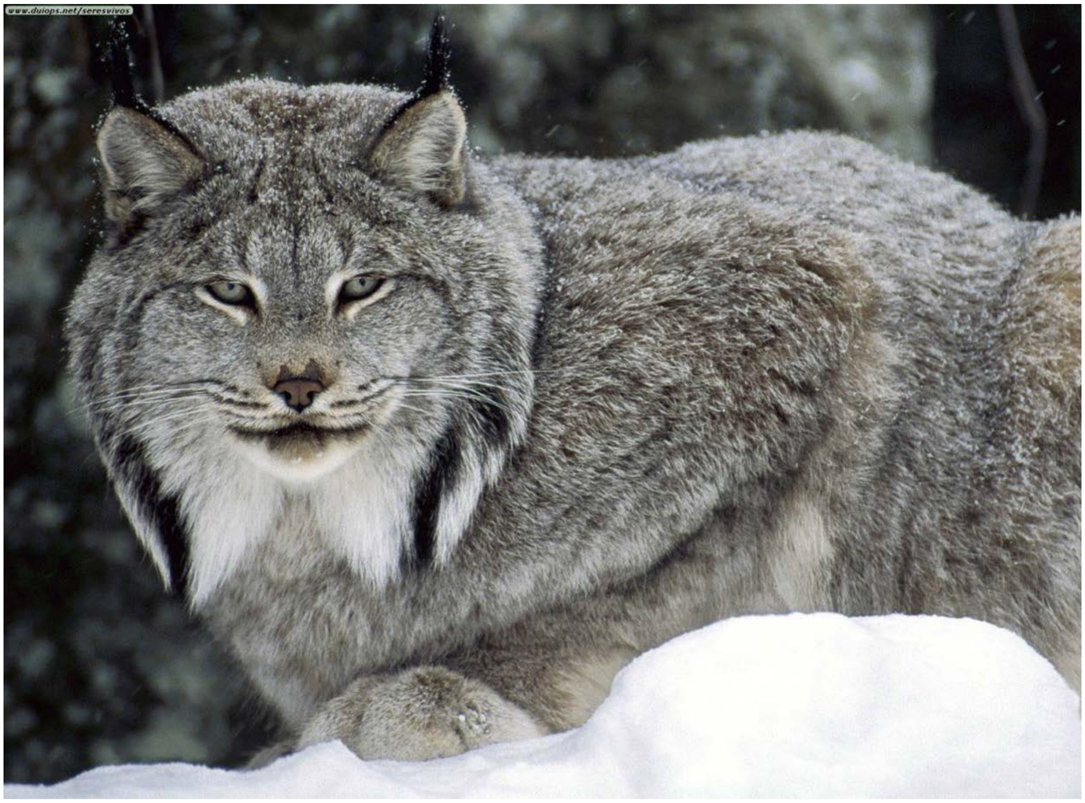
Canada Lynx Expert Elicitation Workshop

October 13-15, 2015 - Bloomington, Minnesota



Final Report

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Canada Lynx Species Status Assessment Team:

Heather Bell, U.S. Fish and Wildlife Service, Headquarters
Kurt Broderdorp, U.S. Fish and Wildlife Service, Western Colorado Field Office
Jonathan Cummings, U.S. Geological Survey, Patuxent Wildlife Research Center
Bryon Holt, U.S. Fish and Wildlife Service, Northern Idaho Field Office
Mark McCollough, U.S. Fish and Wildlife Service, Maine Field Office
Mary Parkin, U.S. Fish and Wildlife Service, Northeast Regional Office
Tamara Smith, U.S. Fish and Wildlife Service, Twin Cities Field Office
Jim Zelenak, U.S. Fish and Wildlife Service, Montana Field Office

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Executive Summary

As part of a species status assessment (SSA) for the contiguous United States distinct population segment (DPS) of the Canada lynx, the U.S. Fish and Wildlife Service (Service) convened an expert elicitation workshop to gather (1) the best available information on the current status of lynx populations within the DPS and (2) the professional judgment and opinions of lynx experts regarding the future viability of the DPS. This report summarizes the results of the workshop regarding the current and likely future condition of lynx populations in six geographic areas within the DPS in terms of representation, redundancy, and resiliency. The Service will incorporate the information gathered at this workshop into the SSA as appropriate, along with the published scientific literature, to inform recovery planning for the DPS and any other determinations the Service is authorized and required to make in accordance with the Endangered Species Act.

Purpose

The purpose of this report is to convey the results of an expert workshop convened by the U.S. Fish and Wildlife Service (Service) in October 2015 to improve our understanding of the status of the contiguous U.S. distinct population segment (DPS) of Canada lynx (*Lynx canadensis*). This workshop was held in conjunction with a species status assessment (SSA; see Appendix 1 [All appendices are accessible at: http://www.fws.gov/mountain-prairie/es/canadaLynx.php]) for the DPS. The SSA, which will incorporate the best available scientific information on lynx, is needed to inform the Service's response to a June 2014 court order to complete a recovery plan for the DPS by January 2018, or make a formal determination that a recovery plan is not necessary.

The workshop was organized by a Lynx SSA Team consisting of Service and USGS staff who have developed and piloted implementation of the SSA framework, and Service biologists who are working on lynx throughout the range of the DPS. In the interest of collaboration and transparency, this team partnered with State agencies, other Federal agencies, and academic researchers to elicit expert input regarding the current and likely future status of lynx populations within the DPS.

Expert input is needed to complement the published scientific literature and other available information on many aspects of lynx population dynamics in the DPS range. In particular, we were looking for additional information on the status, sizes, and trends of lynx populations and on threats to lynx habitats and those of their primary prey, snowshoe hares (*Lepus americanus*). We therefore designed a process to elicit and capture the knowledge, professional judgments, and opinions of lynx experts to help us assess the current status of, and the nature and magnitude of potential threats to, lynx populations and habitats within the DPS. We also sought expert knowledge to help us evaluate the viability of the DPS (in terms of the "3 Rs" - redundancy, representation, and resiliency; see definitions below) under a range of future threats, habitat conditions, and climate scenarios, and to identify and make explicit areas of uncertainty and potential differences of opinion among experts.

The results of the workshop will contribute to the SSA, which will compile and summarize the best available scientific and commercial data, including empirical data, published literature, and expert input. This information will then be used by Service decision makers to inform recovery planning direction, classification decisions, and other determinations required by the Endangered Species Act (ESA).

Background

The Canada lynx is a medium-sized cat with long legs and large, well-furred paws. Its long, black ear tufts and short, black-tipped tail distinguish the lynx from the similar bobcat (*Lynx rufus*), which is much more common in the contiguous U.S. The lynx's large feet and long legs make it highly adapted for hunting snowshoe hares in the deep or powdery snow that persists across much of its boreal forest distribution, most of which occurs in Canada and Alaska. These adaptations provide lynx a competitive advantage over potential competitors, such as bobcats or coyotes (*Canis latrans*), which have much smaller feet and higher foot-loadings that prevent them from hunting efficiently in deep, powdery snow (McCord and Cardoza 1982, p. 748; Buskirk *et al*. 2000, pp. 86–95; Ruediger *et al*. 2000, pp. 1–11; Ruggiero *et al*. 2000, pp. 445, 450).

The southern periphery of the boreal forest extends into parts of the northern contiguous U.S., where it transitions to the Acadian forest in the Northeast (Seymour and Hunter 1992, pp. 1, 3), deciduous temperate forest in the Great Lakes regions, and subalpine forest in the Rocky Mountains and Cascade Mountains in the west (Agee 2000, pp. 40–41). In the contiguous U.S., these transitional boreal forests become discontinuous and patchy, preventing both lynx and hares from broadly achieving densities similar to those of the northern boreal forests (Wolff 1980, pp. 123–128; Buehler and Keith 1982, pp. 24, 28; Koehler 1990, p. 849; Koehler and Aubry 1994, p. 84; Aubry *et al*. 2000, pp. 373–375, 382, 394). These forests eventually become too fragmented and isolated in the contiguous United States to support hares at the landscape densities and distributions necessary to support lynx home ranges (Interagency Lynx Biology Team 2013, p. 77) or lynx populations over time.

The Service designated lynx in the contiguous U.S. as a DPS and listed it as threatened under the ESA in 2000 because of the inadequacy, at that time, of existing regulatory mechanisms. Specifically, at that time the Service believed that most lynx and lynx habitats occurred on national forests, and that the Land and Resource Management Plans that guided management of those forests included "...programs, practices, and activities within the authority and jurisdiction of Federal land management agencies that may threaten lynx or lynx habitat. The lack of protection for lynx in these Plans render them inadequate to protect the species" (65 FR 16052). In 2003, in response to a court memorandum opinion on the 2000 listing rule, the Service reaffirmed its determination of the lynx DPS and its status as threatened under the ESA

(68 FR 40076). The Service completed a recovery outline in 2005 (U.S. Fish and Wildlife Service 2005, entire), designated critical habitat for the DPS in 2006 (71 FR 66008) and, in 2007, again in response to a court order, clarified its determinations of "significant portion of the range" and that all lynx in the contiguous U.S. constitute a single DPS (72 FR 1186). Also in 2007, the Service initiated a 5-year status review of the DPS (72 FR 19549). The Service revised the critical habitat designation for the DPS in 2009 (74 FR 8616) and 2014 (79 FR 54782) and, concurrent with the latter, rescinded the state-based definition of the DPS boundary to extend ESA protection to lynx "where found" in the contiguous U.S., including New Mexico and other states that were not included in the original DPS range (79 FR 54804).

Although the Service originally identified the DPS as occurring in forested portions of 14 states (Colorado, Idaho, Maine, Michigan, Minnesota, Montana, New Hampshire, New York, Oregon, Utah, Vermont, Washington, Wisconsin, and Wyoming) (65 FR 16052, 16085), it recognized at the time of listing that both lynx and the boreal forests that support them in the Lower 48 States are at the southern margins of their ranges, where habitats naturally become patchy and fragmented and snowshoe hare densities in many places are not consistently high enough to support resident lynx populations (65 FR 16052-59). It also recognized that inherent limitations in historic occurrence information made it difficult to distinguish between areas that consistently supported resident populations; other areas that may have occasionally supported resident, breeding lynx; and yet other areas that intermittently and temporarily contained dispersing or transient lynx but did not support lynx home ranges or reproduction (65 FR 16054-59). Many lynx records in the DPS range seem to have been associated with cyclic "irruptions" of lynx from southern Canada into the northern contiguous U.S. when northern hare populations crashed, as they did historically every 8-11 years (Elton and Nicholson 1942, entire; McKelvey *et al*. 2000, entire; Mowat *et al*. 2000, pp. 281–294; Interagency Lynx Biology Team 2013, p. 33). Lack of reliable information also precluded determination of sizes or trends of lynx populations within the DPS.

Recent research and monitoring have improved our understanding of many aspects of lynx biology, distribution, and potential threats in the DPS. However, we still lack reliable estimates of the sizes and important demographic rates of most populations. Likewise, we would benefit from further understanding of the natural range and causes of variation in lynx and hare numbers; hare densities necessary to support resident lynx populations throughout the DPS; the influence of immigration of lynx from Canada on the demographic and genetic fitness of DPS populations; and the timing, extent, magnitude, and severity of potential threats associated with climate change. The Lynx SSA Team organized this expert elicitation workshop to help fill some of these information gaps with the knowledge, professional judgments, and opinions of lynx experts.

Currently, there are five geographic areas known to support resident lynx populations in the DPS: northern Maine (with occasional/sporadic breeding by small numbers of lynx in northernmost New Hampshire and Vermont); northeastern Minnesota; northwestern Montana and northeastern Idaho; north-central Washington; and western Colorado (Figure 1). After statewide surveys conducted in 1978-1997 suggested the absence of viable resident lynx populations in Colorado, the State, from 1999 to 2006, released 218 lynx captured in Canada and Alaska into southwest Colorado to establish the current resident population. Additionally, the Greater Yellowstone Area (GYA) of southwestern Montana and northwestern Wyoming is believed historically (and as recently as 2003-04) to have supported a small but relatively persistent lynx population, but it is uncertain whether it currently supports any resident lynx.

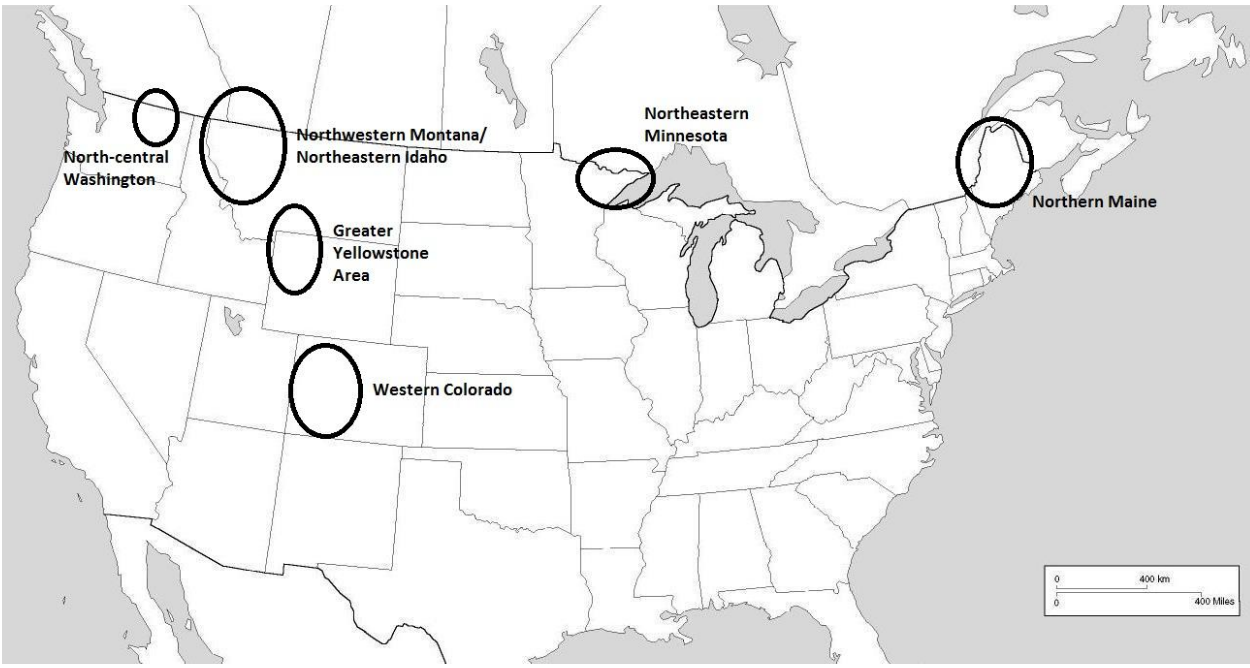

Figure 1. Six geographic units within the range of the contiguous U.S. distinct population segment of Canada lynx (*Lynx canadensis*) that currently support or recently supported (GYA) resident lynx populations.

Expert Elicitation

Workshop Protocol

As mentioned under *Purpose*, above, the Lynx SSA Team convened the October 2015 workshop to elicit expert knowledge and opinion on critical uncertainties regarding the current status and future viability of resident lynx populations within the DPS range, and thus the DPS as a whole. To facilitate this, a 10-member panel of recognized lynx experts from across the DPS range first observed and discussed presentations by subject matter experts summarizing the current state of available information on topics relevant to lynx populations in the DPS (see *Preparing Experts* section below). After subject matter presentations, members of the lynx expert panel presented updates on lynx populations in each of the six geographic areas described above under *Background*. The subject matter and update presentations were intended to ensure that all lynx experts had a common baseline of information prior to the elicitation process.

In accordance with the expert elicitation literature (e.g., Burgman 2005, USEPA 2011, Gregory *et al*. 2012, Drescher *et al*. 2013, Morgan 2014), we then used best practices to elicit opinions from the expert panel. Although invited experts were expected to contribute openly and effectively to group discussions, we did not seek consensus among experts; rather, we probed differences of opinion or interpretation of scientific and technical information. We also asked experts and other participants to focus on scientific questions and to refrain from discussing or recommending management or policy decisions related to the Service's authorities and responsibilities in implementing the ESA.

In addition to the lynx expert panel and subject matter experts, workshop participants included members of the USFWS/USGS Lynx SSA Team, facilitators, and observers (see Appendix 2 for a full list of attendees and their respective roles). As a basic ground rule, only members of the expert panel participated in the elicitation process, although panelists were encouraged to confer with the subject matter specialists and SSA Team members as needed. All workshop participants were welcome to participate in discussions that ensued from review of panel responses to various questions. Due to time constraints and to minimize interference with the elicitation process, observers were encouraged to write and submit "parking lot" questions, which were collected at the end of the first two days of the workshop and presented to lynx and subject matter experts for responses and discussion the following mornings (see workshop notes, Appendix 3). The expert elicitation process was facilitated by USFWS and USGS structured decision making practitioners who encouraged open discussion among experts, structured input from both panelists and subject matter experts, and ensured that observers could witness the process without inappropriately influencing it.

Identifying Experts

SSA Team members reviewed the relevant literature and used their first-hand knowledge to identify experts involved in lynx and hare research or management, boreal forest ecology, and climate modeling. We then developed *a priori* selection criteria based on professional credentials, positions, areas of expertise, and pertinent experience to develop a list of candidate lynx experts and other subject matter experts. Selection criteria (below) helped ensure that invitations to participate were made only to scientists with expertise highly relevant to workshop topics and, further, that the selections were transparent, unbiased, and adequately captured the diversity of expertise and professional judgments related to the topics. Selection was not based on affiliation with a particular organization or interested party; however, States and other partners were asked to review the draft list of workshop invitees and suggest alternate or additional qualified experts. The SSA Team then invited experts who met the selection criteria and represented lynx expertise throughout the range of the DPS and in adjacent southern

Canada. The number of invited experts was necessarily limited to improve the efficiency and effectiveness of the elicitation process, avoid redundancy, maximize scientific discussion among all participants, and maintain an open, comfortable meeting environment.

Expert Selection Criteria

Expert panelist candidates had to meet all of the following criteria:

1. Candidate must hold a graduate degree in a scientific discipline highly relevant to the workshop topics. Typically this may include advanced degrees in wildlife biology, ecology, zoology, genetics, modeling, or statistical inference.

2. Candidate must hold a research position in government (State, Tribal, or Federal), academia, or in the nonprofit research sector; or participant must hold a governmental management agency position with responsibility for the species' conservation.

3. Candidate must have expertise in the ecology or management of the species or related species, demonstrated by recent (within the past 10 years) peer-reviewed publications or related types of professional scientific expression.

Candidates also had to meet one or more of the following criteria:

4. Candidate is directly engaged in the species' management, monitoring, or analysis of populations or habitat.

5. Candidate is directly engaged in the study of a specific workshop topic.

6. Candidate is a government or academic research scientist with expertise in conservation biology, population or landscape ecology, genetics, or other relevant fields, as demonstrated by recent (within the past 10 years) peer-reviewed publications or related types of professional scientific expression.

Using these criteria, the SSA Team identified 19 candidates for the lynx expert panel who were contacted to determine their interest and ability to attend the workshop (Appendix 4). Among those both interested in and able to attend the workshop, the team extended invitations to 13 candidates, 10 of whom ultimately participated as panelists and who together represent lynx expertise throughout the range of the DPS and in southern Canada. Experts who could not attend this workshop may provide their expertise later in the SSA process as peer review experts.

Preparing Experts

Before the workshop, the SSA Team contacted all lynx experts and other subject matter experts by email and phone to discuss their roles and, for some, their willingness to prepare and deliver subject matter or lynx population status presentations at the workshop. Correspondence with lynx and subject matter experts and other workshop participants explained the SSA framework and its application to the lynx DPS, the use of expert elicitation in SSAs, and the workshop's purpose, ground rules, and draft agenda.

At the workshop, the Service introduced the Lynx SSA Team, provided a brief overview of the SSA framework and its application to the lynx DPS, and outlined workshop objectives. Prior to elicitation exercises, subject matter experts presented information on the historic and current distribution of lynx in the contiguous U.S., regulatory mechanisms that apply to lynx on Federal lands, genetics considerations, lynx status and management in adjacent southern Canada, potential climate change impacts on boreal forest vegetation and snow conditions important to lynx, effects of forest management and policy on lynx habitat, and snowshoe hare ecology (see *Subject Matter Presentations*, below). After these presentations, lynx expert panelists provided updates on lynx populations and habitats, research efforts, conservation measures, and potential threats to lynx in each of the six geographic areas (Fig. 1). The subject matter and status-update presentations were intended to provide the expert panel with information that could inform their responses to elicitation questions and to ensure that the panelists shared a common understanding of the current status of lynx throughout the DPS. All workshop presentations are included in Appendix 5 and are accessible at the Service's Region 6 Canada lynx web page (http://www.fws.gov/mountain-prairie/es/canadaLynx.php).

Subject Matter Presentations

Canada Lynx Species Status Assessment, Expert Elicitation Workshop - Jim Zelenak, U.S. Fish and Wildlife Service, Montana Ecological Services Field Office, Helena, Montana

The objectives of this workshop are to (1) gather scientific information from experts on the current status, threats, and future viability of lynx populations in the contiguous U.S.; and (2) where empirical data are lacking, elicit expert knowledge, professional judgment, and opinion on the nature and magnitude of potential threats to DPS populations and the DPS as a whole. We need this information to complete a status assessment for the DPS that will be used by Service decision makers to inform recovery planning and other determinations the Service must make in accordance with the ESA. We have a court order to complete a recovery plan for the DPS by January, 2018, unless we determine that a recovery plan is not necessary (i.e., that the threat for which the DPS was listed has been adequately addressed and ameliorated and no new threats have been identified that pose an immediate or reasonably foreseeable risk of extinction). However, we are not here to make that determination or others regarding the ESA status of the DPS. Rather, we are here to understand the current status of lynx populations and habitats in the DPS and hear from experts on factors influencing the current status and future viability of those populations. The DPS was listed as threatened under the ESA in 2000 because of the inadequacy at that time of regulatory mechanisms in Federal land management plans to protect lynx and their habitats. The Service completed a recovery outline in 2005 and designated critical habitat for the DPS in 2006. In 2007, we clarified our determination of "significant portion of the range" of the DPS and withdrew the 2006 critical habitat designation. We revised critical habitat in 2009 and 2014 and, also in 2014, we received the court order to complete a recovery plan. The results of this workshop will contribute to the SSA, and the expert information gathered here will complement the best available scientific information that will be compiled and summarized in the SSA report. After it is peer-reviewed and finalized, the SSA report will be considered by Service decision makers to inform recovery planning and other determinations required under the ESA.

Historical Distribution of Lynx in the Contiguous U.S. - Dr. Kevin McKelvey, USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana

Understanding historical range is important because it provides context for modern conservation; however, historical data must be interpreted carefully because they may not be representative, are often unreliable, and their meaning may be unclear. This is especially true for rare animals like lynx, and even more so if they are easily mistaken for another more common animal, as bobcats are mistaken for lynx in the southern portion of lynx range. Because even relatively low identification error rates can lead to significant errors in determining distribution, it is important to rely on verified, and not anecdotal, occurrence records, when attempting to establish historical range. The issue is further complicated by the noted cyclicity in lynx population dynamics associated with snowshoe hare population cycles, which resulted historically in irruptions or pulses of lynx from Canada into the DPS when northern hare populations crashed. This can be described as a wave in which a large number of dispersing lynx intermittently flooded into the northern contiguous U.S. over the course of several years into a variety of potentially suitable and unsuitable habitats. As the irruptions waned (i.e., as the waves receded), lynx disappeared relatively quickly from areas of unsuitable or poor habitat, more slowly from areas of marginal or suboptimal habitat, and persisted (like permanent tide pools) in those areas with habitats and hare densities capable of supporting them over time. This yielded verified records in the contiguous U.S. in places that clearly cannot support lynx populations but, in other places where habitats are or appear to be suitable, it also confounds efforts to distinguish between those that have supported persistent lynx populations, those that may occasionally but not consistently support resident lynx ("winked off' more than "winked on" in a metapopulation sense), and those where dispersing lynx occurred regularly, if intermittently, but could not persist. Given these ambiguities, there remains irresolvable uncertainty about the historic distribution of resident lynx in the DPS. Despite this uncertainty, it appears that resident lynx naturally persist now in most areas that the available reliable data most strongly suggest historically supported resident populations in the contiguous U.S. (Maine, Minnesota, Montana, Idaho, and Washington). Several other areas may have historically supported populations but no longer do (with evidence most compelling for northern New Hampshire and Michigan's Upper Peninsula; less compelling for the Adirondack region of northern New York, northern Wisconsin, and northwestern Wyoming).

Canada Lynx Habitat Regulatory Environment - Scott Jackson, USDA Forest Service, National Carnivore Program Leader, Missoula, Montana

Before the lynx DPS was listed under the ESA, there was very little information available and little management direction for lynx habitats on national forests or other Federal lands. Given the uncertain status of lynx and lack of information on habitat relationships, an interagency Lynx Steering Committee was chartered almost immediately after the DPS was proposed for listing in 1998. The committee appointed the Lynx Science Team to assemble the available information on lynx and the Interagency Lynx Biology Team to develop a lynx conservation strategy applicable to Federal lands. In 2000, the Science Team published *Ecology and Conservation of Lynx in the United States* (Ruggiero *et al*. 2000), and the Biology Team completed the *Lynx Conservation Assessment and Strategy* (LCAS; Ruediger *et al*. 2000). The committee also directed the completion of the 1999 biological assessment (BA) in which the U.S. Forest Service (USFS) and Bureau of Land Management (BLM) evaluated potential impacts to lynx of management plans for 57 national forests and 56 BLM units and concluded that implementation of existing plans could result in some adverse effects to lynx. The BA recommended amending or revising management plans to incorporate conservation measures that would reduce or eliminate the identified adverse effects to lynx, and to consider the conservation measures identified by the Science Team and Biology Team, once finalized. In March of 2000, the DPS was listed as threatened due to the inadequacy of existing regulatory mechanisms, specifically the lack of guidance for conservation of lynx in national forest Land and Resource Management Plans and BLM Land Use Plans. In October 2000, FWS completed a biological opinion on the 1999 BA, concluding that if forest plans were revised or amended to incorporate the conservation measures in the LCAS, they would reduce or avoid the potential for adverse effects on lynx. Also in 2000, USFS and BLM entered into conservation agreements with FWS to guide management until plans could be amended or revised. By 2004, BLM revised plans in all units with lynx or potential habitat to incorporate LCAS guidance. By 2006, USFS similarly revised plans for national forests in the Northeast and Great Lakes. In 2007 and 2008, USFS formally amended plans for 18 national forests in the Northern Rockies and 8 in the Southern Rockies to address the risk factors identified in the LCAS and adopt management standards and guidelines. Currently, all national forests and BLM units with lynx or potential habitats are governed by plans that have adopted conservation measures identified in the LCAS, subsequent interagency conservations agreements, or by management direction that formally amended or revised land use plans and established standards and guidelines designed to apply the best available scientific information to avoid and minimize potential impacts to lynx. Future challenges include developing effective responses to larger, hotter, and more frequent fires and extensive insect outbreaks, and designing thinning and salvage harvest treatments conducive to creating habitat conditions favorable to lynx and hares.

Lynx Genetics Considerations - Dr. Michael Schwartz, USDA Forest Service, National Genomics Center for Wildlife and Fish Conservation, Missoula, Montana

Review of lynx genetic studies shows, despite some sub-structuring over distance, high gene flow across the continental range of lynx, likely because of high dispersal rates, large dispersal distances, and few geographic barriers to dispersal. Some research suggests that the Northern Rocky Mountains may provide some gene flow restriction in western Canada, as well as an "invisible barrier" to gene flow in eastern Canada south of James Bay/Hudson's Bay that may be related to differences in snow conditions driven by large-scale climatic factors (e.g., the Pacific-North America and North Atlantic Oscillation climatic systems). North of the DPS, low levels of genetic substructure have been documented in populations in eastern Canada between populations north versus south of the St. Lawrence Seaway, and between island (Newfoundland and Cape Breton islands) and mainland populations. However, there is evidence of genetic interaction among even these relatively isolated eastern Canadian populations. Within the DPS, minor genetic sub-structuring has been documented among lynx subpopulations in western Montana. However, very low F_{st} values (a measure of the proportional reduction in heterozygosity due to population subdivision, with values near zero indicating high levels of gene flow and values approaching one indicating poor gene flow) suggest the absence of significant barriers to genetic interchange throughout much of the lynx range, including the DPS. Across 17 lynx populations in Alaska, Canada, and the contiguous U.S., $F_{st} = 0.033$, and the highest F_{st} for any two populations was 0.070 when lynx from the Kenai Peninsula in Alaska were compared to those in the Seeley Lake area of Montana. Lynx-bobcat hybrids have been documented in Minnesota, Maine, and eastern Canada, but not in the western part of the range. Hybridization does not seem to be a major issue, nor does it appear to be increasing despite significant increases in bobcat numbers in some parts of DPS range. Genomics research (the genetic mapping and DNA sequencing of sets of genes or complete genomes) on lynx would increase power and precision of genetic analyses and perhaps identify genes under selection at the periphery of the range. The goal for lynx in the DPS should be to conserve the genetic diversity currently represented in resident populations, recognizing that maintaining connectivity between DPS and Canadian populations is likely important to achieving that goal. The genetic variation at the edge of the range may be of value to future populations, especially as related to changing climate.

Lynx Distribution, Status, and Management in Southern Canada - Dr. Jeff Bowman, Ontario Ministry of Natural Resources and Forestry, and Trent University, Ontario

Lynx are managed provincially in Canada, with each province responsible for its own management program, harvest (trapping) policies, and conservation strategies. Data from registered trap lines show cyclic decadal peaks in the numbers of lynx harvested, and these align well with (and lag by one year) cyclic peaks in snowshoe hare indices. In western provinces (British Columbia, Alberta, Saskatchewan, Manitoba, Northwest Territories, and the Yukon), the magnitude of lynx cycles appears to have dampened dramatically after the 1980s-1990s, while eastern provinces (Ontario, Quebec, and Newfoundland and Labrador) have seen less dramatic declines in peak lynx numbers trapped. There is some evidence that hare numbers in the Yukon have not recovered to past levels after declines beginning in about 2000, and that hare numbers in southern Ontario have been low for the past 5-6 years. There also is indication that the range of lynx in eastern Ontario has contracted northward since the 1970s, and modeling suggests that this contraction is likely influenced by habitat loss perhaps related to changes in forestry practices and an increase in tolerant hardwoods replacing spruce-fir forests resulting from climate warming (Koen *et al*. 2014). This has been accompanied by reduced genetic heterozygosity (allele richness) at this margin of the lynx range. Recent studies also show some differences in functional genetic markers (unique alleles) in lynx south versus north of the St. Lawrence Seaway/River, suggesting the potential for evolutionarily significant differences in lynx in those areas (Koen *et al*. 2015, Prentice *unpubl.*). Research also suggests an "invisible" genetic barrier south of Hudson's Bay likely related to climate-driven differences in snow conditions, which could be amplified in the future with continued climate warming. A few lynx-bobcat hybrids have been documented. Lynx are listed as endangered provincially in New Brunswick and Nova Scotia, which also have by far the highest numbers of bobcats, and where bobcat populations have been increasing since about 1990. Lynx are considered secure in all other provinces.

Seven Ways a Warming Climate can Kill the Boreal Forest - Dr. Lee Frelich, Director, University of Minnesota Center for Forest Ecology, St. Paul, Minnesota

Northern Minnesota is at the southern edge of the ranges of boreal forest tree species (balsam fir, white spruce, paper birch) and the northern extent of temperate forest species (sugar maple, red maple, red oak). A number of climate-mediated processes are likely to shift these ranges northward, potentially resulting in the complete disappearance of boreal forest from Minnesota before the end of the century. These include projected declines in snow depth, invasion of boreal forests by temperate species and a widening of the mixed forest ecotone, warming summer and winter temperatures, declines in boreal trees under both low- and high-emission climate scenarios, severe wind- and hail-producing thunderstorms (derechos) of greater extent and frequency, large wind-driven fires, heat and drought stress, increased insect infestations due to lack of extreme cold temperatures, and phenological disturbance. These processes, alone or in combination may result in gradual or relatively sudden conversion of boreal forests to temperate forests, savanna, or grassland at the southern edge of the boreal forest range. A mosaic of conversion mechanisms and rates of change will occur at landscape/ecoregion scales. With unmitigated climate change, Minnesota is likely to lose the boreal biome and about one-third of its native species, including lynx, possibly within the next 60-70 years.

Climate Change and Uncertainty: Implications for Canada Lynx Conservation and Management in the Contiguous U.S. - Alexej Siren, DOI Northeast Climate Science Center and University of Massachusetts Department of Environmental Conservation, Amherst, Massachusetts

Climate models are better at detecting long-term trends in temperature and precipitation than short-term climate variability. Generally, projections of precipitation are less robust compared to temperature, and within the lynx DPS units, projected trends in precipitation are more certain for winter than for summer. Consequently, the resulting model biases may affect climate projections. Global surface temperatures have increased steadily over the 20th century, especially since the 1970s, with an overall increase in winter temperatures in the U.S. These changes are most pronounced from the Northern Rockies to the northeastern U.S., where winter precipitation has also increased. However, the northwestern U.S. has experienced drier winters with less snow over the past several decades. Importantly, numerous studies have shown that Canada lynx distribution is related to snowpack characteristics (e.g., snowfall, density, and persistence), which may directly or indirectly affect lynx through 1) increased competition (exploitative and interference) with sympatric carnivores, 2) altering hare and lynx population cycles, and 3) reduced genetic diversity. Therefore, climate projections with a specific emphasis on winter climate are a valuable tool for assessing the long-term viability of lynx in the contiguous U.S. Below are the climate trends for the past several decades and end-of-century model projections for each of the DPS units; projections are multi-model means with the high emissions scenario (A2). In the Northeast, recent trends are toward reductions in snowfall, the number of snow-covered days per season, and the proportion of winter precipitation occurring as snow. Projections include increased winter precipitation, but with a lower proportion occurring as snow, and a decline in snowfall and length of snowpack coverage. In the Great Lakes region, recent trends indicate an increase in lake effect snow and longer snow seasons to the north. Winter precipitation is projected to increase throughout the Midwest, with a lower proportion occurring as snow, except that lake effect snow is projected to increase around Lake Superior and north of the eastern Great Lakes until 2050, and eventually decline towards the end of this century. Overall, models project a decline in snowfall and length of snowpack coverage by 2100 for the Midwestern region. The Northeast and Midwest DPS units are especially vulnerable to snowpack loss due to lack of elevational refugia. In the western DPS units and the Colorado population, recent trends show decreasing spring snowpack at lower elevations, an overall decline in snowpack by the latter half of the 20th century, and a lower proportion of winter precipitation occurring as snow. Projections include decreases in snowfall season and snowfall amount, fewer days with snowfall, and continued reduction in the proportion of winter precipitation occurring as snow. However, projections indicate that snowpack and winter severity may be less impacted in the Northern Rockies compared to other DPS units. In summary, model projections are not favorable for lynx within the DPS units, especially towards the latter half of the 21st century, with less severe winters and diminished snowpack characteristics that favor competing species.

Projected Climate-change Impacts on Snow, Vegetation, and Lynx Populations in the Western U.S. - Dr. Joshua Lawler, University of Washington, School of Environmental and Forest Sciences, Seattle, Washington and Dr. Chad Wilsey, National Audubon Society Science Division, New York, New York

Climate modeling suggests reductions in the amount of precipitation falling as snow and a shift from subalpine forest to temperate evergreen needleleaf forests in a generalized lynx range in the western U.S. Fire is projected to increase in both frequency and fire size, doubling by 2040 and tripling by 2080. Simulated lynx densities were projected for the 2020s, 2050s, and 2090s. Of 25 ecoregions included in the study area, 14 had simulated lynx populations greater than 0.10 individuals/100 km^2 across all time points. Of those, and across various Global Circulation Models (GCMs), 3 ecoregions had simulated increasing populations by the 2050s and 11 had declining populations. Populations were projected to continue increasing in the 3 ecoregions by the 2090s, while declines were projected to deepen in 8 of the remaining 11 ecoregions. Growing populations were projected to occur in the sparsely populated Fescue-Mixed Grass

Prairie, Middle Rocky-Blue Mountains, and Great Steppe ecoregions, whereas the largest proportional declines were projected to occur in the West Cascades, Pacific Northwest Coast, Northern Cascades, East Cascades – Modoc, and Aspen Parkland ecoregions. The study also looked at the effect of population cycling on projected changes and found that simulated declines differed more due to GCM model used than due to population cycling (i.e., modeling suggested lynx population declines were not strongly influenced by population cycles).

Forest Management and Lynx Habitat Trends - Dr. Erin Simons-Legaard, University of Maine School of Forest Resources, Orono, Maine

Lynx in Maine occur in the Northern Appalachian/Acadian Ecoregion where their distribution is governed by snowfall and extent of deciduous cover. The eastern spruce budworm (*Choristoneura fumiferana*) is endemic to forests in this region, and extensive outbreaks of this insect pest occurred in northern Maine in the 1970s-80s, resulting in millions of acres of spruce-fir die-offs, despite extensive aerial insecticide applications. For several decades, salvage logging via extensive landscape-scale clear-cutting occurred in impacted forests, until passage in 1989 of the Maine Forest Practices Act, which regulated clear-cut size, configuration, and regeneration. Regenerating clear-cuts became very dense stands supporting high densities of snowshoe hares. Although the Forest Practices Act reduced the amount of clear-cut harvest over the following two decades, overall harvest increased as partial-cut harvesting replaced clear-cutting. At the same time, land ownership patterns in northern Maine were shifting from large blocks of commercial timber interests to smaller blocks and more diverse land management goals, including development and financial investment, as well as some non-development easements (though these do not regulate forest management). The University of Maine modeled lynx habitat occurrence from snow track data, a series of Landsat satellite time-series imagery since 1970, and indices of hare densities for various stand ages post-timber harvest to model past, present, and future lynx occurrence in northern Maine. They found that the proliferation of regenerating partial-cuts produce lower landscape hare densities than regenerating clear-cuts from the 1970s and 1980s. Landscape hare densities will likely decline in the future as the clear-cut-era stands mature into less dense conifer stands, beginning about 35-40 years post-harvest. High-quality stands are being replaced by lower-quality regeneration of partial harvests. High-quality habitat for lynx/hares is currently about 8% of the northern Maine landscape. Model projections indicate it will decline to about 5% of the landscape by 2030, and then level off, and that the prevalence of partial-harvesting will lead to elimination of many areas with concentrated high-quality habitat and a lower future probability of supporting lynx.

Southern Snowshoe Hares: Updates, Questions, Forecasts - Dr. Karen Hodges, University of British Columbia Okanagan Department of Biology, Kelowna, British Columbia

Northern hare cycles are more variable than commonly portrayed in some literature, with questionable synchrony and variation in peak heights and amplitudes. Some southern hare populations (i.e., within the lynx DPS range) show "cycle-ish" dynamics and high densities, but variability in abundances is not obviously linked to forest stand type (thinned, unthinned, mature). Some areas of high hare density are occupied by bobcats instead of lynx (e.g., the Tally Lake area of the Flathead National Forest in Montana). Hare densities in the western contiguous U.S. differ substantially across regions and landscapes. For example, within the GYA, hare densities varied from very low (0.2 hares per hectare) in Yellowstone National Park to very high (0.5 - 1.7 hares/ha) in the Wyoming Range south of the park. Hare densities also vary in the eastern part of the lynx DPS, with ranges from 0 - 1.8 hares/ha in Maine and, in Minnesota, densities of 0.64 hares/ha in the northeast part of the state (which supports resident lynx) and 0.35 hares/ha in Voyageurs National Park (which does not support resident lynx). Landscape attributes (e.g., tree densities and moisture gradients) also influence stand quality for hares. Hare population dynamics (cyclicity, synchrony, amplitude, and peak densities) also vary regionally. Forest management that reduces stand structure reduces hare abundances. For example, hares declined after experimental precommercial thinning in Montana, and, in Quebec, hare densities increased with time since commercial thinning, harvest, and fire. Fire destroys hare habitat temporarily, but hares return to burned areas as soon as favorable habitat conditions return. Post-fire hare densities also vary regionally; in stands burned by large fires in 1988, hare densities by 2007 were higher in Glacier National Park than in Yellowstone National Park. Hare densities necessary to support resident lynx remain poorly understood but appear to vary regionally, as do lynx diets and home range sizes. If southern boreal/montane forests are lost, hares will decline. Fire, timber harvest, and thinning will result in fewer hares, at least temporarily, and the impacts of post-fire salvage logging are unknown. Understory cover and browse are very important, but we know little about the influence of shrubs or snow on hares. Like lynx, hares in the DPS are at the southern extent of their continental range. Also like lynx, hares show high gene flow across most of the northern range in Canada but lower gene flow (higher genetic structure) in the southern part of the range, with some lineages potentially at risk of genetic drift. Climate-mediated increases in fires and insect outbreaks and changes in forest regeneration may alter hare habitats and, thus, hare distribution and abundance. Climate change may also affect hare vulnerability to predation by creating a mismatch between pelage color, which is controlled by photoperiod, and their surroundings (e.g., reduced snow season resulting in white hares on dark forest floors). It may also alter predator communities, with uncertain impacts on hare populations. Continued research is needed to better explain regional variation in population dynamics and peak abundances, to predict post-fire recolonization and densities and responses to climate change, and to better understand links between physiology and demography (e.g., predation stress and reproduction).

Lynx Status Update Presentations[1]

Status of Lynx in Maine - Jennifer Vashon, Maine Department of Inland Fisheries and Wildlife, Bangor, Maine

Much of the current lynx habitat in Maine was created from extensive harvests to salvage spruce budworm-damaged forests during 1970-1985, and the amount and distribution of high-quality lynx/hare habitat are likely greater now than historic conditions. Many stands were treated with herbicides to create extensive regeneration of spruce and fir. Analysis of Forest Inventory and Analysis (FIA) data indicates that half of the 3 million forested acres of spruce-fir in northern Maine is currently sapling stage that should provide lynx with high quality foraging habitat. Also based on FIA data, the amount of dense spruce-fir (supporting the highest hare densities) increased from 700,000 acres in 2006 to 805,000 acres in 2010. The Maine Department of Inland Fisheries and Wildlife (MDIFW) conducted a telemetry study of lynx from 2000-2011 in a study area with extensive areas of regenerating spruce-fir stands in northwestern Maine and found that lynx had relatively small home ranges. Lynx strongly selected these high-quality hare habitats in former clear-cut areas. Although hare densities declined from 2 hares/hectare to 1 hare/hectare mid-way through the study, lynx did not increase their home range sizes or alter their habitat use. Reproduction declined initially after hare populations declined, but later recovered, with all females producing litters. An average of 65% of females bred each year throughout the study. Litter sizes ranged from 1 to 5 and averaged 2.63 kittens/breeding female. Kitten survival remained high (averaged 78%). Densities of 4.5 adults and 5 to 9 kittens were observed in 100 km^2 areas. Based on estimates of occupied habitat and home range information, MDIFW estimated there were between 750 and 1,000 lynx in northern Maine in 2006, and more than 1,000 lynx in 2015 (or at least more animals than 2006). Indices (number incidentally trapped, observed, or killed on roads) have increased, suggesting there are more lynx than in 2006, and the distribution of the population also appears to be expanding. MDIFW initiated a third round of periodic lynx snow track survey in 2015 that support increased populations and expanding range. Additional surveys are planned in 2016 and 2017 to update estimates. Although a model by the University of Maine suggests the effects of the Maine Forest Practices Act could lead to a decrease in lynx habitat, thus far, it does not appear that lynx have declined in response to aging clear-cuts and the prevalence of partial harvests resulting from the Act. A budworm outbreak is expected in the near future that will also impact future amounts of habitat for lynx and snowshoe hare. MDIFW provides landowners with descriptions of lynx-hare habitat for their management plans through published peer-reviewed papers and reports on lynx status and habitat use in Maine and consultation.

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[1] These are summaries of status updates presented by lynx experts for each of the geographic units in the DPS. Summaries were written by the Lynx SSA Team based on the presentations and notes submitted by expert presenters and on the notes taken at the workshop during presentations. Experts reviewed drafts of these summaries and provided clarifications/ corrections if needed, which were incorporated into the final summaries.

Canada Lynx in Minnesota - Dr. Ron Moen, Natural Resources Research Institute, University of Minnesota Biology Department, Duluth, Minnesota, and Susan Catton, USDA Forest Service, Superior National Forest, Duluth, Minnesota

Prior to 1965, lynx in Minnesota were unprotected, had a bounty placed on them, and were overexploited by trapping. From 1930-1977, harvest in Minnesota was twice that of Montana and 40 times that of other states. In 1976, State protection was provided in the spring and summer months, and in 1984 the trapping season was closed. In the 1990s and when listed under the ESA in 2000, it was unknown if lynx in Minnesota were residents or migrants from Canada, but now it is known that the Minnesota lynx population consists of both residents and migrants from Canada. Since then, there have been hair snare and snow-tracking surveys, DNA analyses, and a multi-year telemetry project – none of these monitoring efforts were designed to estimate densities or abundances of the species. However, as of 2015, it is thought that there are somewhere between 50 and 300 lynx in Minnesota (this expert later refined the range as 50 - 200 lynx, as indicated in the summary presentation preceding the graphing exercise below), with the core habitat in the arrowhead region of the state (St. Louis, Lake, and Cook counties), although there have been verified and probable lynx sightings elsewhere in the state. At least 5 of 27 adult lynx radio-collared in Minnesota were later legally trapped in Ontario, and other collared lynx did not return from Canada, therefore their fates are unknown. Telemetry data showed that about half of males radio-marked in Minnesota moved back-and-forth across the border, traveling at all times of the year; that Minnesota females that dispersed into Canada tended not to return to Minnesota; that males had much larger home ranges (267 km^2) than females (21 km^2); and that females with kittens had the smallest home ranges. About half of the mortality of collared lynx was from vehicle collisions, incidental catch, illegal kills, or unknown causes. Moen *et al*. (2008) documented 10 den sites and showed that denning habitat is not limiting in Minnesota. Since 2000, incidental take of lynx tracked by the USFWS Twin Cities Field Office has ranged from 0-14 per year and included vehicle (car and train) collisions, gunshot, incidental trapping, and unknown causes. Approximately 50% of reported take was of incidentally trapped lynx, about half of which were released alive. Home range analyses showed mean distance to nearest linear feature is approximately 200m, suggesting that lynx do not avoid roads. Bobcat harvest data show a concentration of bobcats adjacent to the core of the lynx range. The IPCC SRES A1B Scenario climate change model (Gonzalez *et al*. 2007, p. 14) shows snow conditions potentially suitable for lynx throughout the northern half of Minnesota to the end of this century; however, the snow and/or biological assumptions in the model need work, because it predicts a range for lynx that is larger than the current suitable range based on snow depth. Other climate modeling (e.g., Morgan, in prep.) suggests that suitable snow-depth range will shrink significantly by 2055, be limited to extreme northeastern Minnesota by 2070, and may be entirely absent from the state by 2095. Since 2000, the Superior National Forest (SNF) and others have identified 268 unique individual lynx (47% Female, 53% Male) from 1,306 DNA samples, primarily from SNF lands. These samples also documented 13 unique individual lynx-bobcat hybrids (5 Female, 8 Male). The DNA analyses also showed persistence of individual lynx in Minnesota of 2 years (N = 27 lynx), 3 years (N = 11), 4 years (N = 5), 5 years (N = 6), and 1 female lynx tracked for over 5 years, who produced 7 kittens in Minnesota. The SNF annually documents 3-5 family groups and is working with

North Carolina State University and the Twin Cities Field Office on a study of the distribution of lynx that can be used to inform future study designs aimed at monitoring lynx occupancy and designing more intensive studies to estimate abundance.

Current Distribution, Status, and Threats to Canada Lynx in Montana and Wyoming - Dr. John Squires, USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana

Northwestern Montana - This area is believed to support the largest lynx population in the western U.S., but minimum population size has not been calculated. The Forest Service's Rocky Mountain Research Station in Missoula initiated a lynx research program in 1998 to investigate lynx resource and prey selection, competition, activity patterns, detection and monitoring, and connectivity. From 1998 to 2007, researchers trapped and radio-marked 175 lynx in northwestern Montana and collected nearly 170,000 GPS and over 3,000 VHS telemetry locations documenting lynx movements, resource use, survival, and productivity. From 1999-2007, litter sizes averaged 2.24 kittens/litter (N = 33) in the Seeley Lake area (the central portion of this geographic unit) and from 2003-2007, 2.95 kittens/litter (N = 22) in the Purcell Mountains (the northwestern portion of the unit). In Seeley Lake, 61% of breeding-age females (N = 52) produced kittens; in the Purcells, 83% of females (N = 28) produced kittens. Recent research (Kosterman 2014) suggests kitten production is correlated positively with mature forest connectivity and negatively with fragmentation in female home ranges. Annual survival rates for subadult and adult female lynx were 0.52 and 0.75, respectively, in Seeley Lake, and 0.68 and 0.85, respectively, in the Purcells. There was no evidence of cyclicity in these vital rates, and no indication of irruptions of lynx into this unit from Canada after the 1980s. Starvation, predation by mountain lions, and human-caused deaths each accounted for roughly one-third of documented sources of lynx mortality. Population viability analyses yielded population growth rates of 0.92 for the Seeley Lake area (i.e., declining population trend, 1999-2007) and 1.16 for the Purcells (increasing trend, 2003-2007). The distribution of lynx in this unit appears to have contracted recently; lynx were documented in the Garnet Mountain Range in the southern portion of the unit from at least 1980 into the early 2000s, but in 2010, extensive research trapping efforts yielded only two males, and snow-track and camera-trap surveys in winter 2014-2015 detected no lynx. Genetic analyses revealed fine-scale genetic sub-structuring among the Garnets, Purcells, and Seeley Lake subpopulations, suggesting some level of relative isolation among lynx in those areas. Most lynx habitat in this unit occurs on Federal lands (USFS, BLM, NPS). Recent conservation land purchases substantially increased protection of lynx habitat in the Seeley Lake core area. The extent of fire in this area has increased, with over one million acres burned in 2000-2013. Forest management (timber harvest, silviculture, and fire management) can have negative, neutral, or positive impacts on lynx habitat; current research is investigating lynx response to management actions.

Wyoming/GYA – The long-term persistence of lynx in the GYA is unknown, but early records from Yellowstone National Park documented lynx presence in the 1920s-30s, and more recent (2001-2004) surveys in the park documented several lynx and evidence of reproduction on the east side of Yellowstone Lake. South of the park, lynx were also detected reliably in the late

1990s-early 2000s in the Union Pass and Togwotee Pass areas of the Wyoming Range in the Bridger-Teton National Forest. Several lynx released in Colorado (1999-2006) dispersed to the GYA and occupied home ranges (including males and females with overlapping home ranges) in areas of the Wyoming Range previously occupied by "native" resident lynx. Recent (2005-2010) research trapping and survey efforts in the Wyoming Range have detected only Colorado-released lynx, and the current status of lynx in the GYA is uncertain but believed to be at low numbers based on on-going surveys. In addition to fire and forest management (as described above for northwestern Montana), oil and gas exploration and development may pose a potential risk to lynx and habitat in the Wyoming Range.

Lynx in Washington: Current Status and Potential Threats – Dr. Benjamin Maletzke, Washington Department of Fish and Wildlife, Olympia, Washington

Lynx in Washington were State-listed as threatened in 1993, but with recent large-scale impacts to lynx habitats and likely declines in lynx numbers, upgrading to State-endangered may be justified. The Washington Department of Fish and Wildlife completed a lynx recovery plan in 2001, and the Department of Natural Resources completed a habitat management plan for its lands in 1996, which it revised in 2006. The majority of lynx habitat in Washington occurs on public lands including State Forests and National Forests. Although individual lynx are occasionally documented in the northeastern part of the state, only the Okanogan area (eastern Cascade Mountains abutting the border with Canada) in the north-central part of the state has consistent records and evidence of a resident breeding population. In terms of the ESA's five listing factors, over-utilization, disease/predation, and inadequacy of existing regulatory mechanisms are not issues for lynx in Washington. Lynx trapping was prohibited in 1991, and only live-trapping is allowed for bobcats, so there is little chance for incidental trapping. There is no documented disease and little evidence of predation (though these could occur/increase with climate change). With ESA and State listings, critical habitat designation, and State recovery and State and Federal habitat management plans in place, regulatory mechanisms appear adequate. Recently, much lynx habitat has been lost, at least temporarily, to frequent large-scale fires and insect outbreaks, and climate change may pose additional (or exacerbate existing) threats to lynx and habitats in Washington. From 1990-2002, there were about 2,600 km^2 of lynx habitat in the Okanogan (Eastern Cascades) area, and female home ranges were estimated at 38 - 41 km^2, suggesting the potential to support roughly 90-115 resident females (home ranges include "matrix" or non-habitat). By 2014, habitat had been reduced by fire to about 1,600 km^2, and habitat loss and fragmentation resulted in female home ranges increasing to an estimated 91 km^2, with a potential to support roughly 27 resident females. Although areas impacted by fires and insects should regenerate to hare/lynx habitat, it may take 35-40 years or more for that to happen. Climate change will likely reduce snow depth, condition, and persistence, potentially influencing interspecific competition. It also may cause temperature- and precipitation-driven changes in vegetation and increased fire frequency, size, and intensity, resulting in further reduction, fragmentation, and isolation of suitable habitats and impacts to prey abundance. Connectivity between the Okanogan area and lynx populations and habitats in Canada seems adequate; it is more tenuous in the northeastern part of the state, where cross-border populations/habitats in Canada are smaller and potential corridors more constricted. It is also possible that legal trapping in southern British Columbia could limit immigration into Washington's lynx population and be a source of mortality for lynx dispersing from Washington into Canada. Potential management and recovery actions could include resuming surveys and monitoring efforts, reviewing current State, Tribal, and Federal management actions to see if they can be more "lynx-friendly," conducting population viability analyses to estimate probabilities of persistence over various time periods, coordinating with British Columbia on cross-border lynx conservation efforts, evaluating the need and feasibility of augmenting female lynx in the Okanogan and reintroducing lynx to the Kettle Crest, up-listing lynx in Washington to indicate the current status and severity of threats, and seeking collaboration and funding to support the measures above.

