simulation.

Results and Conclusions

The likelihood of successfully establishing a Mexican wolf population in the Sierra Madre Occidental (designated SMOCC-N in the 2017 PVA) within 15 years is highly variable and depends strongly on the type of individuals chosen for transfer, the number of wolves transferred each year of the program, and the survival rate of those individuals following their transfer (Figure A-1; Tables A-1 to A-3). These results illustrate the following observations from the analysis:

- Under the conditions simulated here, a total of six wolves transferred each year for ten years – regardless of the transfer method used or the extent of post-transfer survival – is inadequate to successfully establish a demographically healthy wolf population in northern Mexico. The low rate of introducing wolves to an empty habitat as simulated here is insufficient to overcome the stochastic forces that act to destabilize small populations.
- Compared to transfer cohorts composed of mixed-age groups, strategies focusing on transferring only adults or yearlings showed slightly higher probabilities of success in establishing populations of at least 100 wolves in northern Mexico within 15 years at higher post-release survival rates. Replacing some of the adults in a transfer cohort with younger individuals reduces the total number of wolves that survive to breeding age, thereby lowering the aggregate longer-term reproductive output of that cohort.
- Under the conditions and assumptions used to construct this analysis, a transfer program composed of translocating wild wolves from the MWEPA population generally exhibits a greater likelihood of successful Mexico population establishment compared to a transfer program composed only of releasing wolves from the SAFE population (i.e., compare plots A and B of Figure A-1 and Tables A-1 and A-2). This is best explained as a consequence of including the lower rates of post-release survival among adults transferred to Mexico from the SAFE population. However, the comparatively more robust genetic structure of the source SAFE population means that gene diversity retention in the Mexico population can be greater under a Release-Only transfer strategy. For example, at the highest levels of predicted success of a release program – namely 18 wolves

released each year with a mean post-release survival rate of 0.5 (adults) to 0.7 (pups), mean gene diversity in the Mexico population is about 6.7% higher (GD = 0.800: Table A-1, bottom right) than in the same population established solely through translocation from MWEPA (GD = 0.750: Table A-2, bottom right). This is to be expected given the simulation mechanic in which the SAFE source population is more intensively managed than the wild MWEPA population to reduce gene diversity loss resulting from inbreeding and genetic drift.

- When transferring the larger number of 18 wolves each year during a program of this type, a post-transfer survival rate of at least 0.4 appears to provide the greatest chance of establishing a population of at least 100 wolves in northern Mexico within 15 years, with a transfer scheme focused on translocation or combined translocation and release offering the best oppoortunity for demographic success. This threshold survival value is roughlky similar to survival rates used in the original 2017 PVA, albeit with some improvement necessary for adults released from the SAFE population (post-transfer survival of 0.284: Table 3 of Miller 2017).
- As simulated here, the Combination transfer scheme – featuring a 50:50 mix of both release from the SAFE population and translocation from the MWEPA population – gives results that, perhaps not surprisingly, are largely intermediate between the Release Only and Translocation Only transfer schemes. The pattern across specific scenario sets (e.g., types of wolves transferred or total number transferred) does not consistently demonstrate this result, but overall the distribution of outcomes – high likelihood of success, moderately high likelihood, moderately low or low likelihood – in the Combination scenarios is intermediate relative to two more simple transfer schemes.

Finally, Table A-4 shows final population size and gene diversity in the source SAFE and MWEPA populations to facilitate an examination of the cost of the tested transfer strategies on source population viability. The SAFE population, constrained by a lower carrying capacity, demonstrates a marked reduction in population abundance in the latter years of a relatively aggressive Release-Only transfer strategy, as shown in the top-right row of results data in Table A-4. However, since individuals selected for release generally represent at least slightly genetically over-represented founders, the cost to population gene diversity of this reduced abundance is very slight. Overall, impacts on source population gene diversity are negligible for all transfer strategies.

Lastly, it is important to remember that this report is not designed to include specific recommendations for implementing a particular wolf transfer strategy in Mexico. Instead, the results of the many complex simulations are presented in an attempt to provide population managers with valuable information on predicted outcomes of alternative management strategies, with the intention that managers will use the quantitative results to inform thoughtful decision-making designed to improve opportunities for Mexican wolf recovery.

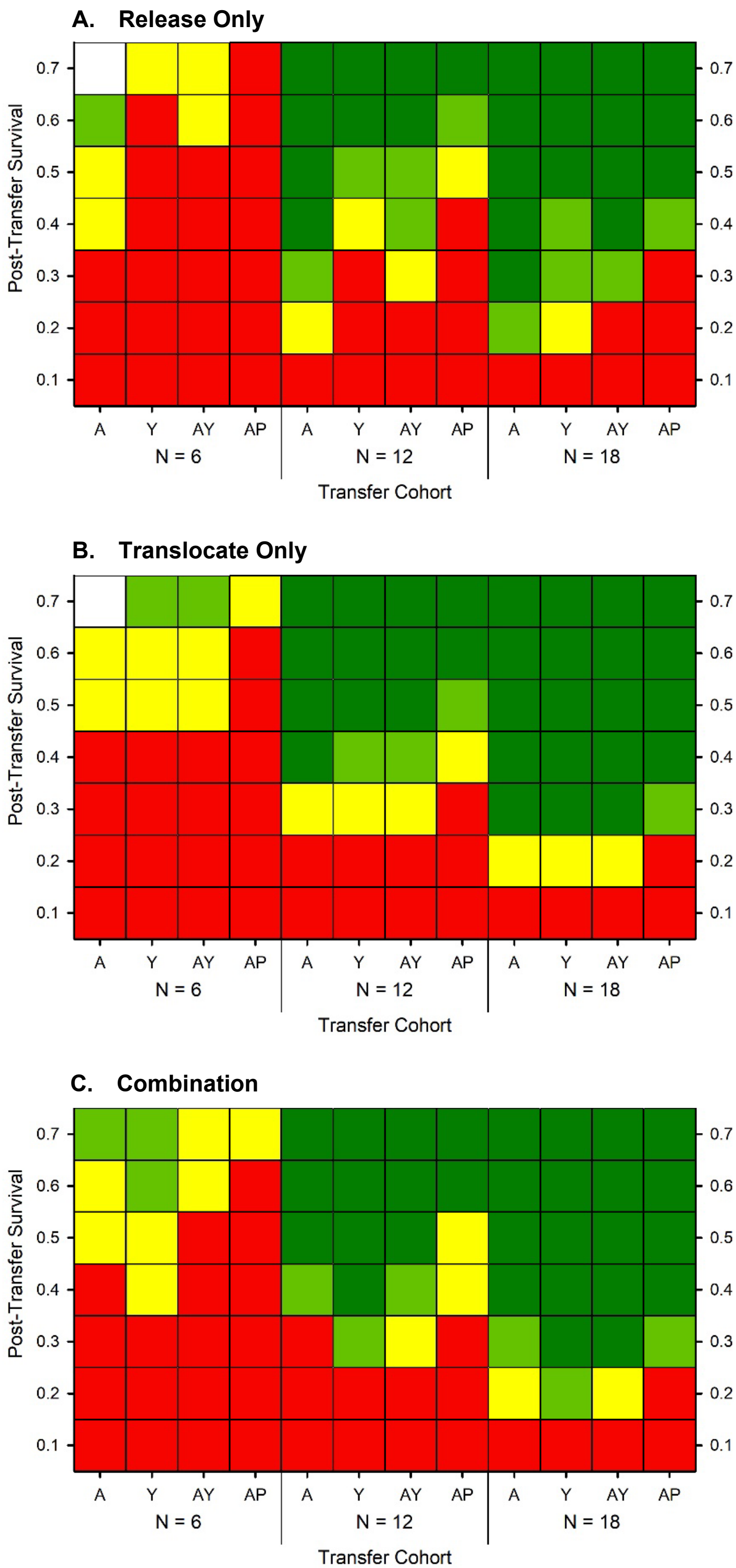

Figure A-1. Probability of the SMOCC-N wolf population in Mexico growing to at least 100 individuals (Prob[N>100]) after 15 years under a range of simulated transfer strategies and post-transfer (six-month) survival rate estimates. Transfer cohort definitions: A, adults; Y, yearlings; AY, adults with yearlings; AP, adults with pups.

Color codes for each cell define Prob[N>100]:

Red = Probability < 0.25;
Yellow = 0.25 < Probability < 0.5;
Light green = 0.5 < Probability < 0.75;
Dark green = Probability > 0.75.

A white cell indicates a scenario that was not implemented for this analysis. Where other scenarios were not implemented (see Tables A-1 to A-3), results were extrapolated with confidence given outcomes of similar scenarios. See text for additional information on model structure and function.