Status of Lynx in Colorado - Dr. Jake Ivan, Colorado Parks and Wildlife, Fort Collins, Colorado

Lynx in Colorado were State-listed as endangered in 1973. Based on statewide surveys conducted in 1978-1997 that found some possible lynx sign (tracks), the State concluded that if lynx were present, too few individuals remained for a viable population and that natural recolonization was unlikely due to geographic isolation. The State initiated a lynx reintroduction program, releasing 218 lynx from source populations in Alaska and Canada from 1999 to 2006. All animals were released into the San Juan Mountains in the southwest part of the state. Many stayed there and used the area heavily; many others established home ranges in the Sawatch Range in the central part of the state, where the bulk of historical records occurred. Although post-release mortality was initially high, it decreased after release protocols were modified and among lynx after they'd been on the ground a year. Mean annual survival was 0.93 for lynx that stayed within the San Juan Mountains core-release area, and 0.82 outside of it. The first den was located in 2003, and 48 dens were subsequently documented in Colorado through 2010, including a third-generation of Colorado-born lynx. The reintroduced population displayed reproduction similar to other areas in the DPS in some regards (e.g., mean litter size was 2.75 kittens), and lower in others (e.g., mean percentage of females that produced kittens was 24% [range = 0% - 46%])[2]. A deterministic model that uses survival estimates and reproduction data from ten years of monitoring reintroduced lynx and assumes that reproductive parameters observed during that time would repeat each decade shows a slightly increasing trajectory through time. Although current population size and survival rates are unknown, photos of females with kittens in 3 sampling units during occupancy monitoring in the San Juan Mountains in 2014-15 and capture of young and unmarked (i.e., "new") lynx during research efforts in 2010-15 provide evidence of continued reproduction. Potential threats to lynx in Colorado include climate change, bark beetle outbreaks, fire, increasing human recreation, and vulnerability to vehicle collisions and disturbance from highways. Climate modeling in 2014, based on the RCP6 (2nd-highest) emissions scenario, suggests that by mid-century temperature will increase by 2°C, precipitation will decrease in the San Juan and other southern mountains, and that spruce-fir habitat will migrate upslope, lagging climate conditions by 50-100

[2] These data were provided by the presenter after the workshop but were not part of the original workshop presentation.

years. Based on this, the overall vulnerability of spruce-fir in the state is considered moderate at mid-century. As of 2014, over 4 million acres of potential lynx habitat has been impacted by bark beetle outbreaks; however, lynx and hares continued to use impacted areas, even when beetle impacts are severe. Red squirrel use declined in areas that were heavily impacted by beetles. Large fires also have impacted lynx habitat, and as elsewhere, fire size, frequency, and intensity are expected to increase with climate change. A cursory, pre-analysis review of location data suggests that lynx make use of landscapes in which heavy winter recreation occurs. However, use of developed ski areas is light, and outside of ski areas, heavy lynx use tends to occur in thick timber that is not used by snowmobilers and other backcountry users. Finally, lynx frequently crossed 2-lane paved highways in home ranges (0.6 crossings/day), more often at dusk and night, coincident with lower traffic volumes, and usually at forested crossings. Recent results from a new large-scale monitoring program indicated that lynx occupied a similar proportion of the landscape in the San Juan Mountains during winter 2014-15 as they did during winter 2010-11.

Expert Elicitation Process

All questions posed to the 10 lynx expert panelists were framed in the context of the 3Rs, a driving principle for evaluating viability under the SSA framework. In questioning, we used a modified Delphi method (e.g., MacMillan and Marshall 2006), which involves eliciting individual responses/scores, exploring response rationale and differences in expert judgment through guided discussions, then allowing experts to reconsider their scores in light of those discussions if they so desire.

In our implementation of the modified Delphi approach, panel members were first asked to respond individually to a particular question and indicate their level of confidence in their response. We then collated and noted the range of responses, which became the mechanism for follow-up discussion. In collating responses, we used a simple numeric coding system rather than the experts' names to provide for a reasonable level of anonymity. We noted where there was high congruence among responses, as well as low congruence and outlying responses. By asking for experts to voluntarily provide their reasoning for particular responses, we were able to delve into the basis for varying opinions. After the discussion period, experts were given the opportunity to revise their scores.

In addition to elicited responses to each question, we received substantial feedback from the experts on definitional issues and the validity of the questions themselves; we revised the questions as needed following these discussions. In the case of a revised question, scores were elicited again following the revision. The second round of scoring was displayed for experts, with a closing opportunity for comment, discussion, or score revision.

All panel members were encouraged to respond to each question but also given the option of abstaining from responding to a question if they felt it was beyond the bounds of their expertise. With few exceptions, all 10 expert panelists responded as requested to every question.

Instances where experts either chose not to reply or otherwise replied in a manner differing from the expected form of response to the question are noted in the responses below.

Lynx Status: Expert Elicitation and Responses

Questions for experts were scripted by the Lynx SSA Team prior to the meeting to facilitate discussion of lynx ecology among the experts, solicit their professional opinions, and to help the Service gather and synthesize biological information for use in the SSA, particularly where empirical data are lacking in the published literature and projecting habitat and population conditions into the future is needed. Because of the uncertainty of quantifying the population status and other aspects of lynx biology, the Service and facilitators decided to generate a series of discussion questions with quantifiable responses (scores) concerning the redundancy, resilience, and representation (3 Rs) of the DPS. Although scores provided a starting point for discussion among experts and are quantified, analyzed, and summarized as appropriate in the following sections of this report, the Service also places high value on the content of the discussion among experts. Therefore, both the analyses of scores and summaries of the discussion content are presented and will be considered during development of the SSA, noting that both were integral to the expert elicitation process.

The types of questions and the format of responses differed based on the information needed to inform the status assessment, and the best way to capture the information relevant to the question being asked. For example, responses were requested in the form of lists, when a set of influences was desired, in the form of a 4 point elicitation (e.g., the most likely, high, and low end of a range, and confidence that the range contains the true value) when an uncertain quantitative value was desired, in the form of graphed trajectories when probabilities of persistence over time were desired, and other forms as necessary (see questions below). Experts submitted their scores independently via submission sheets (sticky notes, index cards, graph paper, etc.) with their ID numbers. Note takers recorded and displayed scores to assist discussion. Facilitators and other members of the SSA Team then asked directed questions to clarify responses from the panelists as needed. Following each round of discussion and clarification, the panelists were provided the opportunity to update their response if desired and the second round of responses were collected and recorded. The final responses are the only responses reported here. The range of individual responses that we received was not combined (e.g., averaged or otherwise) in any way that would obscure or conceal individual responses, and the final scores for each panelist were recorded if the response was revised.

We present the results of the expert elicitation below under the headings of representation, redundancy, and resilience. Under each heading, the following is provided: the definition of the viability category (3 Rs) under consideration, the question(s) asked of the expert panelists, response type (i.e., the form of the response requested of the experts), question clarification (i.e., a narrative description of any additional information provided to the experts by the facilitators for clarification as the questions were asked), expert responses, and notes from the discussion.

Expert Responses

Representation

Definition - ***Representation*** contributes to the adaptability and evolutionary capacity of a species over time, to accommodate long term issues like climate change. The breadth of genetic ecological, demographic, and behavioral diversity across a species' range may contribute to its capacity to adapt over time. Measures of genetic and life history variability among populations, distribution of populations across a range of ecologically diverse locations or niches, etc., are useful proxies to measure. Consider needs for establishing or reestablishing populations in unoccupied habitat that may be necessary or suitable for species adjustment to climate change or other stressors, including the need to replace former populations in no longer represented ecosystems.

Representation Questions

1. Are any of the geographic units susceptible to genetic drift on a scale that would limit genetic viability? If yes, which geographic units?

Response Type: Experts supplied a written response of "yes" or "no," with a yes answer accompanied by a list of susceptible geographic units.

Expert Responses: Five experts responded that none of the geographic units are susceptible to meaningful genetic drift, two experts abstained from answering, and three experts responded that there are geographic units that are susceptible to such genetic drift. Among the latter, one expert responded that the Colorado geographic unit is susceptible over a long period of time, and the other two experts responded that both the Colorado and GYA geographic units are susceptible to genetic drift.

Discussion Points Following Initial Responses: It wouldn't take many immigrating lynx to provide adequate genetic diversity to prevent genetic drift. One reproductively successful immigrating lynx every 5 to 10 years per geographic unit is likely sufficient to prevent genetic drift. Most experts believed there was a low likelihood that even the smaller lynx populations (GYA and Washington) or those in more isolated geographic units (Colorado and GYA) are vulnerable to genetic drift at a scale that would impact viability, though several experts felt that both the GYA and the western Colorado units could experience meaningful drift in the absence of immigration or augmentation. Overall, most experts felt there is a low risk of genetic drift being a problem for lynx in the DPS.

2. Are there locations from a lynx perspective that have unique habitat conditions relative to other areas in the lynx range that are necessary to foster future adaptive capacity of the DPS? If yes, where?

Response Type: Open discussion. No response forms were submitted, but notes were taken on the discussion that followed.

Question Clarification: The experts required some clarification of terms and the intention of this question to respond. Facilitators read the working definition of representation (above), which previously had been provided to the experts. Experts then discussed representation across the lynx DPS from an adaptive capacity perspective.

Expert Responses: The response was an open discussion captured below.

Discussion Points Following Initial Responses: Maintaining genetic variability is important for adaptive capacity. If uncertain about the capacity for lynx to adapt, then experts encouraged that all populations (and hence the genetic variation within each) be maintained. Experts indicated that it doesn't appear that any U.S. population is more or less important to maintain than the others because of relatively similar ecological settings and the generally low level of genetic differentiation across the DPS. Summary: Experts discussed that maintaining representation in the DPS could best be achieved by retaining current DPS populations, maintaining connectivity between DPS and Canadian lynx populations, conserving the genetic diversity currently represented in DPS, and avoiding impacts that could facilitate or increase the potential for or likelihood of genetic drift.

It was also noted that lynx north of the DPS in some parts of eastern Canada (in New Brunswick and Quebec south of the St. Lawrence Seaway and on Newfoundland Island) have some unique alleles, including at functional genes, and should be preserved. Lynx in these areas are relatively more isolated than lynx elsewhere in Canada. Lynx south of the St. Lawrence are separated from lynx to the north by the seaway itself, which historically froze over during winter but which is now kept open to facilitate maritime shipping, perhaps reducing the level of genetic exchange between lynx on opposite sides. Lynx on Newfoundland Island are separated from lynx in mainland Labrador and Quebec by the 15- to 60-kilometer-wide Strait of Belle Isle. Despite the relative isolation of these populations, genetic evidence indicates some interchange between lynx south and north of the St. Lawrence and between Newfoundland Island and mainland populations. Eastern Canadian populations north of the St. Lawrence may have slightly different genetic composition than lynx in the Maine geographic unit.

Redundancy

Definition - ***Redundancy*** contributes to the ability of population types to withstand catastrophic events (hurricanes, wildfires, etc.). The number and distribution of populations of each representative type contribute to the retention of various representative types despite catastrophic events by ensuring that the loss of a population doesn't lead to the loss of representation.

Redundancy Questions

1. List the factors/catastrophic events that could functionally extirpate an entire geographic unit.

Response Type: Each expert supplied a written list submitted via index card of the factors/catastrophic events.

Question Clarification: Three issues required clarification prior to obtaining responses to this question. First, we initially asked about eliminating a "population" rather than a geographic unit. Because some of the geographic units may support several relatively isolated subpopulations, experts questioned whether we meant individual populations or subpopulations. We clarified that we are evaluating the likely persistence of resident lynx populations in each of the six geographic units that currently support or recently supported them; therefore, we are interested in the likelihood that a catastrophic event could result in the extirpation of resident lynx from the entirety of any of the geographic units. Second, we were asked if extirpation meant the complete loss of all lynx from a unit. We clarified that we wanted to know if lynx could be "functionally extirpated" from any geographic unit, with functional extirpation described as the loss of the unit's ability to support a resident breeding population(s) of lynx. Third, experts were not clear what an "event" entailed. After discussion, it was agreed that an event was defined as a single occurrence of some form, such as a fire, drought, hurricane, etc., that occurs over a relatively brief period of time, rather than a series of smaller cumulative events (e.g., a series of climate change-associated occurrences of fires or insect outbreaks over the course of a decade) causing a cumulative catastrophic result.

Expert Response: Six of the ten experts did not list any catastrophic events that could result in the functional extirpation of lynx from any entire geographic unit. Three of the experts listed multiple catastrophic events they felt could result in at least temporary functional extirpation of lynx in a unit. Among these, two of the experts listed fire, three listed disease, one listed insect outbreak, and one listed a failure of winter conditions due to a combination of heat or drought conditions. One expert listed geographic unit-specific events, namely fire or insect outbreak for the Washington geographic unit, insect outbreak in Maine, and either insect outbreak or fire for one of the Minnesota geographic unit's groupings of individuals, but not all.

Discussion Points Following Initial Responses: Experts were told that climate change was not considered a catastrophic event because it is both a driver of events and influences severity, rather than being an event itself as defined above. Experts discussed the possibility that the Washington geographic unit, because of its relatively smaller size and history of recent extensive fires in lynx habitat, may be at risk of functional extirpation from multiple catastrophic events; disease, fire, and beetle outbreak were all mentioned as possible events. One expert suggested that the Minnesota geographic unit could potentially be eliminated by a very large fire, although there was a low probability of this occurring. Experts expressed some uncertainty whether fire could occur at the severity and scale sufficient to eliminate an entire geographic unit; however, a series of fires over a short time period may have the potential to cause functional extirpation of lynx from a geographic unit or significantly reduce the number of resident lynx it could support, at least temporarily.

2. Could any of the catastrophic events listed in response to redundancy question 1 eliminate all 6 geographic units simultaneously?

Response Type: Each expert supplied a written response of “yes” or “no.”

Expert Response: All experts answered “no.”

3. What is the probability (expressed as a percentage) that any single geographic unit could be eliminated by a single catastrophic event in the <u>next 10 years</u>?

Response Type: 1-point elicitation. Each expert supplied a written response of X%.

Question Clarification: In response to the discussion around question #1, which resulted in the inclusion of question 3, this question was modified from its original script to include a 10-year time frame (underlined).

Expert Responses: All responders gave a relatively low probability ($\leq$ 10%, median of 1%) that any single geographic unit could be eliminated (resident lynx functionally extirpated) by a single catastrophic event in the next 10 years (Figure 2).

4. What is the percent likelihood that a series of catastrophic events within the next 10 years could cause functional extirpation of one or more lynx geographic units?

Response Type: 1-point elicitation. Each expert supplied a written response of X%.

Question Clarification: This question was developed after discussion of question 3 to capture the possibility of functional extirpation of lynx from geographic units due to a series of catastrophic events over a relatively short time rather than a single event that occurs at one point in time.

Expert Responses: The percent likelihood ranged from 0.5% to 60%, with a median response of 7.5% (Figure 2). Expert responses indicated a higher probability <u>of a series of catastrophic events over 10 years</u> resulting in functional extirpation than a single event in the next 10 years, as in question 3.

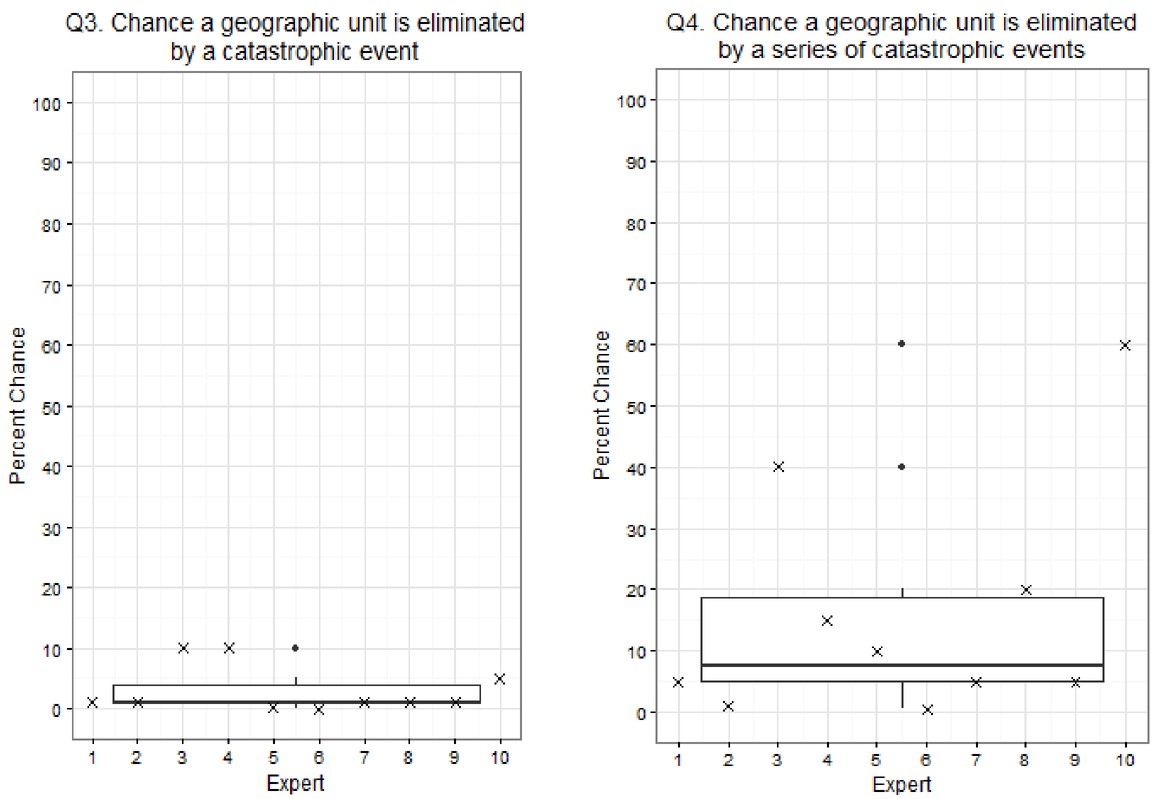

Figure 2. Individual scores and summary boxplots of the percent chance that a geographic unit is eliminated by a single catastrophic event (question #3, left) or a series of catastrophic events (question #4, right) in the next 10 years. Note: This and all subsequent figures below were generated using the statistical software R (Appendix 6).

In Figure 2, individual responses to a single catastrophic event were 0.01%, 0.1%, five responses of 1%, 5%, and two responses of 10%. Individuals responses to a series of catastrophic events were 0.5%, 1.1%, three responses of 5%, 10%, 15%, 20%, 40%, and 60%). Boxplots illustrate response mean values (bold black lines), the 25% and 75% quartiles (upper and lower bounds of boxes), and the highest and lowest values within 1.5 times the quartile range ("whiskers" external to boxes). In this analysis, responses beyond the ends of the whiskers (outside 1.5 times the quartile range) are considered outliers and plotted as points beyond the ends of the whiskers (i.e., experts 3 & 4 in Q3 and experts 3 and 10 in Q4, as indicated by the points plotted between experts 5 and 6). The individual expert responses used to produce the boxplots are indicated by x-marks. Boxplots are provided as a summarizing visualization to aid comprehension of the experts' responses and their range, and the summary values are presented in this context and not intended for use outside of the context of the full set of responses.

Discussion Points Following Initial Responses: One expert noted that the probability of extirpation in any one of the 6 geographic units is greater than the probability of a single specific geographic unit being extirpated. Also, any combination of a series of events over a decade increases the likelihood of extirpation in any one geographic unit relative to the probability of extirpation due to a single event.

Although median probabilities of extirpation were low, experts felt the geographically smallest unit (Washington) and those units believed currently to support the fewest resident lynx (GYA, Washington, and Minnesota) were the most vulnerable geographic units when scoring this exercise. Fire, drought, and beetle kill were the most frequently mentioned events that were considered by the experts when answering this question. Some experts felt that these geographic units may be susceptible to such a scenario because of small geographic and/or population sizes and distribution. In particular, it was noted that this past year there were many fires in lynx habitat, especially in Washington, and another year with similar fire impacts, or a few such fire years in a 10 year period, could lead to extirpation of lynx in the Washington geographic unit. An expert noted there currently may be as few as 24 remaining females in Washington and that with fewer individuals in this area it would result in a higher probability of at least temporary extirpation. Experts noted that fire disturbance data are likely available that could be used to model the likelihood of future fire impacts to each geographic unit.

Experts with outlier responses provided their rationales. Experts having the lowest scores believed that even the smallest geographic units would have only a low probability of extirpation in the next decade - that the time frame under consideration was very short.

5. What length of time would be required for a geographic unit eliminated by a catastrophic event to reestablish naturally?

Response type: 4-point elicitation. Each expert supplied a written response in years for the longest, shortest, and most plausible time periods for reestablishment of a resident lynx population within a geographic unit following functional extirpation. They were also asked to indicate their confidence, as a percentage chance, that the true amount of time necessary for reestablishment would fall between the shortest and longest plausible time periods provided.

Expert Responses: The responses to each of the points elicited are shown below in Table 1. Two experts provided additional information beyond the 4 points elicited when responding. One presented two scenarios, one in which connectivity is intact and the habitat was damaged by the catastrophic event (e.g., insect outbreak or fire) which would require habitat regrowth first, and the second in which the habitat remained present. In the case of habitat being present the most likely time period response was less than 10 years. In the habitat elimination scenario the expert felt given climate changes to habitat that the geographic unit would not re-establish. The second expert responded by geographic unit, with the exception of the Minnesota geographic unit for which there was no response. Their responses are summarized in Table 1 using the overall longest and shortest responses as well as the average of the most plausible time (see footnote 3).

Table 1. Expert responses regarding the natural reestablishment time in years for a geographic unit after extirpation by a catastrophic event.

Expert #	Reestablishment Time in Years			Percent Confidence in Range[3]
	Shortest Plausible Time	Most Plausible Time	Longest Plausible Time	
1	10	40	100	50%
2	15	100	300	80%
3	15	35	60	5%
4[4]	1, will not reestablish	<10, will not reestablish	will not reestablish	100%
5	25	50	100	75%
6	20	30	50	90%
7	15	20	25	90%
8	15	50	will not reestablish	40%
9	20	30	100	50%
10[5]	15	55	200	50%

Expert responses are also visualized in Figure 3 and Figure 4 below. The raw responses are visualized in box plot form to aid communication of the results (Figure 3). Confidence ranges provided in a four point elicitations enable expert responses to be rescaled to produce a common confidence bound across experts using linear extrapolation (e.g., McBride *et al*. 2012). We calculated the 95% confidence interval for the shortest and longest plausible time periods for each expert (Figure 4). In cases where the linear extrapolation resulted in negative years for the shortest time periods, we adjusted to zero. This may indicate underconfidence in the responses provided by the experts, or that the use of linear extrapolation for these 4-point elicitation responses fails to distribute expert uncertainty in a manner consistent with the actual uncertainty present in expert responses (i.e., the experts could have been more confident in their shortest plausible time response than their longest plausible time responses, which the linear extrapolation doesn't account for).

[3] Expert confidence that the true recovery time would fall between the shortest and longest time periods of their response.
[4] This expert provided a response for two scenarios, first that the catastrophic event does not result in habitat loss, and second that habitat is lost and therefore connectivity to extant populations is lost.
[5] This expert provided separate responses for each geographic unit. The values in this table are the overall shortest, longest, and average most plausible number of years indicated in the responses across geographic units.

Figure 3. Years for a geographic unit to become reestablished following extirpation due to catastrophic events.

The raw responses for each of the three time periods (longest plausible time to reestablishment, most plausible time, and shortest plausible time period) are displayed in the box plots in Figure 3 above. Boxplots illustrate response mean values (bold black lines), the 25% and 75% quartiles (upper and lower bounds of boxes), and the highest and lowest values within 1.5 times the quartile range ("whiskers" external to boxes). In this analysis, responses beyond the ends of the whiskers are considered outliers and plotted as points. The individual expert responses used to produce the boxplots are indicated by x-marks. Boxplots are provided as a summarizing visualization to aid comprehension of the experts' responses and their range, and the summary values are presented in this context and not intended for use outside of the context of the full set of responses.

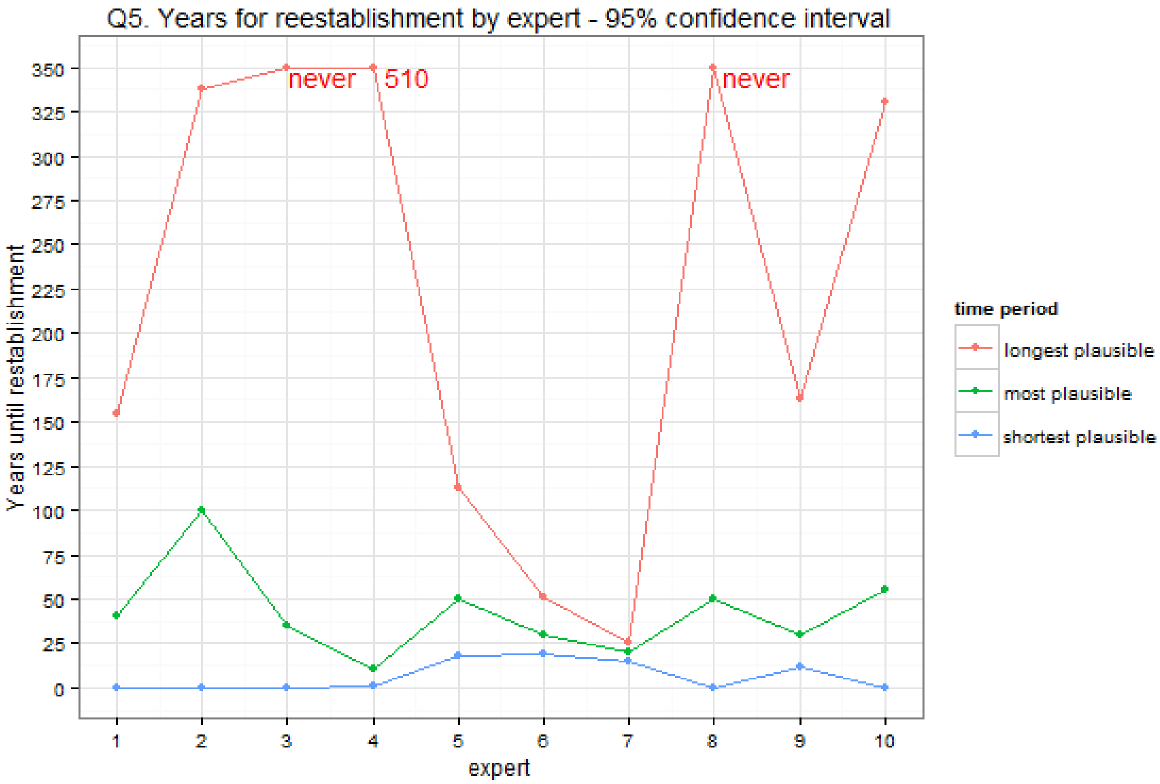

Figure 4. Years for a geographic unit to become reestablished following extirpation due to catastrophic events, adjusted to provide 95% confidence bounds.

In Figure 4, 95% confidence bounds were produced from the 4-point responses using linear extrapolation. Shortest plausible time period is in blue, most plausible is green, and longest plausible is red. For plotting purposes negative shortest time period values were adjusted to zero, and all zeroes in the plot indicate 95% confidence bounds that extended below zero. Longest time periods beyond 350 years were plotted at 350, with the actual time period noted in text left and below those points. Also note that expert 10 responded by geographic unit, so the figure displays the 95% confidence bound adjusted overall longest, overall shortest, and average most plausible time periods across the six units for expert 10.

Discussion Points Following Initial Responses: Experts discussed the amount of time it takes for habitat to recover after catastrophic events (e.g., fire, insects) when considering timeframes for repopulation. Some experts could picture some geographic units never being recolonized again, and that some could be recolonized immediately, depending on which geographic unit is being evaluated and the level of connectivity to other geographic units and to lynx populations in Canada. Washington is more connected to Canada than the Colorado geographic unit for example. The rate of recolonization was variable for each geographic unit because of the size of each geographic unit, status of adjacent source geographic units, and the level of connectivity. Experts found it hard to generalize across the range of the species for this question. The variances in the geographic units across the range need to be considered. Experts believed GYA and CO would have a long period for recolonization, if ever recolonized, after a potential extirpation event because of the lack of connectivity with Canadian populations. It is likely that those geographic units with connectivity to Canada would recover much sooner than geographic units not connected to Canada.

Resiliency

Definition - ***Resiliency*** speaks to an individual population's ability to tolerate environmental and demographic stochasticity, such as fluctuations in temperature or genetic drift. It is often measured in terms of population size and growth rate, but in fact is dependent on a number of traits, both demographic and environmental. These include, among others: age or stage class distribution, genetic heterogeneity, birth rates, annual survivorship, sex ratios, etc., and the quality and extent of habitat, the degree of disease, competition, etc. Metapopulation dynamics and distribution can also contribute to population resiliency in some species.

Resiliency Questions: Probability of Persistence Exercise

Exercise Summary

The first two resiliency questions were asked concurrently as part of a probability-of-persistence exercise conducted for each geographic unit. Experts were asked to graphically provide the probability of persistence of resident lynx through time for each geographic unit, as well as the major factors influencing persistence in those geographic units, one geographic unit at a time. Experts were asked to provide persistence probabilities and influencing factors for the near-term (2025), mid-term (2050) and longer-term (2100). Experts were also asked to indicate on each of their graph sheets the emissions scenario (low, moderate, or high/status quo) they were considering in graphing persistence probabilities and listing influencing factors.

We began this exercise with the Northern Maine geographic unit, and the discussion and questions among experts that followed the initial persistence-graphing and factor-listing efforts indicated that a review of the status and major issues confronting lynx in each unit (a quick reminder and summary of the earlier status update presentations) would be helpful. Therefore, prior to expert responses for the remaining units, the expert(s) most familiar with the geographic unit in question gave a 5-10 minute summary of what they viewed as the most relevant information about the current and likely future status of lynx populations and habitats in that unit. They also presented any other conditions or issues they thought could affect the probability of persistence of resident lynx in that unit. All experts then completed their graphs and lists of the factors that influenced the probabilities of persistence they selected for each time frame for the geographic unit in question. For the Maine unit, the discussion following initial responses served the same purpose, and after that discussion, experts were given the opportunity to revise their responses if they felt it necessary.

After all experts completed their responses, the graphs and influence lists from each expert were posted on the wall, and workshop participants were invited to gather around to view and discuss the range of responses. Facilitators and SSA Team members then polled the experts about what drove their responses. These questions were a mix of directed questions about unique responses, the role of particular factors noted in the responses, and open-ended questions to allow experts to describe their thinking. Experts and team members were also encouraged to ask clarifying questions about the responses. Experts were encouraged to modify their responses by posting a revised sheet above their first response if they wished to adjust their responses based on the discussions.

1. What is the probability of persistence over time (particularly at present, 2025, 2050, and 2100) for each of the 6 major geographic units?

Response Type: Graphical 3-point elicitation. Each expert was provided a blank sheet of graphing paper with a y axis of probability of persistence, and an x axis of time, with 4 time periods bolded (2015, 2025, 2050, and 2100). For each of those years, experts were asked to add a point to the graph representing the lowest, highest, and most likely probabilities of persistence at that time period. Experts were also asked to connect the points through time.

Question Clarification: It was explained that the most likely point should represent the probability of persistence that the expert anticipates to be most likely to occur for that geographic unit at each time period, and that the points for lowest and highest probability of persistence were intended to capture the expert's uncertainty in the future probability of persistence. Experts preferred to indicate a most likely probability and to provide a full confidence interval (i.e., upper and lower bounds within which they felt 100% certain the future probability of persistence would fall) rather than indicate a confidence level associated with the lowest and highest probability responses.

Expert Responses: Responses are by geographic unit and are presented below in conjunction with the responses to question #2 below.

2. What are the major drivers/factors (up to 3) reducing probability of persistence for each of the major geographic units?

Response Type: Ranked list of top three factors, for each point in time (present, 2025, 2050, and 2100), with % contribution of each factor.

Question Clarification: Resiliency questions 1 and 2 were asked concurrently. Experts were provided a sheet of paper for each geographic unit and the area at the bottom of the sheet below the graphing area was used to list the three major factors they expected would most significantly influence the probability of persistence at each time period. Influencing factors were described as those anthropogenic or naturally-occurring activities, events or factors that could influence the probability that resident lynx populations will persist in a given geographic unit.

Expert Responses: For each geographic unit, an overview of the unit from the area expert are provided, as well a summary of the hand drawn graphs via a figure (Figures 5 - 10), the responses and major factors are summarized via text, and the discussion that the responses generated are presented.

Results by Geographic Unit

Northern Maine

Pre-graphing Overview from Unit Experts: This step was not added to the process until after the probability of persistence exercise for this unit. Because this unit was the first for which experts attempted to graph persistence over time, there were many questions and much discussion about process and intent. It was the discussion following this initial graphing exercise that led the SSA Team to request unit summaries prior to subsequent graphing exercises. The Team felt that overview information similar to that provided prior to graphing persistence for subsequent units (below) came out during the discussion. Further, because experts were encouraged to update their Northern Maine geographic unit responses as necessary following that discussion, the Team felt that the results of the graphing exercise for the Northern Maine geographic unit were valid and comparable to the results generated for the other units.

Expert Responses: All experts indicated an initially high and subsequently declining probability of persistence of resident lynx in Maine through the end of the century, with uncertainty (range between lowest and highest probabilities) also increasing over time. Nearly all experts predicted near-term (year 2025) persistence probability >= 90% and mid-century persistence >= 70%. All experts predicted end-of-century persistence probability >= 50% for this unit, with most predicting a 40% to 60% probability of persistence by 2100 (Figure 5). Near-term drivers that influenced experts' probabilities of persistence for this geographic unit were changes in private forest land ownership, changes in forestry management (timber harvest methods, volumes, and spatial distributions), habitat decline (succession of previous clear-cuts from young, dense regenerating stands to mature stands less conducive to high hare densities), spruce budworm outbreak, climate change-induced loss of spruce-fir habitats, and competition with bobcats due to climate change-induced loss of snow conditions that favor lynx. Longer-term (2050, 2100) drivers similarly included changes in forestry practices, but also climate-driven loss of snow conditions favorable to lynx/competition with bobcats, and loss of spruce-fir forest. As with responses for other geographic units, not all experts provided the factors that influenced their persistence probabilities for each time period, and not all provided the percent contribution of each factor.

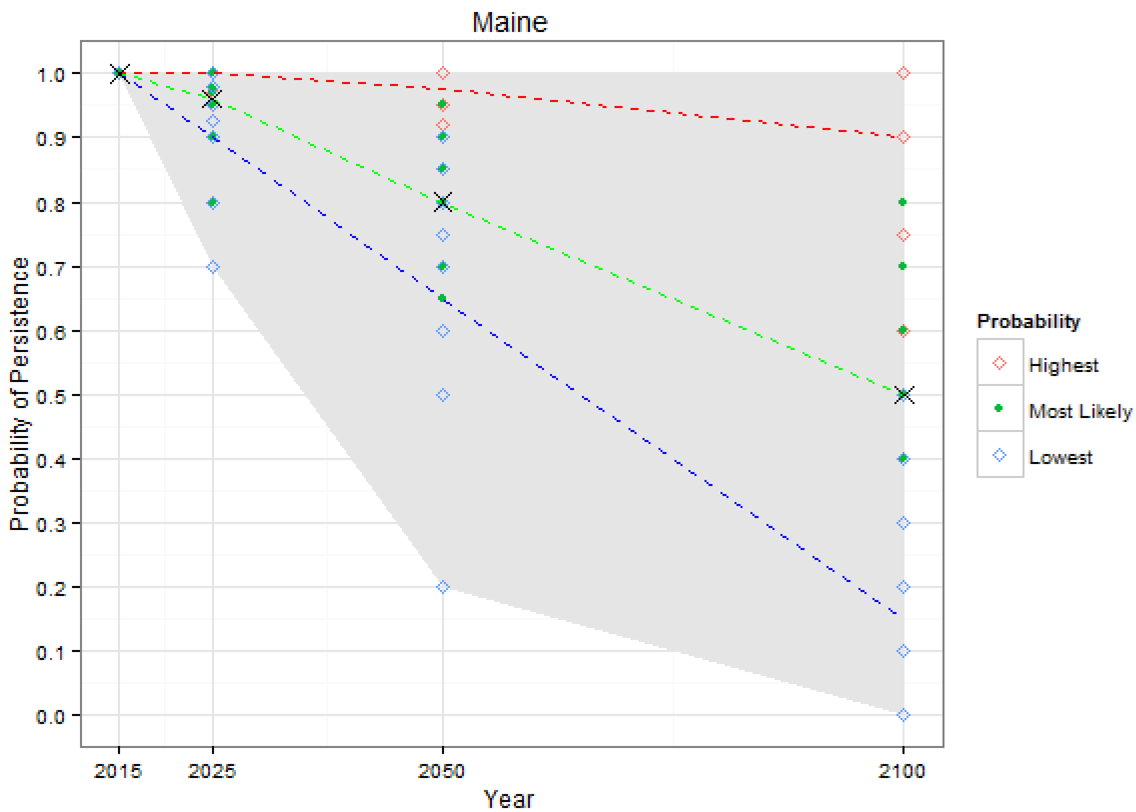

Figure 5. Expected probability of persistence for the Northern Maine geographic unit at present, 2015, and in 2025, 2050 and 2100.

Note: In Figure 5, above, and figures 6 through 10, below, points for each of the 10 expert responses, for each of the three probability of persistence levels, i.e., highest, most likely, and lowest probabilities of persistence, are represented by the hollow red, filled green, and hollow blue points respectively. The black x mark is the median of the most likely responses across the experts in each response year. The red, green, and blue dashed lines connect the median of the highest, most likely, and lowest probability of persistence responses across the experts in each response year. The edges of the grey area were defined by the extreme responses, i.e., the range from the largest of the highest probability of persistence responses to the smallest of the lowest probability of persistence responses. The median lines and grey area are provided as a summarizing visualization to aid comprehension of the experts' responses and their range, and should not be viewed as a substitute for individual responses or presented outside the context of the accompanying discussion.

Discussion Points Following Initial Responses: One expert expressed confidence that the lynx population in Maine will be stable in the near term; that climate change out to 2050 will primarily affect coastal areas, which support few lynx; and that there will likely still be favorable conditions for lynx in northern Maine where most lynx currently occur. A second expert disagreed, and indicated that a combination of aging of the last of the budworm-era (1970s-80s) clear-cuts, the cumulative effects of the last 25-years of partial harvesting (in accordance with the Maine Forest Practices Act), and the coming spruce budworm outbreak will all substantially reduce the amount of high quality lynx/hare habitat in this unit. Projecting past 2050, experts generally agreed that climate change will likely create unfavorable conditions (e.g., insufficient snow, loss [northward migration] of spruce-fir forests) in northern Maine's core area for lynx, and the probability of persistence will decline over the longer term. Although uncertainty increases with time from the present, climate-related loss of favorable snow conditions (amount, consistency, and duration), loss of spruce-fir, and bobcat competition will likely reduce the probability of persistence in this unit beyond 2050.

There was some concern that timber companies would not respond to the pending spruce budworm outbreak like they did in the 1970s (extensive clear-cuts). Some experts also expressed concerns about the effects of the current clear-cuts aging past conditions that support hares and lynx. Out to year 2050, changes in snow conditions and loss of spruce-fir associated with climate change will contribute to habitat loss. Past 2050, diminished snow, successional loss of high-quality habitats, increased competition from bobcats, and spruce-fir decline will make conditions unfavorable for lynx. Some experts assumed a high-emissions climate change scenario, but others said their predictions would not change under moderate emissions scenarios. The second expert (above) indicated that current data show spruce-fir habitat is being replaced with a hardwood forest (red maple) system, and that this will continue throughout the century. This expert indicated hardwood forest invasion isn't being controlled by herbicides as it was in the last budworm outbreak. The first expert (above) disagreed and said that lynx are resilient and forestry practices will likely sustain spruce-fir habitats in Maine, providing an example of one timber company that has already invested in spruce plantations. The second expert indicated that most of the land base is owned now by Timber Investment Management Organizations and Real Estate Investment Trusts who will not employ intensive or expensive (plantation, herbicide) forms of forestry. In summary, experts expressed a variety of opinions about how forest management may change in the future in Maine and, in particular, how forest landowners and managers may respond to the pending spruce budworm outbreak, and how these responses may impact resident lynx.

Other factors considered by the experts included budworm outbreaks, the potential for disease in a lynx population (not currently a recognized or documented threat and typically unexpected, but always a possibility), ecosystem change induced by climate change, forest tree species composition changes, competition with other temperate forest animals. There are many interrelated factors and different stresses and factors that may occur in the future. It is difficult to anticipate the factors that will affect lynx in the future.

Experts discussed the role of competition between lynx and other carnivores, especially bobcats, throughout the DPS. One expert remarked that in some parts of Montana there is complete overlap of lynx and bobcat home ranges and little or no evidence of competition effects. Others indicated relatively narrow regions of overlap and sharp demarcation between areas that support home ranges of the two species that correspond with annual snowfall amounts in Maine and Minnesota. Experts were unsure whether bobcat-lynx overlap is more a function of snow conditions in these areas or competition between the species (i.e., competition for food or behavioral competition). Although separation of the species has been documented, the nature and causes of the separation are not certain. Bobcats are a more generalist predator than lynx and less reliant upon hares than lynx. Experts expressed varying opinions regarding seasonal differences in overlap among lynx and bobcat diets, the effect and importance of competition between the two species, and whether it is behavioral or resource competition.

Lynx in Maine have not responded to changes in hare abundance exactly as lynx in Canada and Alaska have to hare population cycles. In Maine, the proportion of females that reproduced and average litter size declined during low hare years, as in the north, but home range sizes in Maine did not increase as they did in the north when hare abundance was low. Hare densities do not appear to have dropped below a critical threshold to alter lynx home range size in Maine as in the North.

An SSA Team member asked how hare cycles or fluctuations may affect predictions of persistence in Maine. The first expert (above) said that hare declines documented by University of Maine monitoring is likely due to the aging forest, and that lynx in Maine haven't yet responded biologically to the range of hare densities observed in Maine, as suggested by the lack of change in home range sizes and survival. The second expert (above) disagreed, and cited University of Maine research that showed hare populations declined by ~50% in all stand types sampled starting in 2006, that forests where hares were monitored have not yet progressed to the self-thinning stage, and that the hare decline in Maine is mirrored by hare data from southern Quebec.

Northeastern Minnesota

Pre-graphing Overview from Unit Experts: There are probably 50-200 resident lynx in Minnesota but there is much uncertainty and survey protocols do not support generation of precise abundance estimates. Lynx occupancy and reproduction both have been consistently documented in the state since it was listed in 2000. Lynx in this geographic unit are interacting with, and possibly depending on, southern Ontario populations. Although females exhibit high reproductive rates, radio-telemetry data suggest low recruitment of Minnesota-born kittens into the breeding population of this geographic unit. Bobcats are a potential future stressor as they are encroaching into lynx areas; fire is a threat in dry years (e.g., there have been 3 fires in last 15 years that have burned approximately 20% of lynx habitat). The forest management industry is tied to softwoods and continued management of softwood tree species is expected in the future.

Expert Responses: As with the previous unit, all expert graphs showed initially high and subsequently declining probability of lynx persistence in Minnesota over time, along with increasing uncertainty through the end of the century. Nearly all experts predicted near-term (year 2025) persistence probability >= 90%, and all experts predicted mid-century persistence at 60% to 90% (median = 80%). Experts predicted end-of-century persistence probabilities of 10% to 60%, with a median of 35%, by 2100 (Figure 6). Near term drivers were reduced snow, bobcat competition, disease in lynx (e.g., lungworm, liver fluke, feline leukemia), and forest insects. Long term drivers were reduced snow, competition with bobcat, loss of spruce-fir forests, fires, and climate change.

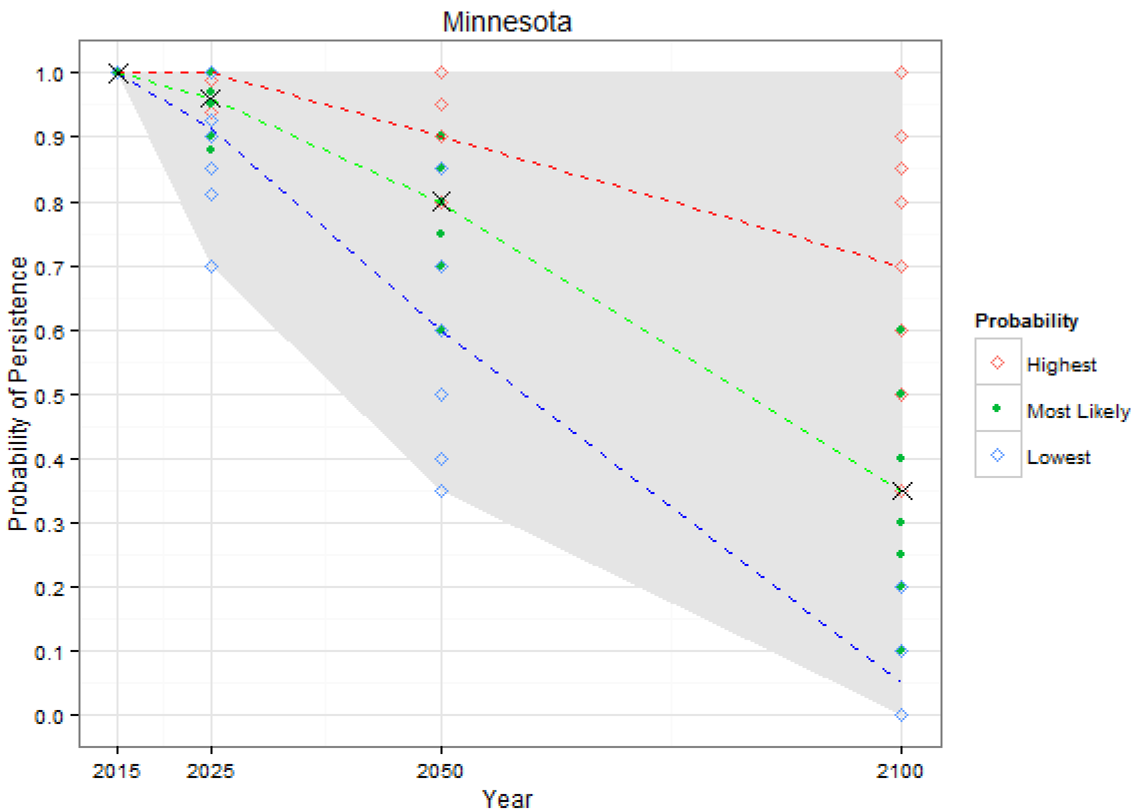

Figure 6. Expected probability of persistence for the Minnesota geographic unit at present (2015), and in 2025, 2050 and 2100.

Discussion Points Following Initial Responses: Some experts expressed uncertainty whether potential climate change impacts will be realized in the short term, but that the cumulative effects of climate-induced changes seem more likely in the longer term. This uncertainty may be a source of variability in predicted persistence probabilities.   Some experts expressed uncertainty about the accuracy of the rough estimate of the size of the lynx population in this unit because surveys were not designed to provide population estimates. Some experts wanted clarification on the distribution of lynx in the state, and which areas of the state have the highest use. The core-use spatial extent was described as a 20-mile-wide strip inland from the north shore of Lake Superior and extending about 60 miles from the northeast tip of the “arrowhead” southwest into the Superior National Forest (SNF). Lynx occasionally occur further west in the SNF and in other areas such as Voyageurs National Park. Recent snow-track surveys suggest lynx may be using a larger portion of the arrowhead region, and radio-telemetry data have documented travel to and from southern Ontario. Lynx also have been documented to use the

1-million-acre Boundary Waters Canoe Area Wilderness (BWCAW) that borders Canada for dispersal in both directions across the border. However, because the BWCAW has not been surveyed for lynx, the number of lynx that may use this area is unknown. The SNF does not actively manage the BWCAW. The current connectivity between lynx in this unit and the larger population in Ontario reduces the likelihood of local extirpation in this geographic unit, but the likelihood would increase if connectivity was compromised and cross-border interactions reduced.

Factors considered included potential disease, fire, loss of boreal forest, competition with bobcats and possibly other hare predators. Some experts questioned the validity of disease as an influence in this and other geographic units because although disease has been documented in some felines, it has not been documented as a threat to lynx in any of the DPS populations to date. Some experts speculated that because there is a link between disease and temperature increases in other animals, projected climate warming could contribute to disease in lynx. Therefore, although not a factor for lynx currently, it is not unreasonable that disease could impact lynx populations in the DPS in the future, so we may want to consider disease in future conservation planning. Experts also discussed the possibility that climate warming may facilitate the westward expansion of the spruce budworm outbreak that is projected for Maine and eastern Canada into southern Ontario and the Minnesota geographic unit.

Northwestern Montana/ Northeastern Idaho

Pre-graphing Overview from Unit Experts: There are likely 200-300 lynx in this unit in several subpopulations (expert stressed that this is a guess and not a true population estimate), and there is currently a connection with lynx in Canada. Climate models project that some boreal forest will persist in this unit and that it will maintain snow into the future. In this unit, lynx primarily occupy public lands, which are actively managed for lynx into the future. In recent decades, fires have occurred on a large scale, with high intensity and increasing frequency. There have been no documented cases of beetle infestations in lynx habitats in this unit.

Expert Responses: As for previous units, all expert graphs showed an initially high and subsequently decreasing probability of persistence for this unit, with increasing uncertainty over time, but a higher probability of persistence at all time frames than other units. All experts predicted near-term (year 2025) persistence probability >= 95%, and all predicted mid-century persistence at 70% to 100% (median = 90%). All experts predicted end-of-century persistence probabilities >= 50%, with a median of 78%, by 2100 (Figure 7).