Table A-1. Results of simulation models evaluating the efficacy of the Release-Only transfer strategy on establishing a population of Mexican wolves in the northern Sierra Madre Occidental (SMOCC-N). Column headings define the details of transfer strategies, according to the number of wolves transferred each year during the simulated program (N = 6, 12 or 18) and the cohort type used in the transfer (A, adults; Y, yearlings; AY, adults and yearlings; AP, adults and pups). Row headings at the far left of the table give the range of post-transfer survival rates. Each cell represents a unique model scenario, with numerical output listed as the probability of the SMOCC-N wolf population abundance exceeding 100 individuals after 15 years (top), the mean number of wolves across iterations in which the population was extant after 15 years (middle), and the mean population gene diversity at the end of the simulation (bottom). See accompanying text for more information on model structure and function.

Release Only

	N = 6				N = 12				N = 18			
	A	Y	AY	AP	A	Y	AY	AP	A	Y	AY	AP
0.1	0.000 17.0 0.558	0.001 13.5 0.514	0.000 14.2 0.516	NA	0.022 34.2 0.705	0.003 22.0 0.670	0.002 26.5 0.678	NA	0.111 58.2 0.745	0.023 38.0 0.729	0.058 43.4 0.730	NA
0.2	0.022 34.0 0.700	0.003 22.3 0.674	0.004 20.4 0.643	0.002 15.4 0.581	0.289 81.7 0.761	0.071 50.2 0.747	0.045 44.7 0.739	0.017 32.9 0.721	0.61 120.3 0.779	0.255 79.5 0.769	0.218 74.4 0.765	0.081 52.7 0.752
0.3	0.133 60.4 0.745	0.011 35.4 0.726	0.025 34.8 0.714	0.001 19.8 0.653	0.616 120.1 0.778	0.229 76.3 0.769	0.262 81.3 0.768	0.047 44.1 0.745	0.871 157.3 0.791	0.542 112.3 0.783	0.599 118.2 0.784	0.205 71.9 0.768
0.4	0.277 80.6 0.761	0.075 50.0 0.744	0.077 52.3 0.745	0.015 31.0 0.716	0.826 147.3 0.787	0.457 101.4 0.779	0.536 110.9 0.781	0.193 71.1 0.767	0.961 175.3 0.796	0.748 135.7 0.791	0.852 153.4 0.793	0.529 110.1 0.784
0.5	0.443 102.2 0.771	0.136 61.7 0.757	0.186 69.7 0.759	0.04 44.0 0.740	0.909 164.5 0.792	0.633 123.7 0.786	0.746 137.3 0.788	0.431 99.0 0.779	0.981 183.3 0.799	0.865 156.0 0.795	0.960 174.8 0.797	0.821 144.5 0.791
0.6	0.636 122.3 0.778	0.209 74.7 0.766	0.315 85.0 0.769	0.121 59.3 0.756	0.961 175.8 0.795	0.729 135.6 0.790	0.869 155.7 0.793	0.637 123.5 0.786	0.996 186.5 0.800	0.923 166.3 0.797	0.980 180.6 0.799	0.992 160.9 0.796
0.7	NA	0.354 89.2 0.774	0.441 101.0 0.775	0.190 71.3 0.765	NA	0.831 149.7 0.793	0.932 168.9 0.796	0.814 143.2 0.791	NA	0.965 174.9 0.800	0.991 184.7 0.801	0.948 172.5 0.799

Table A-2. Results of simulation models evaluating the efficacy of the Translocate-Only transfer strategy on establishing a population of Mexican wolves in the northern Sierra Madre Occidental (SMOCC-N). Column headings define the details of transfer strategies, according to the number of wolves transferred each year during the simulated program (N = 6, 12 or 18) and the cohort type used in the transfer (A, adults; Y, yearlings; AY, adults and yearlings; AP, adults and pups). Row headings at the far left of the table give the range of post-transfer survival rates. Each cell represents a unique model scenario, with numerical output listed as the probability of the SMOCC-N wolf population abundance exceeding 100 individuals after 15 years (top), the mean number of wolves across iterations in which the population was extant after 15 years (middle), and the mean population gene diversity at the end of the simulation (bottom). See accompanying text for more information on model structure and function.

Translocate Only

	N = 6				N = 12				N = 18			
	A	Y	AY	AP	A	Y	AY	AP	A	Y	AY	AP
0.1	0.000 13.8 0.497	0.000 14.0 0.515	0.000 15.0 0.499	0.000 12.0 0.452	0.010 28.7 0.651	0.014 31.1 0.653	0.010 27.9 0.641	0.001 20.1 0.605	0.075 51.1 0.692	0.069 49.2 0.690	0.065 47.1 0.686	0.013 31.4 0.666
0.2	0.017 30.2 0.650	0.009 28.9 0.649	0.012 29.2 0.641	0.001 20.5 0.610	0.169 68.3 0.708	0.17 68.5 0.707	0.172 65.8 0.706	0.053 45.8 0.692	0.474 103.4 0.725	0.490 103.9 0.725	0.414 98.9 0.723	0.198 71.8 0.713
0.3	0.066 50.7 0.692	0.058 48.9 0.691	0.055 45.2 0.686	0.011 30.0 0.666	0.468 102.6 0.726	0.471 104.0 0.725	0.464 102.8 0.724	0.216 73.8 0.715	0.800 145.0 0.737	0.797 143.9 0.737	0.792 143.6 0.736	0.535 109.8 0.729
0.4	0.170 66.6 0.707	0.161 68.2 0.708	0.173 66.5 0.706	0.053 44.5 0.691	0.723 132.5 0.734	0.719 132.4 0.734	0.716 130.4 0.733	0.423 99.0 0.726	0.930 166.7 0.743	0.934 169.0 0.743	0.928 165.0 0.742	0.803 142.7 0.738
0.5	0.304 84.7 0.178	0.327 87.2 0.717	0.324 87.0 0.717	0.104 57.5 0.705	0.875 153.7 0.739	0.894 156.8 0.739	0.864 154.2 0.739	0.641 122.7 0.733	0.980 178.3 0.745	0.978 180.8 0.746	0.98 177.6 0.745	0.910 161.3 0.742
0.6	0.457 102.1 0.725	0.469 103.8 0.724	0.482 93.1 0.724	0.219 73.2 0.714	0.938 167.4 0.743	0.935 168.4 0.743	0.935 167.5 0.742	0.806 142.5 0.738	0.990 182.3 0.747	0.994 183.9 0.747	0.991 183.8 0.747	0.951 172.6 0.745
0.7	NA	0.617 120.1 0.730	0.613 118.7 0.730	0.312 83.7 0.721	NA	0.980 176.8 0.745	0.957 176.3 0.744	0.873 155.4 0.741	NA	0.997 185.9 0.748	0.996 184.6 0.748	0.975 178.9 0.747

Table A-3. Results of simulation models evaluating the efficacy of the Combination transfer strategy (50:50 distribution of Release and Translocation strategies) on establishing a population of Mexican wolves in the northern Sierra Madre Occidental (SMOCC-N). Column headings define the details of transfer strategies, according to the number of wolves transferred each year during the simulated program (N = 6, 12 or 18) and the cohort type used in the transfer (A, adults; Y, yearlings; AY, adults and yearlings; AP, adults and pups). Row headings at the far left of the table give the range of post-transfer survival rates. Each cell represents a unique model scenario, with numerical output listed as the probability of the SMOCC-N wolf population abundance exceeding 100 individuals after 15 years (top), the mean number of wolves across iterations in which the population was extant after 15 years (middle), and the mean population gene diversity at the end of the simulation (bottom). See accompanying text for more information on model structure and function.