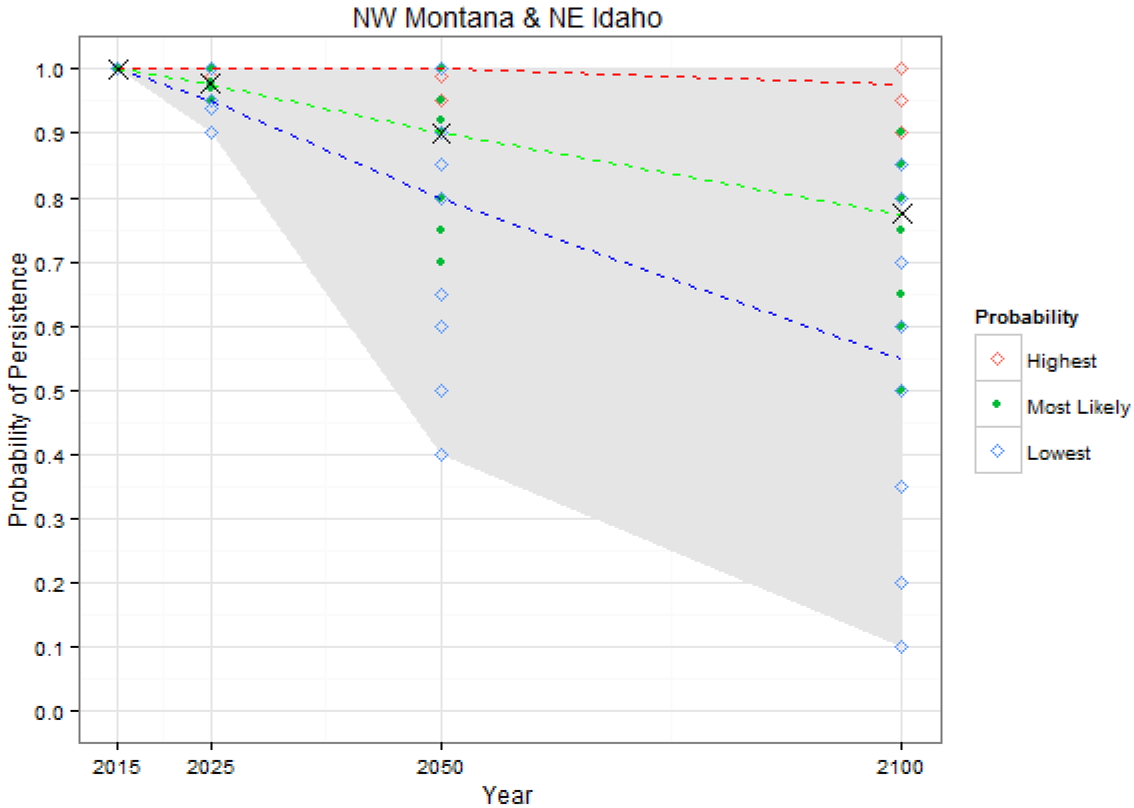

Figure 7. Expected probability of persistence for the Northwestern Montana/Northeastern Idaho geographic unit at present, 2015, and in 2025, 2050 and 2100.

Discussion Points Following Initial Responses: Overall, experts assigned a higher probability of persistence in this unit compared to the other two units discussed thus far. Most lynx habitats in this unit occur on Federal lands that are managed for lynx conservation, but one expert noted that little has been done to document whether lynx are responding to this management. The recent sale of large tracts of private commercial timberlands in the central part of this unit to The Nature Conservancy has increased protection for lynx via conservation easements managed for lynx. Habitats in some areas should improve in the near future as previously cut or burned areas mature into dense stands. Unlike the Maine and Minnesota geographic units (but similar to most other western units), high elevations in this unit could buffer the effects of climate change by providing for the upslope migration of lynx habitats and snow conditions that climate models predict. However, this would result in even patchier and more isolated islands of habitat in high elevation areas that would be more prone to extirpation due to catastrophic or stochastic events. Competition from coyotes and bobcats seem to be less of a concern for this unit.

This unit has unimpeded connectivity with Canada, but some experts questioned whether this geographic unit depends on intermittent immigration of lynx from Canada, and whether the historic lynx population cycles in Canada believed to have fueled such immigration are still occurring or will into the future. There doesn't appear to be much demographic input from recent cycles. There is evidence of lynx from this unit moving north into Canada, but little evidence of demographic interactions among the three subpopulations (Purcell Mountains, Seeley Lake, and Garnet Mountains) in this unit. Experts noted that the Garnets Mountains subpopulation at the southern end of this unit may have recently become extirpated.

Discussion among experts indicated that fire was more of a concern for this area. Increased fire extent and severity or other catastrophic events and small subpopulation effects in separated mountain ranges could affect lynx persistence in the future in some parts of this unit. Fire exclusion in this area for the last 100 years likely resulted in the accumulation of fuels; however, this unit may have a reduced probability of a catastrophic fire over time because of recent changes in management and recent fires that may have reduced fuels. Out to 2050 and beyond, some experts felt there may be more pressure on lynx populations in this unit from continued increases in fire extent and severity. Other experts expressed a different opinion of the overall effect of fire in this unit, indicating that it may actually improve habitat over time, and that whether fires improve or degrade habitat depends on the frequency, intensity, size and spatial extent of future fires.

Experts discussed the possibility for increased precipitation and warmer temperatures in this unit because of climate change, and how this might affect lynx habitats. Boreal/subalpine forest may move up in elevation as described above; however, experts expected a shift in forest composition and diminished lynx habitat quality in future with climate change. It is unknown how much the distribution of dry ponderosa pine (non-habitat for lynx) will increase with climate change, but it is likely to happen at some level. One expert reminded that some climate modelers estimated that vegetation will lag about 50 years behind the projected changes in temperature and precipitation. Snow levels in lower elevation areas are already decreasing in some areas, which could lead to smaller areas for lynx to use in winter in future.

North-central Washington

Pre-graphing Overview from Unit Expert: This geographic unit is thought to currently support roughly 50 resident lynx. There may have been more lynx prior to recent major fires. This unit is currently connected to Canada, and there is no indication that this connection will be disrupted. Some of the best lynx habitat in this unit occurs on plateaus that may be more vulnerable to impacts of climate change because of the absence of higher-elevation areas to which habitats, lynx and hares could migrate in response to warming. In areas that receive maritime climate influences, projected climate-induced changes to snow conditions could be detrimental for lynx. Studies have shown good lynx survival rates in this unit.

Expert Responses: Compared to the previous units, most expert graphs showed a lower probability of persistence for this unit over the short term, and then lower probability of persistence along with increasing uncertainty by 2100, reflecting a more pessimistic outcome for this unit compared to previous units (Figure 8). Experts predicted near-term (year 2025) persistence probabilities of 60% to 90% (median = 80%), and mid-century persistence at 30% to

80% (median = 70%). All experts predicted end-of-century persistence probabilities less than 50%, with a median of 38%, by 2100 (Figure 8). However, one expert predicted an increase in persistence probability by mid-century as habitats impacted by recent large-scale fires regenerate into optimal hare-lynx habitat.

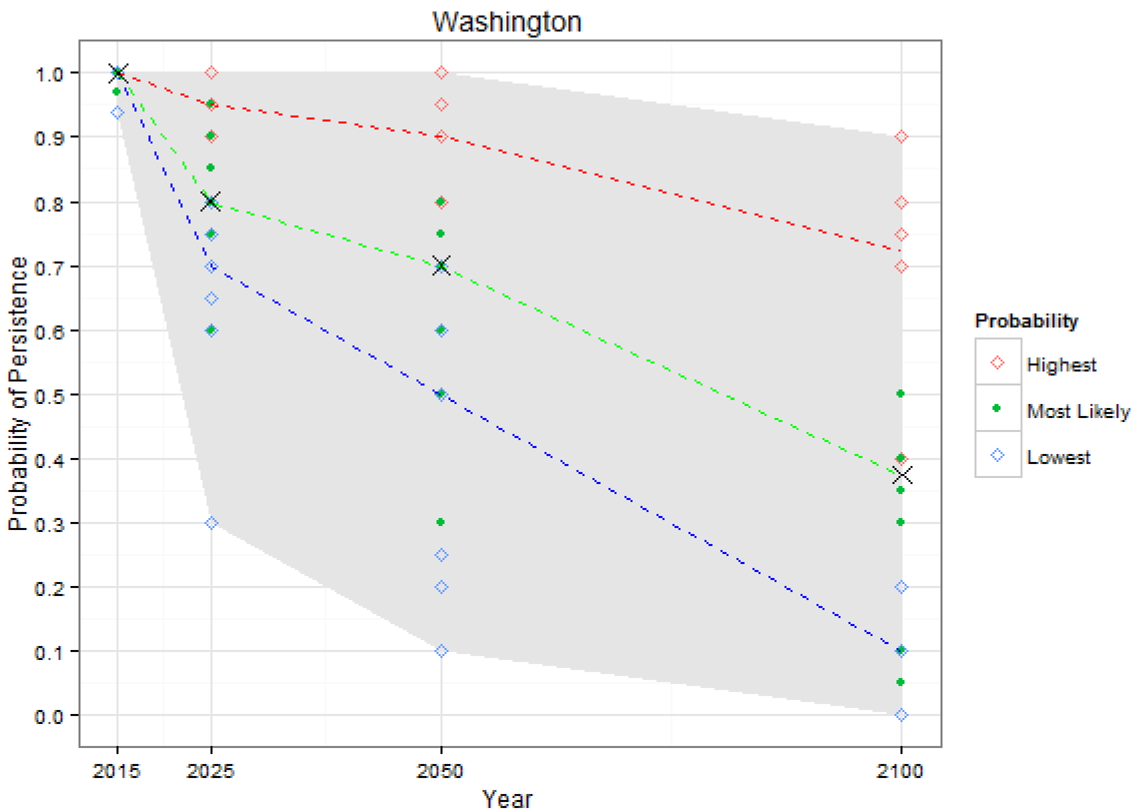

Figure 8. Expected probability of persistence for the North-central Washington geographic unit at present, 2015, and in 2025, 2050 and 2100.

Discussion Points Following Initial Responses: The probability of lynx persistence in this unit could decrease sharply over the next 10-20 years because of extensive recent fires in lynx habitats and the time needed for these areas to regenerate back to good hare/lynx habitat. After that, the probability could rebound (or decline more slowly) over the longer term as these large areas return to prime habitat providing high hare densities. The current small population is likely at greater risk of extirpation because of stochastic events, particularly if large fires in lynx habitat continue to occur in the near future as they have in the recent past. A small population also could be more susceptible to disease, though none has been documented among lynx in this unit. Experts discussed the extent to which small lynx populations could be reduced before they would become highly susceptible to stochastic demographic effects. It was suggested that 15-20 breeding individuals might be the minimum needed to avoid such susceptibility. Unimpeded connectivity between Canada and the Okanogan area of this unit could allow lynx to repopulate currently-unsuitable areas after the habitat recovers. Lynx in this unit are likely the southern portion of a larger population in Canada, not really a separate, isolated small population. Factors that influenced expert persistence probabilities for this unit included fire, habitat loss, and the future loss of favorable snow conditions predicted by climate change models.

Greater Yellowstone Area (GYA)

Pre-graphing Overview from Unit Experts: This unit has a long history of lynx presence, but the consistency of occupancy over time is uncertain. Research and surveys since 1997 have detected few lynx in this unit. Lynx are likely spatially limited within the unit because of the patchy distribution of high-quality habitat and the generally low or marginal hare densities in much of the unit. Lynx have large home ranges in this area, an indicator of lower habitat quality. Nevertheless, until recently, this unit appears to have supported a small resident lynx population. The current lynx population in this unit is very small - likely fewer than 10 lynx, and possibly zero. This population may have been somewhat larger in the past; however, there is some uncertainty about this. Recent surveys and trapping efforts have not detected resident lynx, only several that were previously released in Colorado. Several Colorado-released lynx have established home ranges in the GYA unit, and there is evidence of overlapping male and female home ranges. In the late 1800s and early 1900s, there was notable predator control in some parts of this unit. There currently is oil and gas exploration and development activity in parts of this unit, but potential impacts to lynx are uncertain, and projects are attempting to minimize impacts to lynx habitat.

Expert Responses: The expert graphs for this unit were widely variable and had different outcomes and high uncertainty at all time frames. Experts predicted near-term (year 2025) persistence probabilities of 10% to 70% (median = 52%), and mid-century persistence at 15% to 60% (median = 35%). All experts predicted end-of-century persistence probabilities less than 50% for this unit, with a median of 15%, by 2100 (Figure 9). This was the only unit for which most experts believed the present probability of persistence is low (i.e., that it is uncertain whether this area currently supports a resident lynx population). Some experts increased probability of persistence into mid-century as the 1980s-era fires regenerate into hare/lynx habitat, and with the possibility of continued immigration of lynx from Colorado. Other experts project a 10% to 20% probability of persistence by 2100. One reason given for wide variability in responses is because of the uncertainty whether a population currently exists. There were wide confidence intervals around the probabilities for all time periods for this area.

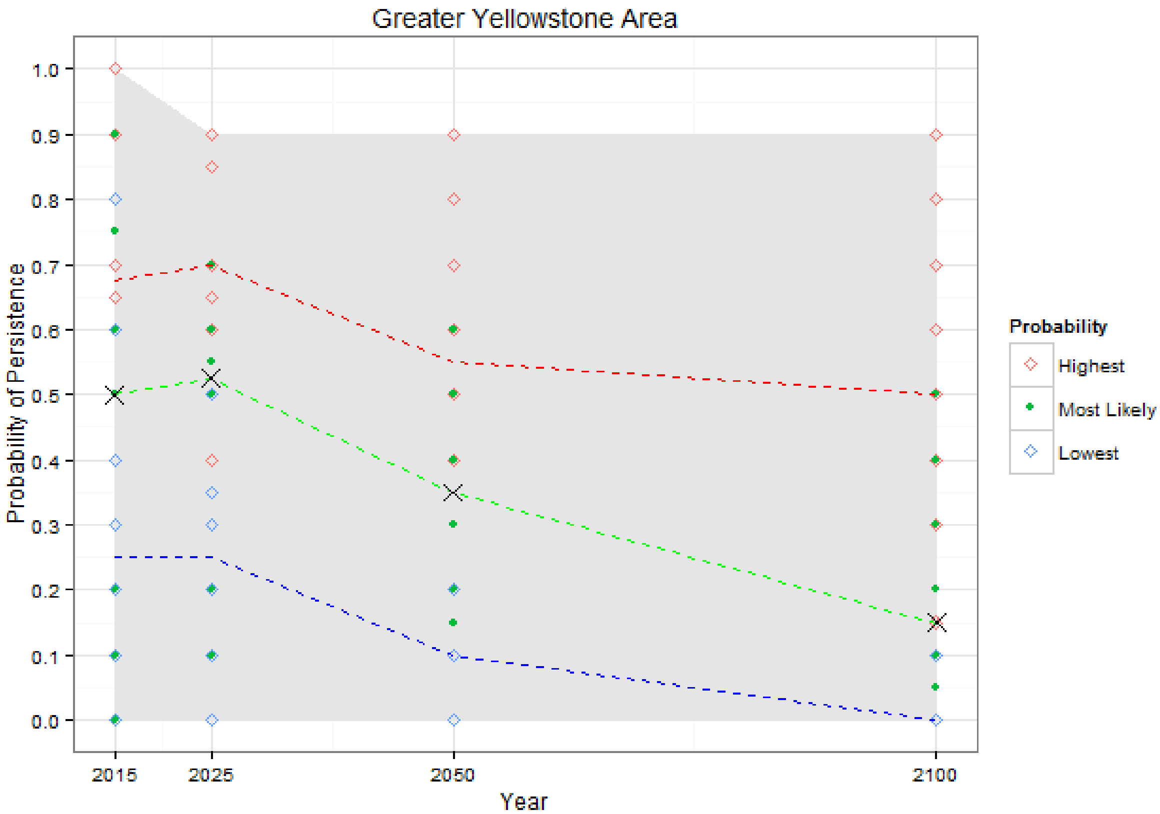

Figure 9. Expected probability of persistence for the GYA geographic unit at present, 2015, and in 2025, 2050 and 2100.

Discussion Points Following Initial Responses: Current and future factors expressed by experts as influencing probability of persistence for this unit included small population size, forest disease and insect pests, and fire. Some experts doubt that the GYA unit currently supports a resident breeding population of lynx. Experts indicated that climate models predict that some parts of the GYA unit could provide refuge from climate change impacts because of their high elevations and potential to maintain winter snow levels into the future. Summer conditions in this unit, however, could be drier in the future, resulting in increased fire frequency, extent and intensity, and additional temporary habitat loss. However, regeneration of these areas and the extensive areas that have burned in the recent past may provide good habitat over the next several decades. Lynx immigrating to this unit from Colorado could occupy such improved habitats in the near future. Colorado lynx have made exploratory movements into the GYA in summer months, and analysis of available data could improve our understanding of Colorado lynx movement into and use of the GYA. It is possible that lynx from Colorado are maintaining or could maintain lynx in GYA.

Western Colorado

Pre-graphing Overview from Area Expert: From 1999 to 2006, Colorado Division of Wildlife (CDOW; now Colorado Parks and Wildlife [CPW]) released 218 Canadian and Alaskan lynx into western Colorado. Survival and litter sizes have been similar to rates observed in other DPS populations. There are probably 100-250 lynx in Colorado today. There are currently 5-6 million acres of habitat in this unit thought capable of supporting lynx and where hares are present in sufficient numbers to support persistent reproduction. Extensive bark beetle infestations have impacted large areas of lynx habitat, but snowshoe hare are still occupying areas with beetle damage. Three large fires have occurred in recent years, resulting in some lynx habitat burned. Salvage operations in burned areas could diminish future habitat quality. This unit is more isolated from Canadian and other DPS lynx populations; separated by a large swath of inhospitable habitat. Road mortality of released lynx was initially high but it doesn't seem to be a problem now (about 1 per year killed on roads on average since the first year of the reintroduction). There is no incidental take from trapping because foothold traps are banned in Colorado. Climate models show CO will maintain habitat over time with anticipated climate changes. Like other western units, habitat is patchily-distributed across this unit.

Expert Responses: Similar to most of the other units, most expert graphs indicate an initially high probability of persistence in this unit that will decline gradually with increasing uncertainty through the end of the century. Experts predicted near-term (year 2025) persistence probabilities of 60% to 100% (median = 90%), and mid-century persistence at 50% to 85% (median = 80%). Experts predicted end-of-century persistence probabilities of 20% to 70% for this unit, with a median of 50%, by 2100 (Figure 10).

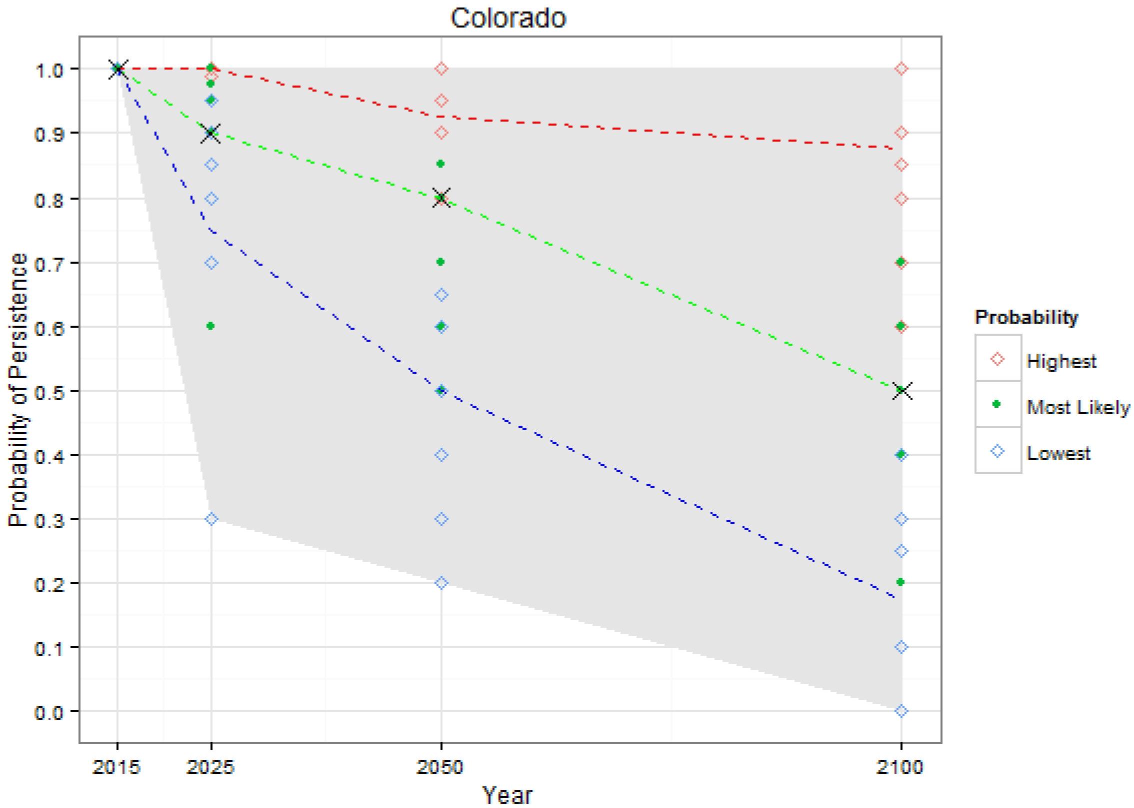

Figure 10. Expected probability of persistence for the Western Colorado geographic unit at present, 2015, and in 2025, 2050 and 2100.

Discussion Points Following Initial Responses: Some experts indicated that beetle kill and fire could potentially create poor habitat conditions in large areas of this unit by mid-century, but that regeneration after these impacts could result in good lynx/hare habitats. Others expressed uncertainty about whether fire and insect impacts would be temporary or permanent, especially considering climate change and the potential for conversion from boreal/subalpine forests to other forest types. Although 8 of 10 experts graphed 50% to 70% probability of persistence at 2100, during subsequent discussions, several expressed greater uncertainty about whether resident lynx will persist in the unit at the end of the century. Higher-quality lynx habitat occurs primarily in two areas and is patchily-distributed. Lynx in this unit may occur as several smaller, relatively isolated subpopulations, which are likely more vulnerable to stochastic events (similar to MT). This unit's relative isolation may limit exchange with other lynx populations, increasing the likelihood of genetic drift and reducing the chance of demographic rescue or recolonization if extirpated. There was discussion about whether ski areas may affect daily movements of lynx, and hares may be declining in ski areas. Ski areas tend to expand and may, therefore, have larger impacts on lynx in future. There is some evidence of lynx using ski areas in summer months but avoiding them during the ski season. It is uncertain whether ski areas may affect genetic connectivity within the Western Colorado geographic unit. Two-thirds to three-quarters of the lynx in this unit are in the southern portion of the range in the San Juan Mountains. There is a large area (Weminuche Wilderness) in Colorado that has not been well surveyed for lynx, so it is possible that lynx also could be using that area.

Summary across Geographic Units

This section extrapolates from the probability of persistence responses for each geographic unit in the section above. In this section we show the combined probabilities of persistence for those geographic units to provide a sense of what the DPS-wide results could be when the results for the individual geographic units are combined. This is shown as a summary of the probability that a given number of geographic units persist into the future (See Figure 11) using the probabilities provided for each individual unit. Note that no additional information was elicited to produce this summary; rather, the probabilities for each geographic unit were treated as independent probabilities of persistence and used to determine the joint probability of persistence for a given number of geographic units in total. Computationally these joint probabilities were computed using a convolution of the Bernoulli probability distribution of persistence for each geographic unit via a custom convolve function executed in the statistical software R (see Appendix 6 for the R code used to produce these and the other summaries and figures presented in the report). The results of this convolution are shown in two forms, first is the probability that a particular number of geographic units persists (Figure 11) and the second is the cumulative probability that at least a given number of geographic units persist (Figure 12).

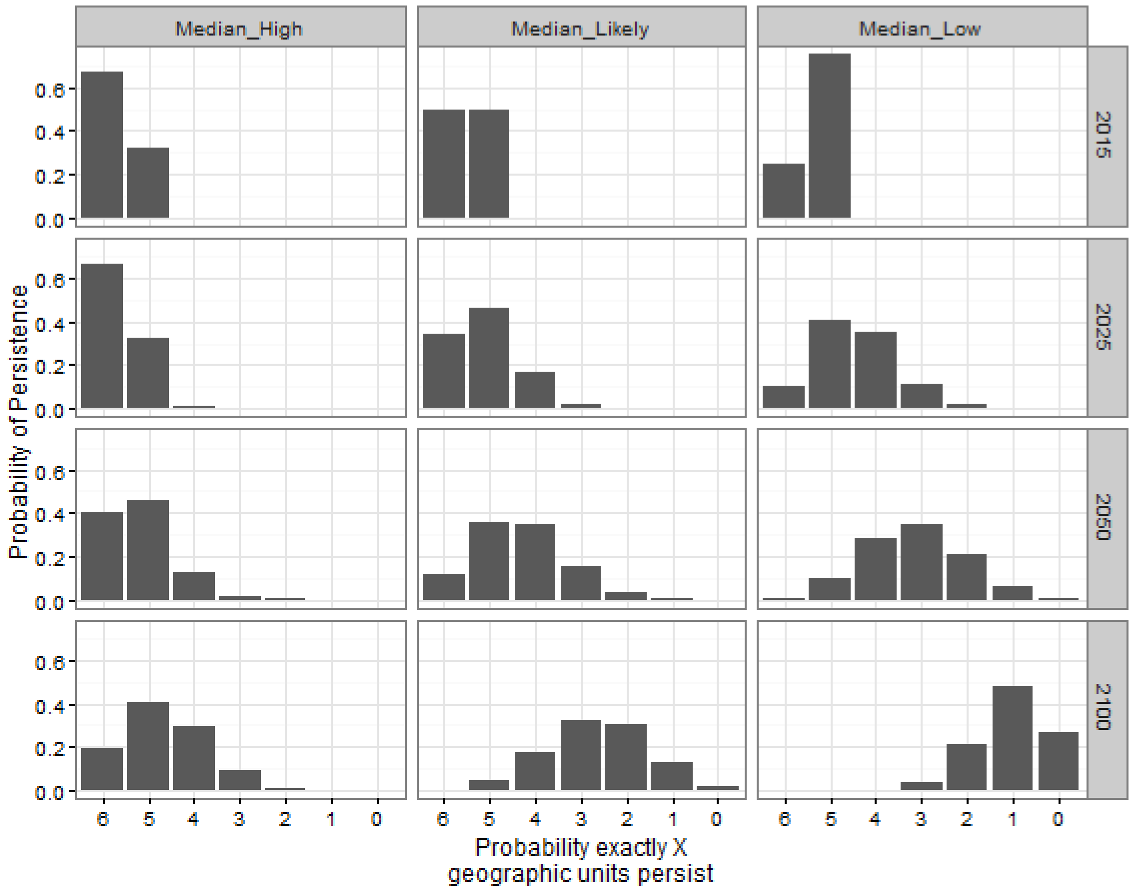

Figure 11. Summarized probability of persistence of a given number of geographic units given the probability of persistence for each individual geographic unit.

The y axis of each grid in Figure 11 is the probability that the specific number of geographic units indicated by the x axis of the grid persist. The probability sums to one in each grid. Moving from top to bottom the grids show the probabilities of a specific number of geographic units persisting by time period (2015, 2025, 2050, and 2100). Moving from left to right the grids show the range of expert responses by selection type and probability response.[6] Therefore looking down a column of grids provides a view of the trend in persistence through time and looking across a row of grids provides a view of the range of uncertainty in persistence experts had for a given time period. The summarized probabilities presented here are provided to aid understanding of the implications of the individual persistence probabilities provided above, and

[6] "Median_High" is the probability of persistence generated by selecting the ***median*** probability of persistence across experts from the ***highest*** probability response in each geographic unit. "Median_Likely" is the probability of persistence generated by selecting the ***median*** probability of persistence across experts from the ***most likely*** probability response in each geographic unit. "Median_Low" is the probability of persistence generated by selecting the ***median*** probability of persistence across experts from the ***lowest*** probability response in each geographic unit.

are derived directly from those responses and therefore should be presented and considered in conjunction with those figures.

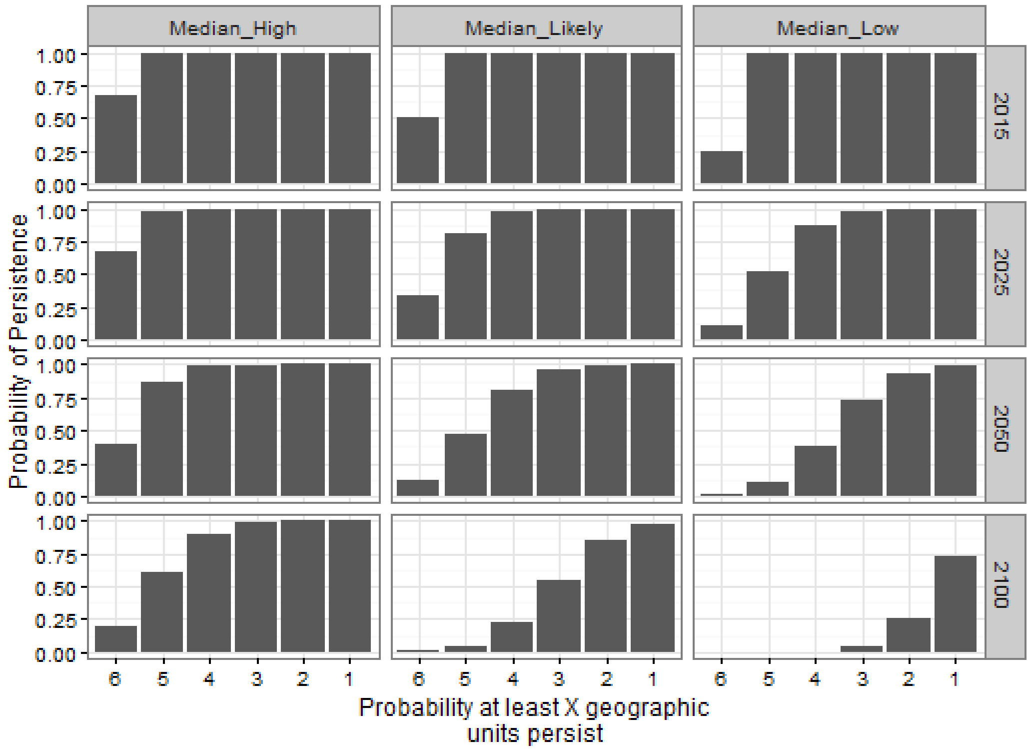

Figure 12. Summarized probability of persistence of at least a given number of geographic units given the probability of persistence for each individual geographic unit.

The y axis of each grid in Figure 12 is the probability that at least the number of geographic units indicated by the x axis of the grid persist. The probability in a bar reaches 1 when there is no probability of fewer geographic units persisting. Moving from top to bottom the grids show the probabilities by time period (2015, 2025, 2050, and 2100). Moving from left to right the grids show the range of expert responses by summary selection type and probability response as in Figure 11. Therefore looking down a column of grids provides a view of the trend in persistence through time and looking across a row of grids provides a view of the range of uncertainty in persistence for a given time period. The summarized probabilities presented here are provided to aid understanding of the implications of the individual persistence probabilities provided above, and are derived directly from those responses and therefore should be presented and considered in conjunction with those figures.

Expert Assumptions during Persistence Graphing Exercises

Experts were asked to summarize the assumptions that informed their responses to resiliency questions 1 and 2. This was done via open discussion, with facilitators asking both direct questions about particular issues that could impact responses (e.g., climate change conditions), and open ended questions (e.g., what other assumptions were considered?).

Notes: Climate-change emissions scenarios considered during this exercise differed among experts (and some responses did not indicate an emissions scenario). However, in discussions following the graphing exercise, experts indicated that the confidence intervals around their persistence probabilities were likely to capture the variance associated with different emission scenarios and other climate change uncertainties.

Experts were asked whether regulatory protections influenced their predictions. Some experts assumed the status quo (i.e., continued protections under the ESA and current Federal and State land management policies). Others indicated their persistence probabilities were not influenced by regulatory considerations but that doing so would not have altered their projections. Their focus was on the biology and ecology of the species, not listing status-related impacts or regulatory scenarios in the future, and they felt that factors influencing lynx persistence on the landscape are independent of ESA listing status.

Experts were asked what they meant by “small population size effects.” They explained that because small populations are more vulnerable to both demographic and genetic impacts and at increased risk from catastrophic and other stochastic events than are larger populations, they also have a lower likelihood of persistence. Experts indicated that connectivity with other populations reduces the vulnerability of small populations as it does for larger populations.

Experts were asked if their projections were influenced by considerations of whether historical patterns of cyclic irruptions of lynx into the DPS from Canada will continue in the future. Most agreed that the magnitude of irruptions has declined from the historical highs of the 1960s and 1970s, and that irruptions may have ceased in recent decades in some parts of the range, particularly in the West. However, most experts felt that connectivity remains good between Canada and those DPS geographic units that abut the international border, and most assumed some level of regular or intermittent interaction between lynx in those units and Canada, even if full-blown irruptions have not been documented recently. Some experts said that the likelihood of future irruptions had little influence on their persistence graphs, especially for the more isolated units (GYA and Western Colorado), where an influx of lynx from Canada may be less likely.

Conservation Actions to Address Influencing Factors and Increase Probability of Persistence

3. What conservation actions could be taken that would address the factors impacting the probability of persistence, or would otherwise increase the probability of persistence?

Response Type: Individual list with rounds responses. Experts were given 5 minutes to write a list of three potential conservation actions that could be taken. Facilitators then asked one expert at a time to provide one item from their list, cycling through the set of experts until all experts had exhausted their lists. Experts were given the opportunity to add items when it was their turn that had not been on their written lists. Experts were not asked if they agreed with conservation actions presented by other experts, thus the following list should not be viewed as consensus among lynx experts.

Expert Responses: List of potential conservation actions in the order provided.

- Reduce CO^2 emissions
- Continue protections associated with Federal and/or State listing
- Adjust forest management to retain spruce and fir, and reduce fire burn rates
- Promote/maintain habitat connectivity with Canadian populations through coordinated cross-border land use planning
- Manage salvage logging associated with fire and insect damage to minimize impacts to and/or facilitate restoration of lynx/hare habitats
- Configure and design lynx-friendly landscapes at appropriate scales; design and maintain a mosaic of lynx/hare habitats
- Manage fuels reduction (fire management) projects while maintaining or enhancing hare/lynx habitat features.
- Augment small populations and reintroduce lynx to former, historic range with suitable habitat (GYA, Kettle Range in Washington, perhaps other areas); bolster populations before future climate change impacts
- Support additional research to fill knowledge gaps, particularly related to effectiveness of conservation efforts – it remains unclear exactly what is needed for lynx across the range to achieve/maintain viability (e.g., habitat quality/amount/distribution, landscape-level hare densities, forest conditions that support hares, etc.)
- Enhance cross-border cooperation with Canada to increase near-border lynx populations and maintain connectivity
- Consider cumulative impacts of mining, ski areas, oil and gas, etc., in management
- Promote reforestation of heavily fragmented areas (e.g., some parts of the GYA and Minnesota units); reduce fragmentation
- Apply strategic habitat conservation concepts; model and identify key areas and focus on those areas still in need of protection and management (e.g., private forest lands)
- Maximize redundancy of lynx populations throughout the DPS
- Implement fire management Best Management Practices (BMPs)(e.g., allow/encourage burns to occur in a way that creates high- and low-intensity mosaic fire patterns)
- Evaluate whether there is a need for monitoring lynx (and hares) using consistent methods throughout the DPS, perhaps coupled with monitoring of other carnivores; structured occupancy modeling with genetics sampling could be very informative and is cost effective; also known-fate monitoring; monitoring pellet plots is proven and reliable way to monitor hares
- Devote increased funding to lynx conservation - lynx are in worse shape than other mesocarnivore species, but receive less funding than those species that have more secure populations and appear less vulnerable to climate change

Other Considerations

After completing the elicitation exercises and prior to adjourning the workshop, facilitators asked if there were any other considerations the lynx experts or subject matter experts felt are relevant to the SSA. One subject matter expert indicated that monitoring of prey base (hares, red squirrels) would help inform lynx recovery, and that pellet-based or mark-recapture methods are most reliable. This expert suggested a need to determine whether areas that we think are going to become poor habitat for a variety of reasons could still hold hares and lynx in the future. Maybe hares still can use areas we think will be poor habitat, and monitoring these areas could help inform our understanding of how lynx persist at the edge of their range.

Synthesis

Although uncertainty remains about the historical distribution and sizes of resident lynx populations in the DPS, as well as current population sizes, much more is known now than when the DPS was listed under the ESA in 2000. Based on research conducted since the DPS was listed, including the summaries of that work provided at this workshop, as well as ongoing research, conservation, and management efforts, we have a much better understanding of the distribution and status of populations throughout the DPS range. For example, in 2000, it was unclear whether Maine and Minnesota supported resident populations or were only occasionally visited by lynx dispersing from Canada during and after northern hare population crashes. We now know that both northern Maine and northeastern Minnesota support resident lynx populations, and both are likely larger now than they were historically (Maine), or before they were protected by State and Federal regulations (Minnesota). In contrast, resident lynx appear to be naturally less abundant and more patchily-distributed in some parts of the DPS than thought at the time of listing, including the West (Interagency Lynx Biology Team 2013, p. 23), where potential lynx habitats also appear to have been initially overestimated. We also have a better understanding of the habitat features and hare densities that appear necessary to support resident lynx at the southern margin of the species' range, and of the parts of the contiguous U.S. that contain these features. The presentations in conjunction with expert elicitation responses at this workshop have informed and refined our understanding of key aspects of the status of, and potential threats to, the lynx DPS.

For example, we were provided a thorough history of the evolution of regulatory mechanisms that have been developed and implemented through conservation agreements and formal amendments to Federal agency management plans to address the singular threat for which the DPS was listed under the ESA - the inadequacy of regulatory mechanisms in Federal land management plans prior to listing. Given our improved understanding of resident lynx populations in Maine and Minnesota (above), where State and private lands constitute much more of the lynx habitat than elsewhere in the DPS (98.9% in Maine; 51.7% in Minnesota), an assessment of the adequacy of regulatory mechanisms on those State and private lands will be a necessary component of the status assessment. Likewise, our understanding of lynx genetics also has improved, with evidence of continued high levels of gene flow range-wide, despite fine-scale genetic sub-structuring in some populations and additional evidence of lynx hybridization with bobcats. Bobcats appear to be encroaching at the edge of the lynx range in Minnesota (Appendix 3, p. 9) and their numbers appear to have increased recently in New Hampshire, Vermont, and southern Quebec (Lavoie *et al*. 2009, entire; Roberts and Crimmins 2010, p. 170; Broman *et al*. 2014, p. 230) adjacent to the northern Maine lynx distribution. Whether this represents a threat to lynx populations in Minnesota and Maine via increased hybridization, behavioral mechanisms, or competition for hares is not documented at this time; however, encroachment of bobcats in the southern periphery of lynx range may result in lynx displacement or niche contraction (Peers *et al*. 2013, entire).

Canadian researchers also provided updated information on lynx status, management (including legal harvest), threats, genetics, and hare population cycles in southern Canada, adjacent to some DPS lynx populations. Forest ecologists and climate modelers also presented information regarding potential impacts of timber management and climate change on lynx and boreal forest habitats in the contiguous U.S. Knowledge of lynx and hare responses to various silvicultural treatments continues to improve, although the need for continuing research remains. Climate models continue to point toward the future northward and upslope migration of lynx and hare habitats and loss of snow conditions favorable to lynx, although uncertainty remains regarding the timing, extent, and biological consequences of such impacts. Increases in the size, intensity, and frequency of wildfires and insect outbreaks in boreal/subalpine forests may also be related to climate change, but whether these represent temporary or permanent impacts to lynx habitats remains unclear. Finally, much research has been done on hare population dynamics and habitat relationships at the southern extent of their range, much of which overlaps that of lynx in the contiguous U.S., but questions remain regarding regional variation in hare densities and what landscape-level hare abundances are necessary to support persistent resident lynx populations across the DPS.

Based on the summaries of post-listing research and the status and threat updates provided at this workshop, and on the results of the expert elicitation process, the Service provides the following synthesis of the status and likely viability of the DPS in terms of the 3 Rs. This information will be considered as appropriate, along with more detailed analysis of the published literature, in the subsequent SSA report for the DPS. The conclusions below are based on the information provided and the results of expert elicitation conducted at this workshop; they may be complemented or altered by the additional analyses yet to be conducted as part of the SSA process.

Representation

Expert presentations on lynx genetics in the DPS and in Canada and expert responses and discussion with regard to representation questions suggest few threats to the genetic fitness or adaptive capacity of lynx in the DPS. High gene flow across the continental lynx range, indicated by very low F_{st} values (see *Subject Matter Presentations*, above), suggests the absence of substantial barriers to genetic interchange, and little evidence or risk of significant genetic drift among DPS populations. Most experts indicated that none of the six geographic units known or thought to support lynx populations in the DPS is susceptible to meaningful genetic drift, although several experts indicated that the more geographically isolated units (the GYA and Western Colorado units) are likely more susceptible to such drift than the units that are directly connected to lynx populations and habitats in Canada. Overall, according to both the expert panel and the subject matter presentations, there appears to be a low risk of biologically consequential drift for lynx populations in the DPS. Likewise, expert responses indicated that the generally low level of genetic differentiation and relatively similar ecological settings across the DPS suggest little life history variability or niche differentiation among DPS populations that would indicate that any are more or less important to maintain than others in terms of representation. Individual experts indicated that representation can best be maintained by conserving current DPS populations (and hence the genetic variation in each), maintaining connectivity between DPS and Canadian populations, and avoiding impacts that would facilitate or increase the potential for or likelihood of genetic drift. Our interpretation of this part of the elicitation is that the adaptability and evolutionary capacity of the DPS over time does not appear to have been diminished and is unlikely to become so, independent of threats that may impact the redundancy and persistence of lynx populations. We will consider this information along with available empirical data and the published literature when evaluating representation in the DPS for the SSA.

Redundancy

With resident lynx populations and subpopulations in at least five of six large (the smallest is over 2,000 square miles, the others are all over 8,000 square miles), widely-distributed (from Maine to Washington and south along the Rocky Mountains), and relatively discrete geographic areas (see Figure 1), the DPS as a whole appears invulnerable to extirpation from a single catastrophic event. Expert responses indicated no catastrophic event that could result in the functional extirpation of the entire DPS and, further, no or a very low likelihood of functional extirpation of any of the individual geographic units due to a single catastrophic event. We interpreted these responses to indicate there is a small chance of decreased redundancy from a single catastrophic event because the probability of any geographic unit being lost to a catastrophic event is low. Experts indicated that functional extirpation of the geographically smallest unit (Washington) and those supporting the fewest resident lynx (Washington, GYA, and perhaps Minnesota) would be more likely to occur as a result of a series of catastrophic events over a 10-year period than to any single event over the next 10 years (see Figure 2 above). Experts listed fire, drought, insect outbreaks, loss of favorable winter conditions, and disease as potential events that could lead to functional extirpation in these units. In Washington in particular, where large fires have impacted nearly 40 percent of the occupied lynx habitat over the past 10-15 years, experts felt that several more successive years of such fires could result in functional extirpation. However, because fire and insects are likely to cause only temporary (20-40 years) losses of lynx and hare habitats, and because connectivity between the Washington unit and lynx habitats and populations in southern British Columbia remains intact, experts indicated this unit (and others abutting habitats and lynx populations in Canada) would likely be naturally re-colonized relatively quickly by dispersing lynx. Therefore, extirpation in these units because of catastrophic events (or a series of them over time) would be temporary (likely lasting only one or several decades) unless events permanently altered the habitats. Experts indicated that if lynx were functionally extirpated in the GYA or western Colorado units, which are not connected to habitats or populations in Canada and are relatively isolated from other DPS populations, natural re-colonization would be less likely, would take longer, or may never occur.

Overall, expert responses indicated that extirpation of the DPS as a whole, or of resident lynx populations in most individual geographic units, because of a catastrophic event is very unlikely. Because we lack evidence that persistent resident lynx populations occurred historically but have been lost from any other large geographic areas in the contiguous U.S., it also seems that redundancy in the DPS has not been meaningfully diminished from historical levels. That is, the loss of resident lynx populations in the DPS, to the extent suggested by the historic record, was likely in areas (e.g., northern New Hampshire, Michigan's Upper Peninsula, the Kettle/Wedge area of northeastern Washington, perhaps Isle Royale in Lake Superior) peripheral to the geographic units that currently support resident lynx, and not in discrete geographic units that would have represented greater redundancy in the contiguous U.S. However, the implications of the potential recent loss of resident lynx in the GYA for the redundancy of the DPS are unclear. The historic record and recent research show that the GYA has supported resident lynx, but it is unclear whether the area consistently supported a persistent resident population over time or whether it naturally supported resident lynx only some of the time (was "winked on" in a metapopulation sense) when habitat conditions and hare densities were favorable, and at other times, when habitats and hare densities were less favorable, it did not support resident lynx ("winked off" in a metapopulation sense). Given the protected conservation status of millions of acres in the GYA unit (Yellowstone and Grand Teton National Parks; all or parts of the Absaroka-Beartooth, Bridger, Gros Ventre, Lee Metcalf, Northern Absaroka, Teton, and Washakie Wildernesses), its apparent recent inability to support resident lynx may be a reflection of naturally marginal and patchy habitats and relatively low hare abundance in much of the unit, resulting in only an intermittent ability of this unit to support resident lynx. If so, its contribution to redundancy within the DPS is questionable.

Resiliency

Because we lack reliable estimates of the sizes and trends of most lynx populations in the DPS, we are unable to use these parameters to evaluate the resiliency of individual populations or the DPS as a whole. Efforts to understand resiliency are also confounded by the metapopulation structure thought to govern lynx populations at the southern margin of their continental range (i.e., populations and subpopulations in the DPS), the related uncertainty about the extent to which DPS populations may rely on cyclic immigration of lynx from Canada during population irruptions, and the ambiguity in the historic record that limits our understanding of the relative persistence of lynx in various geographical areas of the contiguous U.S. and, thus, the contribution of those areas to the viability of the DPS. Our evaluation of the resiliency of lynx populations in the DPS is limited, therefore, to a largely qualitative assessment of the current status of populations in each of the six geographic units along with the quantitative summary of expert professional judgment of their likelihood of persistence over time given known or perceived potential threats.

As expected, both expert estimates of probability of persistence and expert confidence in those estimates were higher over the short-term than the long-term. Median probability of persistence (MPOP) at year 2025 was >= 0.90 for all but one of the six geographic areas. The GYA had a MPOP of 0.52, apparently reflecting the uncertainty regarding whether this unit consistently supported a resident lynx population historically and whether it currently supports resident lynx. At year 2025, confidence bounds were smallest (indicating higher expert confidence) for the units with the highest MPOPs (Northern Maine, Northeastern Minnesota, and Northwestern Montana/ Northeastern Idaho), and larger for units with lower MPOPS (North-central Washington, GYA, and Western Colorado). At mid-century, MPOP declined for all units but remained >= 0.70 for all but the GYA (0.35), and confidence bounds increased for estimates for all units but the GYA, where it remained the same as at year 2025. At end-of-century, persistence probabilities declined further, as expected, and only the Northern Maine, Northwestern Montana/ Northeastern Idaho and Western Colorado units had MPOPs >= 0.50. Also as expected, confidence bounds were very large around persistence estimates at year 2100, with the median confidence range extending across more than 50% of the range of possible outcomes for all but the Northwestern Montana/ Northeastern Idaho population, and the extremes of the range nearly covering the full range (0% to 100% probability of persistence) of possible outcomes.

Experts listed a number of factors that influenced their probability of persistence estimates for each unit (see unit summaries above in the *Resiliency* section). Near-term factors varied by unit (e.g., post-harvest forest succession in Maine, where hare abundance is expected to decline as currently dense regenerating clear-cuts mature; continued large-scale fires in lynx habitats in Washington; and insect outbreaks in Maine, Minnesota, and Colorado), but longer term factors seemed to coalesce around anticipated direct and indirect effects of climate change. These included potentially climate-driven increases in the size, frequency, and intensity of fire and insect outbreaks; decreases in snow amount, duration and quality, leading perhaps to increased competition with bobcats and other hare predators; and the projected warming-induced northward and upslope migration of boreal and subalpine forests that would result in the loss and further fragmentation and isolation of lynx and hare habitats in the contiguous U.S. Expert responses and ensuing discussions indicated that continued climate warming and associated direct and indirect effects will likely exert the greatest negative influence on the probability of persistence for lynx populations in the DPS regardless of which climate emissions scenario is used to model future conditions, although the timing, extent, and magnitude of impacts is uncertain and will likely vary by scenario.

Overall, expert responses to this part of the elicitation indicate that all five of the geographic units known to currently support resident lynx populations have a greater than 70% expectation of doing so by mid-century, but a declining likelihood and greater uncertainty of doing so by the end of the century. It is uncertain whether the remaining geographic unit (the GYA) currently supports resident lynx, and expert responses indicate a lower probability that it will do so in the future compared to the other units. Responses also suggest that the overarching threat to the long-term persistence of lynx populations in the DPS is climate change, which is anticipated to result first in loss of snow conditions favorable for lynx and, after an uncertain lag time following continued climate warming, loss (northward and upslope migration) of boreal forest habitats, although the timing and magnitude of such losses are uncertain.

Conclusion

The Service and the Lynx SSA Team appreciate the willingness of lynx and subject matter experts to attend this workshop and share their knowledge, professional judgments, and opinions. We have gained considerable insight into the current status of lynx populations throughout the DPS and the factors most likely to influence the DPS's future viability - including information that is not currently available in the peer-reviewed literature. We will incorporate this information into the SSA as appropriate, along with the published scientific literature, to inform recovery planning for the DPS and any other ESA-related determinations the Service is authorized and required to make. As we develop the SSA report, we will continue to solicit expert input from workshop panelists and from other lynx and subject matter experts who were unable to attend this workshop, including peer review of the SSA report.

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Appendices

All appendices are available on the Service's Region 6 Canada lynx webpage (http://www.fws.gov/mountain-prairie/es/canadaLynx.php).

U.S. Fish & Wildlife Service

The Species Status Assessment Framework

An Integrated Framework for Conservation

"The greatest danger in times of turbulence is not the turbulence; it is to act with yesterday's logic."

— Peter Drucker

Although significant progress has been made in safeguarding species and their habitats, limited resources and an ever-increasing workload jeopardize our long-term effectiveness at fulfilling our responsibilities. In addition, novel and significant conservation challenges lie ahead, including a changing climate. While we continue to build on our successes, ensuring successful conservation and recovery of the nation's species requires an increasing commitment to new ways of thinking, working, and sharing. From a budgetary and conservation standpoint, we simply cannot afford business as usual. The Species Status Assessment (SSA) Framework, in concert with other transformative efforts, better allows us to meet the complex challenges ahead and guide our efforts to continually enhance our conservation success.

The SSA Framework

The SSA Framework is an analytical framework for assessing a species' biological condition and level of viability. Building on the best of our current analytical processes and the latest in conservation biology, this framework integrates analyses that are common to all ESA functions, eliminates duplicative and costly processes, and allows us to strategically focus on our core mission of preventing extinction and achieving recovery. In addition, the SSA Framework provides a structure for effectively engaging with our State partners and soliciting peer review.

Our Vision

Our vision is a common, consistent, repeatable, scientifically sound approach that will serve as the basis for future ESA decisions. Using the SSA Framework early provides the context for a decision on whether protections are warranted, then for decisions regarding what is needed for its conservation and recovery, what the greatest research needs are, and how public or private actions may affect the species. Staff in each region are available to provide support and training to help ensure we continue to build on the successes the SSA Framework has already delivered.

"The Species Status Assessment offers a unique opportunity to transform how the U.S. Fish and Wildlife Service delivers conservation."

– Gary Frazer, Assistant Director
Ecological Services Program

Realized Benefits

By having the biological analyses in the SSA report, and referencing it in the proposed listing rule, we saved an estimated 65 pages of Federal Register printing – a $30,000 cost saving – for the New Mexico meadow jumping mouse proposed rule alone.

Efficiency – structured and repeatable biological analysis saves time

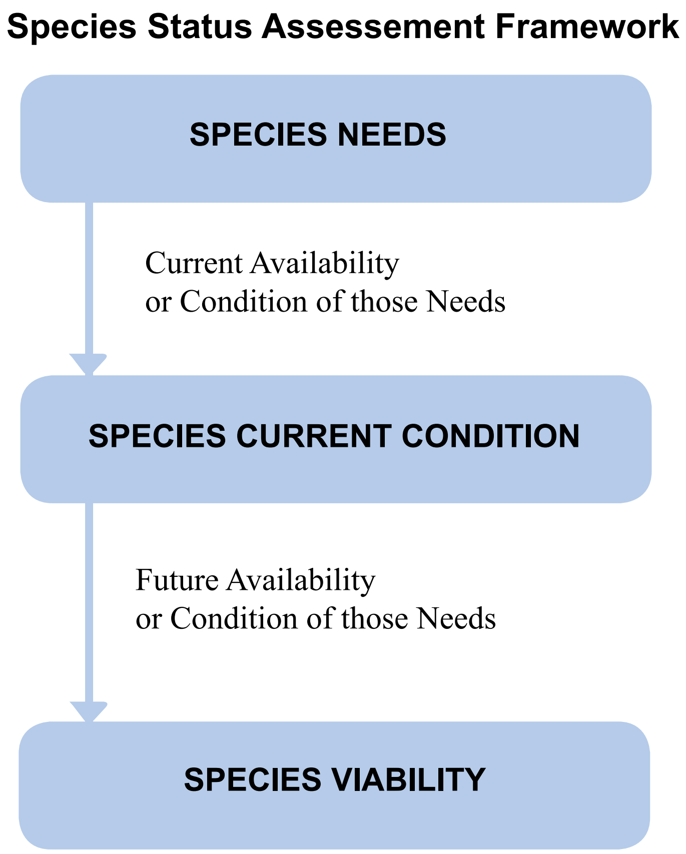
Defensibility – analysis grounded in accepted science and a logical process with explicit assumptions and complete reasoning will inform our statutory decisions

Consistency – consistent framework and terminology will be used across all ESA functions and across regions and field offices

Effectiveness – clearly articulated reasoned decisions will foster effective communication and make for better conservation

Collaboration – a better forum for being inclusive; partners, particularly States, are more likely to understand and support

New Mexico meadow jumping mouse.
Credit: USFWS



Assessing the species level of viability is achieved by completing the above assessment framework. Credit: USFWS

Gunnison's prairie dog. Credit: USFWS

Applying SSA

We begin an SSA with an understanding of the species' unique life history, and from that evaluate a species' needs or biological requirements at the scales of individuals, populations, and species. We then consider the current and future availability or condition of those needs and investigate the reasons those needs are missing. The consequences of any missing needs are assessed to describe the current condition of the species, and project the future species condition over time. Using the principles of resilience, representation, and redundancy, the species' level of viability and risks to its viability are evaluated and characterized. Generally, the more redundant, representative, and resilient a species is, the more likely it is to persist over time, even under changing environmental conditions. The characterization of viability is enhanced by estimates at multiple time intervals under a range of probable scenarios to describe the possible changes in viability over time and to characterize the uncertainty.