Combination

	N = 6				N = 12				N = 18			
	A	Y	AY	AP	A	Y	AY	AP	A	Y	AY	AP
0.1	0.003 15.8 0.522	0.001 16.2 0.525	0.000 13.1 0.508	0.001 11.0 0.449	0.016 32.8 0.681	0.014 31.8 0.684	0.020 30.7 0.672	0.004 22.1 0.633	0.116 57.1 0.722	0.079 53.3 0.723	0.080 51.3 0.717	0.019 33.9 0.689
0.2	0.01 25.65 0.641	0.018 31.6 0.676	0.005 23.7 0.666	0.002 19.2 0.628	0.095 54.8 0.721	0.208 72.3 0.741	0.165 67.0 0.375	0.044 43.6 0.709	0.332 88.0 0.746	0.592 115.2 0.758	0.494 106.2 0.755	0.204 71.9 0.736
0.3	0.02 38.09 0.685	0.085 54.0 0.721	0.037 41.1 0.721	0.011 30.0 0.699	0.246 78.1 0.738	0.532 110.8 0.759	0.458 101.3 0.755	0.115 56.3 0.750	0.655 124.7 0.759	0.871 156.6 0.771	0.835 147.3 0.767	0.524 109.0 0.753
0.4	0.14 62.63 0.719	0.261 79.0 0.739	0.085 55.7 0.745	0.036 42.4 0.727	0.573 114.5 0.758	0.804 144.7 0.768	0.714 132.2 0.765	0.364 92.7 0.749	0.903 160.9 0.770	0.964 177.7 0.775	0.951 170.1 0.774	0.793 141.9 0.763
0.5	0.27 81.79 0.734	0.46 102.0 0.751	0.233 75.6 0.758	0.100 55.8 0.744	0.807 148.9 0.767	0.899 164.2 0.773	0.897 158.4 0.773	0.645 125.1 0.758	0.969 178.2 0.776	0.988 184.1 0.778	0.982 182.0 0.777	0.918 163.7 0.768
0.6	0.42 99.34 0.742	0.558 112.4 0.758	0.350 90.2 0.766	0.174 68.6 0.753	0.909 163.4 0.772	0.944 171.0 0.777	0.958 169.8 0.777	0.805 143.2 0.764	0.989 183.0 0.778	0.997 187.9 0.780	0.997 184.9 0.779	0.968 174.9 0.771
0.7	0.59 117.3 0.748	0.655 125.4 0.763	0.484 105.1 0.772	0.271 81.7 0.760	0.964 176.2 0.775	0.962 177.2 0.780	0.980 178.8 0.780	0.872 153.0 0.768	0.996 186.0 0.780	0.997 186.9 0.782	0.998 186.1 0.781	0.980 181.7 0.773

Table A-4. Demographic and genetic characteristics of the SAFE and MWEPA source populations from simulation models evaluating the efficacy of each transfer strategy on establishing a population of Mexican wolves in the northern Sierra Madre Occidental (SMOCC-N). Column headings are defined as in Tables 2 through 4. Transfer strategies abbreviated as “Release” (Release-Only); “Transloc” (Translocate Only): and “Combo” (Combination). Data for final (year 15) population abundance (N) and gene diversity (GD) are reported as proportional values calculated relative to a “control” scenario in which transfers were not implemented. For example, “N: 0.752” indicates a transfer scenario category in which the final abundance of the source population is 75.2% of that population when transfers are not implemented in the “control” scenario. Note that the values reported here are averaged across all post-transfer survival rates for a given transfer strategy (e.g., value of N = 0.912 for the “Release / N = 12 / AY” scenario set represents an average across the range of post-transfer survival rates tested with that strategy). See accompanying text for more information on model structure and function.

	N = 6				N = 12				N = 18			
	A	Y	AY	AP	A	Y	AY	AP	A	Y	AY	AP
Release (SAFE)	N: 0.991 GD: 1.000	N: 0.986 GD: 0.999	N: 0.990 GD: 1.000	N: 0.988 GD: 0.999	N: 0.917 GD: 0.998	N: 0.923 GD: 0.998	N: 0.912 GD: 0.998	N: 0.919 GD: 0.999	N: 0.759 GD: 0.993	N: 0.802 GD: 0.995	N: 0.756 GD: 0.993	N: 0.752 GD: 0.995
Transloc (MWEPA)	N:0.994 GD: 1.000	N: 0.978 GD: 1.000	N: 0.991 GD: 1.000	N: 0.993 GD: 1.000	N: 0.977 GD: 0.999	N: 0.967 GD: 0.999	N: 0.970 GD: 0.999	N: 0.983 GD: 1.000	N: 0.940 GD: 0.996	N: 0.922 GD: 0.999	N: 0.931 GD: 0.996	N: 0.966 GD:0.999
Combo (SAFE)	N: 0.998 GD: 1.000	N: 0.998 GD: 1.000	N: 0.992 GD: 1.000	N: 0.993 GD: 1.000	N: 0.993 GD: 1.000	N: 0.987 GD: 0.999	N: 0.989 GD: 1.000	N: 0.988 GD: 1.000	N: 0.981 GD: 1.000	N: 0.960 GD: 0.999	N: 0.976 GD: 0.999	N: 0.978 GD: 0.999
Combo (MWEPA)	N: 0.991 GD: 1.000	N: 0.992 GD: 1.000	N: 0.998 GD: 1.000	N: 0.995 GD: 1.000	N: 0.991 GD: 1.000	N: 0.993 GD: 0.999	N: 0.990 GD: 1.000	N:0.991 GD: 1.000	N: 0.985 GD: 1.000	N: 0.982 GD: 0.999	N: 0.982 GD: 1.000	N: 0.987 GD: 1.000