Where to Learn More

Visit **https://sites.google.com/a/fws.gov/ssa/** to see examples of SSA reports, connect with others who have applied the Framework, get answers to frequently asked questions, find contact information for your Region's SSA Framework Implementation Team member, and access the guidance on applying the draft SSA Framework.

"The SSA is an intuitive framework that, once completed, allowed me to more clearly and quickly develop, explain, and write my listing argument."

– Craig Hansen, Species Lead for Gunnison's prairie dog

U. S. Fish and Wildlife Service
Endangered Species Program
4401 N. Fairfax Drive, Room 420
Arlington, VA 22203
703-358-2171

March 2014

Appendix 2. Workshop Participants and Roles

Canada Lynx Expert Elicitation Workshop, October 13-15, 2015, Bloomington, Minnesota

Participant	Role	Affiliation
Baker, Richard	Observer	Minnesota Department of Natural Resources
Bell, Heather	Lynx SSA Team, Facilitator	USFWS - Headquarters
Bowman, Jeff	Lynx Expert Panelist	University of Trent, Ontario
Broderdorp, Kurt	Lynx SSA Team	USFWS - Western Colorado Field Office
Bush, Jodi	Observer	USFWS - Montana Ecological Services Office
Catton, Susan	Lynx Expert Panelist	USFS - Superior National Forest
Bjornlie, Nichole	Observer	Wyoming Game and Fish Department
Cummings, Jonathan	Lynx SSA Team, Facilitator	USGS - Patuxent Wildlife Research Center
Frelich, Lee	Subject Matter Expert – Boreal Forest	University of Minnesota
Hodges, Karen	Subject Matter Expert – Snowshoe Hares	University of British Columbia - Okanagan
Ivan, Jake	Lynx Expert Panelist	Colorado Parks and Wildlife
Jackson, Scott	Subject Matter Expert – Regulations	USFS - R1/National Carnivore Coordinator
Josh Lawler	Subject Matter Expert – Climate Change	University of Washington
Kolbe, Jay	Lynx Expert Panelist	Montana Department of Fish, Wildlife & Parks
Maletzke, Benjamin	Lynx Expert Panelist	Washington Department of Fish and Wildlife
McCollough, Mark	Lynx SSA Team	USFWS - Maine Field Office
McKelvey, Kevin	Lynx Expert Panelist	USFS - Rocky Mountain Research Station
Moen, Ron	Lynx Expert Panelist	University of Minnesota
Parkin, Mary	Lynx SSA Team, Facilitator	USFWS - Northeast Regional Office
Roberts, Nathan	Observer	Wisconsin Department of Natural Resources
Schwartz, Michael	Subject Matter Expert – Lynx Genetics	USFS - National Genomics Center
Simons-Legaard, Erin	Lynx Expert Panelist	University of Maine
Siren, Alexej	Subject Matter Expert – Climate Change	University of Massachusetts
Smith, Tamara	Lynx SSA Team	USFWS – Twin Cities Ecological Services Office
Squires, John	Lynx Expert Panelist	USFS - Rocky Mountain Research Station
Vashon, Jennifer	Lynx Expert Panelist	Maine Department of Inland Fisheries and Wildlife
Willey, Seth	Observer	USFWS – Mountain-Prairie Regional Office
Wilsey, Chad	Subject Matter Expert – Climate Change	California Audubon
Zelenak, Jim	Lynx SSA Team	USFWS - Montana Ecological Services Office

Canada Lynx SSA Expert Elicitation Workshop – Notes

Bloomington, Minnesota - October 13-15, 2015

U.S. Fish and Wildlife Service

*<u>Note to Reviewers</u>: These notes were taken by the U.S. Fish and Wildlife Service (Service) during a Canada lynx (*Lynx canadensis*) Expert Elicitation Workshop the Service convened to inform its species status assessment (SSA) for the Contiguous U.S. Distinct Population Segment (DPS) of lynx. The lynx DPS was designated as threatened under the Endangered Species Act (ESA) in 2000 due to the inadequacy, at that time, of existing regulatory mechanisms, particularly those governing management of federal lands. The SSA will rely on the best available information to evaluate the current status of, and the nature and magnitude of potential threats to, lynx populations and habitats within the DPS, and it will provide the scientific basis for determinations the Service is required to make in accordance with the ESA. The Service convened this workshop to elicit and capture the knowledge, professional judgments, and opinions of lynx experts to inform the SSA, particularly with regard to aspects of lynx population ecology for which we lack sound empirical data and which are not otherwise captured in the existing scientific literature or other sources of available information.*

These notes were reviewed, and in some cases amended with notes taken separately, by other members of the Lynx SSA Team in attendance. The notes were then sent to workshop experts and other participants for their reviews. <u>Annotations in these final notes, in the form of strikethrough and colored text, indicate where experts edited or clarified the notes pertaining to their presentations or responses during the workshop</u>.

The Service has prepared and disseminated to workshop participants a Workshop Report summarizing the proceedings and providing the Service's analysis and assessment of the information gathered at the workshop. These final notes constitute Appendix 3 of the Workshop Report. Presentations and some of the other materials referenced in these notes are also appendices of the Workshop Report, and they are available on the Service's Region 6 Canada lynx web page under Species Status Assessment *at: http://www.fws.gov/mountain-prairie/es/canadaLynx.php, as are other materials referenced here that are not appendices to the Workshop Report.*

<u>Workshop Attendees</u> - See Workshop Report, Appendix 2.

<u>Day 1</u>

<u>Introductory Presentations by USFWS</u>

Welcome and introduction from Jodi Bush, Field Supervisor of the Service's Montana Ecological Services Field Office. Thanks to everyone for joining us for this important meeting. As you know, we are here to assess the current condition and future viability of lynx in the contiguous U.S. distinct population segment (DPS). This workshop is intended to inform the Species Status Assessment (SSA) that we've undertaken for the DPS, which will inform future decisions we need to make under the ESA, including recovery planning. However, this workshop is just about the science and best professional judgments of the experts; we will not be discussing ESA policies or making decisions about the listing status of the DPS or future recovery goals or criteria, etc.

Goals/objectives/background – See Jim Zelenak Overview slides (this presentation and all others from the workshop are included in Appendix 5 of the Workshop Report and available at *http://www.fws.gov/mountain-prairie/es/canadaLynx.php*). Where data are lacking, elicit expert opinion on the status, threats, and future viability of the lynx DPS. Complete a SSA for lynx – will be the scientific underpinning for decisions on lynx in the future. SSA will inform recovery planning and 5-year review. Provided overview of listing history. Six areas within the range of the listed DPS currently or recently (GYA) support lynx populations.

Covered FACA/APA concerns given the information from the handout (attendees were given the handout "Using Expert Meetings for SSA" whitepaper) prior to and again at the workshop. Clarified to the participants that all info from the workshop is subject to FOIA. Meeting is not to make policy decisions (e.g., whether there should be multiple DPSs), develop recovery goals or objectives, determine the "right" answer or seek consensus. Rather it is to document range of knowledge and opinion regarding current status and likely future conditions for lynx in the Lower 48 states.

SSA framework overview covered – SSA fact sheet provided to attendees (Appendix 1 of Workshop Report).

Conceptual model handouts provided – in draft form, will be used for elicitation process this week, looking for feedback from the experts.

Overview of the expert elicitation process – we will be eliciting expert judgment/opinion on areas of uncertainty concerning lynx. We will use modified Delphi approach to elicitation – involves eliciting individual input from the experts. Will explore what information/data/reasoning is influencing expert opinion on a particular question. There will be opportunity for reconsideration after discussion. We are not seeking consensus answers to questions asked. We hope to raise the level of lynx related knowledge of the group as we progress through the workshop.

Overview Presentations: (See also the presentation files from presenters)

Historic and Current Distribution of Lynx in the Contiguous US – Kevin McKelvey

- Issues w/ lynx distribution – frequently confused w/ bobcats, a problem for relatively rare species like lynx, which can cause misidentification to corrupt the data without proper screening of occurrence records.
- Provided examples of potential error rates when a similar species (bobcat) is much more abundant; even with relatively high (90%) identification success, only a few misidentified bobcats can cause significant error in lynx "observations."

- Described need to rely on "verified records" to screen out poor data/misidentification.
- Lynx periodically move south in pulses/waves (irruptions) from Canada. Some lynx end up in places that may support them over time; others end up temporarily in places where they cannot persist. How to determine which places support permanent populations vs those that only have lynx temporarily during or after pulses?
- Largest pulses of lynx seem to be ~1960, 1970, 1980, and lesser pulses in recent decades.
- Evidence of historical populations in WA, ID, MT, MN, ME, MI, NH based on persistence over time and/or evidence of reproduction, habitat, etc.
- No current populations in NH, NY, VT, MI, WI. May be a small population in Greater Yellowstone Area (southwest MT/northwest WY).
- No evidence that lynx were widespread across contiguous U.S. historically.
- Nearly all areas of suitable habitat (with adequate snow resources) seem to be occupied in the lower 48 states. There are a few exceptions.
- The historic data are in the form of recorded occurrences, which allows for inference about past distribution but not abundance.
- Historic records are both finite and often unreliable.
- Group discussion following this presentation brought up the fact that IUCN is updating their Red List evaluation of lynx, to be released in November, which will include their estimate of distribution and trends (Vashon).
- It was asked why lynx appear unable to establish/maintain populations in most of Idaho, given seemingly viable habitat and many historic records. Presenter indicated there is no clear answer based on the evidence in the record.

Lynx Regulatory Environment 2000-2015 – Scott Jackson

- Pre listing, there was very little regulation on Forest Service lands specifically for lynx.
- Pre listing, interagency lynx steering committee, science team and bioteam were formed to direct compilation of the Lynx Science Report, Lynx Conservation Assessment and Strategy (LCAS, 2000), Biological Assessment of 1999, all to guide conservation and land use management on Federal lands.
- Listed due to inadequacy of existing regulatory mechanisms.
- FWS Biological Opinion in 2000 directed USFS to revise 113 forest plans and develop Conservation Agreements to guide management and lynx conservation until forest plans were revised. Some units are still operating under Agreements, though most national forests with lynx or potential lynx habitat have formally amended their Forest Plans.
- Post listing, Conservation Agreements between USFWS, USFS, BLM – "likely to adversely affect" projects would no longer occur. BLM and USFS began updating land use plans to align w/ LCAS (2000) standards and guidelines. LCAS was revised in 2013.
- LCAS (2000) principles: identified 17 risk factors and measures to reduce these risks, guidance on how to map Lynx Analysis Units (LAUs), forest management prescriptions to benefit lynx.

- Revised LCAS (2013) – new science, core area emphasis, anthropogenic influences (2 tiers) instead of "risk factors", fewer conservation measures (vs. "standards and guidelines" from 2000 LCAS). Secondary/ peripheral habitat combined into "non-core" areas in the revised LCAS.
- Focus of regulations has been on Federal land, primarily in the West. There are other issues on private lands and unique regulatory issues in Maine (Maine Forest Practices Act of 1989).
- LCAS (2013) identified greatest potential influences from climate change, forest fragmentation, wildland fire management, and vegetation management (timber harvest/mgmt. and silvicultural treatments).
- Areas of greatest uncertainty = large scale, high intensity fires in the West, wide scale insect outbreaks, changes in silviculture that may or may not benefit hares and lynx.
- Amount of lynx habitat in Federal ownership varies among 6 units from 98% in the Cascades to 1% in the Northeast.
- A question regarding landownership was raised - do we have a breakdown of land-ownership for each of the 6 geographic areas? JZ – we have broken each critical habitat unit by ownership, but we did not designate CH in Colorado/S. Rockies, though ownership info there is also probably readily available.

Lynx Genetics Considerations – Michael Schwartz

- Reviewed all published papers on lynx genetic studies in N. America; summary that global results for measure of genetic variation (17 populations) shows high genetic mixing, some sub-structuring over distance, but ample gene flow continent wide.
- N. Rockies provide some gene flow restriction, as well as an invisible barrier to gene flow in eastern Canada south of James Bay/Hudson's Bay that may be related to snowfall. Other than these, there are unlikely to be barriers to genetic interchange throughout much of the lynx range in boreal forest.
- River systems can influence genetic sub-structuring.
- Some genetic drift within the smallest populations; some genetic substructure in populations in eastern Canada and south of the St. Lawrence, island populations (Newfoundland and Cape Breton); however, there is evidence that there is interchange of lynx between each generation in eastern Canadian populations.
- Some evidence that we are seeing gene flow out of Canada into US lynx populations during population surges.
- Discussed levels of genetic sub-structuring of lynx in MT – river valley and highway may be causing sub-structuring.
- Hybridization w/ bobcats does occur – studies have shown hybrids in MN, and Maine, no hybridization in west detected so far. Very low numbers. Does not seem to be a major issue nor is there evidence that hybridization is increasing despite significant increases in bobcat numbers.
- Genomic studies can increase power and look for genes under selection.

- Recommended conservation goal for lynx should be to conserve genetic diversity currently represented in the 6 populations in the lower 48 states. Recognize that this variation at the edge of the range may be of value to future populations, especially as related to changing climate.

Lynx Distribution, Status, and Management in Southern Canada – Jeff Bowman

- Each province has its own management program for lynx, each with its own harvest (trapping) policies and strategies.
- British Columbia, Alberta, Saskatchewan, Manitoba – trapping numbers show peaks in 60's, 70's and 80's. Smaller peaks in lynx numbers trapped since then. Eastern provinces show higher peaks in lynx trapped in 1990, 2000 than the western provinces.
- Peaks in lynx numbers lag behind hare peaks by one year. Peaks occur roughly every 10 years. [*Note to presenter - please clarify if this statement is correct or if the lynx peaks in the east followed lynx peaks in the west by one year]*.
- Potential range contraction in eastern Ontario from 1960's to 2010, southern boundary moving north. Genetic study also supports trailing range-edge effect.
- New Brunswick and Nova Scotia have listed lynx as endangered provincially; these two provinces have high numbers of bobcats, probable correlation. Other provinces status seems secure (COSEWIC review).
- Data show large peaks of hares/lynx in 1960, 1970, 1980; cycles since then are dampened, may be a future trend?
- Noted recent genetic studies show some genetic differences (unique alleles) south of the St. Lawrence, but differences are not large.
- Lynx range contraction in southern Ontario because of changes in forest practices, increase in tolerant hardwoods. Seeing less genetic heterozygosity (allele richness) at the range margin.
- "Invisible" genetic barrier south of Hudson's Bay likely related to winter snow. Effect will likely increase in the future with climate change. May be habitat "imprinting" (snow conditions) between east and west Canadian populations.
- Nova Scotia and New Brunswick have largest bobcat populations in Canada.
- There was a question: Why are forests changing in Southern Ontario? It is likely a combination of things - the movement towards management of small scale disturbances, increased control of fire and other disturbances, less wide-scale logging than in the past, now more natural hardwood forests than in previous years. Management not caribou driven (caribou are farther north).

Introduction and Discussion of Lynx Conceptual Models – Jonathan Cummings

- Presented the 4 draft conceptual models to the experts (see handouts).
- Simplified viability model, and one each for resiliency, redundancy, and representation.

- We will be seeking expert input on the models this week, will inform elicitation

Day 2

Overview Presentations (continued):

7 Ways a Warming Climate can kill the Boreal Forest – Lee Frelich

- Boreal forest may disappear from Minnesota by end of century.
- Temperate tree species are invading boreal forests at local and regional scales, mixed ecotone spreading; deer herbivory may temporarily slow hardwood invasion of conifer stands.
- Higher summer temperatures in northern MN (5 to 12 degree F increases projected by 2100).
- Prairie-forest border may move north by 150-300 miles by 2100.
- Some authors project a 300 mile northward movement of boreal forest continent wide by end of the century.
- Severe drought 8 of last 10 years.
- High emissions scenario – no paper birch in US.
- Aspen, fir, spruce will be reduced to absent in US.
- Insect outbreaks will increase with climate change.
- Small triangle of boreal forest in northeast MN (Arrowhead region) likely to hang on to end of the century because of higher elevation of area and lake-effect snow. This is not the entire arrowhead region, just a small proportion of it that is of relatively higher elevation.
- Discussed 7 ways in which boreal forest will be converted to temperate forest over time w/ climate change.
- Frequency of large damaging storms will increase, facilitating temperate forest conversion.

Climate Change and Uncertainty: Implications for Canada lynx Conservation and Management in the Contiguous US – Alexej Siren

- Lynx presence associated w/ snowpack persistence greater than 4 months and deep (>270 cm per year in Northeast), fluffy snowfall.
- Discussed ways in which climate may influence lynx - population cycles and viability, increased competition with bobcats, hare coat-color mismatch, access to hares.
- Warmer global mean surface temps in recent decades and into the future.
- Warmer winter temps, especially in the Northeast US where increases will be greatest.
- Winter precipitation projected to increase in eastern US, drier in western US.
- Discussed emissions scenarios and projected changes across the range of lynx, see presentation file.
- Northwest - overall drying, slight increase in winter precipitation, unsure how much will be snow (vs. rain).

- Northern Rockies - increased winter temperature and precipitation but not in NW Montana; long term may have best snow conditions for lynx because of high elevation; depends on snow depth and quality.
- Southern Rockies - declining number of days below freezing, decline in winter snow and snowpack.
- Great Lakes - increase in winter temperatures but increase in lake-effect precipitation and snow because of loss of ice on great lakes; in short term - best snow conditions for lynx.
- Northeast - increase in winter temperatures and precipitation, dryer in summer, decrease in days below freezing and persistence of snowpack.
- Generally across the range warmer winters, less snowfall and snowpack, warmer summer temps, increase in winter precipitation and non-snow precipitation in winter, less precipitation in summer, decreased snowpack period.

Projected Climate-change Impacts on Snow, Vegetation, and Lynx Populations in the Western US – Josh Lawler and Chad Wilsey

- Vegetation modeled across western range of lynx under climate change projections to end of century – shift from subalpine forest to temperate evergreen needleleaf forests in western lynx range.
- Projected decrease in lynx-appropriate forest across range in western states.
- Fire projected to double by 2040 and triple by 2080; projected increase in fire frequency and larger fires.
- Modeled lynx habitat and lynx ecological traits w/ climate change scenarios – projected simulated densities in lynx in western range in 2020s, 2050s, 2090s.
- Shows some decrease in lynx densities across western range; decline of lynx habitat suitability in the Northwest; greatest likelihood of persistence in NW Montana.
- Also looked at effect of population cycling impact on projected changes – overall changes in density not affected by population cycling.
- On average simulated moderate declines in Canada lynx – some growing populations and some declines.

Forest Management and Lynx Habitat Trends – Erin Simons-Legaard

- Eastern spruce budworm outbreak cycles in Maine ~~became~~ may have become more ~~wide ranging~~ frequent since 1970's (historically outbreaks at roughly 65-year intervals; recently 30-40 years; severe outbreak in the 1970s).
- Severe spruce and fir budworm mortality was followed by large-scale clear cuts mid-1970s - mid-1980s to salvage-harvest trees - created current lynx habitat.
- Regulations (Maine Forest Practices Act 1989) then put in place to manage clearcutting making cuts smaller, shift from clearcutting to various forms of partial harvesting; this caused the annual harvest footprint to double in northern Maine with lower quality habitat.;

since 1989, 65% of landscape has been affected by partial harvesting, which supports lower hare densities than regenerating clearcuts.

- Ownership changes in northern Maine, more and diverse ownership now than historically; REITS and TMOs; short-term investment horizon and different forestry outcomes.
- Non-development easements in place in many areas of northern Maine, but they do not regulate forest management.
- Conifer stem density influences hare density in Maine - hare/lynx habitat created by even-aged management and dense regeneration of spruce-fir.
- Timber harvest levels increased over past several decades; modelinged emulated 2000-2010 harvest rates ~~tree species change over this time.~~
- Modeled lynx habitat into the future. Assumptions of forest practices used by current landowners. Also used stochastic modeling (which includes harvest).
- Lynx foraging habitat – spruce-fir forest – modeled to 2050 – high quality habitat for lynx is currently about 8% of the northern Maine landscape. Projections are that habitat and lynx occurrence will decline to about 5% of the landscape by 2030, and then level off.
- Prevalence of partial harvesting will lead to elimination of most areas with concentrated high-quality habitat. Most of the landscape will have a low (<30%) ~~probability of supporting lynx~~ percentage of high-quality habitat for snowshoe hare at the lynx home-range scale.
- As clear cuts regenerate and age, become less appropriate for hares and lynx at about 35-40 years post-harvest, probability of lynx occurring in areas where they currently are will go down over time to 2050.
- When forest is disturbed, composition shifts to red maple and balsam fir; however, next outbreak of spruce budworm coming in 2 to 5 years, which may greatly affect fir component of lynx habitat.
- It is unlikely budworm will be controlled by spray; unlikely that landowners will clearcut and herbicide as they did in the last budworm outbreak.
- Quebec – currently being heavily impacted by spruce budworm outbreak, spreading to Maine, not likely to be managed in Maine.
- Snow will decrease in Maine in light of climate change (20% projected decline in snowfall).
- If quality hare habitat ~~is greater than~~ requires only 50% spruce-fir forest, ~~habitat for lynx should increase over time~~ after reaching a low point in 2030, habitat may increase between 2030-2040 and then level off at ~5% of the landscape. But if hares require higher spruce-fir content, lynx habitat would ~~go down~~ not rebound 2030-2040 (remaining at only 2-3% of the landscape) as there will be fewer areas w/ high percentage spruce-fir content.
- Climate envelope modeling suggests balsam fir, white spruce, and red spruce will be largely gone from Maine and areas of eastern Canada by 2060.

Southern Snowshoe Hares: Updates, Questions, Forecasts – Karen Hodges

- Northern hare cycles are highly variable; peaks and amplitudes do not line up as nicely as has been described in the literature.

- Some southern hare populations show “cycle-ish” dynamics and high densities.
- Flathead National Forest, MT in lynx CH, has high hare densities but no lynx, has bobcats, why?
- Regional differences in maximum hare abundances observed in highest quality habitats across western and eastern landscapes – presented distributions of hares in western and eastern states in lynx range, see presentation file for numbers.
- Reported hare densities w/ habitat attributes.
- Forestry that reduces stand structure reduces hare abundances, hares increase w/ number of years since pre-commercial and commercial thinning.
- Hares recolonize burned areas as soon as they become suitable as the stand regenerates over time.
- How many hares do we need to keep lynx around? Landscape hare densities of 0.5 hares/ha (LCAS) to 1.1 to 1.3 (Steury and Murray). Maine and MN landscape hare densities needed to support lynx in between these values. Question why the GYA with low landscape hare densities still (may) support lynx.
- Red squirrels are major alternative prey to snowshoe hares – little known about their densities.
- If we lose boreal forests we will lose snowshoe hares.
- Hares and shrubs – understory important to hares, but little studied. Need to be studying understory structure - are those data collected on National Forests?
- Impacts of climate change on hares – changes to habitat structure and changes from boreal forest to other types will impact hare abundance.
- Salvage vs clearcut – salvage logging post fire will lengthen time for hares to recolonize burned areas. In Quebec harvest may create higher hare densities than fire.
- Climate change will affect hares. Increased fire and insect outbreaks. Forests may not regenerate to boreal forest. Coat change mismatch (Mills paper) - had some concerns.
- Changing forest community - hare is only ~20% of bobcat diet (bobcats eating primarily red squirrels), hares used by fishers, raptors, coyotes, fox, etc. - diverse predator assemblage at southern edge of range.
- Uncertain of the impacts of bobcats moving into lynx territory.

<u>Lynx Population Status and Threats Updates:</u>

Maine/Northeast – Jennifer Vashon

- A “happy story.”
- 1990’s to today – extensive areas of regenerating spruce-fir forest in Maine – good for hares and lynx.
- This has resulted in a presumed increase in suitable habitat above likely historic conditions.
- 18 million forested acres in Maine; 6 million acres of spruce-fir, of which 3 million acres are lynx habitat.

- Lynx habitat (sapling habitat in Forest Inventory and Analysis [FIA] data) increasing in the state; 40% of total spruce-fir is in sapling stage.
- 2006 - 700,000 acres of dense spruce-fir stands; 2015 – now 805,000 acres.
- Discussed telemetry study in Maine, conducted from '99-'11, with 191 individuals – see presentation file for more details.
- Demographic values from the telemetry study resulted in an estimated reproductive rate of 65%, an average of 2.63 kittens per breeding female, and a 78% kitten survival rate, see presentation for full details.
- 4.5 adult lynx/100 square km in study area with 5 to 9 kittens.
- Strong selection for spruce-fir sapling habitat.
- Measured ~~some~~ demographics on survival and reproduction.
- 2006 pop estimate 750-1000 adult lynx, 2015 more lynx than 2006 and various indices (road mortality, track surveys and incidental trappings) suggest population still increasing.
- ~~This estimate is based on estimated extent/amount of suitable lynx habitat and estimates of lynx density derived from the telemetry study. Total amount of habitat (from FIA data) X proportion of townships with lynx tracks X densities observed on the study area = total Maine lynx population.~~ This estimate is based on data of extent/amount of suitable lynx habitat, occupancy from systematic surveys, and estimate of lynx density derived from a 12 yr telemetry study. See Day 3 parking lot questions on page X for more detail explanation~~.~~
- Budworm outbreak and clearcutting to occur in the near future.
- Clear cuts still providing good conditions for lynx and hare 30 years post clear cut.
- Future impacts of changes to forestry resulting from Forestry Practices Act are unknown. ~~but likely will result in a decrease in lynx habitat~~.
- The current abundance of habitat for lynx in Maine following extensive clear-cutting of budworm impacted stands prior to forest harvest restrictions (i.e., Forest Practices Act).
- ~~Does not believe that forestry guidelines are needed. Allow landowners to make choices on what they believe lynx need.~~ An objective of IFW/USFWS lynx telemetry study was to provide landowners with the forest stand characteristics that support lynx to guide their management on private lands.
- Lynx population connected to neighboring Canadian provinces.

Minnesota/Upper Midwest – Ron Moen and Susan Catton

- "Non-estimate/guess" of 50-300 lynx in MN, confident of minimum of ~50 due to genetic sampling, but the other end of the range is speculative. High degree of uncertainty. In 2015, there were 133 DNA samples collected - 48 individuals with 20 recaptures.
- Lynx population in MN connected to Ontario, not separated; dispersal into and from Ontario is common.
- Discussed home ranges and cover types in home ranges - amount of regenerating (young) forest is predictive.

- Studied hare densities in NE MN, higher in southern Ontario. Much fluctuation in hare numbers in recent years.
- Lynx are concentrated on the landscape in areas of high-quality hare habitat.
- Majority of mortality in MN observed in radio telemetry study was human caused (incidental trapping, road mortality). This was a small study with ~20 collared individuals. *Tamara Smith noted that Twin Cities FO maintains an incidental take database that is cross-referenced to the Superior National Forest (SNF) DNA database.*
- Bobcats are moving into NE MN; harvest increasing from 2000 to 2015, but still very few in the Arrowhead (northeastern MN, where the lynx are).
- Projected to lose lynx habitat in the future w/ climate change. Several modeled scenarios show almost complete loss of snow suitable for lynx by 2095, only a small area extreme NE Minn may retain.
- Documented hybridization w/ bobcats, 13 hybrids among 268 individual lynx identified from DNA samples.
- In general male lynx in MN were more migratory, moving in and out of Ontario, whereas females tended to disperse and then remain in the new location, either going to Ontario to stay, or vice versa
- SNF conducts focused snow track surveys in areas known to have lynx. SNF collects genetic samples to identify individual lynx and to track persistence. Additional DNA samples are collected opportunistically (e.g., from road kills, incidental trapping, etc.). Their database contains 268 identified individuals (48 individuals identified in 2014-15 winter - 20 recaptures [including 2 hybrids] and 28 new lynx).
- SNF annually collects/tracks 3-5 family groups.
- Reproduction documented each year. One female lynx was tracked for 5 years - she produced 7 kittens in MN.
- SNF is working with Twin Cities FO and NC State University to refine the survey protocol to get more meaningful data with little added effort.

Montana and Greater Yellowstone – John Squires

- <u>Wyoming</u> – in 1990's and early 2000's ~~few detections of lynx~~ lynx were detected reliably in the Wyoming Range, Union Pass, and both sides of Togwotee Pass.
- The long-term persistence of lynx in the GYA is unknown, but early records from Yellowstone Park documented presence in the 1920-1930s.
- Yellowstone – 3 lynx confirmed and reproducing in 2000-2004; few, if any, lynx remaining in the Wyoming Range and on Togwotee Pass based on recent surveys. The presence of lynx throughout the remainder of the ~~and~~GYA is unknown. ~~since then despite extensive survey effort.~~
- Presence confirmed in Wyoming Range ~~Teton area~~ in early 2000s; 2 individuals collared and movements recorded.

- Snow track surveys have been conducted over time and indicate a clear pattern of lynx presence in the Wyoming Range, Union Pass and Togwotee Pass~ 6 tracks per year of survey. However, the current status of this population is unknown, but believed to be at low numbers based on current on-going surveys. The distribution of lynx in the Yellowstone National Park was determined with an extensive survey (2001 – 2004) that indicated lynx were present and documented reproduction; additional representative surveys were not conducted.~~, without any notable pattern, which have found ~ 6 tracks per year of survey.~~
- Reintroduced ~~2010 genetic sampling resulted in no "native" GYA Lynx individuals being identified - only~~ lynx from Colorado have traveled to the GYA and occupied previous home ranges of "native" lynx in the Wyoming Range and on Togwotee Pass, including males and females with overlapping home ranges.~~that dispersed from Colorado.~~
- Oil and gas leasing – potential risk to lynx in WY, overlaps lynx range in the Wyoming Range of western/northwestern WY.

- Montana – more lynx in northwest MT than GYA.
- Studied reproduction and litters in MT in Seeley Lake Area and Purcell Mts.
- 175 individuals were collared; the average lifespan for lynx in this area is 8.6 years.
- An average of 2.5 kittens per litter (2.25 in Seeley Lake and 2.95 Purcell Mtns.). Productivity was ~0.7 on average, and annual survival was 0.5 for sub-adults and 0.75 for adults on average.
- Lambda (rate of population increase) was 0.92 for the Seeley Lake area (e.g., population declining) and 1.16 for the Purcell Mtns. (population increasing).
- Lynx have recently contracted/perhaps extirpated from the Garnet Range.
- Modeled monthly survival rates – see presentation file for numbers.
- Predation (mountain lions), starvation, and human-caused mortality each about 1/3 of documented mortality in MT.
- Evidence of cyclicity in vital rates was not observed.
- ~~Most of MT probably decreasing lynx abundance.~~Areas outside the Purcell Mountains in Montana may have declining population numbers based on PVA analyses.
- Protection of lynx habitat in core area in Seeley Lake increased substantially with conservation land purchases.~~, hundreds of thousands of acres "protected"~~
- 2000-2013 over a million acres burned in lynx range in MT.
- Good habitat is habitat in which females produce litters, positively related to connectivity to mature forest and low fragmentation.
- ~~Lynx persisted in low population numbers in WY and MT, may not currently be any lynx in WY.~~Montana is believed to support the largest lynx population in the western United States, but minimum population sizes have not been calculated. Lynx in Montana are more abundant compared to Wyoming.
- Last surge/wave of lynx out of Canada was in 1980s; no recent surges have been observed in sampling areas, is this related to the status in MT today?

- Fire prevalence in the last 13 years is far greater than it was for the previous decadal periods going back to the 19~~2~~60s? *[Note to Reviewer- is this date correct?]*. Major factor in persistence of lynx in MT.
- Silviculture in MT has both positive and negative effects - research is currently investigating lynx-use of forest management ~~not much evaluation of whether the USFS guidelines are working.~~
- No evidence of "waves" of lynx during hare/lynx peak: little demographic effects. Are we in a "lynx drought?" Recent wave of lynx from Canada seem relatively low magnitude, thus MT population slowly declining?
- Lynx in Montana exhibit fine-scale genetic sub-structuring.

Parking Lot topics (Answered on day 3)

- 2000 LCAS is adopted in Forest Service plans, still operating under 2000 LCAS standards and guides. The 2013 LCAS is less restrictive than 2000 version, so by operating under the 2000 version the 2013 standards and guides are sufficiently covered.
- If Maine's lynx population is so large, why was the State's incidental take request for lynx relatively low?
- How exactly did Maine estimate lynx population?

Northern Washington – Ben Maletzke

- Lynx are state-threatened in WA; possible justification to update to endangered status based on current status of threats.
- DNR has a management plan (HCP) and recovery plan for lynx.
- USFS has 98% of lynx habitat in WA.
- Okanogan Lynx Management Zone (LMZ) only area in WA w/ consistent lynx records from 2005-2015
- Went over 5 listing factors in WA:
    - Reg mechs/lynx plans in place;
    - No disease, little predation, could increase w/ climate change and snow changes;
    - Bark beetle, bud worm – trees dying, increased fire, many burned areas in previously good lynx habitat, see presentation file for numbers;
    - Regeneration of burned areas could create good habitat, but takes 20-40 yrs for these areas to grow up to hare/lynx habitat again;
    - Climate change may have effects on veg cover, precipitation, fire size and frequency, prey densities;
    - Small blocks of populations, vulnerable to stochastic events;
    - Connectivity of Okanogan w/ Canada okay, Kettle crest less connected to Canada.
- Rough ideas on population. 1990s there were 90 to 120 females, currently as few as 24 females.

- Lynx currently have larger home ranges, reduced habitat. May be vulnerable to trapping in BC Canada. No long term studies - snapshots of data.
- Discussed WA potential management and recovery actions - concerned about climate change effects on snow depth, quality (crusting), duration and effects on fire frequency.
- Connectivity during surge events from Canada more important for areas other than Okanogan in WA; have not seen waves of lynx during recent high hare/lynx years in Canada.
- Thoughts for future study include probability of population persistence, need and feasibility for augmentations, collaboration with British Columbia, state status in WA, management, surveys and monitoring.

Colorado/Southern Rockies – Jake Ivan

- Showed map of 90% UD – most hanging around southwest and central CO.
- State endangered (1973); widespread federal predator control 1910s-1920s .
- 1978-1997 statewide surveys (11) found only a few tracks.
- 1999-2006: 218 lynx translocated from Canada and Alaska. During the period of monitoring (1999-2010) the population persisted and had relatively high annual survival, relatively high reproduction.
- First denning documented in 2003, 48 dens by 2010.
- Modeled population – trajectory of pop is slightly increasing maybe, but at least holding steady.
- Intensive monitoring concluded in 2010; now conducting occupancy monitoring (only in San Juan Mountains now; hope to expand to rest of potential habitat and for 10 years) and hope to be able to detect trends.
- Evidence of some continued reproduction 2010-2015 (kittens at camera stations, and 38% of Squire's captures were "new" individuals).
- Current survival unknown.
- Potential threats – climate change, bark beetle epidemics, fire, concentrated recreation (seem tolerant of humans, but more and more people in the backcountry), highways.
- Spruce-fir moderately vulnerable to climate change, habitat expected to migrate upslope over time.
- 4 million acres of trees killed by bark beetle, but lynx are still using beetle kill areas for now as long as understory vegetation is available for hare production.
- Potential elevation refugia may be unique for lower 48 states for climate change.
- ~~Development (extensive ski areas) may be affecting lynx (avoidance).~~ A cursory, pre-analysis review of location data suggests that lynx make use of landscapes in which heavy winter recreation occurs. However, use of developed ski areas is light, and outside of ski areas, heavy lynx use tends to occur in thick timber that is unused by snowmobiles and other backcountry users.
- Red squirrels can provide 25% (Jake - was this 25% or 20%?) of lynx diet, but losing cone-producing trees at large geographic scale after beetle outbreak may be significant during

landscape level dips in hare density. Over 10 winters of snow-tracking in Colorado, red squirrels comprised an average of 25% (range = 7-72% for any given year) of lynx diet by occurrence; they comprised an average of 6% (range = 1-32%) by biomass.

- Lynx snow track and camera surveys have been initiated.

Expert Elicitation of lynx status via questioning on representation, redundancy and resiliency

Following the presentations, an expert elicitation was conducted to collect additional information on the status of lynx for each the three measures of viability used in a species status assessment, namely the levels of representation and redundancy for the DPS, and resiliency for each lynx population/geographic area within the DPS.

Redundancy Questions:

1. List the factors/catastrophic events that could eliminate an entire population.
Response Type: index card list
- Some discussion around defining catastrophic event – a single point in time event, ex. Hurricane, large fire vs event that takes 10 yrs to occur or series of events. For this question the event was defined as a single point in time. And discussion around population – in this case each of the 6 geographic areas is a "population". Eliminate means functional extirpation.

- Experts asked whether climate change was considered a catastrophic event; USFWS answered that because it operates and its effects are manifested over longer time frames, it should not be considered a catastrophic event for the purposes of this elicitation.

- Experts asked whether the "population" lost meant the DPS in its entirety or a single one of the 6 subpopulations or units. Experts were asked to consider the loss of any one subpopulation.

- See Redundancy expert response handout.

2. Could any of the catastrophic events listed eliminate all 6 populations/geographic areas simultaneously?
Response type: experts supplied a written response of yes or no.

- See Redundancy expert response handout.

3. What is the probability that any single population could be eliminated by a single catastrophic event in the next 10 yrs?
Response type: 1-point elicitation.

- See Redundancy expert response handout.

4. What is the percent likelihood that a series of catastrophic events within the next ten years could cause functional extirpation of one or more lynx populations?

Response type: 1-point elicitation.

- See Redundancy expert response handout.

5. How long would a population eliminated by a catastrophic event require to become reestablished naturally?
Response type: 3-point elicitation.

- See Redundancy expert response handout.

Day 3

Parking lot questions: How was pop estimate in Maine done? – Jen Vashon answered: FIA data to estimate the amount of spruce-fir forest in the core lynx range, FIA data to measure how much was sapling, winter snow track surveys used to estimate the proportion of habitat that was occupied. Looked at areas to likely have lynx vs all the areas, tells how much of the habitat is likely occupied by lynx in 2006. Looked at home ranges of lynx, how many acres are in a female and male home range. If lynx could occupy all the spruce-fir and all the spruce-fir sapling available to give estimate of number of lynx.

How did you determine primary predation in Maine? Jen Vashon: Found primary predator was fisher. A lot of initial skepticism around this. Close tie to snow storms and lynx bedding in ~~hardwood~~ mature softwood forests, where fisher are. Assume ~~they~~ many were killed while bedding. ~~All~~ Most were killed by bite around the neck. Forensic evidence at the sites was consistent w/ fisher predation. We have a draft manuscript in prep.

For Maine, w/ a pop maybe greater than 1000, why is incidental take in the trapping HCP so low? Jenn Vashon: MDIFW implemented measures we thought would reduce trapping injury and mortality leading up to the time we submitted the ITP application. We used the recommendations in the AFWA booklet and killer-type traps on a leaning pole 4 feet off the ground at a 45 degree angle. We believed that these measures would result in low mortality, thus a request of 3 lynx mortalities in traps over the next 15 years.

Question about pellet index vs live trapping of hares – Karen Hodges answered: Pellet counts are proven to be robust & are the most reliable survey index method to provide ~~variance~~ population estimates; differences in methodology don't explain variation in survey results across range. Pellet counts have been thoroughly studied by many researchers and we know they relate well to snowshoe hare densities across the range and through the cycle. They do a much better job than tracks or browse or other index methods. Mark-recapture is still the gold standard because it is an estimator, not an index, but pellets are by far the best index because their properties are well known and they do map onto capture-mark-recapture estimates well.

Resiliency Questions: Probability of Persistence Exercise

1. What is the probability of persistence over time (particularly currently and at 2025, 2050, 2100) for each of the 6 major geographic units with lynx populations?
Response type: 3-point elicitation. What are the lowest probability, highest probability, and most likely probability of persistence? Experts were asked to connect the points through time to create a risk profile for each of the 6 geographic units.

- See Resilience expert response handout.

2. What are the major drivers/factors (up to 3) reducing or influencing probability of persistence for each of the major geographic units?
Response type: Ranked list of factors, for each point in time (2025, 2050, and 2100), with % contribution of each factor.

- See Resilience expert response handout.

Conservation Brainstorming Exercise

3. What conservation actions could be taken that would address the factors impacting the probability of persistence or otherwise increase the probability of persistence?

Response type: Individual list with rounds responses. Experts were asked to each write their own list of conservation actions that could be taken. They were given 5 minutes for this task. Facilitators then asked one expert at a time to provide one item from their list, cycling through the set of experts until experts had exhausted their lists. Experts were given the opportunity to add items when it was their turn that had not been on their written lists.

List of potential conservation actions:

Reduce CO2 emissions.

Continue protections associated w/ Federal and/or State listing.

Adjust forest management to retain spruce-fir and reduce fire burn rates.

Conserve/promote habitat connection w/ Canada populations through land use planning.

Management of salvage logging associated with fire and insect damage to facilitate/expedite conditions favorable to hares and lynx.

Configure and design lynx-friendly landscape at appropriate scales; maintain habitat mosaic.

Manage fuels-reduction (wildland fire) projects to maintain hare/lynx habitat features.

Population augmentation/reintroductions for currently small or extirpated populations (GYA, Kettle, etc.); bolster populations before future impacts.

Additional research to fill knowledge gaps (particularly related to conservation effects) – forest conditions that support hares, hare densities needed for lynx, range of habitat needed for lynx, unclear exactly what is needed for lynx across the range, viability, landscape hare densities, etc.

Cross border cooperation with Canada to increase near border populations, maintain connectivity.

Consider cumulative impacts of mining, ski areas, oil and gas, etc. in management decisions.

Promote reforestation of heavily-fragmented areas (WY, MN); reduce fragmentation.

Strategic habitat conservation, model and identify key areas and focus on those areas still in need of protection and management (e.g. private forest lands).

Maximize redundancy of lynx populations throughout the DPS.

Develop fire-management BMPs to create high- and low-intensity mosaic fire patterns to benefit lynx and hare habitats.

Is there a need for a consistent lynx (and hare?) monitoring strategy? Maybe could couple w/monitoring of other carnivores. Structured occupancy modeling with genetics sampling, could be very informative, and is cost effective. Known-fate monitoring. Monitoring pellet plots is proven and reliable way to monitor hares.

Could benefit from more funding specially devoted to mesocarnivores. Lynx are in worse shape than other carnivores that receive a lot of funding, have more secure populations, and will respond to climate change better.

Representation Questions –

1. Are any of the populations susceptible to genetic drift on a scale that would limit genetic viability? If yes, which populations?
Response type: Experts supplied a written response of yes or no, with a yes answer accompanied by the list of populations.

- See Representation expert response handout.

2. Are there locations from a lynx perspective that have unique habitat conditions relative to other areas in the lynx range that are necessary to foster future adaptive capacity of the DPS? If yes, where?
Response Type: Open discussion.

- See Representation expert response handout.

Other things the experts thought we should consider –

Monitoring of prey base (hares, red squirrels) should be considered, would be very informative. Pellet based or mark recapture are most reliable methods. Need to sort out if these areas that we think are going to become poor habitat for a variety of reasons could still hold hares and lynx in the future. Maybe hares still can use areas we think will be poor habitat. Monitoring of these areas could help inform.

[Participants are invited to provide additional notes in this section]

MEETING ADJOURNED

Appendix 4. Lynx Expert Panel Candidates - Lynx SSA Expert Elicitation Workshop, October 13-15, 2015, Minneapolis, Minnesota

Expert Candidate	Geographic Area	Affiliation	Expertise
Clayton Apps	Southern British Columbia & Alberta	Independent Researcher, Aspen Wildlife Research Inc.	Dr. Apps is an independent research ecologist whose work in western Canada over the past 24 years has focused on understanding and predicting relationships of wide-ranging species with habitat and human influence across scales to support environmental assessment and conservation planning. He is especially interested in spatial and temporal factors affecting species movements, habitat selection, abundance, distribution and survival. Within the southern Canadian Rocky Mountains, Dr. Apps carried out a 5-year study of lynx ecology representing his dissertation research, and he has conducted several other shorter-term field and modeling projects pertaining to lynx. Clayton has also recently authored British Columbia's current lynx management plan.
Keith Aubry	Washington/Northwest	USDA Forest Service - Pacific Northwest Research Station, Olympia, WA (retired)	Dr. Aubry is an Emeritus Scientist (formerly Research Wildlife Biologist) with the U.S. Forest Service's Pacific Northwest Research Station in Olympia, WA. He has been conducting research on terrestrial wildlife in the Pacific Northwest for almost 40 years. Recently, his research has focused on generating new information that will enable conservation biologists and resource managers to make more-informed decisions about the conservation status of rare and elusive forest carnivores, including the fisher, Canada lynx, Cascade and Sierra Nevada red foxes, coastal marten, and wolverine. Dr. Aubry was a member of several national scientific teams, including the Forest Carnivore Conservation Assessment Team, the Lynx Science Team, and the Wolverine Science Team, and was the leader of the Fisher Science Team. He has directed several multi-year field studies of the Canada lynx in the North Cascades of Washington, and has authored or co-authored a number of peer-reviewed publications on lynx conservation, their distribution in the contiguous U.S., their ecology and population dynamics, and the risk of relying on anecdotal occurrence data for conserving rare or elusive species.
Jeff Bowman	Southern Canada/Ontario	Ontario Ministry of Natural Resources and Forestry, and University of Trent, Ontario	A Research Scientist with the Wildlife Research & Monitoring Section, Ontario Ministry of Natural Resources and Forestry and an Adjunct Professor in the Environmental & Life Sciences Graduate Program, Trent University, Dr. Bowman's focus is on population and landscape ecology. He and his colleagues and graduate students have published many peer-reviewed articles on lynx landscape ecology and genetics at the population's southern range boundary in Ontario in an effort to assess the functional connectivity and population dynamics of lynx at their southern range periphery.
Susan Catton	Minnesota/Great Lakes	USDA Forest Service – Superior National Forest	Susan has been working as a biologist on the Superior National Forest (SNF) since 2001 and is an expert on lynx biology, ecology, and management on the SNF. She has participated in surveys for the species and is very knowledgeable about lynx and their habitat on the SNF. Susan is a current member of the Interagency Lynx Biology Team.

Tim Catton	Minnesota/Great Lakes	USDA Forest Service – Superior National Forest	Tim is a biologist on the SNF and for a number of years has been leading a lynx tracking project to detect and monitor lynx populations across the SNF. Tim and others (e.g., Dan Ryan, SNF) have been collecting lynx genetic material to augment an existing lynx DNA database and further the knowledge of lynx presence and persistence on the SNF and in Minnesota.
Dan Harrison	Maine/Northeast	University of Maine	Dr. Harrison has been the principle advisor for many University of Maine graduate students working on snowshoe hares and forest management, lynx history, and lynx spatial and habitat/occupancy models. He and his students have published extensively, and he is considered one of the top hare, lynx, and habitat modeling experts in North America.
Karen Hodges	Southern Canada/DPS-wide (hares)	University of British Columbia–Okanagan	Dr. Hodges is an Associate Professor in the Department of Biology at the University of British Columbia – Okanagan, where she focuses her research on how range position and habitat configuration affect species interactions and endangerment of at-risk species, understanding population dynamics at the periphery of species' ranges, and on snowshoe hare population dynamics. She has authored and co-authored many peer-reviewed hare articles.
Jake Ivan	Colorado/Southern Rocky Mountains	Colorado Parks and Wildlife	Dr. Ivan, a Wildlife Researcher with CPW's Mammals Research Section, has conducted research and published peer-reviewed articles on hares and lynx in Colorado and the Southern Rockies and has developed a non-invasive monitoring strategy to track Colorado's lynx population.
Gary Koehler	Washington/Northwest	Washington Department of Fish and Wildlife (retired)	Dr. Koehler, a retired Research Biologist, has conducted research on lynx and hares in Washington for more than 30 years. Also a member of the Lynx Science Team, his research was among the earliest to investigate lynx and hare habitat relationships and the effects of forest management practices in the Lower 48 states. He has published numerous peer-reviewed articles on lynx conservation ecology in southern boreal forests, lynx and hare surveys, habitat and topographic use patterns, and management of spruce-fir forests to conserve hares and lynx.
Jay Kolbe	Northern Rocky Mountains	Montana Fish Wildlife and Parks	Jay has worked for over a decade on lynx research and management in western Montana and has authored and co-authored numerous peer-reviewed lynx publications on topics including trap-design, lynx activity patterns, denning, snow-tracking, radio-telemetry, seasonal resource selection, predicting dispersal corridors, and effects of recreation.
Kevin McKelvey	DPS-wide (distribution)	USDA Forest Service - Rocky Mountain Research Station, Missoula, MT	A Research Ecologist, Dr. McKelvey works to develop methods to evaluate status and trends of organisms across broad spatial and temporal scales, including genetic monitoring techniques to measure population connectivity across complex landscapes. He was a member of the Lynx Science Team and was the Science lead for the National Lynx Survey, which provided reliable presence/absence data for lynx on over 50 national forests, 5 national parks, and numerous other areas managed by the BLM and several Tribal Nations. He has authored and co-authored many peer-reviewed articles on lynx conservation, history and distribution in the Lower 48, and population ecology/dynamics, and on the dangers of relying on anecdotal occurrence data for rare or elusive species.

Ron Moen	Minnesota/Great Lakes	University of Minnesota and Natural Resources Research Institute	Since 2003, Dr. Moen has studied lynx to understand their distribution, abundance, persistence, movements and habitat use in and near the Superior National Forest in northeastern Minnesota as well as conducting some studies in the greater Upper Great Lakes Region (including Wisconsin and Michigan). He has authored numerous reports and manuscripts on his studies of lynx in Minnesota, and he and his graduate students also conducted studies that used pellet counts to estimate snowshoe hare numbers.
Garth Mowat	Southern British Columbia & Alberta	British Columbia Ministry of Forests, Lands and Resource Operations	Dr. Mowat manages the Research Section for the Resource Stewardship Division in the Kootenay Region of British Columbia, Canada, where his current research varies from geomorphology to ecosystem classification and wildlife ecology, particularly population dynamics of mammals. Garth has published many peer-reviewed articles on lynx including behavior and natural history, capture and immobilization techniques, lynx and hare population dynamics, and lynx pregnancy rates and litter sizes.
Kerry Murphy	Wyoming/Greater Yellowstone	USDA Forest Service	Dr. Murphy is the Zone Wildlife Biologist on the Bridger-Teton National Forest (B-TNF) stationed in Jackson, Wyoming. He has extensive experience monitoring, managing, and surveying Canada lynx and their habitat, and in documenting aspects of other carnivore populations. From 2000-2005, Kerry worked in Yellowstone National Park cooperatively with the Rocky Mountain Research Laboratory, Missoula, to document lynx presence and distribution, and worked with researchers to document snowshoe hare abundance, distribution, and habitat affinities in the park. On the B-TNF, Kerry worked to document snowshoe hare abundance and population trends in different forest types, and lynx presence and distribution. He also recently assisted the U.S. Fish and Wildlife Service by providing a peer-review of the proposed rule revising the lynx critical habitat designation.
Dennis Murray	Southern Canada/Ontario	University of Trent, Ontario	Dr. Murray is the Canada Research Chair in Integrative Wildlife Conservation, Bioinformatics, and Ecological Modeling and a Professor of Biology at Trent University. He also serves on the Scientific Advisory Committee for the Canadian Institute of Ecology and Evolution, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and the IUCN Lagomorph Specialist Group. He has authored and co-authored many peer-reviewed articles on lynx, including conservation needs at the southern edge of the species' range, genetics and functional connectivity among lynx populations, hare habitat and response to forestry management, lynx-bobcat competition, and impacts of climate change on southern lynx populations.
Michael Schwartz	DPS-wide (genetics)	USDA Forest Service - National Genomics Center for Wildlife and Fish Conservation	Director of the National Genomics Center, Dr. Schwartz focuses on population, conservation, and landscape genetics/genomics, genetic monitoring, and the ecology of threatened and endangered species. He has investigated and published peer-reviewed results on lynx genetic variation, population structure, and population connectivity, including documentation of Canada lynx-bobcat (*Lynx canadensis* x *L. rufus*) hybrids at the southern periphery of lynx range in Maine, Minnesota and New Brunswick. He and colleagues also have validated DNA collection as a means of documenting lynx presence and they have developed DNA markers for identifying individual snowshoe hares using field-collected pellets.

Erin Simons-Legaard	Maine/Northeast	University of Maine	An Assistant Research Professor in forest landscape modeling, Dr. Simons-Legaard and her colleagues have developed a forest landscape change model to do retrospective, current, and future forecasts of forest conditions in northern Maine. She has been refining methods for forecasting effects of spruce budworm and climate change on Maine's forest, which she is using to expand her lynx habitat model. This will enable her to forecast future conditions for lynx in Maine considering anticipated changes from climate change effects on Maine's forest composition, current trends in Maine forestry practices, and spruce budworms. Erin has authored and co-authored several peer-reviewed publications on lynx and also recently assisted the U.S. Fish and Wildlife Service by providing a peer-review of the proposed rule revising the lynx critical habitat designation.
John Squires	Northern and Southern Rocky Mountains (Montana, Wyoming, Colorado)	USDA Forest Service - Rocky Mountain Research Station, Missoula, MT	A Research Wildlife Biologist, Dr. Squires leads a team of researchers responsible for discovering and synthesizing information that is needed to conserve threatened, endangered, and sensitive forest carnivores throughout the Rocky Mountains. Also a member of the Lynx Science Team, John has published many peer-reviewed articles on lynx conservation, habitat use/selection, dispersal, denning, developing and improving survey and monitoring techniques, and the effects of forest management and recreation on lynx. He also recently assisted the U.S. Fish and Wildlife Service by providing a peer-review of the proposed rule revising the lynx critical habitat designation.
Jennifer Vashon	Maine/Northeast	Maine Department of Inland Fish and Wildlife	Jennifer led a 10-year study of lynx in Maine, published two manuscripts in the Journal of Wildlife Management in 2008, and co-authored other manuscripts with Dr. Harrison's graduate students and other lynx researchers. In 2012, she authored a Canada lynx assessment for the State of Maine, which summarizes published and unpublished data from the 10-year study and summarizes current knowledge of lynx in Maine.

Canada Lynx
Species Status Assessment
Expert Elicitation Workshop

Bloomington, Minnesota
October 13-15, 2015

Objectives

- Why are we here?
  - Gather scientific information from experts on current status, threats, and future viability of lynx populations in the contiguous U.S.
  - Where data are lacking, elicit expert knowledge, professional judgment, and opinion on the nature and magnitude of potential threats to DPS populations and the DPS as a whole
- Why do we need this information?
  - Complete a Species (DPS) Status Assessment for lynx
  - Court-ordered deadline for completing a recovery plan

Objectives

- Why are we *NOT* here?
  - To make policy or ESA status/listing decisions
  - To develop recovery goals, objectives, criteria
  - To "settle" or resolve disagreements or differences of opinion/interpretation where there is uncertainty, limited data, or a range of potential outcomes
  - To determine the "right answer"
  - To seek consensus

Brief Listing History

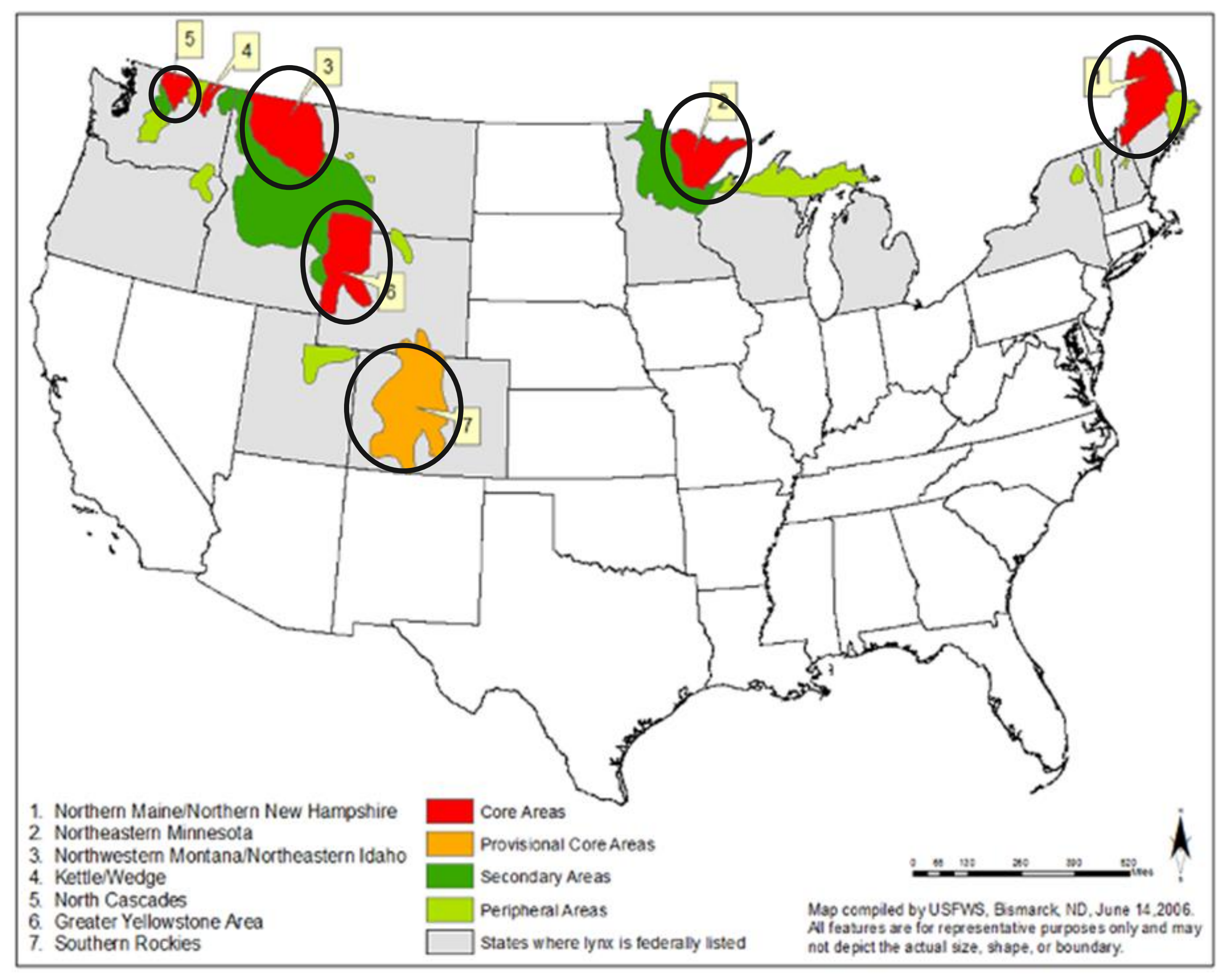
- 2000 (& 2003) - Contiguous U.S. DPS listed as threatened:

"…by the inadequacy of existing regulatory mechanisms. Current U.S. Forest Service Land and Resource Management Plans include programs, practices, and activities within the authority and jurisdiction of Federal land management agencies that may threaten lynx or lynx habitat. The lack of protection for lynx in these Plans render them inadequate to protect the species."

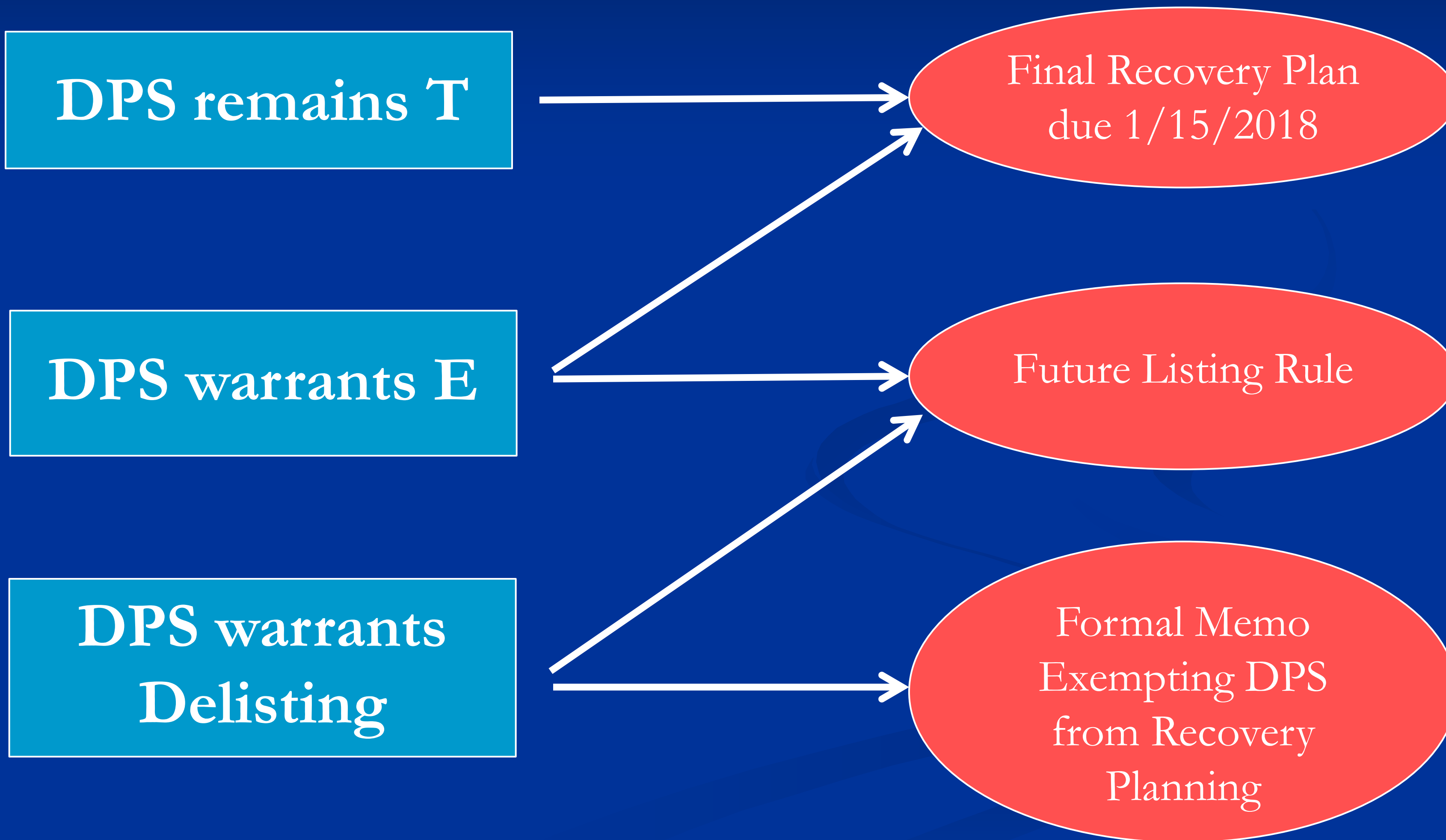
Brief Listing History

- 2005 - Recovery Outline
- 2006 - CH designated
- 2007 - SPR Clarification
  - Service withdrew 2006 CH
- 2009 & 2014 - Revised CH
- June 25, 2014 – Court order to complete Recovery Plan by Jan. 15, 2018

Lynx DPS Subpopulations



Potential Findings



Schedule

- Court order to finalize recovery plan by Jan. 2018
- Dec. 2014/Jan. 2015 – announced re-initiation of 5-year status review
- Mar. 2015 – Decision to implement SSA framework
- Dec. 2015 – Finish SSA to allow completion of final recovery plan by court-ordered deadline
- Jan. 2016 to Jan. 2017 – Draft recovery plan
- Jan. 2017 to Jan. 2018 – Final recovery plan

Proposed Schedule

Project Plan - DRAFT Canada lynx DPS - SSA/ 5-Year Review/ Recovery Plan Conceptual Schedule*

(Calendar Years)	2015				2016				2017				2018			
Activities/Products *(Quarters**)*	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
SPECIES STATUS ASSESSMENT (SSA)																
Form SSA Team																
Complete Species Needs																
Identify Model Scenarios***																
Model development																
Identify model framework & scientific validity																
Build model (e.g., BBN - Bayesian Belief Network)																
Prototype model structure																
Expert elicitation for "current conditions into future" scenario****																
Run "current conditions into future" scenario																
Evaluate 3Rs for first scenario/determine need for additional scenarios																
SSA Peer review																
If needed, run additional management scenarios, including EE, for REV																
5-YEAR REVIEW																
5-year review recommendation																
REV, IF NEEDED																
Draft RP																
Comments/peer review																
Final RP																
Develop RIS																
Summary																
SSA Analysis and Documentation																
5-year Review (to final recommendation)																
Recovery Planning (to Final Plan)																

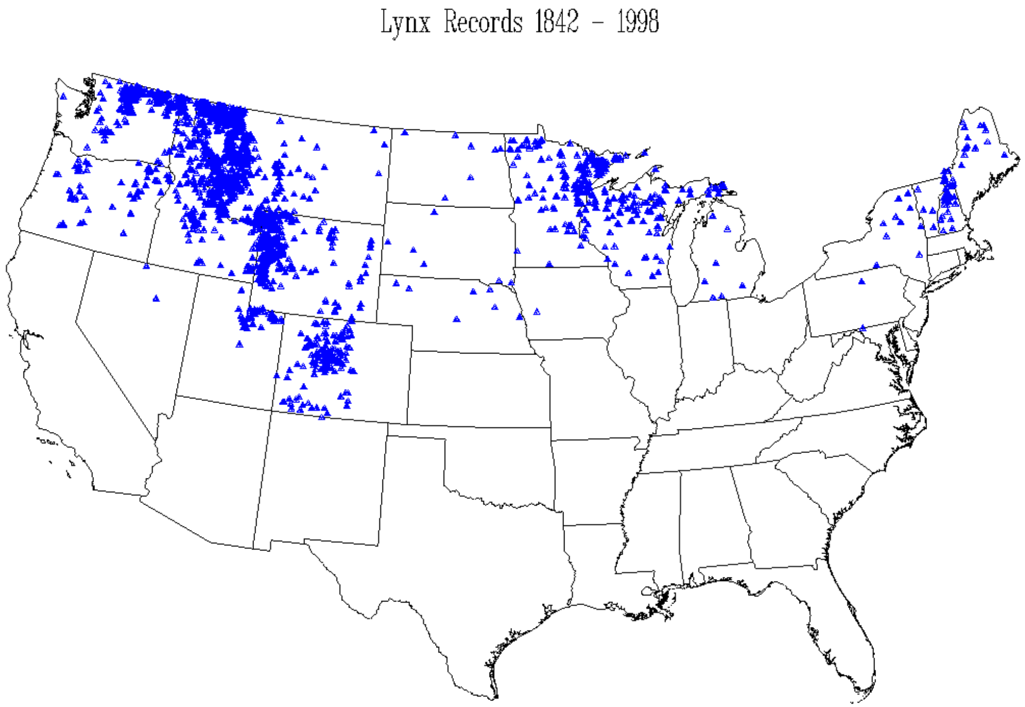
Next Steps

- Compile notes and summarize proceedings of this workshop; distribute for review by experts and presenters
- Complete SSA report by end of 2015; conduct peer-review and distribute to partner agencies
- Convene recovery planning team if necessary


ww.duiops.net/seresvivos
Questions?

Historical distribution of lynx in the contiguous U.S.

Kevin S. McKelvey
Keith B. Aubry
Yvette K. Ortega



From: McKelvey, K. S., K. B. Aubry, and Y. K. Ortega. 2000. History and distribution of lynx in the contiguous United States. pgs. 207-259. *In*: Ruggiero et al., Ecology and conservation of lynx in the United States. University Press of Colorado, Boulder Colorado, 480 p. ; RMRS GTR-30

Historical range important: provides context for modern conservation

Generally weak

Seton 1929

Issues associated with historical data

Not representative

Oftentimes not reliable

Meaning unclear

Everything has something that it is confused with

Lynx and bobcats are closer than many

Lynx or Bobcat?: You Make the Call

Mike Schwartz
March 2002

The problem with relatively rare organisms

Actual population = 0.1x

1000 detections
90% success in identification
Equal detection likelihood

90	900
100	10
53% misidentification	1% misidentification

In the extreme…

Actual population = 0

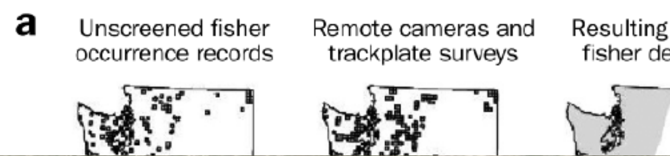
0
100

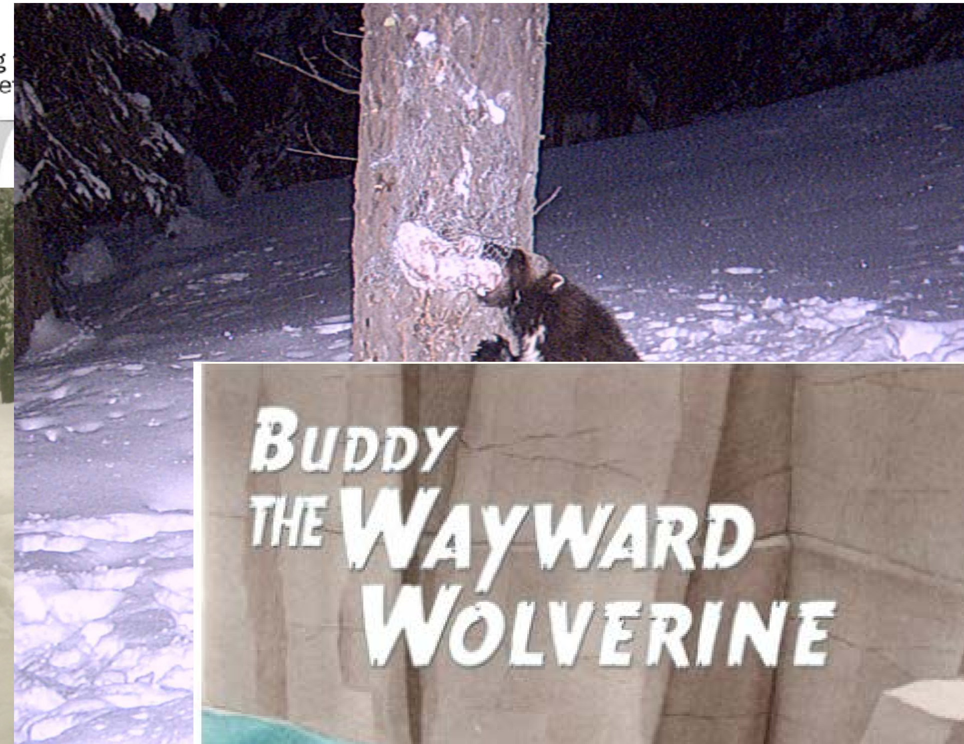
1000 detections
90% success in identification
Equal detection likelihood

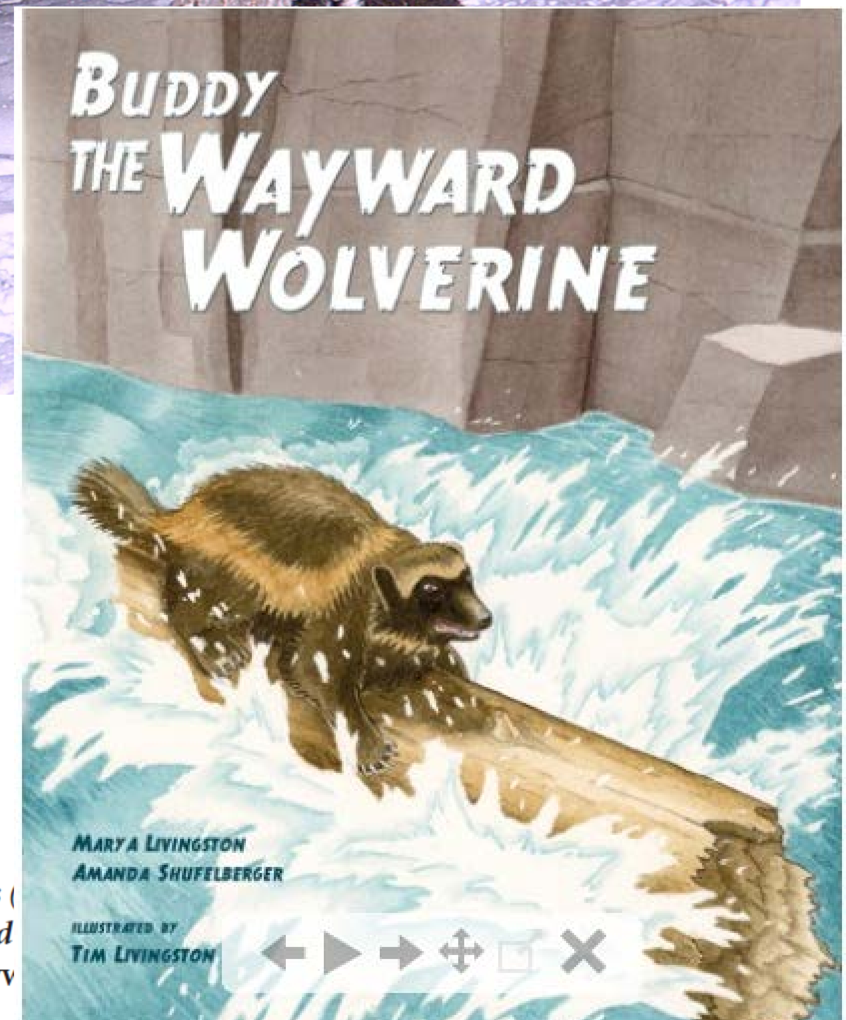
900
0

100% misidentification

0% misidentification







Numerous photos
20 DNA samples (most recent 2014)
Named: "Buddy"

Figure 1. Recent occurrence records for (a) fisher in the Pacific states (
[2003]), (b) wolverine in California (ca. 1960–1974; map reproduced
woodpecker in the southeastern states (1944–2005; modified from wv

Animals will leave reliable occurrence data

A population over time = many organisms

Heavy screening is warranted

Need stringent standards; can't eliminate all locations

Another problem with historical data: it's finite

Goldilocks problem: verified records

formal analyses based on these designations. Rather, for analyses where high reliability for each occurrence is essential, we used a subset of these data we call "verified records." We considered a record to be verified only if it was represented by a museum specimen or a written account in which a lynx was either in someone's possession or observed closely, i.e., where a lynx was killed, photographed, trapped and released, or treed by dogs. Information obtained from snow-tracking surveys conducted by trained individuals are discussed where appropriate, but neither tracks nor sighting reports were considered to represent a verified record.

Novak et al. 1988 Furbearer harvests in North America 1600-1984

COMMENTS

In the pre-20th century fur trade, a distinction was not always made between lynx and bobcat pelts. The bobcat was variously referred to as bay lynx, cat common, lynx cat, or wild cat by fur dealers; the lynx was referred to as lynx.

Given the Hudson's Bay Company's area of operation until the early 1800s and the geographic range of the lynx and bobcat, it seems likely that few bobcats were obtained by Hudson's Bay Company traders. Indeed, Poland (1892) noted that "cat common" were rarely imported by the Hudson's Bay Company, although a few were obtained from their Columbia Department. Both lynx and cat common are listed in the tables of quantities of non-Hudson's Bay Company furs imported to London. However, Davidson (1918) simply lists "cased" and "open" cats exported by the North West Company. As there is no reason to assume that lynx and bobcats were skinned differently, no subdivision of the harvest can be made on that basis. Because of the inconsistency in recording of these pelts we have lumped the data for the pre-20th century period; these data are presented in Table 15. The 20th century harvest data for lynx are presented in Table 16; that for the bobcat in Table 7.

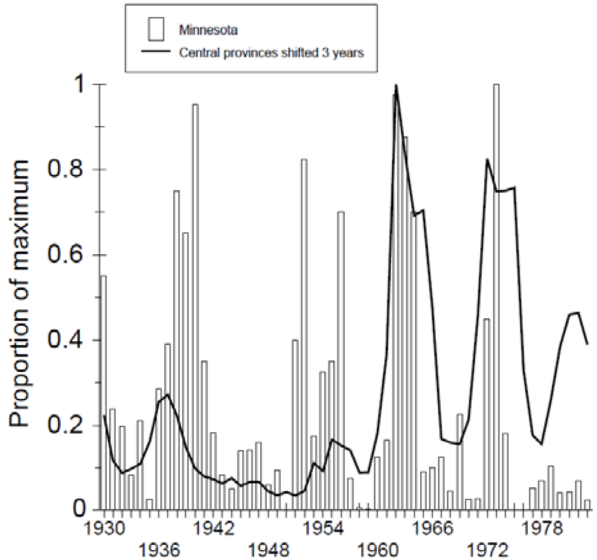


Figure 8.10—Lynx trapping data from Minnesota (Fig. 8.4) overlaid on lynx trapping data from Ontario, Manitoba, and Saskatchewan combined (Fig. 8.3). The strongest correlation between these data sets was with a three-year lag between Minnesota and south-central Canada.

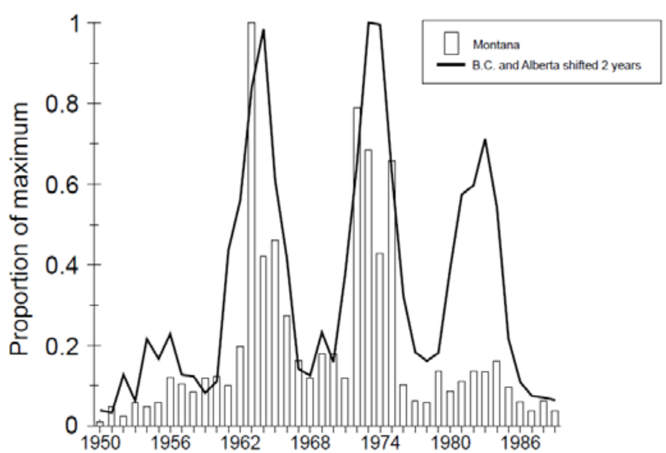
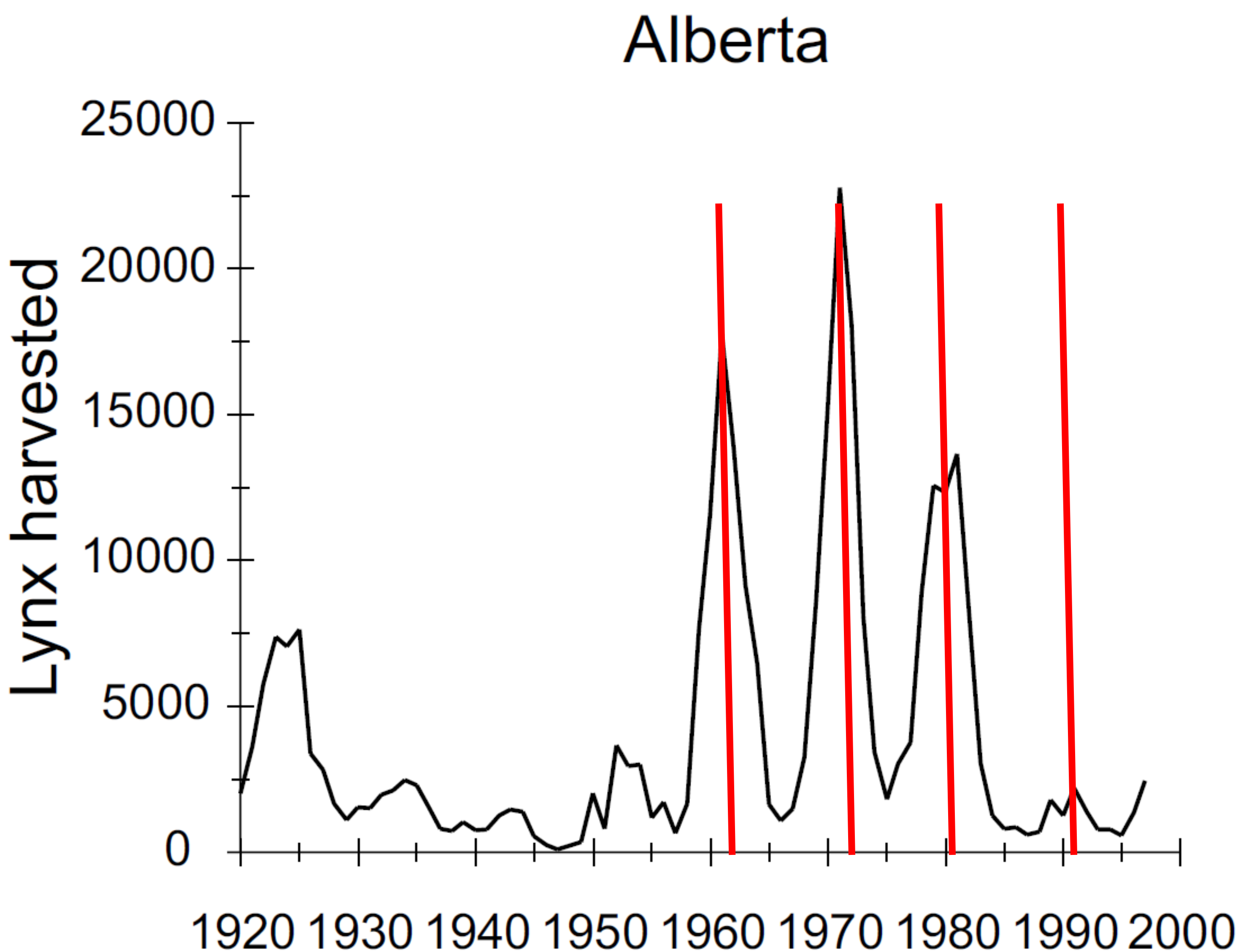


Figure 8.11—Lynx trapping data from Montana (Fig. 8.5) overlaid on lynx trapping data from Alberta and British Columbia combined (Fig. 8.6). The strongest correlation between these data sets was with a two-year lag between Montana and southwestern Canada.

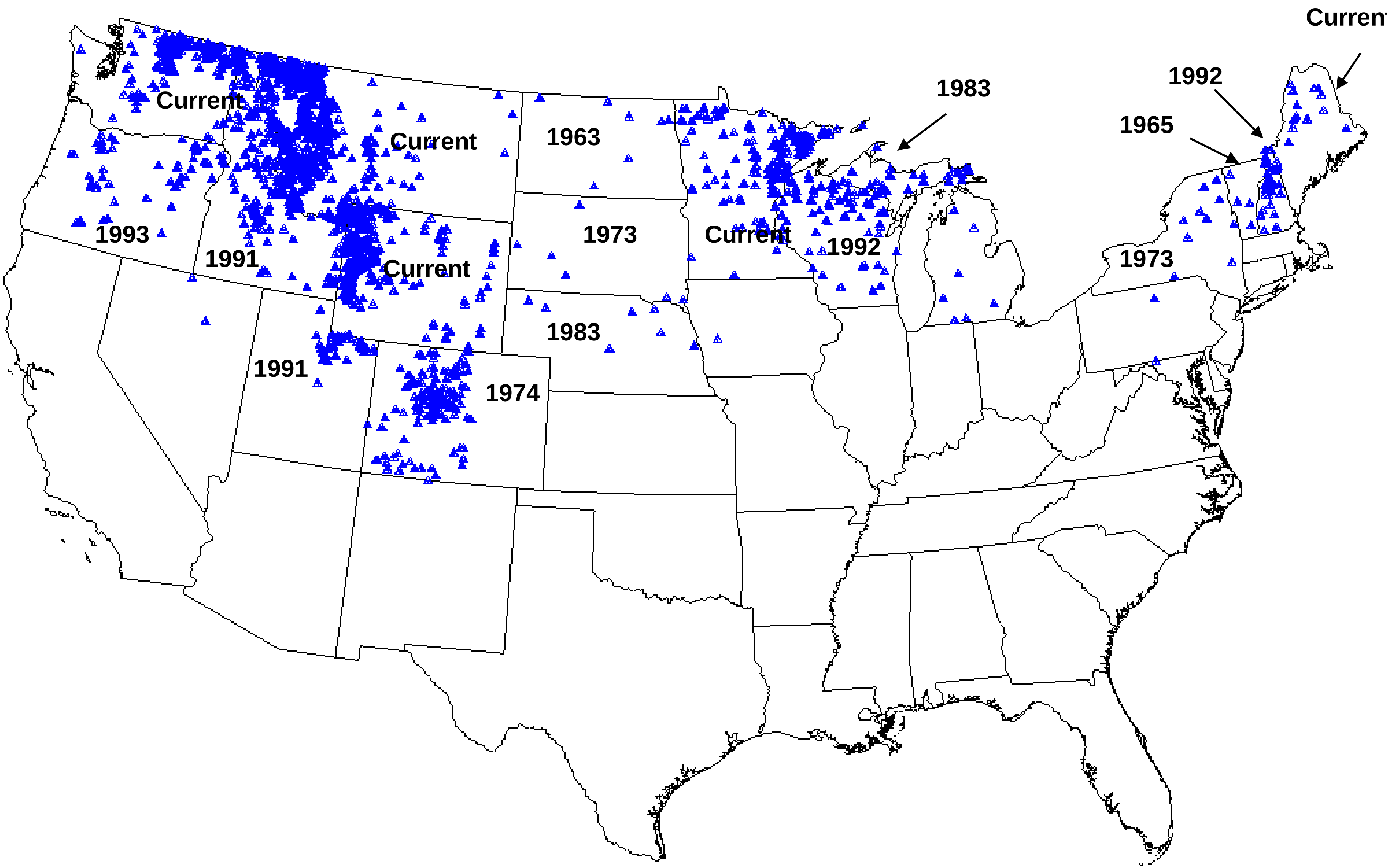
Lynx periodically move south from Canada after eruptions

Figures from McKelvey et al. (2000)

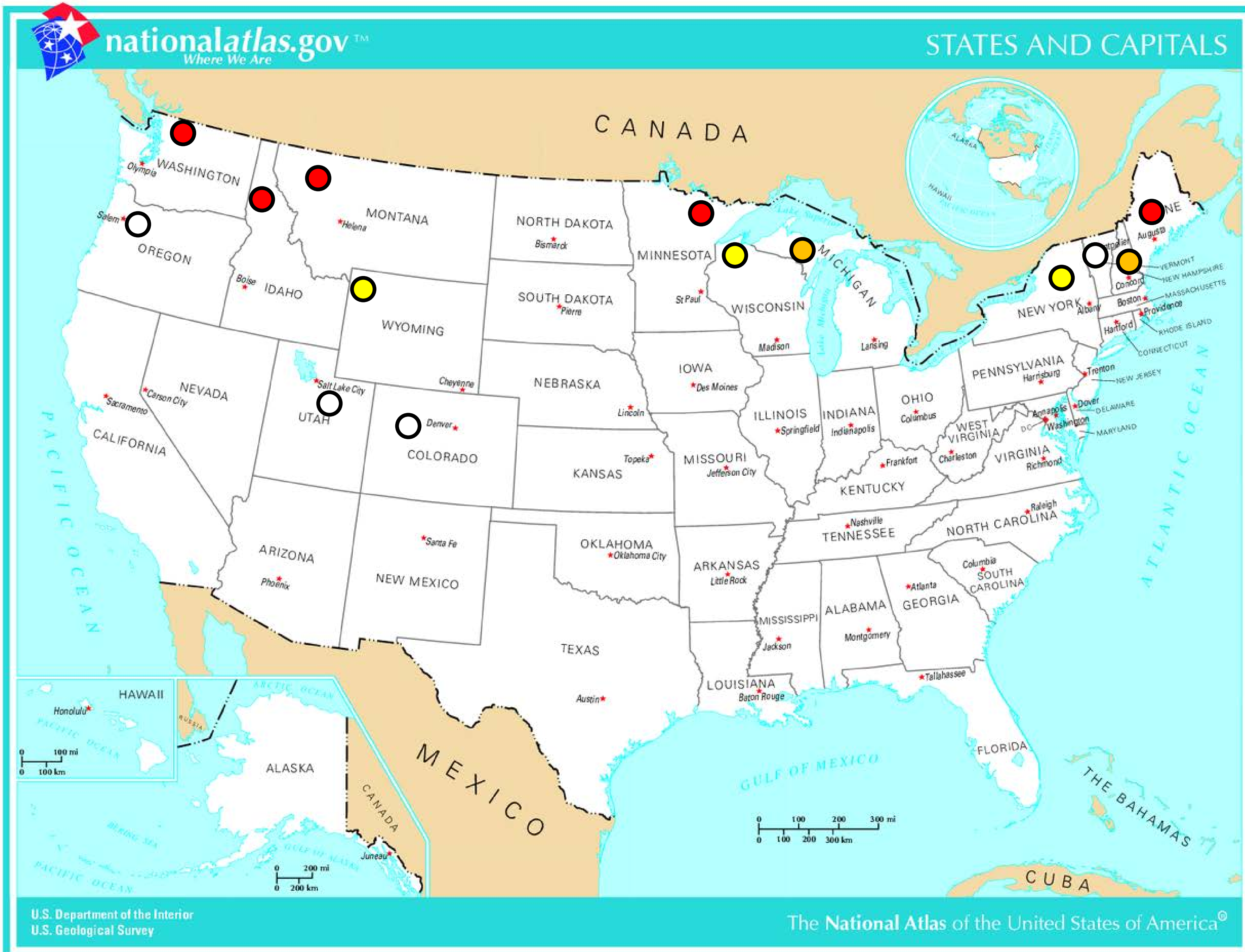


Data from Novak et al. 1988

Lynx Records 1842 - 1998



From: McKelvey, K. S.., K. B. Aubry, and Y. K. Ortega. 2000. History and distribution of lynx in the contiguous United States. pgs. 207-259. *In*: Ruggiero et al., Ecology and conservation of lynx in the United States. University Press of Colorado, Boulder Colorado, 480 p.



states_capitals2.pdf INTERIOR-GEOLOGICAL SURVEY, RESTON, VIRGINIA-2003

Peer Reviewed

DNA Analysis of Hair and Scat Collected Along Snow Tracks to Document the Presence of Canada Lynx

KEVIN S. McKELVEY,[1] *Rocky Mountain Research Station, United States Forest Service, Missoula, MT 59807, USA*
JEFFREY VON KIENAST, *Rogue River National Forest, United States Forest Service, Prospect, OR 97536, USA*
KEITH B. AUBRY, *Pacific Northwest Research Station, United States Forest Service, Olympia, WA 98512, USA*
GARY M. KOEHLER, *Washington Department of Fish and Wildlife, Olympia, WA 98501, USA*
BENJAMIN T. MALETZKE, *Department of Natural Resource Sciences, Washington State University, Pullman, WA 99164, USA*
JOHN R. SQUIRES, *Rocky Mountain Research Station, United States Forest Service, Missoula, MT 59807, USA*
EDWARD L. LINDQUIST, *Superior National Forest, United States Forest Service, Duluth, MN 55808, USA*
STEVE LOCH, *Superior National Forest, United States Forest Service, Duluth, MN 55808, USA*
MICHAEL K. SCHWARTZ, *Rocky Mountain Research Station, United States Forest Service, Missoula, MT 59807, USA*

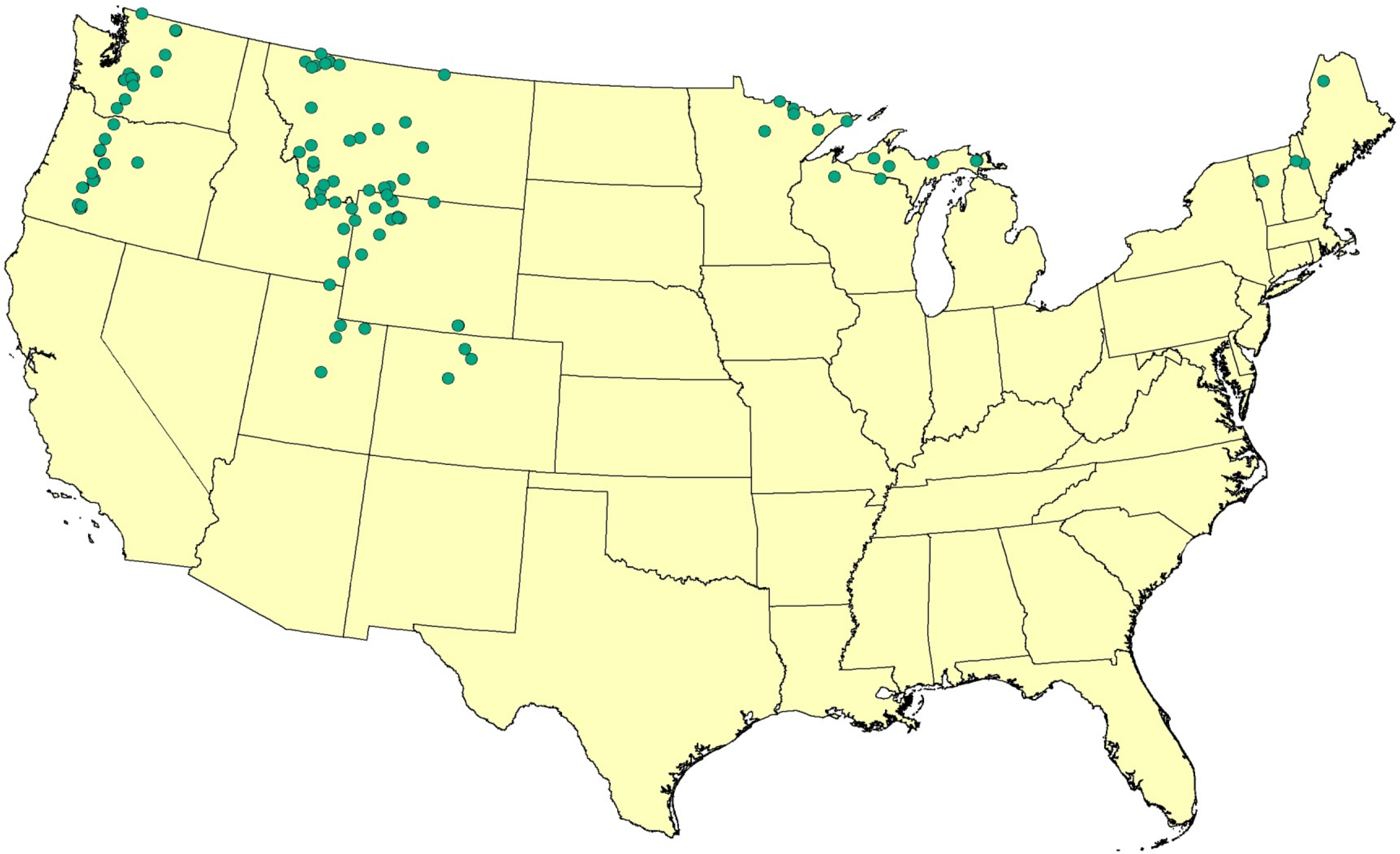
Efficacy of lures and hair snares to detect lynx

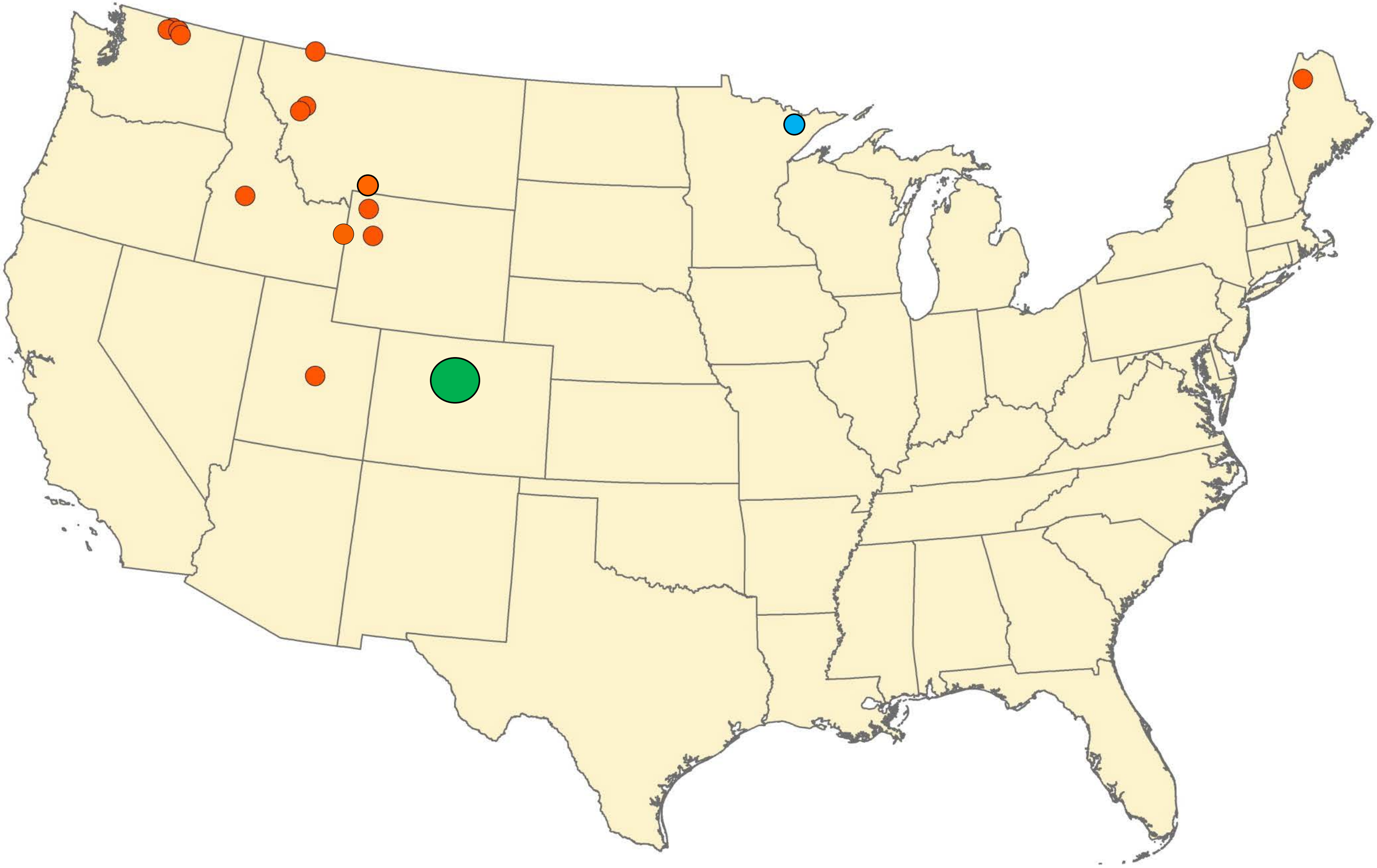
Gregory W. McDaniel, Kevin S. McKelvey, John R. Squires, and Leonard F. Ruggiero

A Snow-tracking Protocol Used to Delineate Local Lynx, *Lynx canadensis*, Distributions

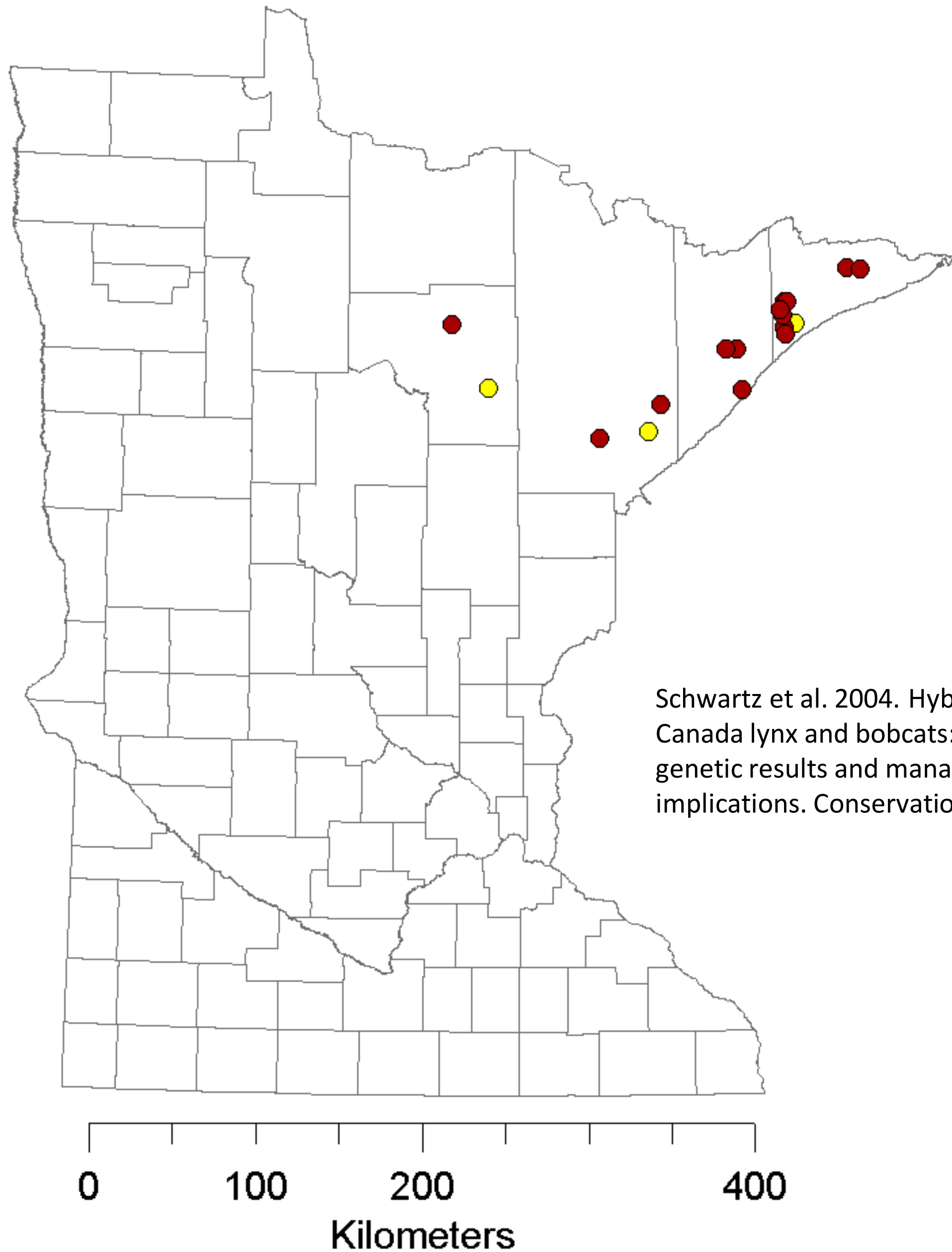
JOHN R. SQUIRES, KEVIN S. MCKELVEY, and LEONARD F. RUGGIERO

National Lynx Survey Grid Locations





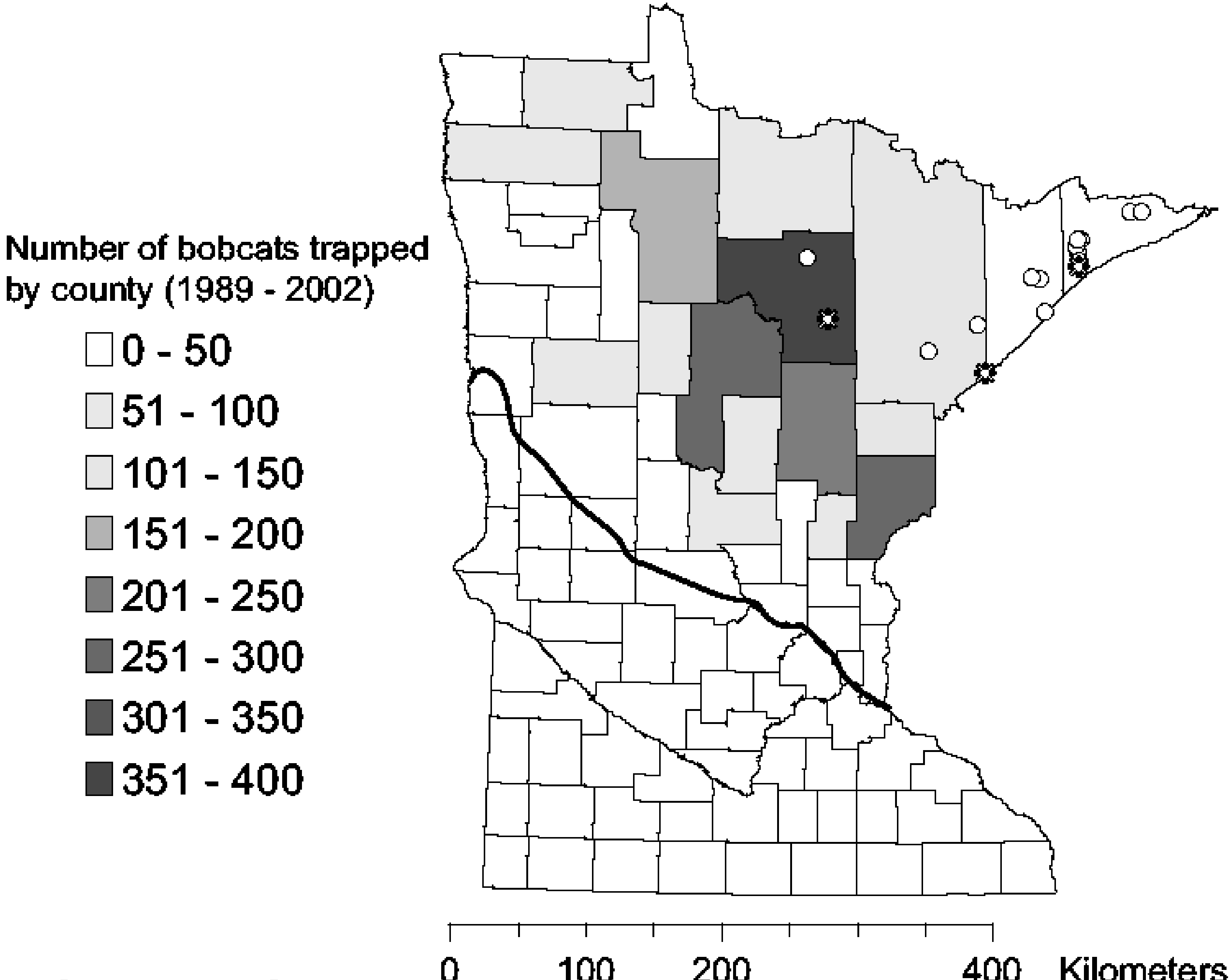
Grids on which the National Lynx Survey has detected lynx , 1999-2003



Schwartz et al. 2004. Hybridization between Canada lynx and bobcats: genetic results and management implications. Conservation Genetics 5 (3), 349-355

Hybrids

Unique Lynx



Schwartz et al. 2004

Conclusions:

Historical lynx data are fraught with ambiguities

- Confusion with bobcats
- Periodic immigration obvious
- Dependency unknown

Strong data streams consistent with persistent lynx populations:

- Maine
- New Hampshire
- Michigan
- Minnesota
- Montana
- Idaho
- Washington

Specific location data in these states: proximity to Canada important

Losses: New Hampshire, Michigan (New York, Wisconsin)
Additions: GYA

Canada Lynx Habitat Regulatory Environment

Milo Burcham

Scott Jackson
National Carnivore Program Leader
US Forest Service

Pre-Listing

- Sensitive species status within Forest Service
- Evaluated in Biological Evaluation
  - Did FS actions contribute to a trend toward listing – not much data or direction available
- 1991 – 1998 several petitions filed requesting FWS to list lynx as endangered. Lawsuit finally resulted in a settlement agreement between FWS and Plaintiffs to propose listing of lynx.

Steering Committee

- 1998
- USFS, BLM, USFWS, NPS
- Provided guidance to science and biology teams that were established to address lynx conservation issues on federal lands.
- Directed the compilation of three documents considered essential for understanding lynx ecology and appropriate conservation measures on federal land…

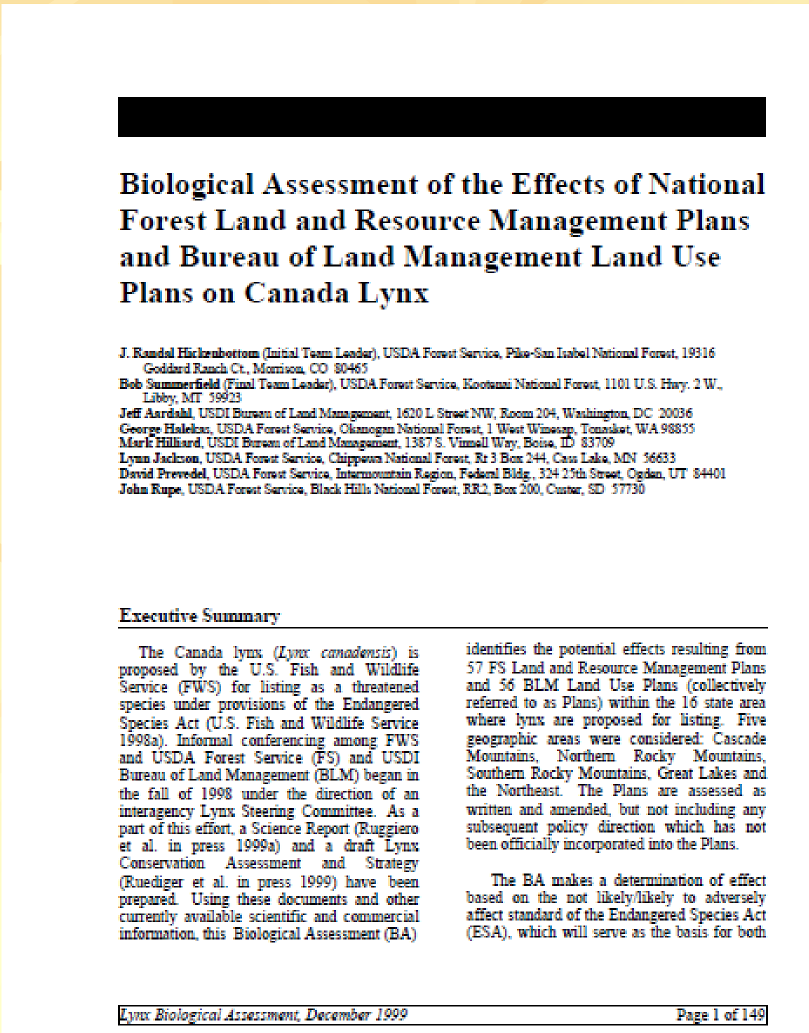
Ecology and Conservation of Lynx in the United States

- “Science Report”
- Science Team
- Completed 1999
- Published 2000

Lynx Conservation Assessment and Strategy

- LCAS
- 2000
- Interagency Lynx Biology Team

Biological Assessment 1999



Biological Assessment of the Effects of National Forest Land and Resource Management Plans and Bureau of Land Management Land Use Plans on Canada Lynx

J. Randal Hickenbottom (Initial Team Leader), USDA Forest Service, Pike-San Isabel National Forest, 19316 Goddard Ranch Ct., Morrison, CO 80465
Bob Summerfield (Final Team Leader), USDA Forest Service, Kootenai National Forest, 1101 U.S. Hwy. 2 W., Libby, MT 59923
Jeff Aardahl, USDI Bureau of Land Management, 1620 L Street NW, Room 204, Washington, DC 20036
George Halekas, USDA Forest Service, Okanogan National Forest, 1 West Winesap, Tonasket, WA 98855
Mark Hilliard, USDI Bureau of Land Management, 1387 S. Vinnell Way, Boise, ID 83709
Lynn Jackson, USDA Forest Service, Chippewa National Forest, Rt 3 Box 244, Cass Lake, MN 56633
David Prevedel, USDA Forest Service, Intermountain Region, Federal Bldg., 324 25th Street, Ogden, UT 84401
John Rupe, USDA Forest Service, Black Hills National Forest, RR2, Box 200, Custer, SD 57730

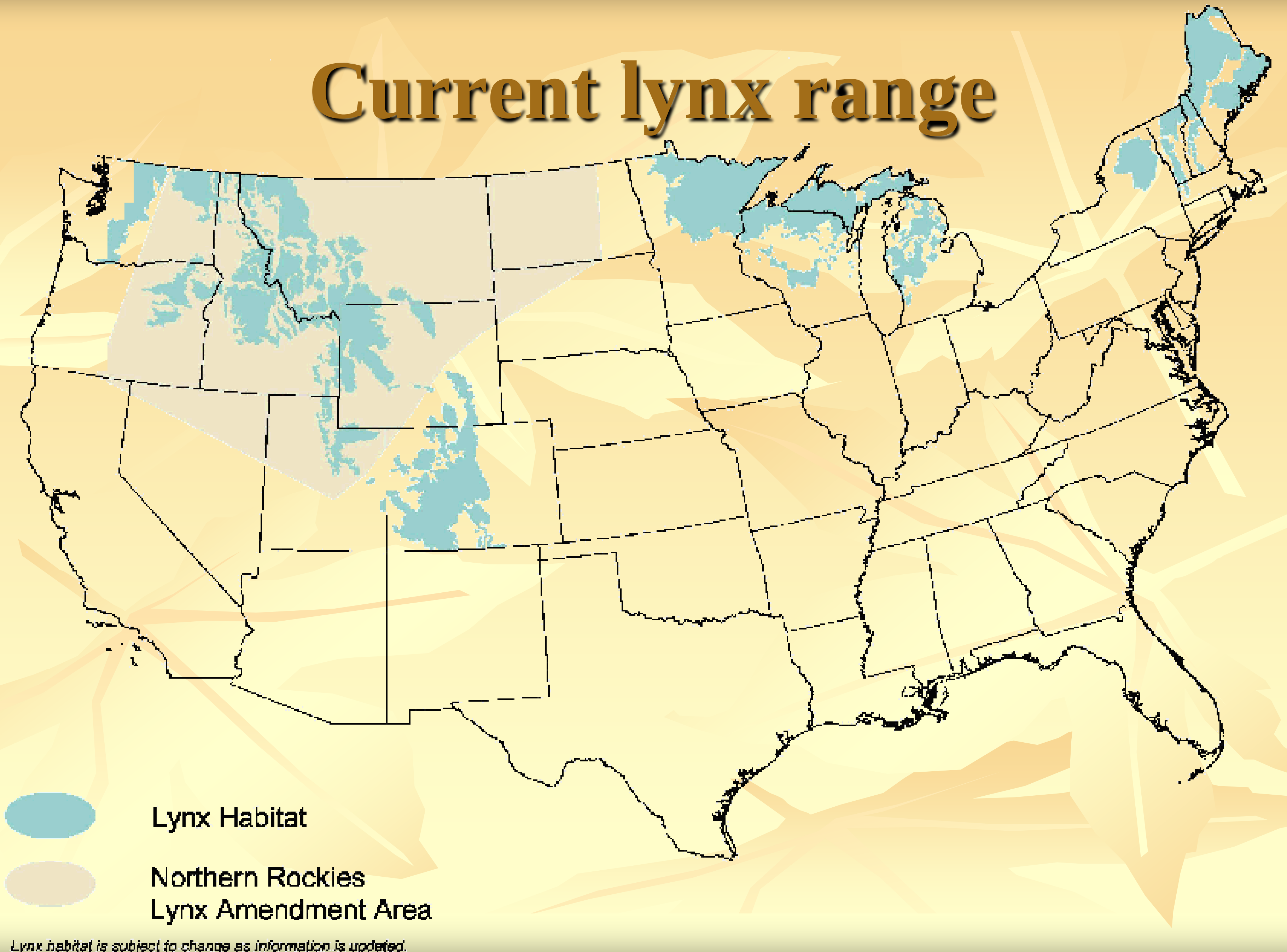
Executive Summary

The Canada lynx (*Lynx canadensis*) is proposed by the U.S. Fish and Wildlife Service (FWS) for listing as a threatened species under provisions of the Endangered Species Act (U.S. Fish and Wildlife Service 1998a). Informal conferencing among FWS and USDA Forest Service (FS) and USDI Bureau of Land Management (BLM) began in the fall of 1998 under the direction of an interagency Lynx Steering Committee. As a part of this effort, a Science Report (Ruggiero et al. in press 1999a) and a draft Lynx Conservation Assessment and Strategy (Ruediger et al. in press 1999) have been prepared. Using these documents and other currently available scientific and commercial information, this Biological Assessment (BA) identifies the potential effects resulting from 57 FS Land and Resource Management Plans and 56 BLM Land Use Plans (collectively referred to as Plans) within the 16 state area where lynx are proposed for listing. Five geographic areas were considered: Cascade Mountains, Northern Rocky Mountains, Southern Rocky Mountains, Great Lakes and the Northeast. The Plans are assessed as written and amended, but not including any subsequent policy direction which has not been officially incorporated into the Plans.

The BA makes a determination of effect based on the not likely/likely to adversely affect standard of the Endangered Species Act (ESA), which will serve as the basis for both

- 57 NFs
- 56 BLM units
- Five Geographic Areas
    - Cascades
    - N. Rockies
    - S. Rockies
    - Great Lakes
    - Northeast

Current lynx range

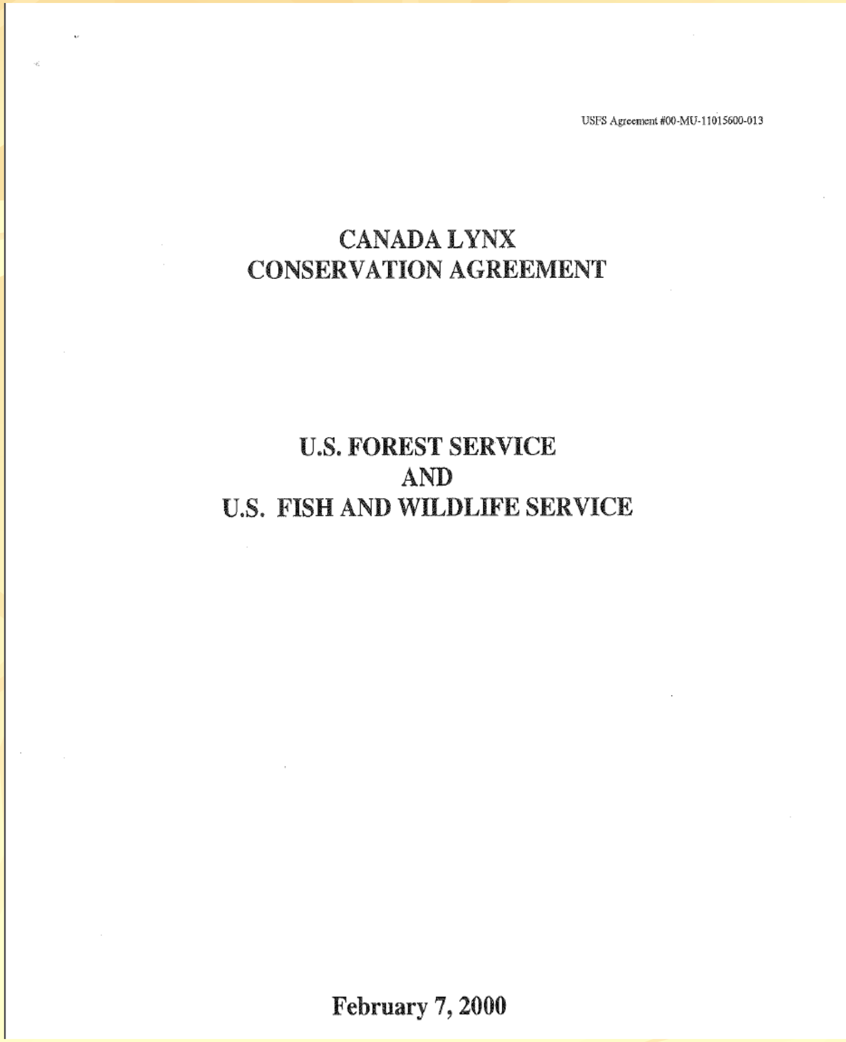


Final Rule Listing Lynx as Threatened

Conclusion:

Primary threat to lynx in the contiguous United States was the lack of adequate regulatory mechanisms in LRMPs

Conservation Agreements



USFS Agreement #00-MU-11015600-013

CANADA LYNX
CONSERVATION AGREEMENT

U.S. FOREST SERVICE
AND
U.S. FISH AND WILDLIFE SERVICE

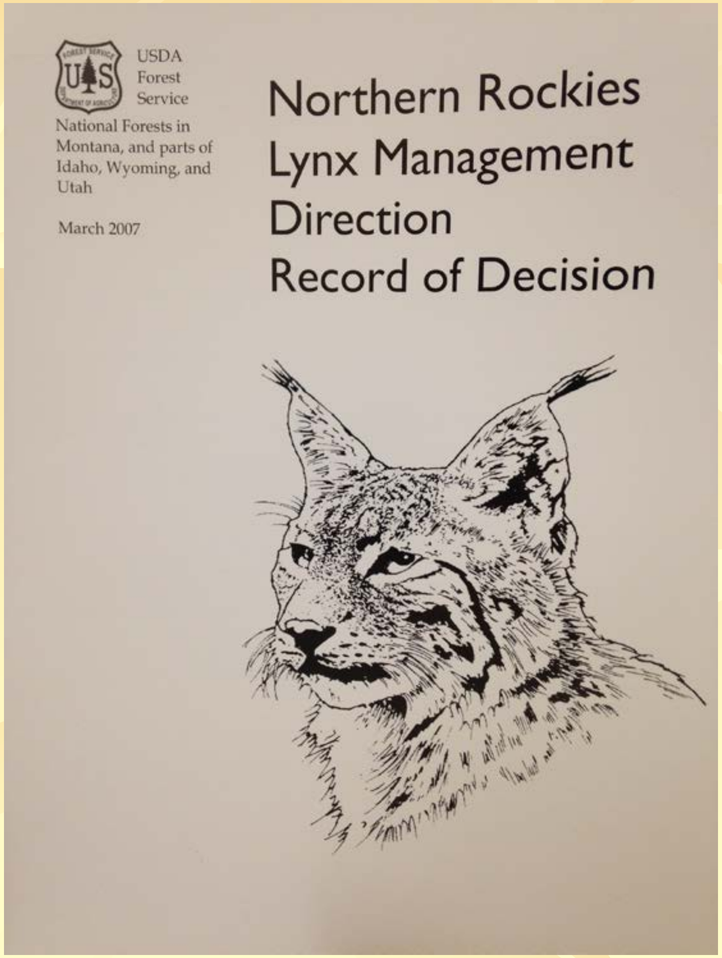
February 7, 2000

- Agreements between USFWS and USFS and BLM

- First signed in 2000.

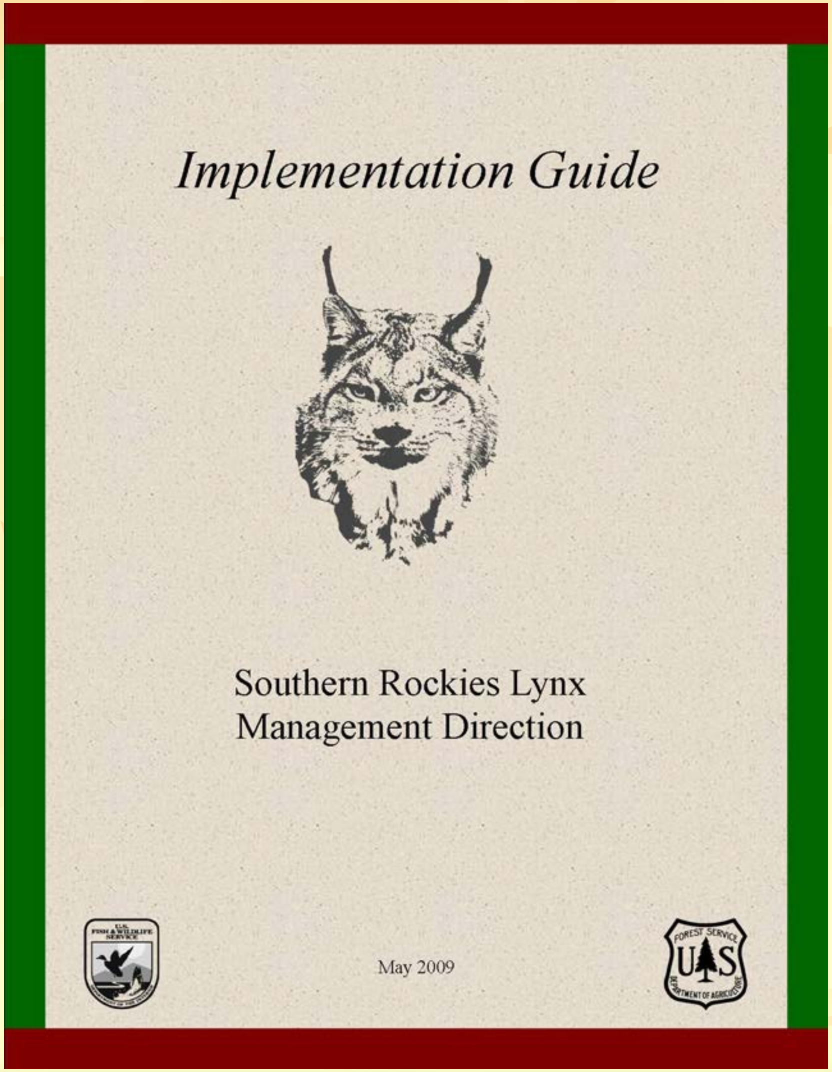
Lynx Geographic Areas

Northern Rockies Lynx Management Direction



- 2007
- Amended 18 National Forests in ID, MT, WY, UT
- >18 million acres of lynx habitat across >38 million acres of NF

Southern Rockies Lynx Management Direction

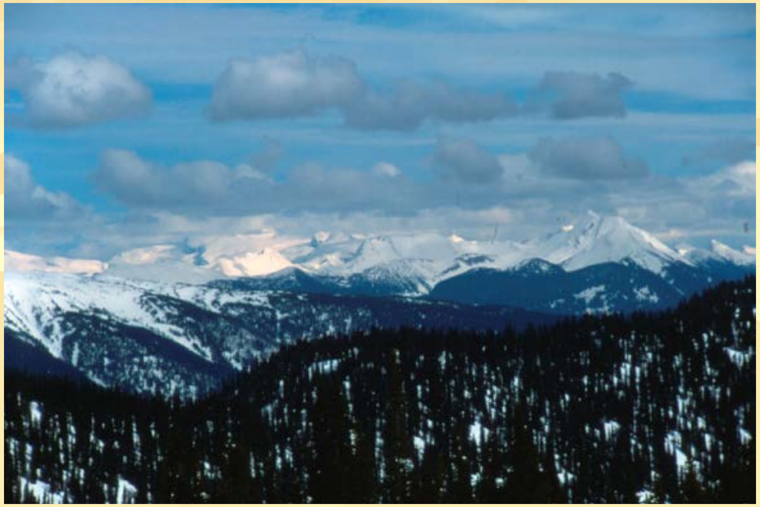


- 2008
- Amended 8 Forest Plans in CO
- Covered 7.5 million acres of lynx habitat within 15 million acres of NF.

Lynx Conservation Assessment and Strategy

- Identified 17 risk factors affecting:
  - productivity
  - mortality
  - movements
  - other large scale factors

Canada Lynx Habitat



- Mesic coniferous forests
- Dry, deep snow conditions
- Prey base of SSH
- Dense horizontal cover protruding above snow in mid-winter
- Dense horizontal cover during non-snow periods

Some Challenges

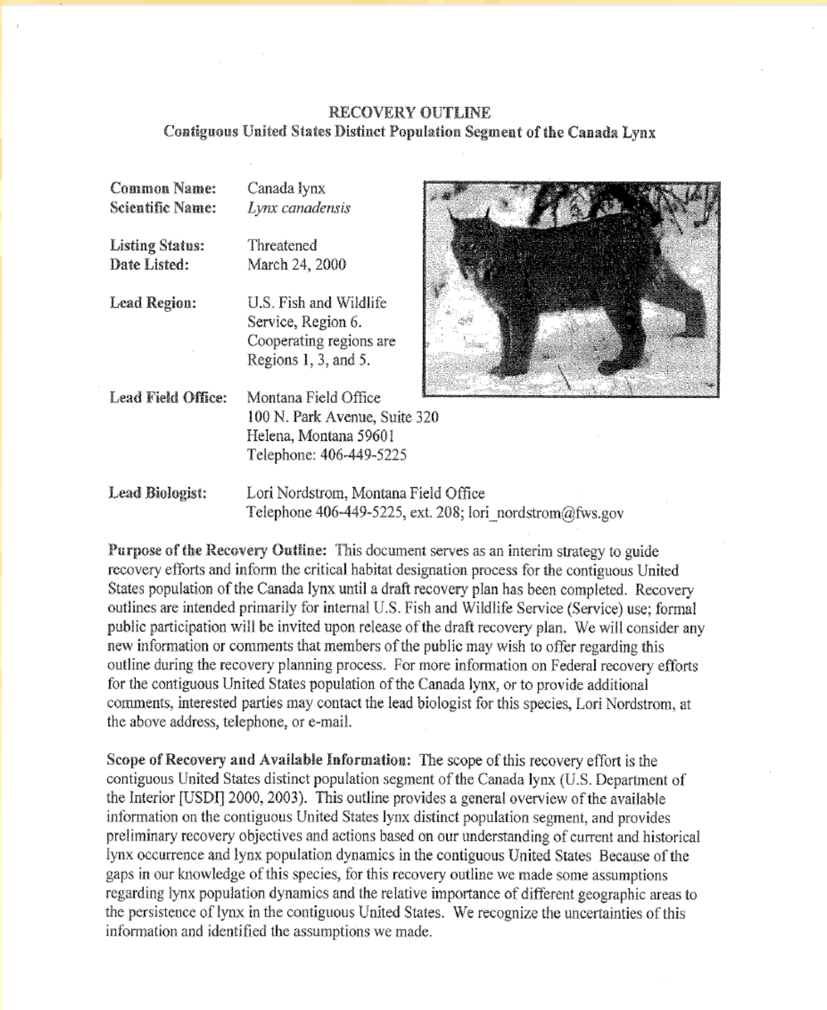
- Effects of vegetation mgmt activities on winter snowshoe hare habitat in multistory forests
- Effects of limiting pre-commercial thinning
- Effects of limiting growth of groomed or designated winter over-the-snow routes
- Effects of vegetation mgmt standards on wildland fire risk to communities

Vegetation Management

- Objectives: Provide a mosaic to support snowshoe hares; focus management to improve habitat.
- Standards:
  - If >30% of lynx habitat is in stand initiation stage, no additional habitat may be regenerated; no more than 15% regenerated in a 10-yr period.
  - Pre-commercial thinning that reduces snowshoe hare habitat is not allowed.

    (exceptions for defensible space, research, aspen restoration)
  - Retain understory cover in multistoried stands

Recovery Outline


RECOVERY OUTLINE
Contiguous United States Distinct Population Segment of the Canada Lynx

Common Name: Canada lynx
Scientific Name: *Lynx canadensis*

Listing Status: Threatened
Date Listed: March 24, 2000

Lead Region: U.S. Fish and Wildlife Service, Region 6. Cooperating regions are Regions 1, 3, and 5.

Lead Field Office: Montana Field Office
100 N. Park Avenue, Suite 320
Helena, Montana 59601
Telephone: 406-449-5225

Lead Biologist: Lori Nordstrom, Montana Field Office
Telephone 406-449-5225, ext. 208; lori_nordstrom@fws.gov

Purpose of the Recovery Outline: This document serves as an interim strategy to guide recovery efforts and inform the critical habitat designation process for the contiguous United States population of the Canada lynx until a draft recovery plan has been completed. Recovery outlines are intended primarily for internal U.S. Fish and Wildlife Service (Service) use; formal public participation will be invited upon release of the draft recovery plan. We will consider any new information or comments that members of the public may wish to offer regarding this outline during the recovery planning process. For more information on Federal recovery efforts for the contiguous United States population of the Canada lynx, or to provide additional comments, interested parties may contact the lead biologist for this species, Lori Nordstrom, at the above address, telephone, or e-mail.

Scope of Recovery and Available Information: The scope of this recovery effort is the contiguous United States distinct population segment of the Canada lynx (U.S. Department of the Interior [USDI] 2000, 2003). This outline provides a general overview of the available information on the contiguous United States lynx distinct population segment, and provides preliminary recovery objectives and actions based on our understanding of current and historical lynx occurrence and lynx population dynamics in the contiguous United States. Because of the gaps in our knowledge of this species, for this recovery outline we made some assumptions regarding lynx population dynamics and the relative importance of different geographic areas to the persistence of lynx in the contiguous United States. We recognize the uncertainties of this information and identified the assumptions we made.

- USFWS
- Sept. 2005
- Interim guidance for consultation and recovery until formal recovery plan approved.
- Lynx habitat stratified into core, secondary and peripheral areas.

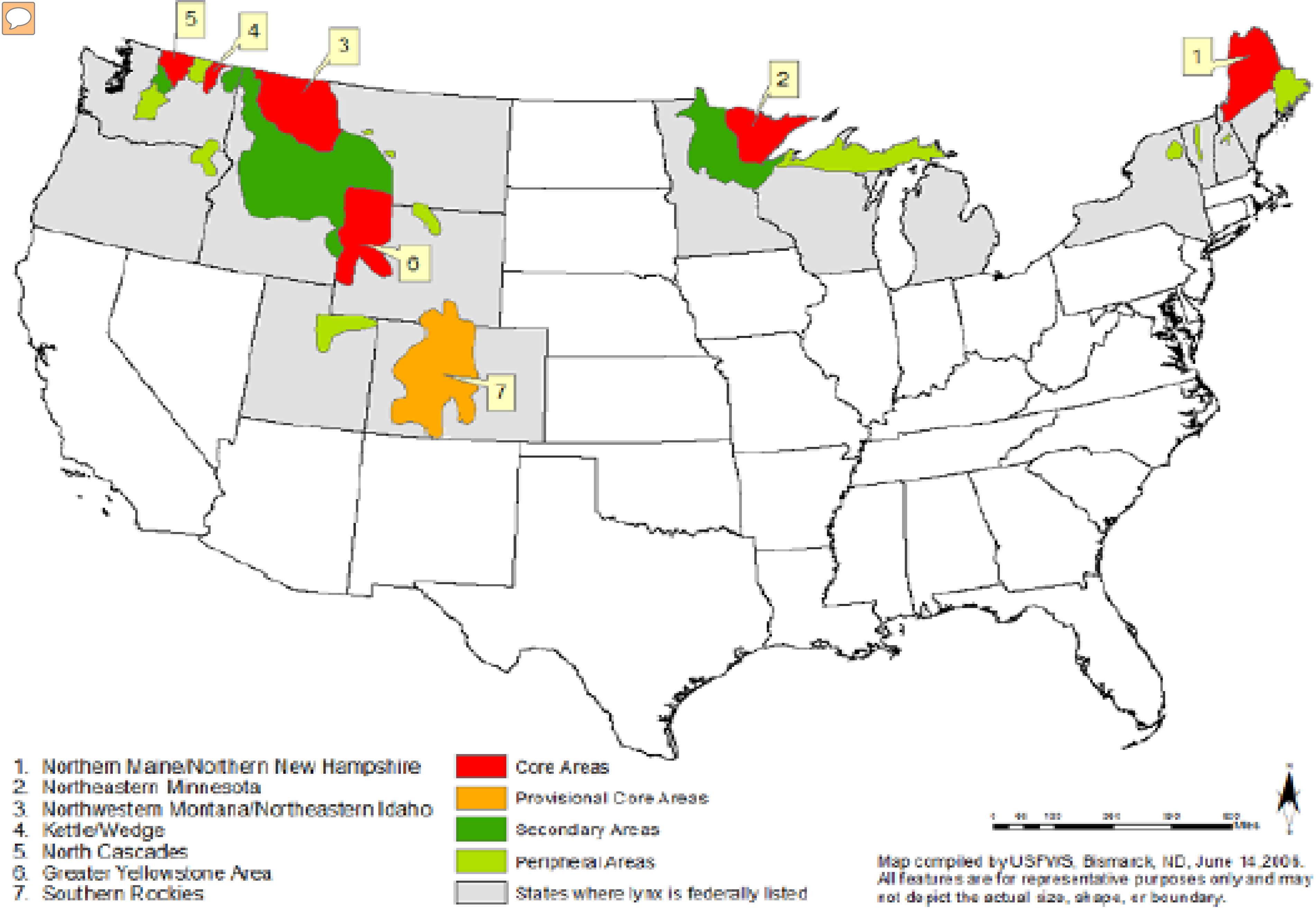
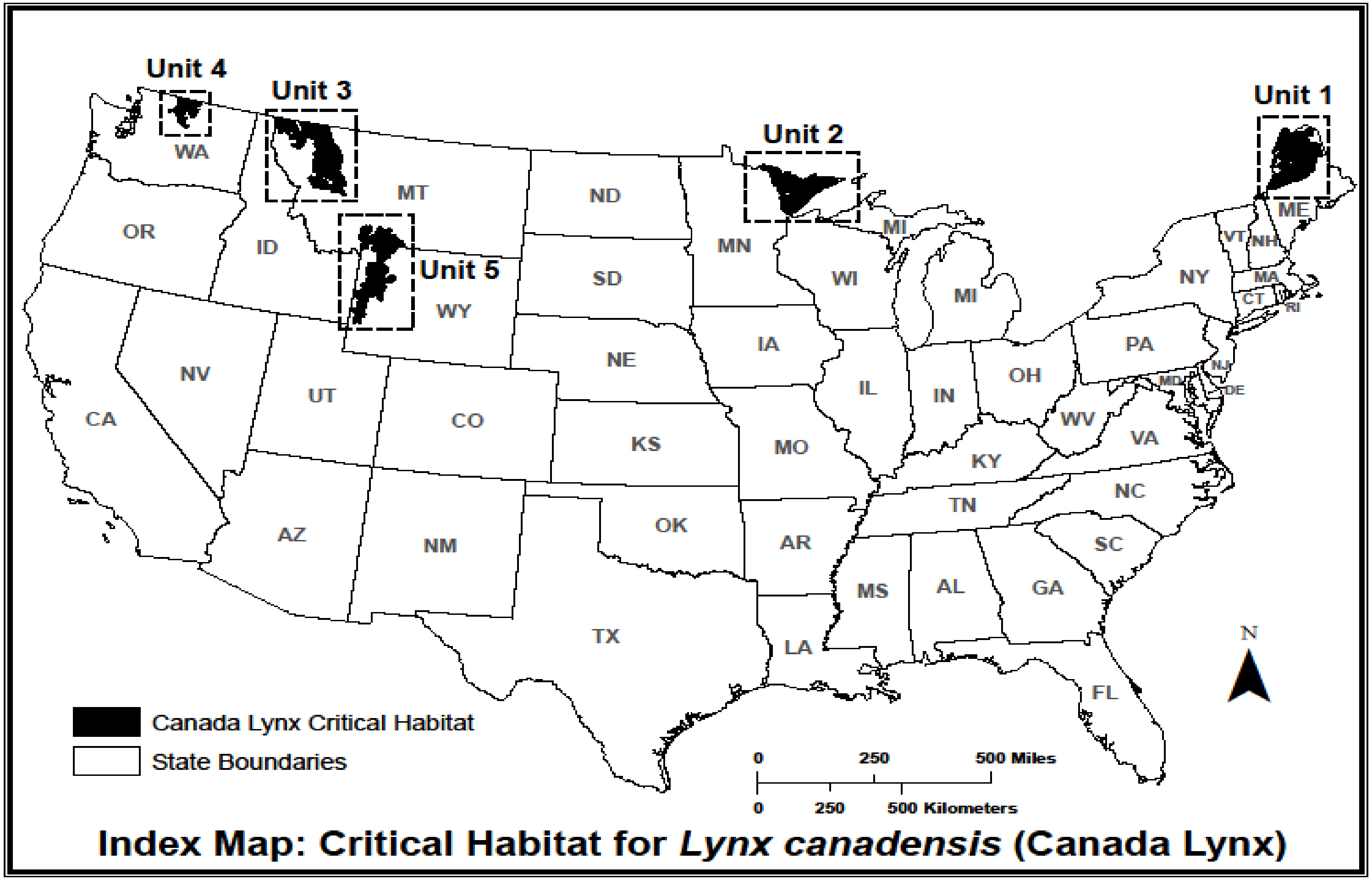
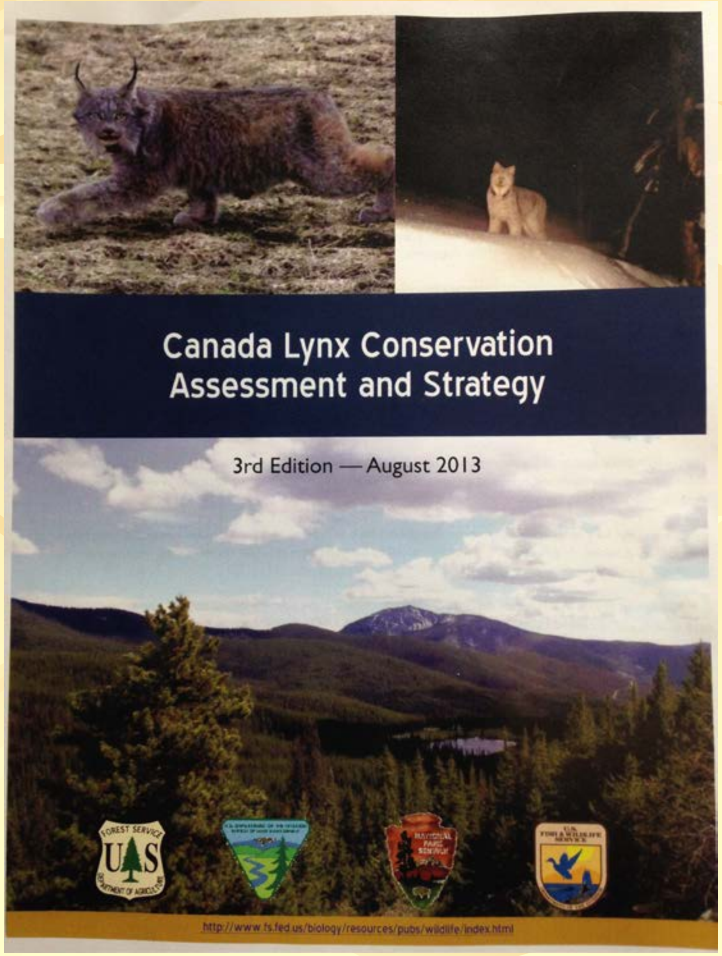


Figure 3.1. Areas identified as core, secondary, and peripheral as depicted in the Canada Lynx Recovery Outline across the states where the lynx is listed (U.S. Fish and Wildlife Service 2005).

Critical Habitat



LCAS 2013



- New science
- Core Area emphasis
- Anthropogenic Influences
  - Two tiers
- Conservation Measures

Current Regulatory Environment

Future challenges?

Questions?

Lynx Genetic Considerations

Michael Schwartz

John Squires

Kevin McKelvey

Kristy Pilgrim

National Genomics Center for Wildlife and Fish Conservation

Rocky Mountain Research Station

Big Topic, Turned to October Headlines for Focus

UPI — Lynx on the brink

StarTribune — **Foul trouble dooms Lynx**

TwinCities.com Pioneer Press — Lynx lose to Fever

Genetics of Disease?
Avian Malaria? WNV?

Turns out, we don't need to worry……..

UPI

Minnesota Lynx on the brink of title after Maya Moore's winning shot

StarTribune

WNBA Finals: Foul trouble dooms Lynx as Fever force Game 5

TwinCities.com
PIONEER PRESS

Lynx lose to Fever, head home for Game 5

By Candace Buckner
Special to the Pioneer Press

MINNESOTA LYNX

DECIDING GAME 5
WNBA Finals | Wednesday, October 14 7:00 PM

Lynx Genetic Considerations

1) Mini review of lynx population genetic studies

2) Review of lynx hybridization studies

3) Needed genomic data

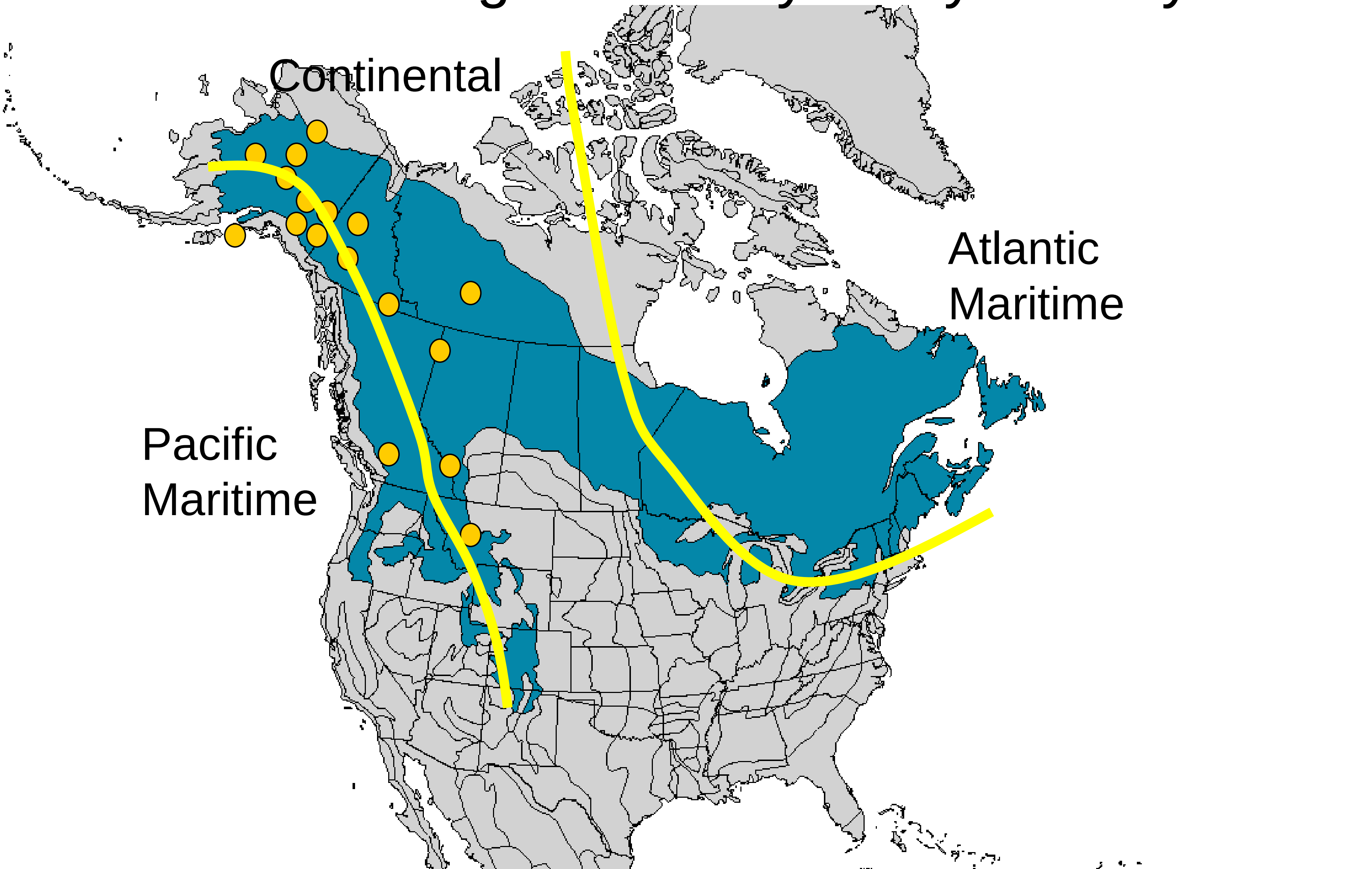
Population Genetics of Lynx

letters to nature

DNA reveals high dispersal synchronizing the population dynamics of Canada lynx

Michael K. Schwartz*†, L. Scott Mills*, Kevin S. McKelvey†, Leonard F. Ruggiero† & Fred W. Allendorf‡

Stenseth et al. (1999) Suggest Climate Causes Large Scale Cycle Synchrony



Lynx Isolated

"The conservation of lynx populations is of greatest concern in the western mountains of the conterminous United States at the southern periphery of the species range. Recruitment is low in this region and many lynx populations….are geographically isolated."

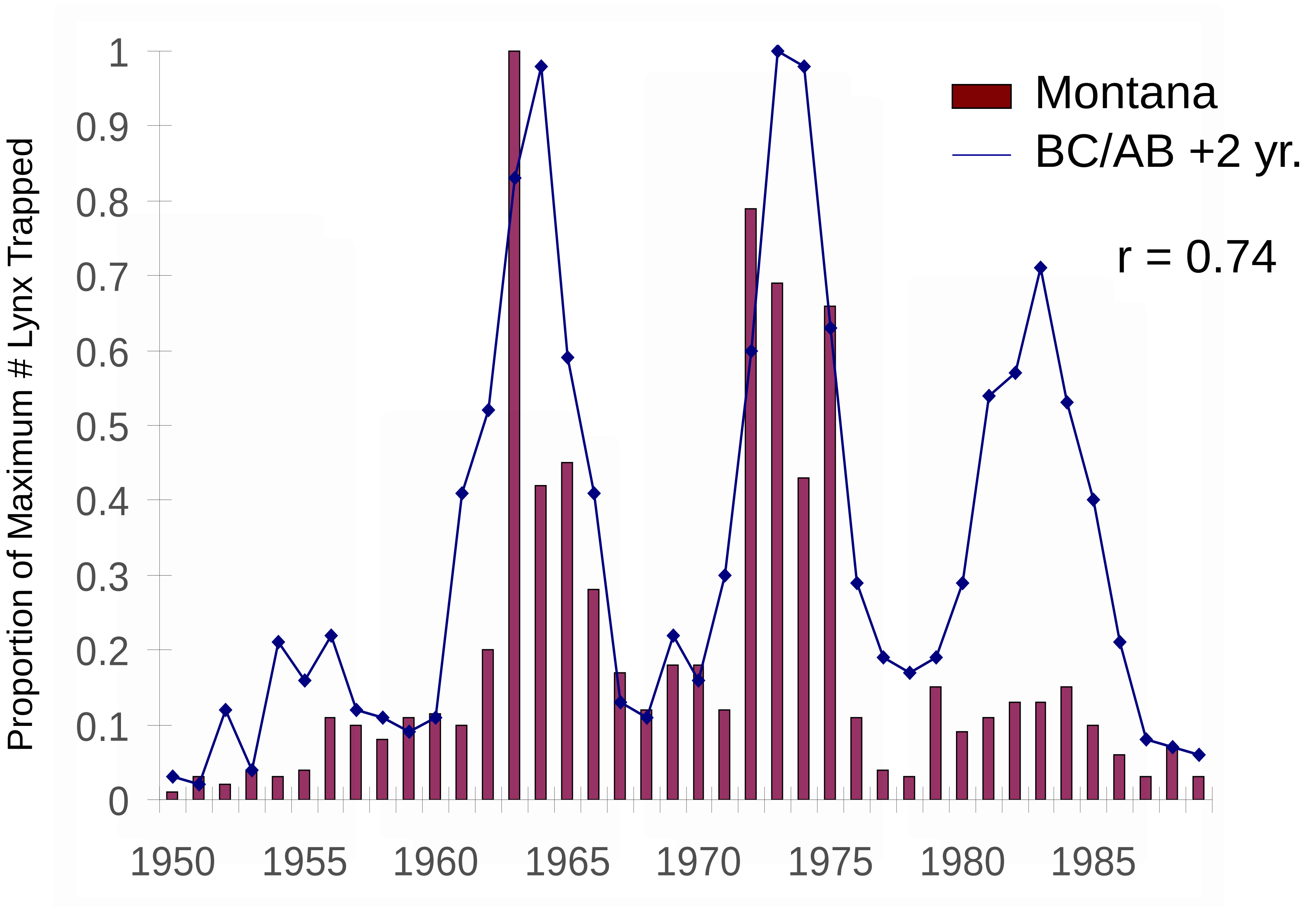
- Koehler and Aubry 1994

Lynx Connected: Large Scale Spatial Synchrony

We let dispersal between patches be distance-dependent in an exponential fashion and fixed the fraction of migrants leaving each patch each generation.

(p.1622 Ranta, *Science*)

Lynx Trapping Data Suggests Dispersal Common (McKelvey et al. 2000)



Population Structure and Migration

F_{st}

- Proportional reduction in heterozygosity due to population subdivision (0-1).

- High levels of gene flow drives F_{st} to 0.

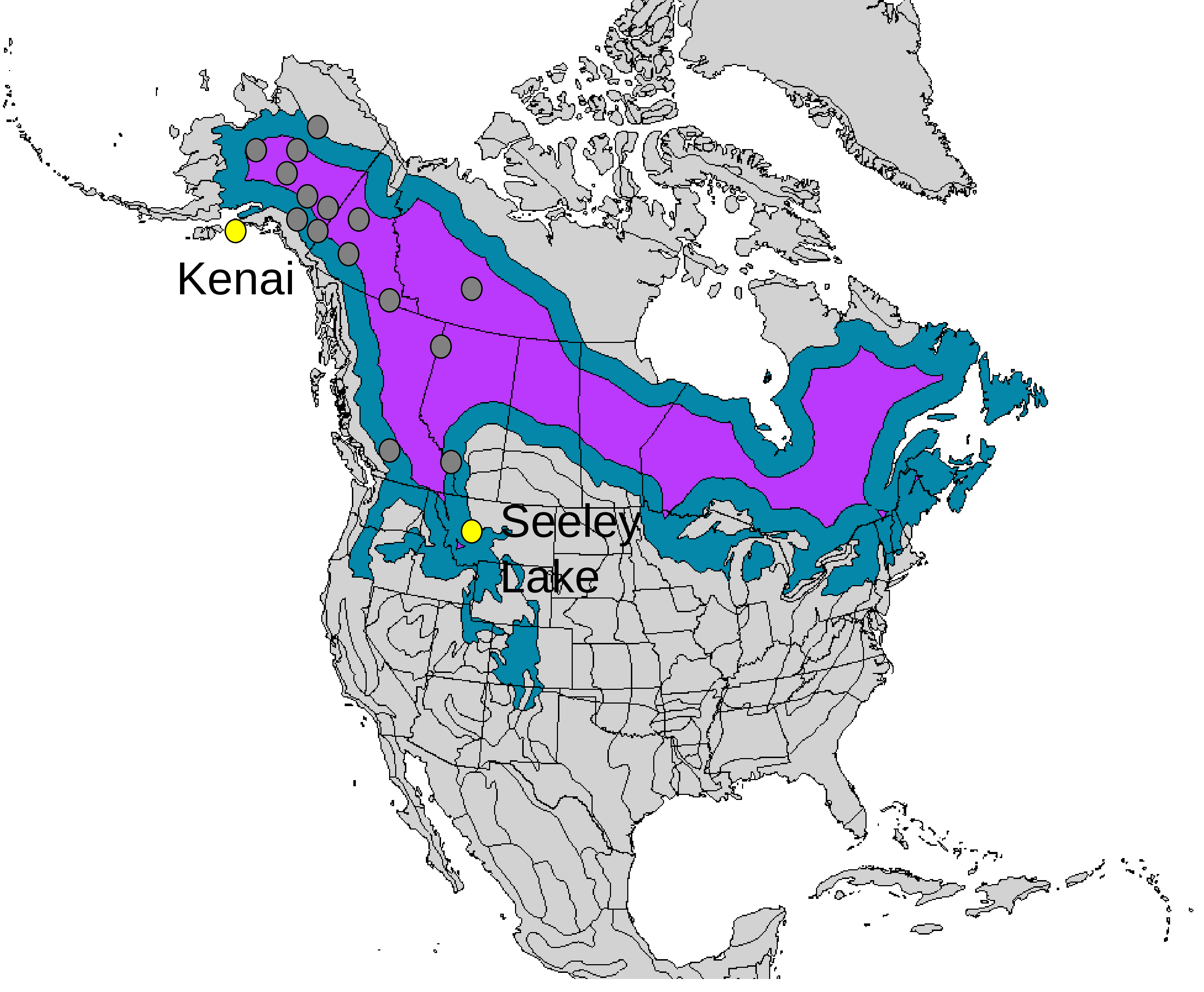
F_{st} Results

Global Results (17 Populations):

F_{st} = 0.033 (+/- 0.002).

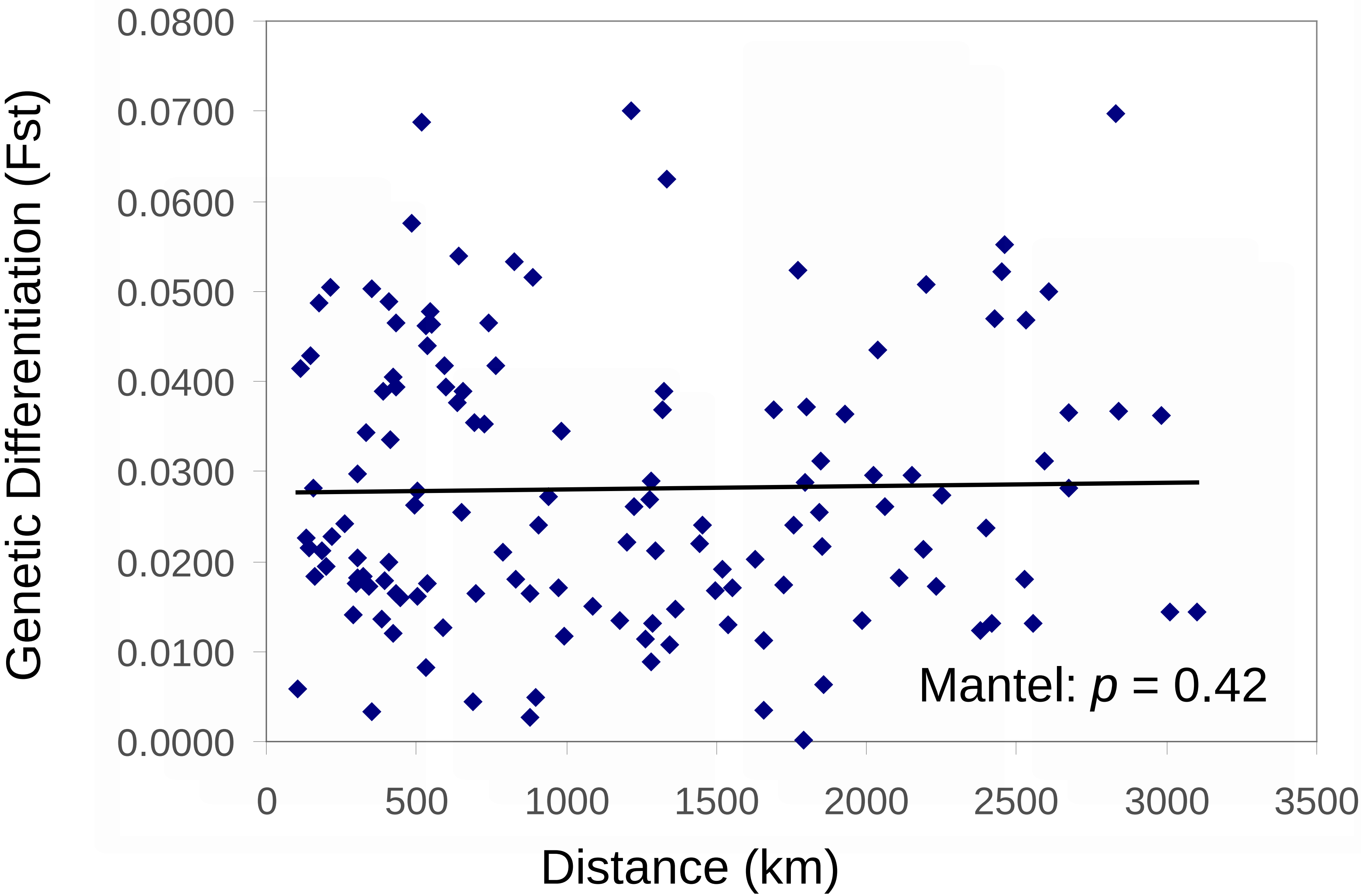
Pair-wise Results (Extremes):

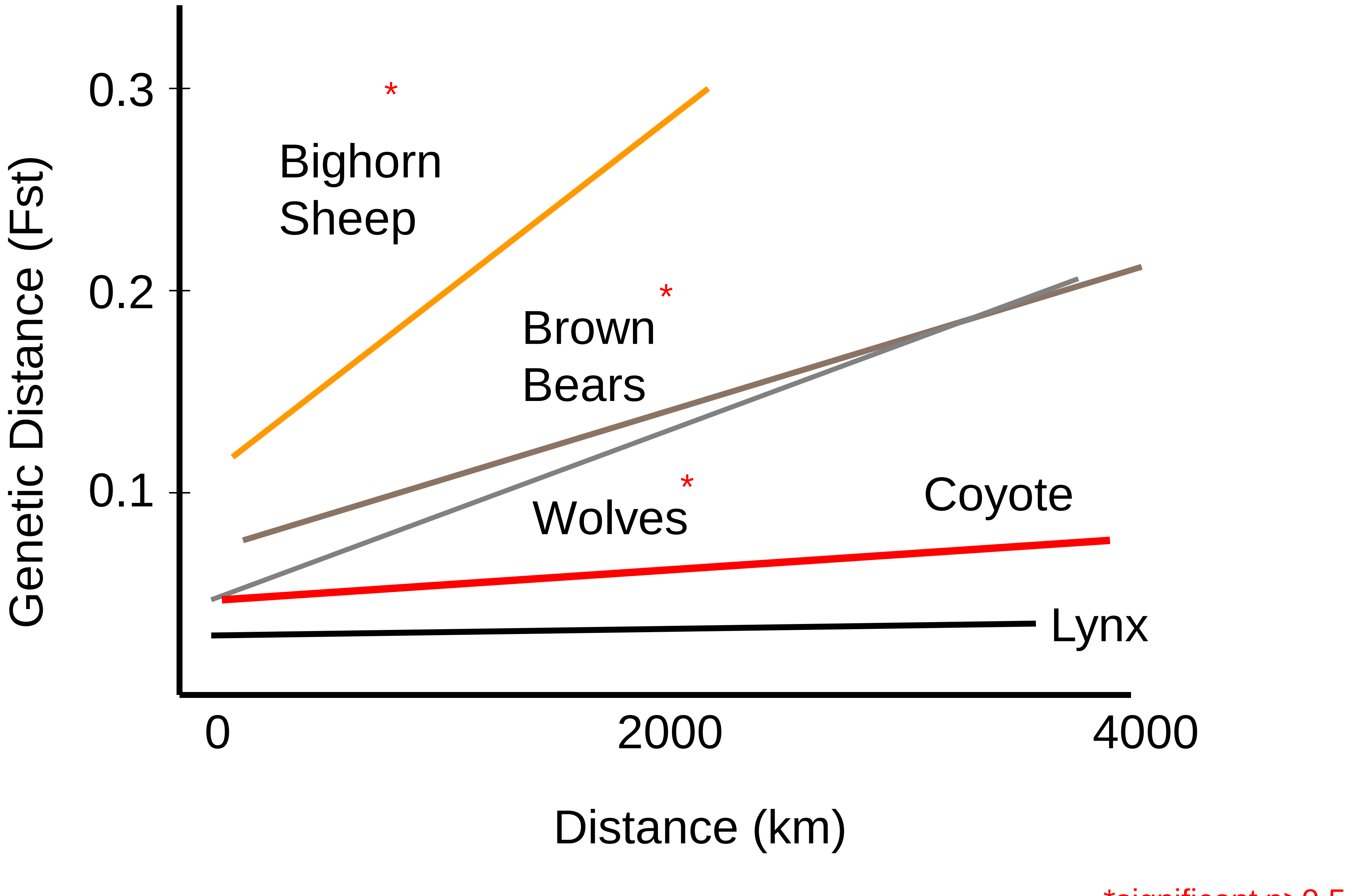
	F_{st}	/ Migrants
Fairbanks to Ladue Yukon:	0.001	≅ High
Kenai P. to Seeley Montana:	0.070	≅ 3.0



Kenai
Seeley
Lake

Distance Does Not Lead To Structuring





Adapted from Forbes and Hogg (1999)

High gene flow across range

letters to nature

DNA reveals high dispersal synchronizing the population dynamics of Canada lynx

Michael K. Schwartz*†, L. Scott Mills*, Kevin S. McKelvey†, Leonard F. Ruggiero† & Fred W. Allendorf‡

Our Initial Conclusions

- Ample gene flow continent wide
- Limited structure possible at the edges (Kenai,Seeley)
- Tide Pool Model
- One Evolutionary Significant Unit

Ecological and genetic spatial structuring in the Canadian lynx

Eli Knispel Rueness[1], Nils Chr. Stenseth[1], Mark O'Donoghue[2], Stan Boutin[3], Hans Ellegren[4] & Kjetill S. Jakobsen[1]

[1]*Centre for Ecological and Evolutionary Synthesis, Department of Biology, University of Oslo, P.O. Box 1031 Blindern, N-0315 Oslo, Norway*

- Rockies as barrier to gene flow in western Canada and “invisible barrier” south of Hudson coinciding with ecological Continental and Atlantic regions.

Very, very low Fst

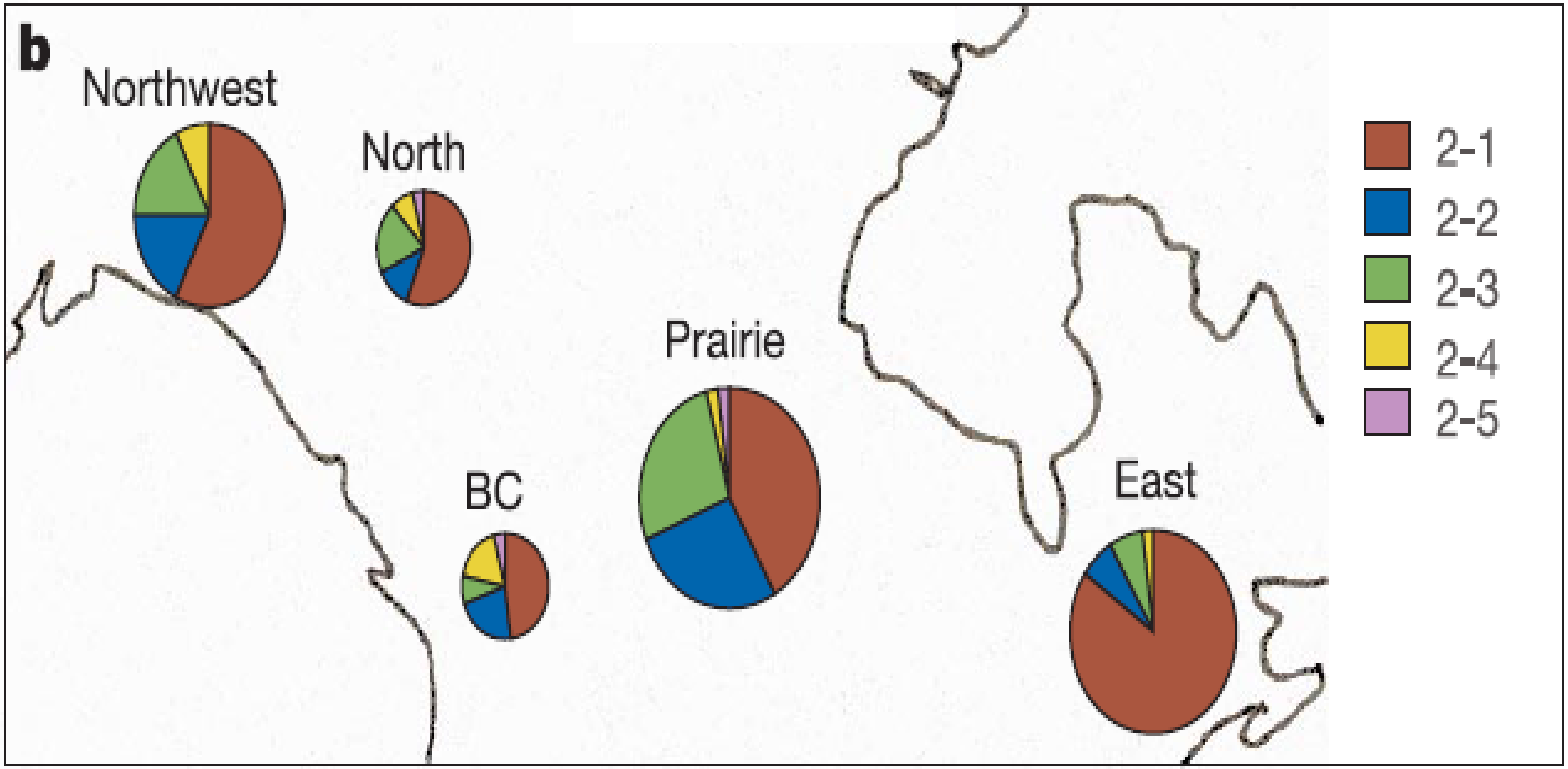
Table 1 **Genetic differentiation between geographical regions**

Microsatellites	Mitochondrial DNA				
	East	Prairie	North	Northwest	BC
East		0.0622**	0.0223*	0.0342*	0.0422*
Prairie	0.0062**		0.0301	−0.0074	0.0119
North	0.0091*	0.0017		0.0261	0.0027
Northwest	0.0156***	0.0095**	0.0027*		0.0073
BC	0.0136**	0.0097**	0.0172**	0.0244***	

Pair-wise F_{ST} estimates for microsatellites below diagonal and mtDNA above diagonal. Significant values indicated as * at the 0.05 level, ** at 0.01 level and *** at the 0.001 level.

Reuness et al. 2003

Mitochondrial DNA



Rueness et al. 2003

Dispersal promotes high gene flow among Canada lynx populations across mainland North America

J. R. Row · C. Gomez · E. L. Koen ·
J. Bowman · D. L. Murray · P. J. Wilson

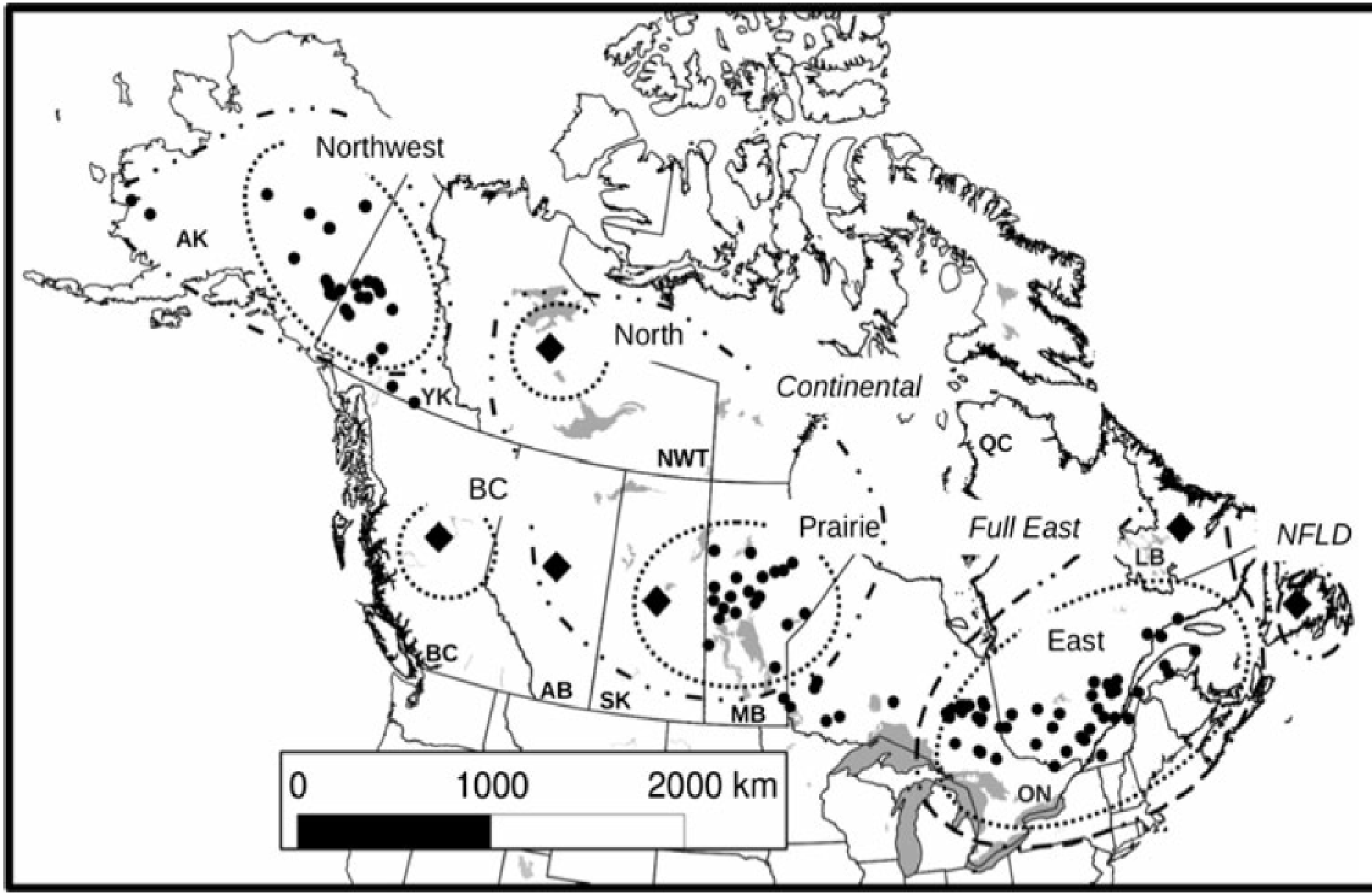
- 17 microsatellites

- Large differentiation on Newfoundland vs. Mainland
  - Fst – 0.19 between NF and Mainland

- “subtle gene flow restriction between Ontario and Manitoba”

- Bayesian clustering - 2 clusters NF vs others.

Lynx Sample Distribution



Row et al. 2012

Again, very low Fst

Conserv Genet (2012) 13:1259–1268 1263

Table 2 Pairwise F_{ST} (lower)[a] and R_{ST} (upper) between populations of Canada lynx across North America using data subset A

	East	Prairie	North	Northwest	BC
East		0.0069	0.0021	0.0004	0.0000
Prairie	0.0071***		0.0001	0.0030	0.0100
North	0.0080***	0.0018		0.00113	0.0002
Northwest	0.0069***	0.0061***	0.0035**		0.0034
BC	0.0077***	0.0034***	0.0008	0.0008	

Row et al. 2012

Global Change Biology (2014), doi: 10.1111/gcb.12526

The subtle role of climate change on population genetic structure in Canada lynx

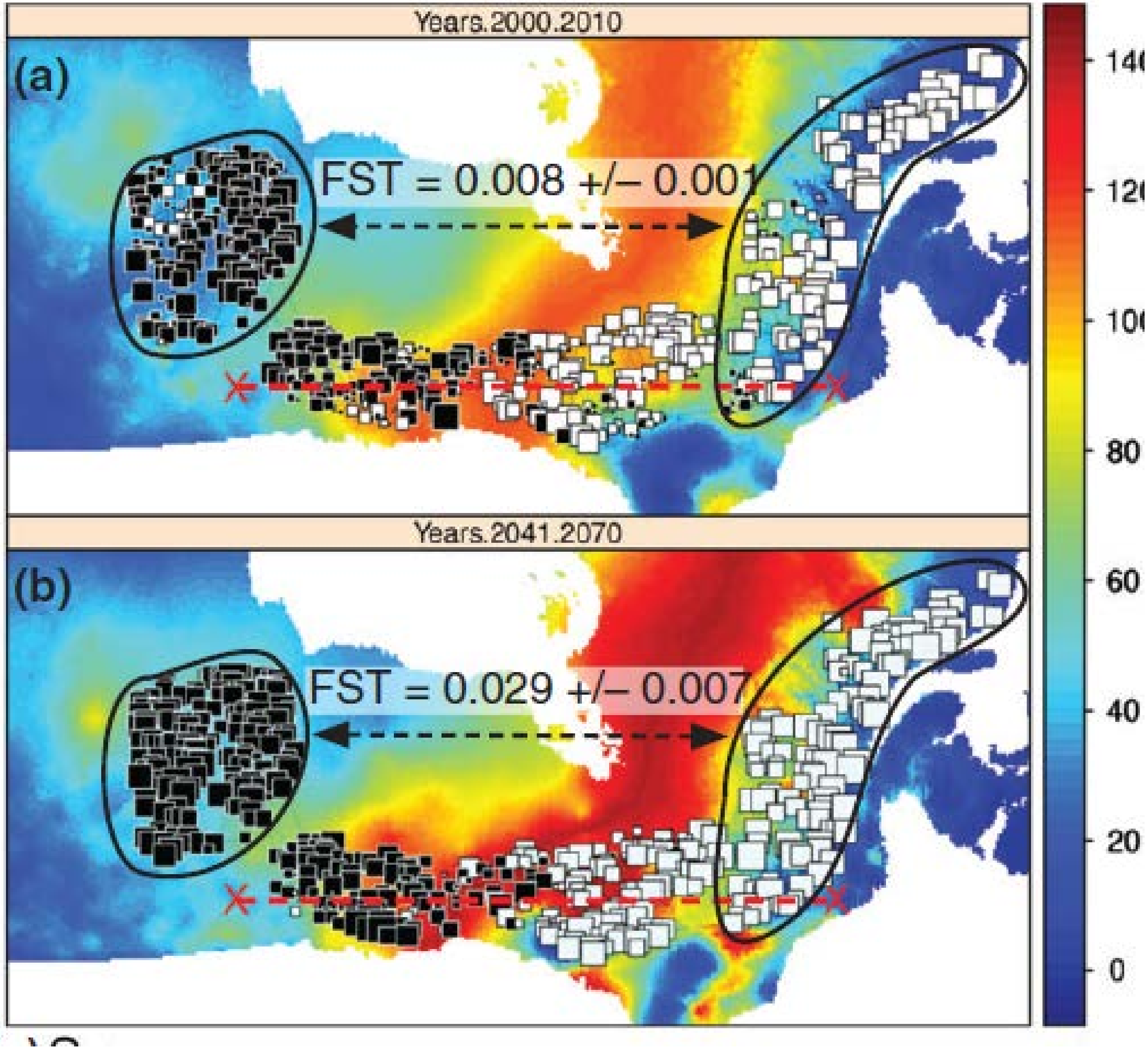
JEFFREY R. ROW[1], PAUL J. WILSON[2], CELINE GOMEZ[1], ERIN L. KOEN[2], JEFF BOWMAN[3], DANIEL THORNTON[1,4] and DENNIS L. MURRAY[1]

- Genetic variability correlated with winter climate gradient (snow depth and winter precipitation) – using spca (not with Bayesian clustering)
- Stronger relationship than IBD
- W-E genetic cline driven by PNO and NAO
- Individuals restrict dispersal across climate boundaries in absence of changes in habitat quality.
- Imprinting on snow conditions

✓ Climate Conditions: min and max temp, snow depth , precip, diff|max-min|

✗ Ecological Conditions: open needle-leaved conifer, broad-leaved deciduous, close needle-leaved conifer, closed broad leaved decid.

PNA/NAO snow the “invisible barrier” to gene flow



Fine-scale genetic structure and dispersal in Canada lynx (*Lynx canadensis*) within Alberta, Canada

Véronique Campbell and Curtis Strobeck

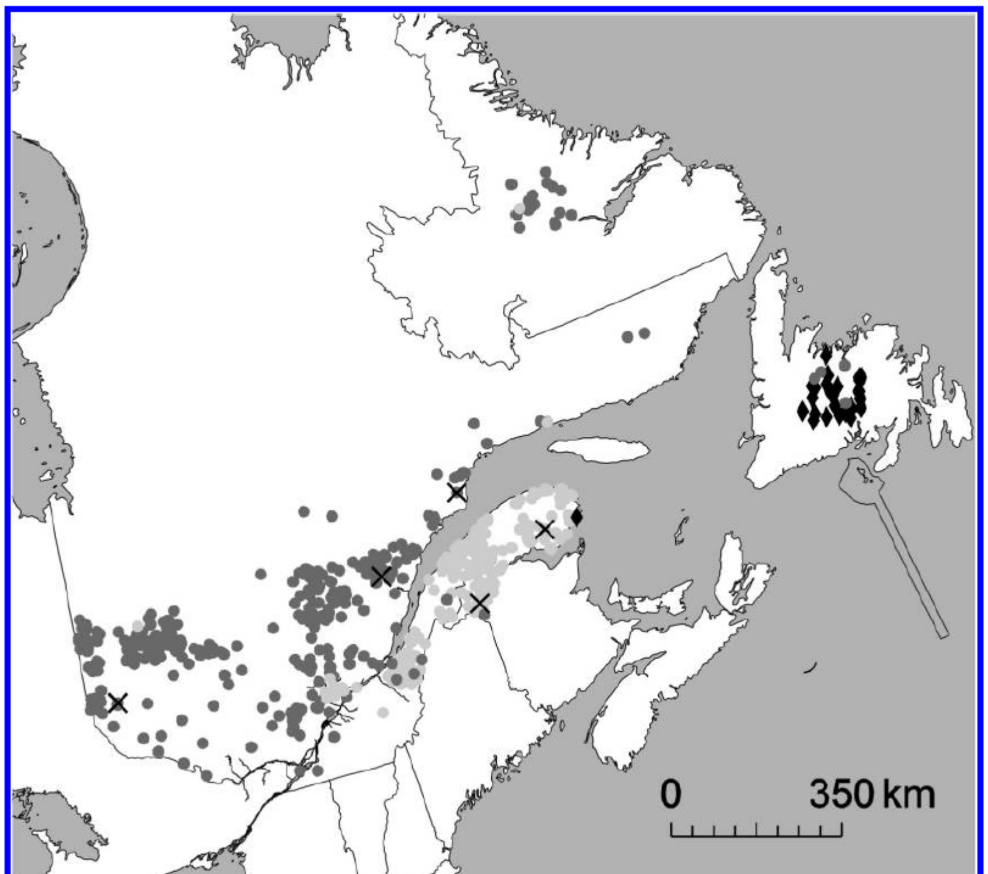
Abstract: Although mammals are typically characterized by male-biased dispersal, field studies of lynx conflict as to whether dispersal is male-biased or lacks sex-bias. To resolve this issue we dissect fine-scale genetic structure and analyze dispersal in regard to gender using 19 microsatellite loci, teemed with extensive sampling (n = 272 adults) of Canada lynx (*Lynx canadensis* Kerr, 1792) throughout Alberta. The level of genetic variation was high (mean H_e = 71.6%), as reported in previous genetic studies of lynx. No significant barriers to gene flow were detected within Alberta's lynx population. Despite several reports of long-distance movements in lynx, we observed a slight significant negative correlation between pairwise relatedness values and geographic distance (r_M = –0.025, P = 0.048), indicating a decrease in relatedness between individuals as their sampling distance increases. When the same analysis was performed separately on sexes, the slopes of the individual regressions did not differ significantly between males and females (P = 0.708). Our molecular results suggest a lack of sex-biased dispersal in Canada lynx, similar to reports on other lynx species.

NRC Research Press
ARTICLE

Isolation of peripheral populations of Canada lynx (*Lynx canadensis*)

E.L. Koen, J. Bowman, and P.J. Wilson

- 14 microsatellites and 558 lynx to test "riverine barrier hypothesis"



- St. Lawrence River is a barrier
- Not absolute – 24 indiv. crossing

NRC Research Press

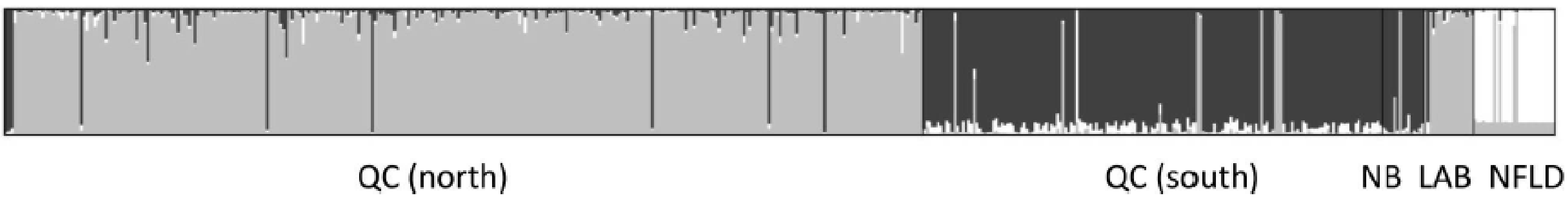
ARTICLE

Isolation of peripheral populations of Canada lynx (*Lynx canadensis*)

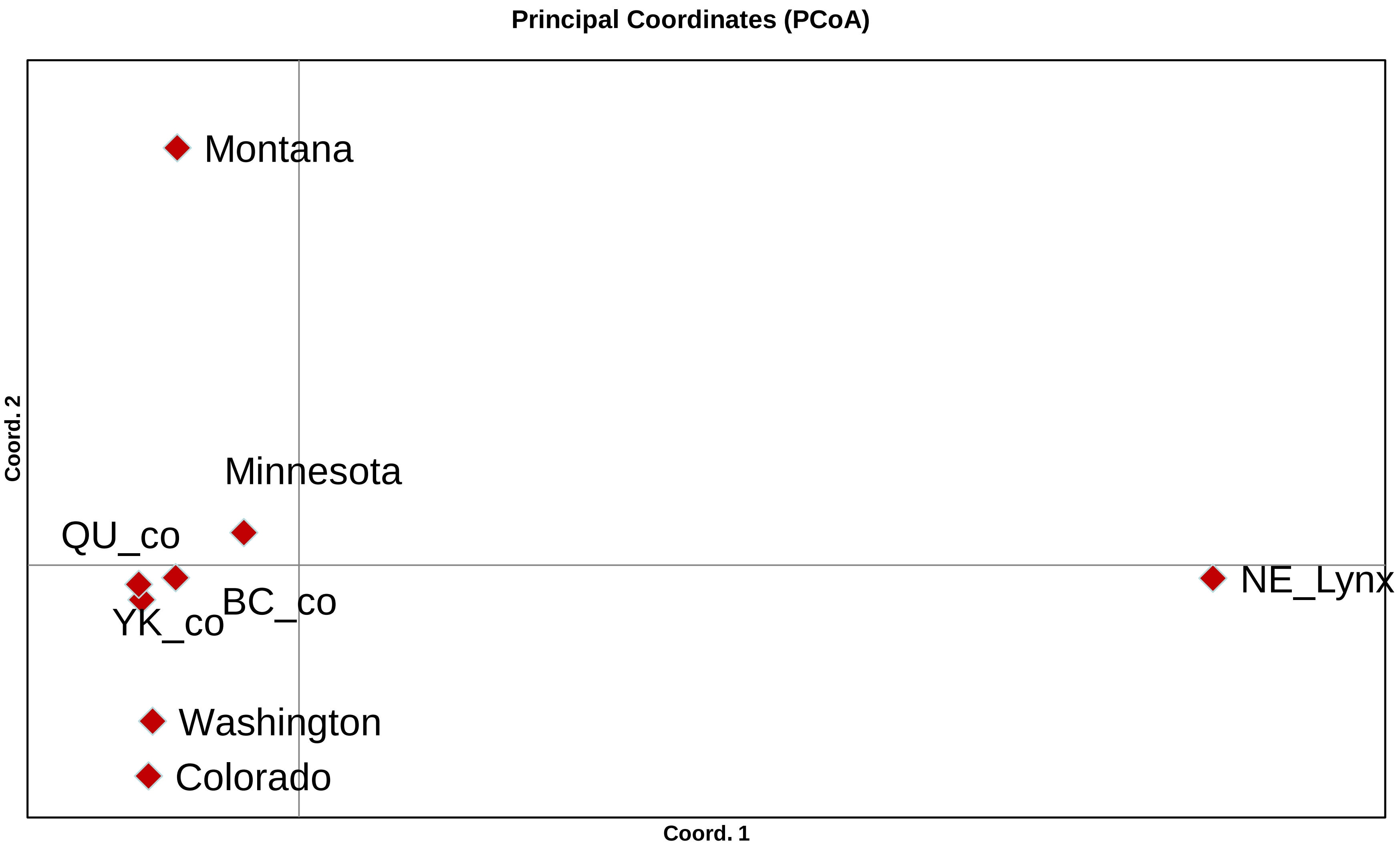
E.L. Koen, J. Bowman, and P.J. Wilson

- 14 microsatellites and 558 lynx to test "riverine barrier hypothesis"

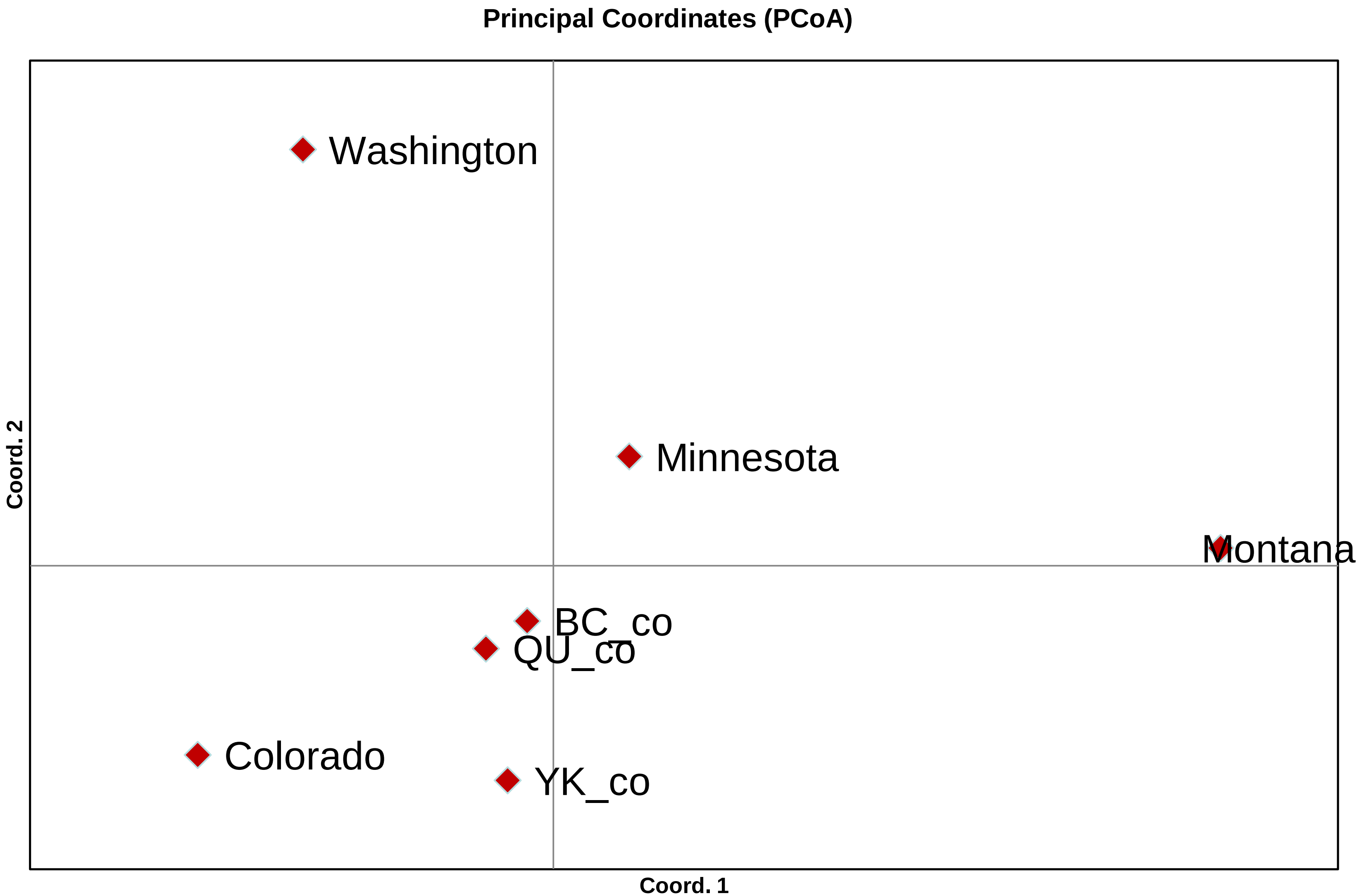
Fig. 3. STRUCTURE plot (Pritchard et al. 2000), based on 10 replicates, representing the proportion of an individual's genome assigned to one of three populations. Individual Canada lynx (*Lynx canadensis*) are grouped based on sample site (QC north, north of the St. Lawrence River in Quebec; QC south, south of the St. Lawrence River in Quebec; NB, New Brunswick; LAB, Labrador; NFLD, Newfoundland) and shading represents cluster assignment.



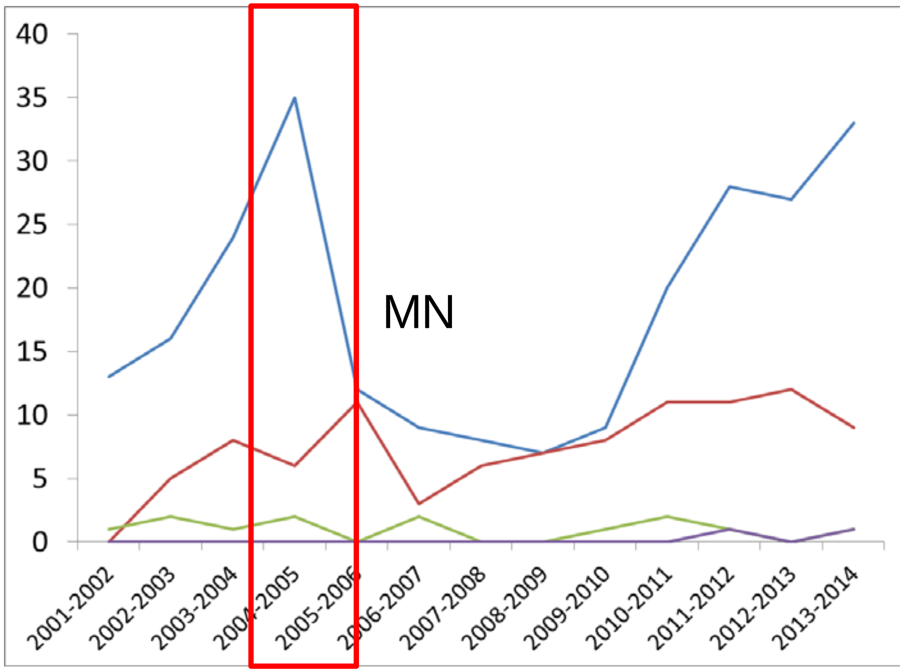
RMRS Genetic Data (2004-2006 only)

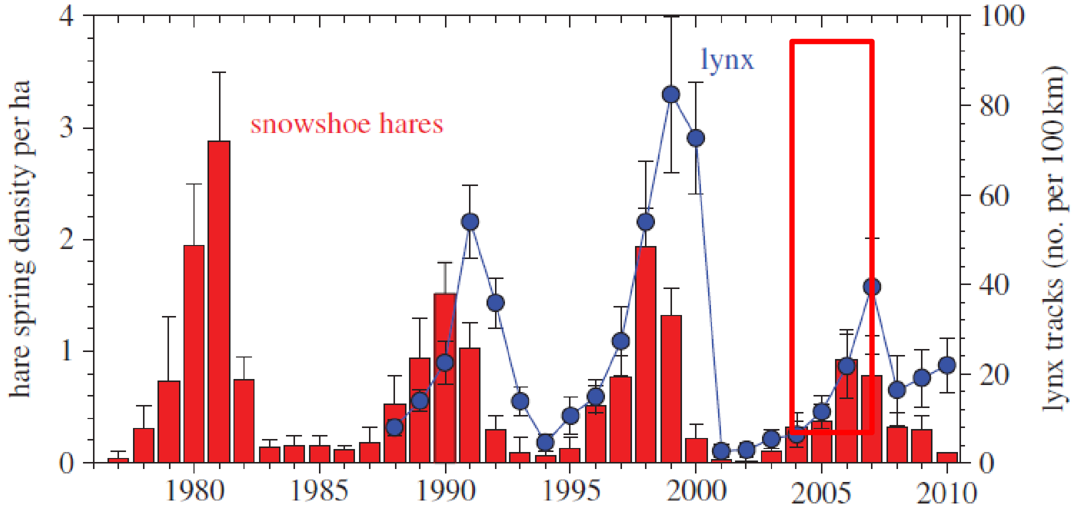


RMRS Genetic Data (2004-2006 only)



Lynx Cycles

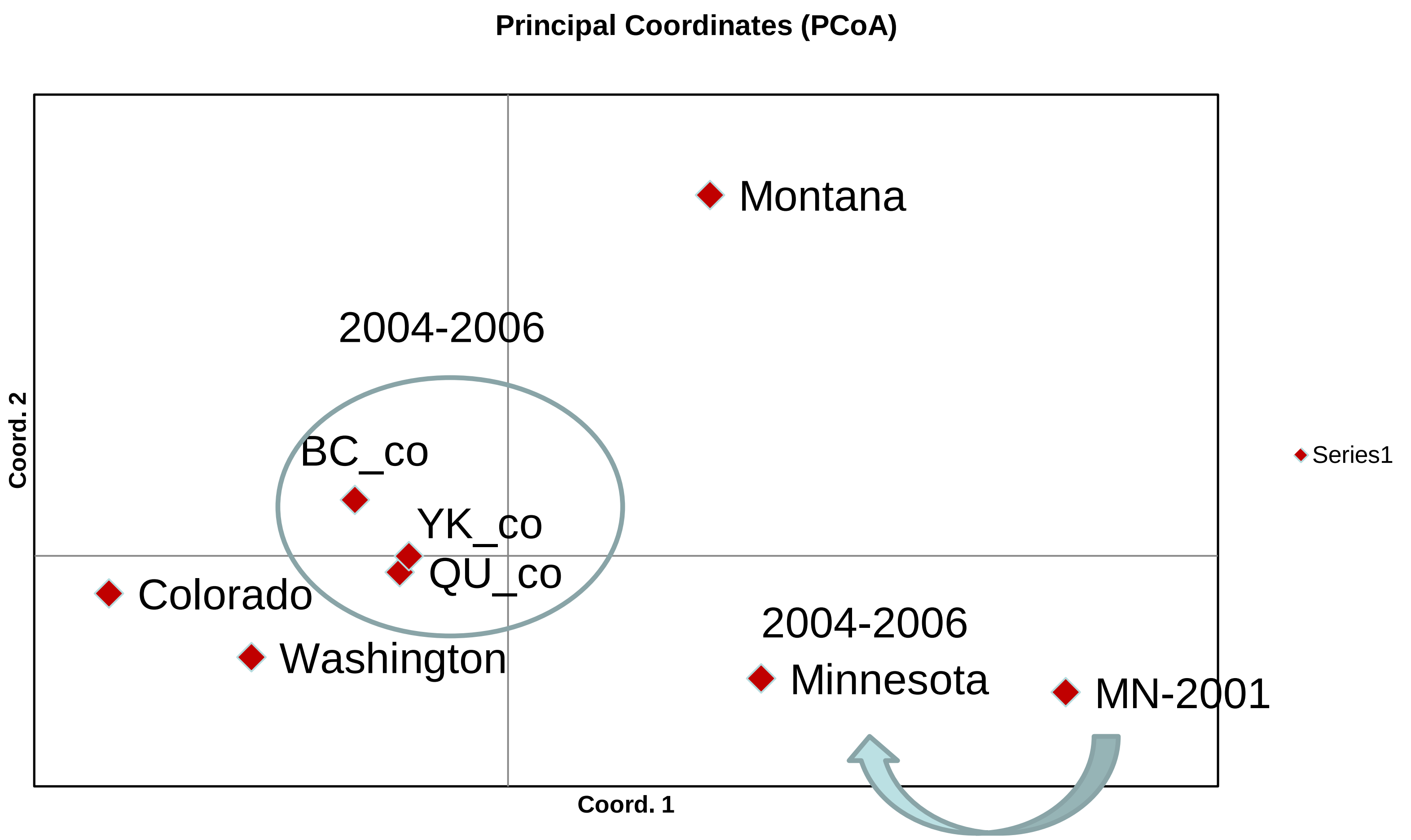




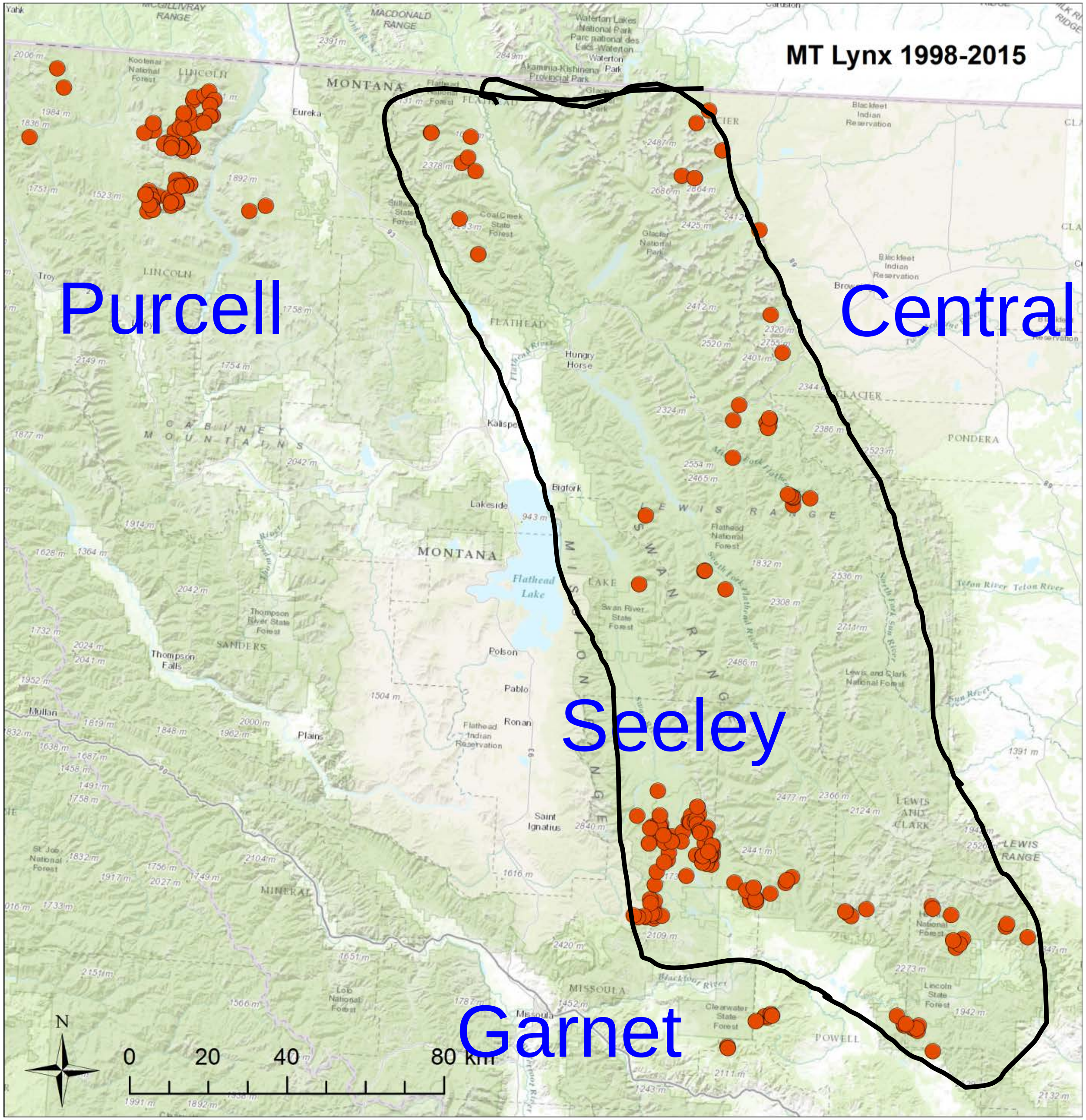
YU (Krebs et al. 2011)

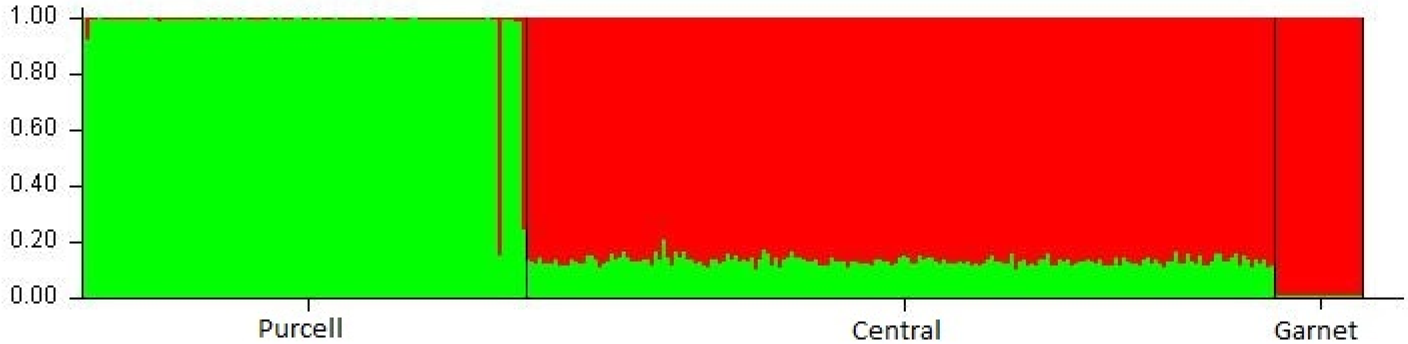
Figure 4. Snowshoe hare spring density at Kluane Lake, Yukon, 1977–2010, and an index of lynx numbers from winter snow tracking, 1988–2010. Lynx data from winters are plotted over the year ending each winter. Estimates with 95% confidence limits are given.

RMRS Genetic Data (2004-2006 only, MN 2001)

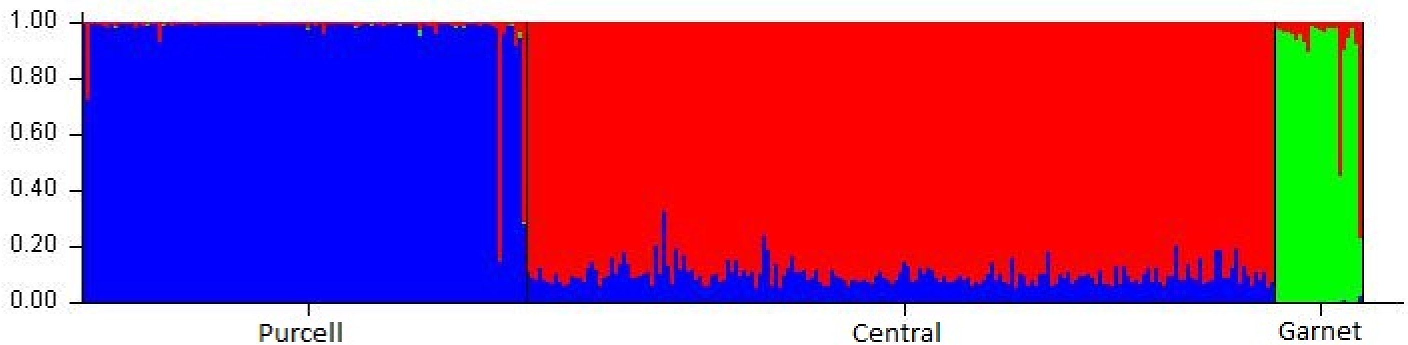


Squires 1998-2015 lynx genetic data

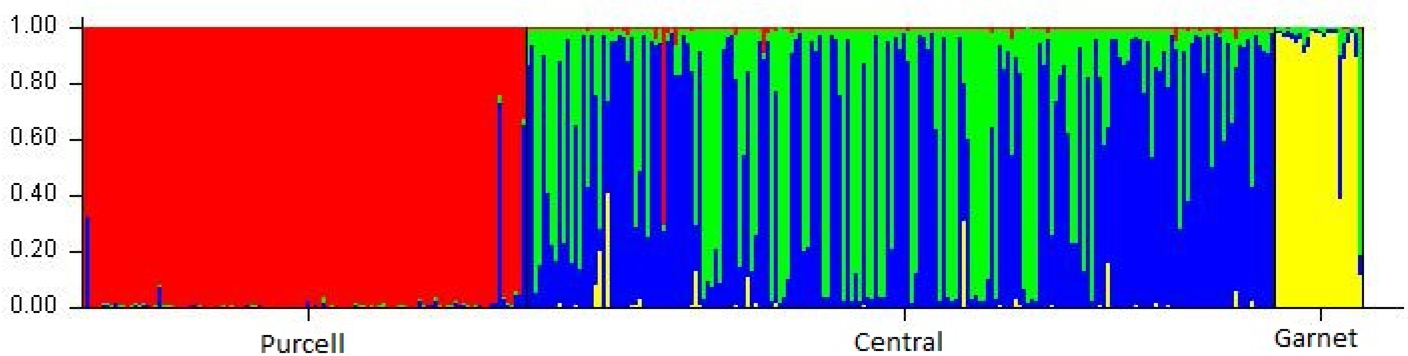




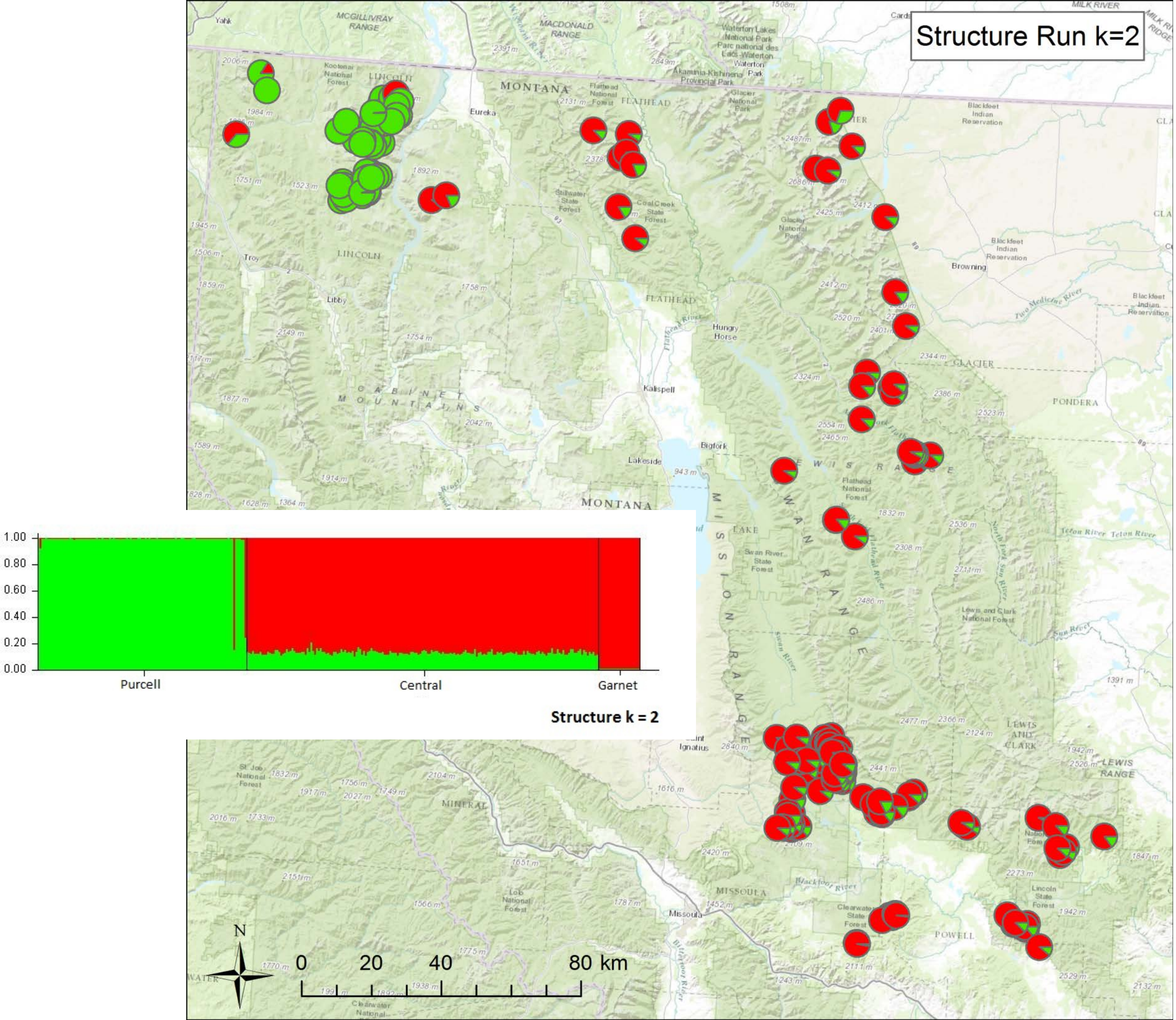
Structure k = 2

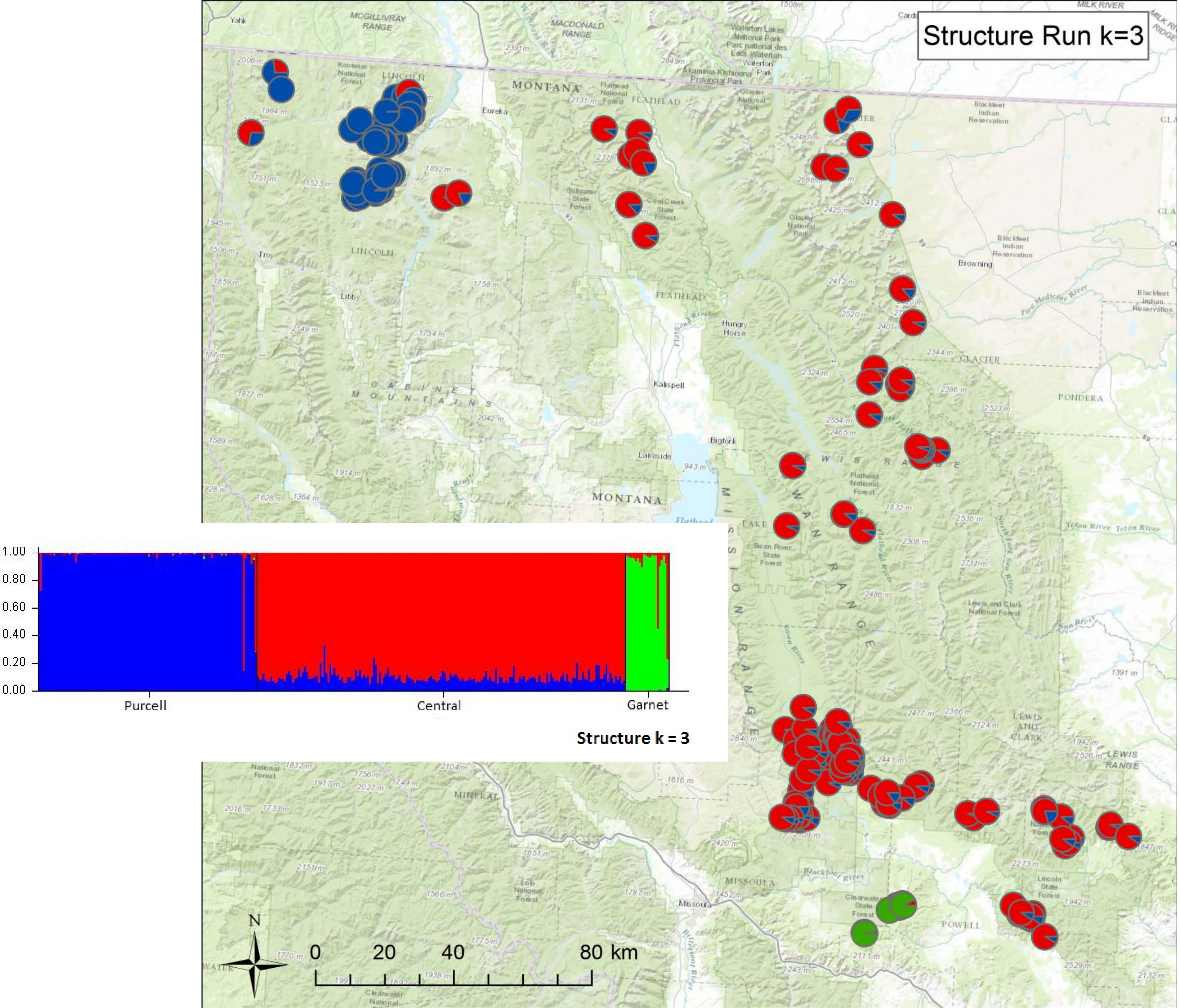


Structure k = 3

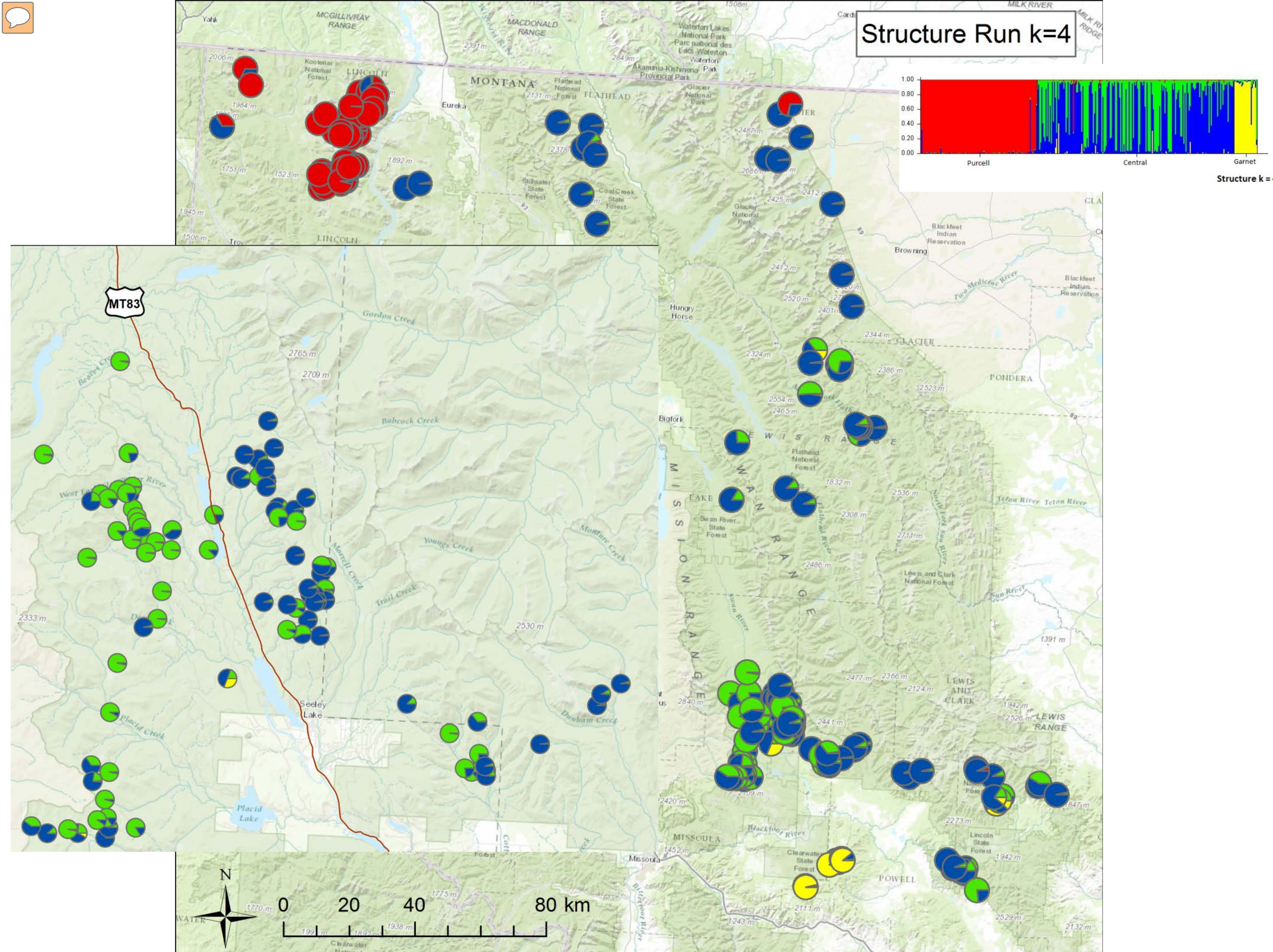


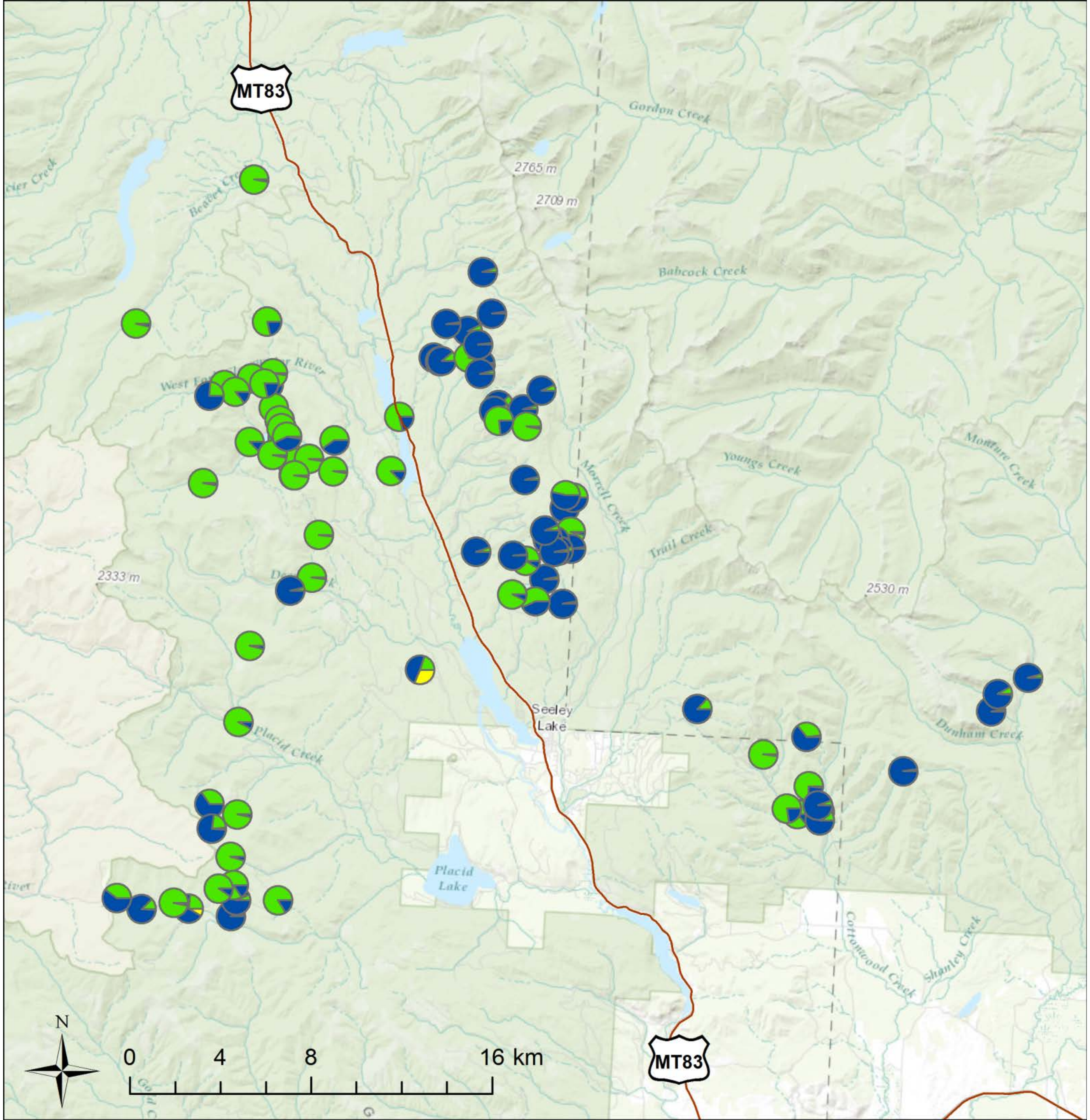
Structure k = 4

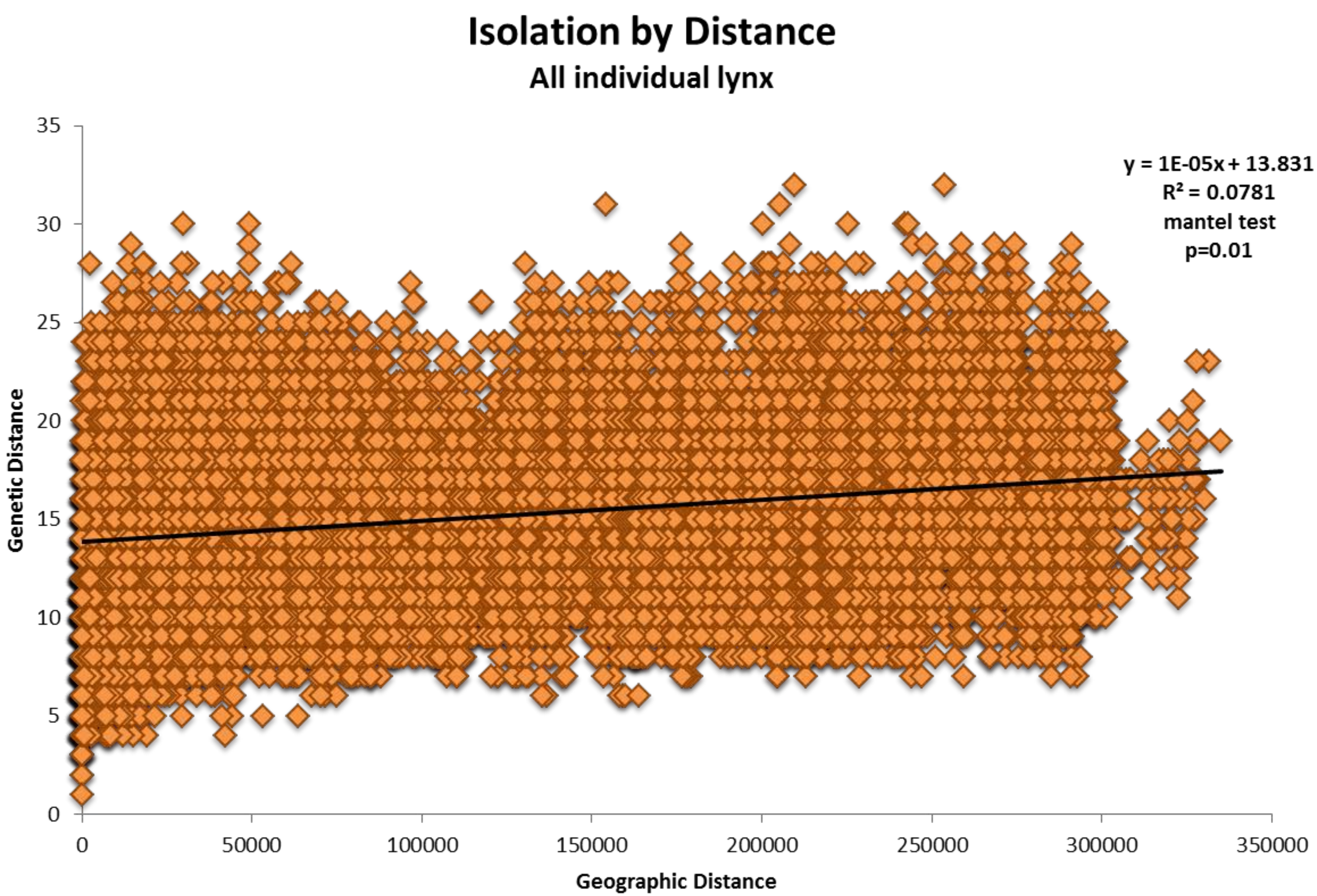

Structure Run k=2
1.00
0.80
0.60
0.40
0.20
0.00
Purcell
Central
Garnet
Structure k = 2
N
0
20
40
80 km
MONTANA
Eureka
Kalispell
Bigfork
Lakeside
Hungry Horse
Browning
Missoula
LINCOLN
FLATHEAD
GLACIER
PONDERA
MISSOULA
POWELL
LEWIS AND CLARK
MISSION RANGE
SWAN RANGE
LEWIS RANGE
CABINET MOUNTAINS
Libby
Troy
Yahk

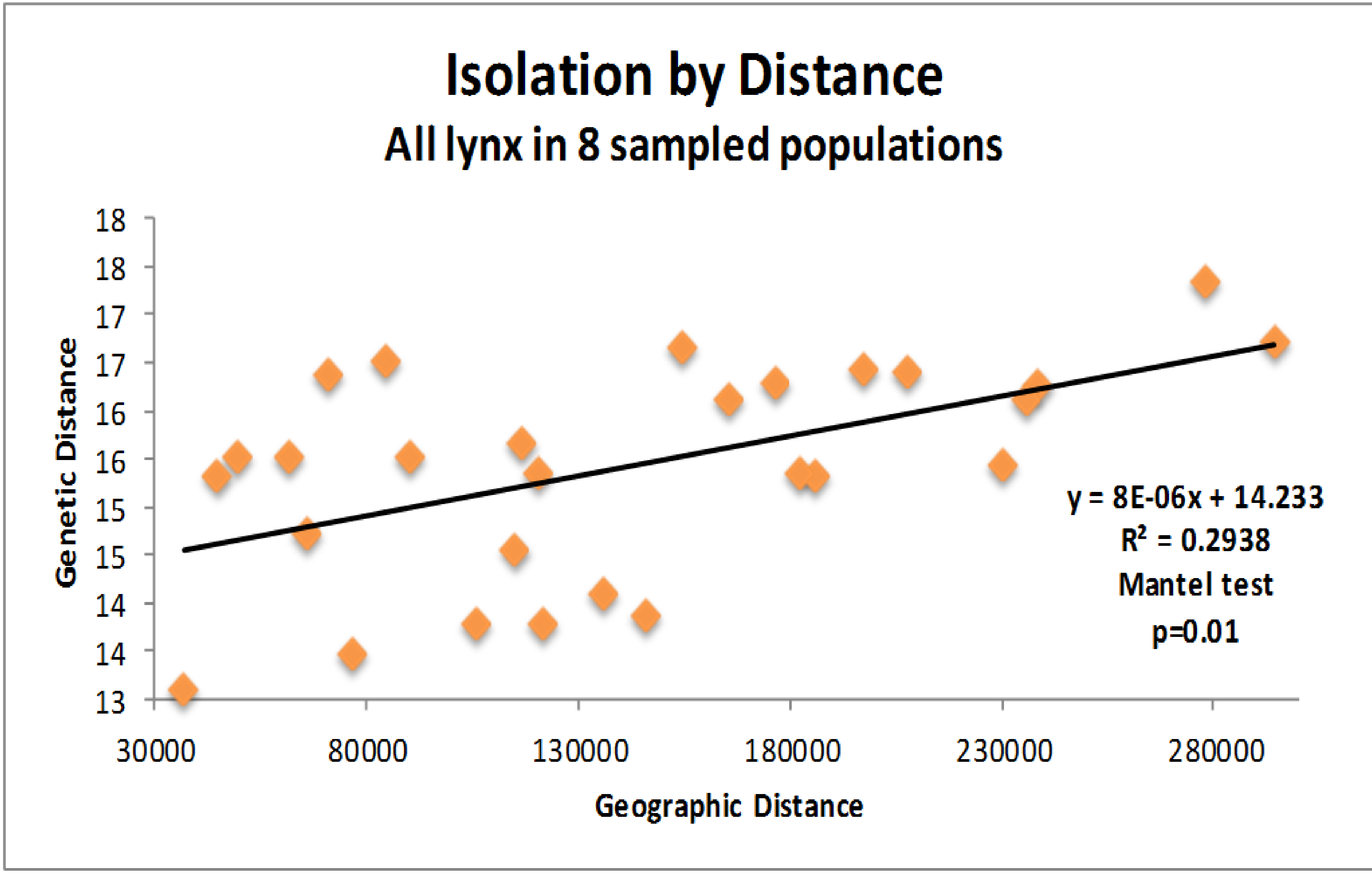


Structure Run k=3
1.00
0.80
0.60
0.40
0.20
0.00
Purcell
Central
Garnet
Structure k = 3
0
20
40
80 km
N
MONTANA
LINCOLN
FLATHEAD
GLACIER
PONDERA
MISSOULA
POWELL
LEWIS AND CLARK
Eureka
Troy
Libby
Kalispell
Bigfork
Lakeside
Hungry Horse
Browning
Missoula
Yahk
MCGILLIVRAY RANGE
MACDONALD RANGE
CABINET MOUNTAINS
SWAN RANGE
MISSION RANGE
LEWIS RANGE
Kootenai National Forest
Flathead National Forest
Stillwater State Forest
Coal Creek State Forest
Swan River State Forest
Glacier National Park
Blackfeet Indian Reservation
Waterton Lakes National Park
Lewis and Clark National Forest
Lincoln State Forest
Clearwater State Forest
Lolo National Forest
Blackfoot River
Two Medicine River
Teton River
Sun River
Swan River
Flathead River


Structure Run k=4
1.00
0.80
0.60
0.40
0.20
0.00
Purcell
Central
Garnet
Structure k = 4
MT83
N
0
20
40
80 km


MT83
Gordon Creek
2765 m
2709 m
Beaver Creek
Babcock Creek
West Fork
River
Morrell Creek
Youngs Creek
Monture Creek
Trail Creek
2333 m
2530 m
Seeley
Lake
Dunham Creek
Placid Creek
Placid
Lake
Cottonwood Creek
Shanley Creek
N
0
4
8
16 km
MT83


Isolation by Distance
All individual lynx
y = 1E-05x + 13.831
R² = 0.0781
mantel test
p=0.01
Genetic Distance
Geographic Distance
0
5
10
15
20
25
30
35
0
50000
100000
150000
200000
250000
300000
350000

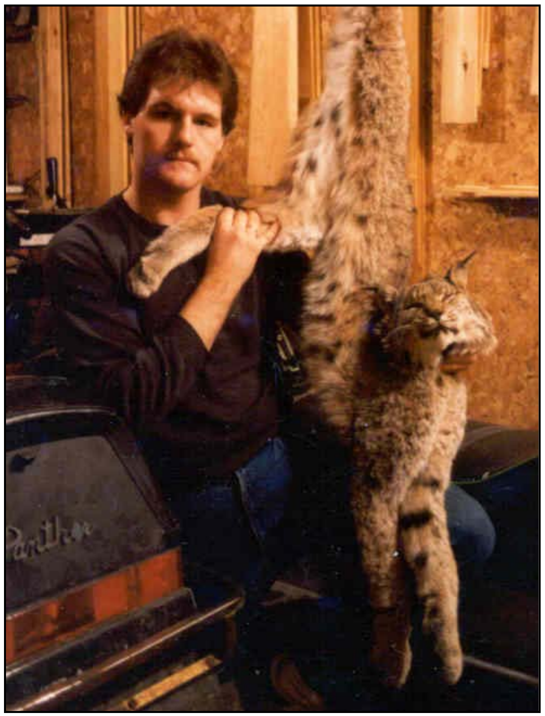

Isolation by Distance
All lynx in 8 sampled populations
Genetic Distance
18
18
17
17
16
16
15
15
14
14
13
30000
80000
130000
180000
230000
280000
Geographic Distance
y = 8E-06x + 14.233
R² = 0.2938
Mantel test
p=0.01

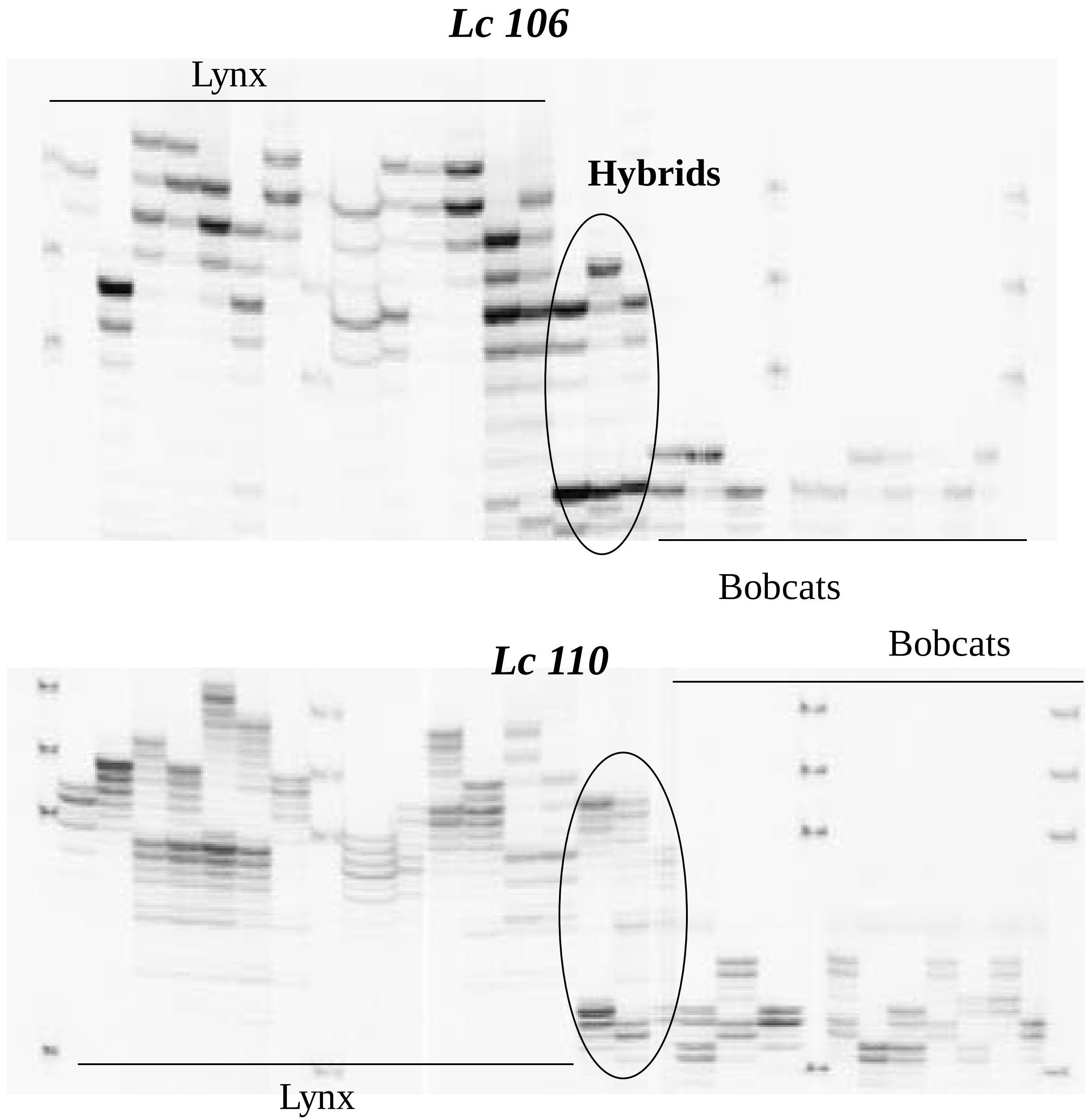
Lynx Genetic Considerations

1) Mini review of lynx population genetic studies

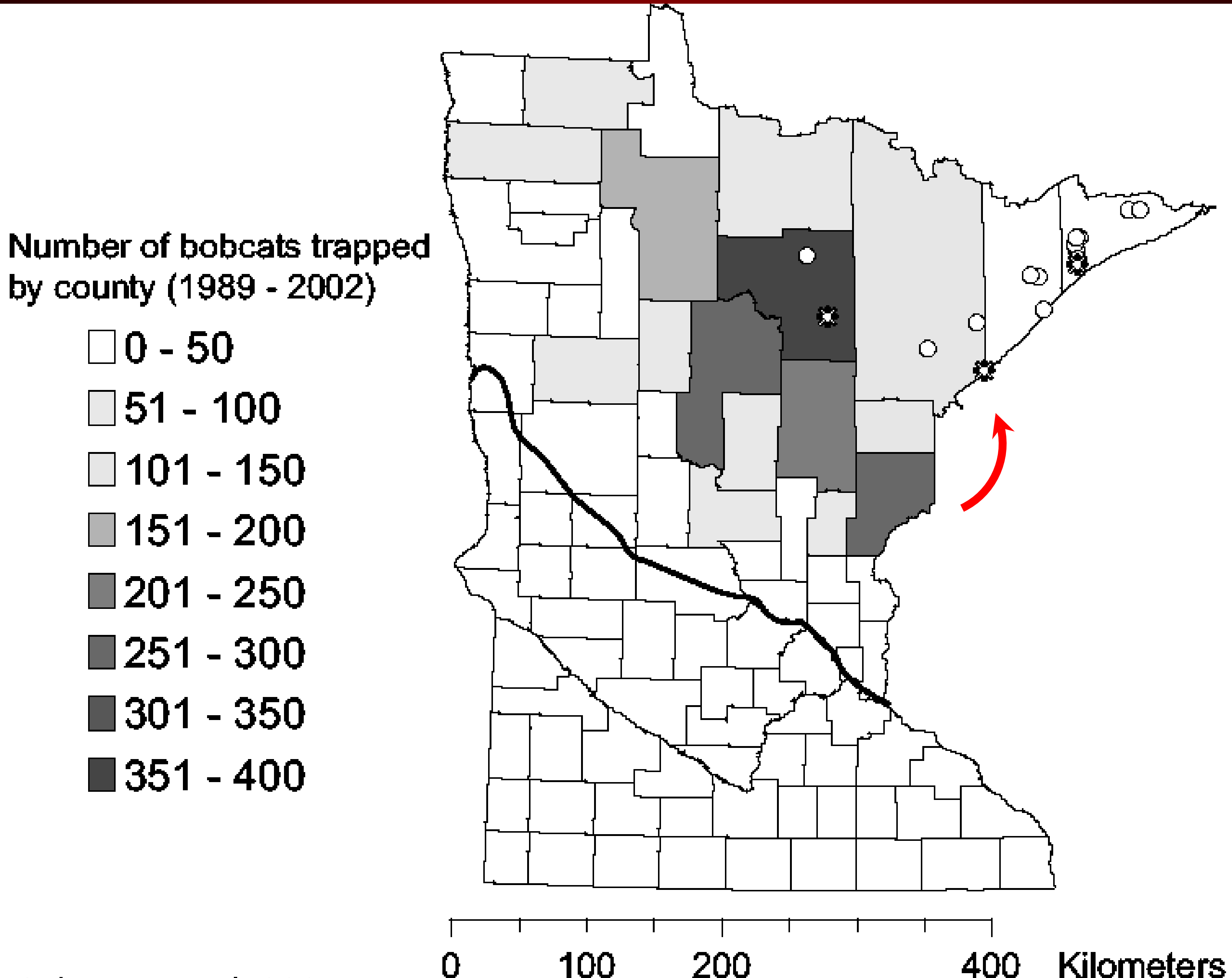
2) Review of lynx hybridization studies

3) Needed genomic data





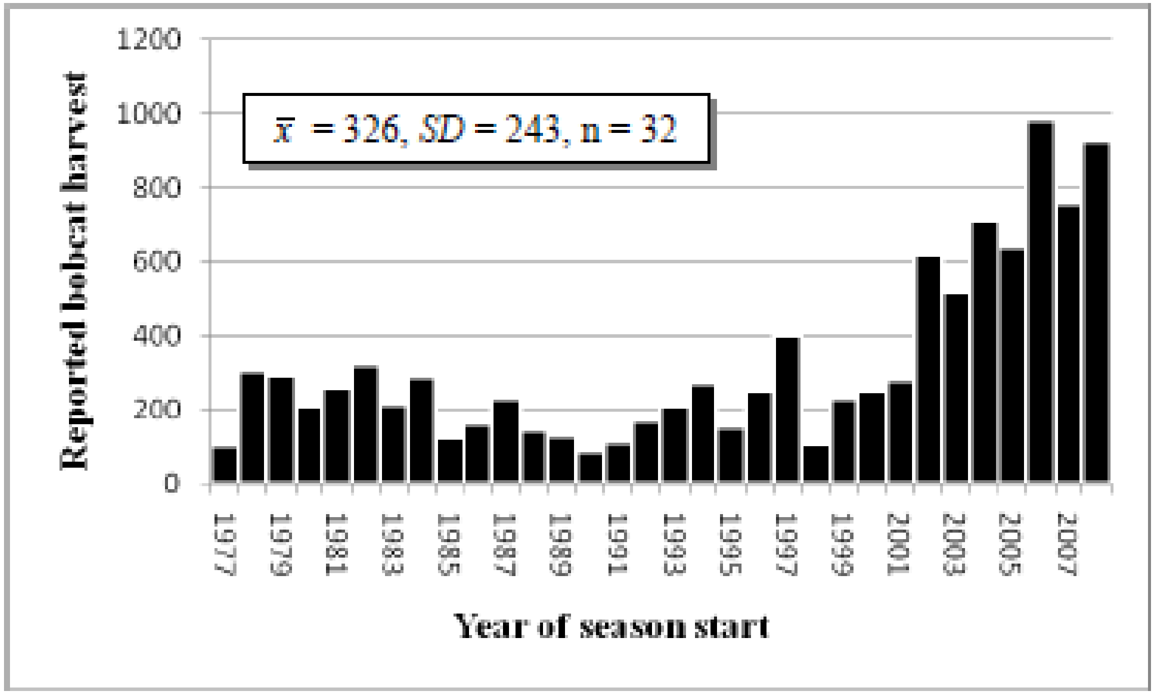
Schwartz et al. 2004



Schwartz et al. 2004

Bobcat Numbers on the Increase

Figure 1.2. Reported harvest of bobcats in Minnesota from 1977-1978 through 2008-2009 seasons.



Kapfer 2012

Genetic Monitoring of Lynx in Minnesota

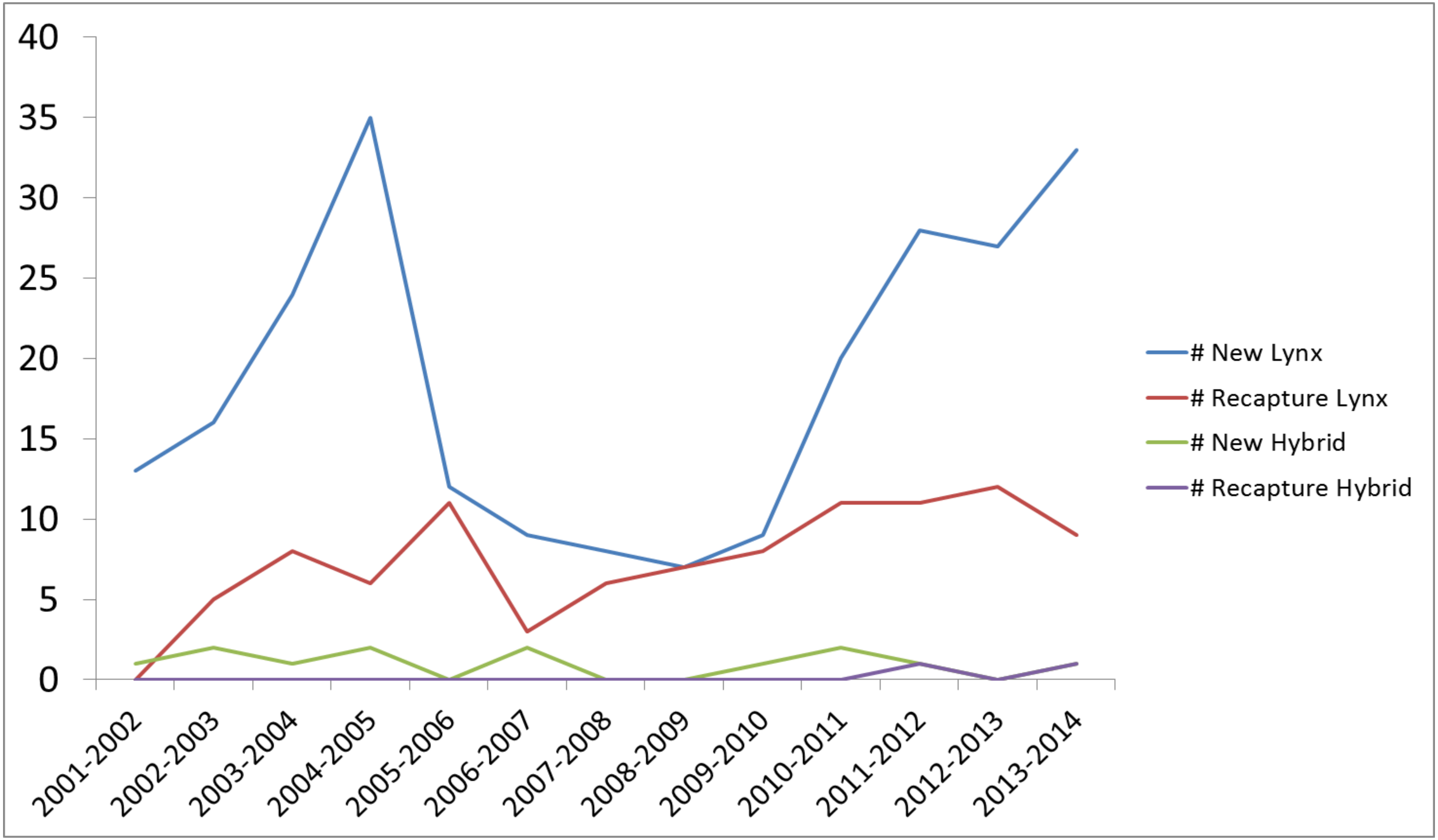


TABLE 1.—Physical characteristics of five Canada lynx (*Lynx canadensis*) – bobcat (*L. rufus*) hybrids collected from 1986–2003 in Maine and Minnesota, USA and New Brunswick, Canada compared to published estimates for diagnostic characters of parent species

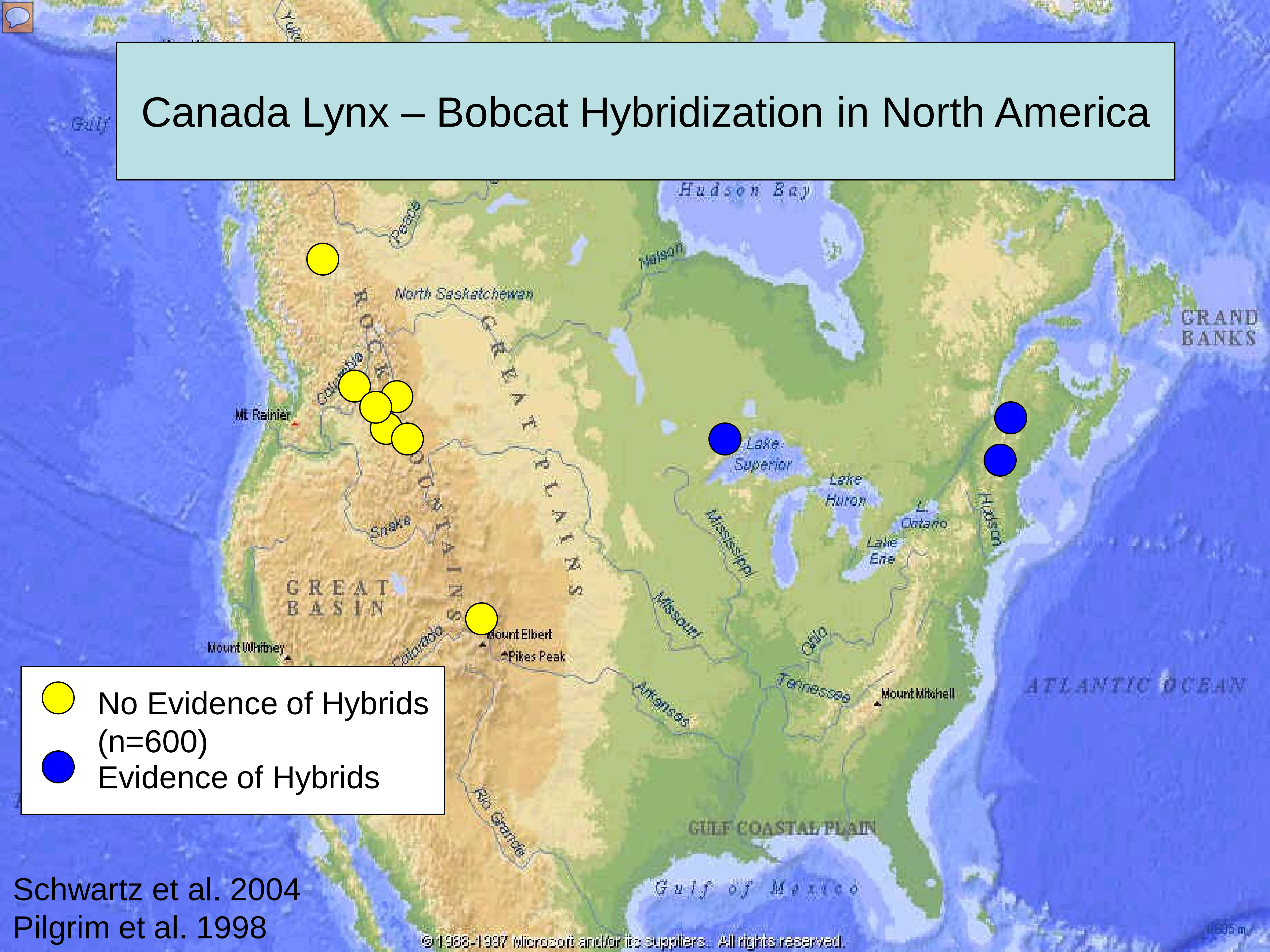
	Diagnostic characters[a]			
	Ear tuft length	Tail coloration	Hind feet	Pelage
Bobcats	<2.5 cm long	White hairs on ventral surface	Smaller, less fur males = 17.0 cm, females = 15.5 cm	Distinct spots, reddish
Canada lynx	>2.5 cm long	Tip completely black	Heavily furred in winter, 20.3–25.0 cm long	Gray, few spots
1998 Maine hybrid[b]	4.0/3.5 cm	A few white hairs interspersed	17.5 cm long	Reddish brown, few spots on ventral surface
2002 Maine hybrid[b]	3.8/3.8 cm	A few white hairs interspersed	20.0 cm long	Reddish brown, some spotting present
All Hybrids (n = 5)	5 lynx-like	5 intermediate in character	5 intermediate in character	At least 3 with bobcat-like spots

[a] Ear tuft lengths, tail coloration and pelage reported by Anderson and Lovallo (2003). Hind foot lengths reported for bobcats by Larivière and Walton (1997) and for lynx by Tumlison (1987)

[b] Individual measurements provided for those hybrids with most complete morphology

Homyack et al. 2008; placental scars on NB hybrids, kittens on tree.

Canada Lynx – Bobcat Hybridization in North America



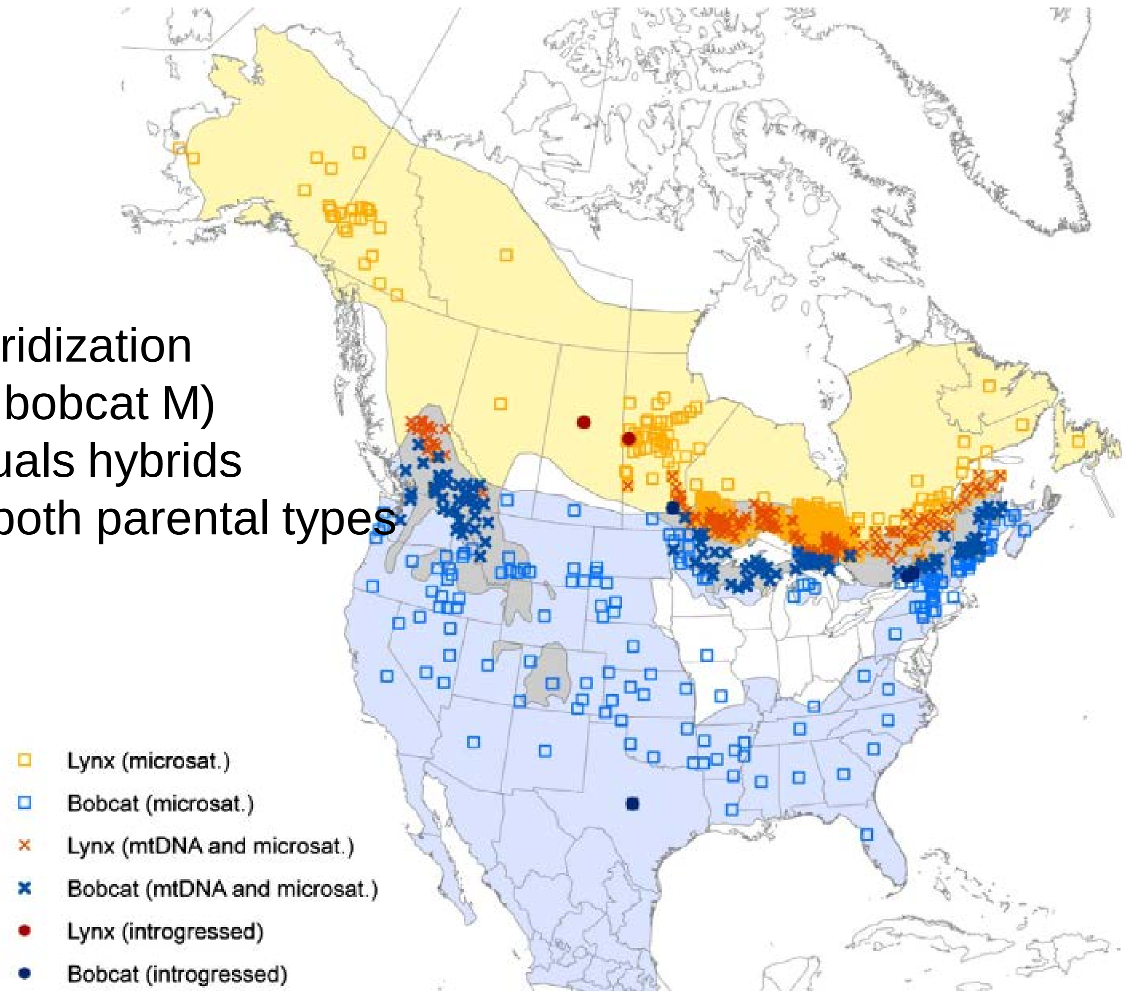
Schwartz et al. 2004
Pilgrim et al. 1998

Continental-scale assessment of the hybrid zone between bobcat and Canada lynx

Erin L. Koen [a,b,*], Jeff Bowman [b], Jillian L. Lalor [c], Paul J. Wilson [a]

[a] Biology Department, Trent University, 2140 East Bank Drive, Peterborough, Ontario K9J 7B8, Canada
[b] Wildlife Research & Monitoring Section, Ontario Ministry of Natural Resources and Forestry, 2140 East Bank Drive, Peterborough, Ontario K9J 7B8, Canada
[c] Environmental and Life Sciences, Trent University, 2140 East Bank Drive, Peterborough, Ontario K9J 7B8, Canada

- bi-directional hybridization (mostly lynx F x bobcat M)
- 7 of 2851 individuals hybrids
- Backcrossing to both parental types



Lynx Genetic Considerations

1) Mini review of lynx population genetic studies

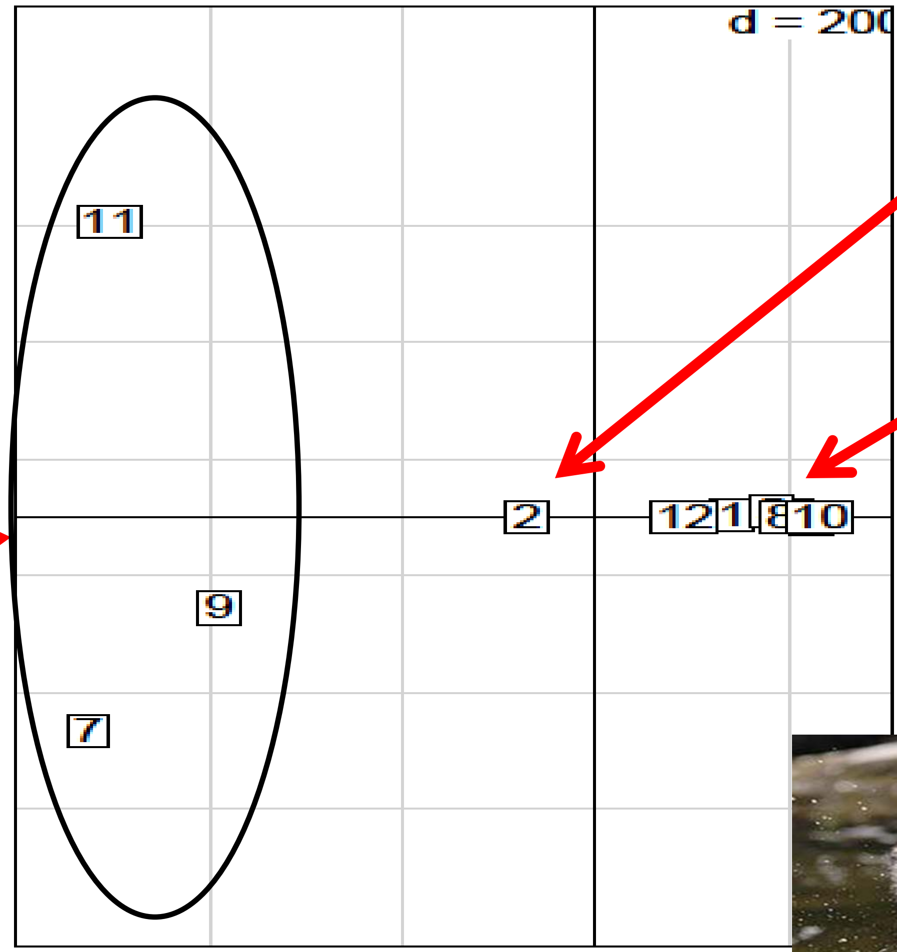
2) Review of lynx hybridization studies

3) Needed genomic data

What is Genomics?

Genomic data: genetic information (e.g. DNA sequences) at thousands to millions of loci across the genome of a sample of organisms. Often focuses on mapping of these sequences and understanding their interactions

#1: Increase Power and Precision



Dog-Wolf Hybrid

Wolves from 3 Locations in Italy

Domestic Dogs

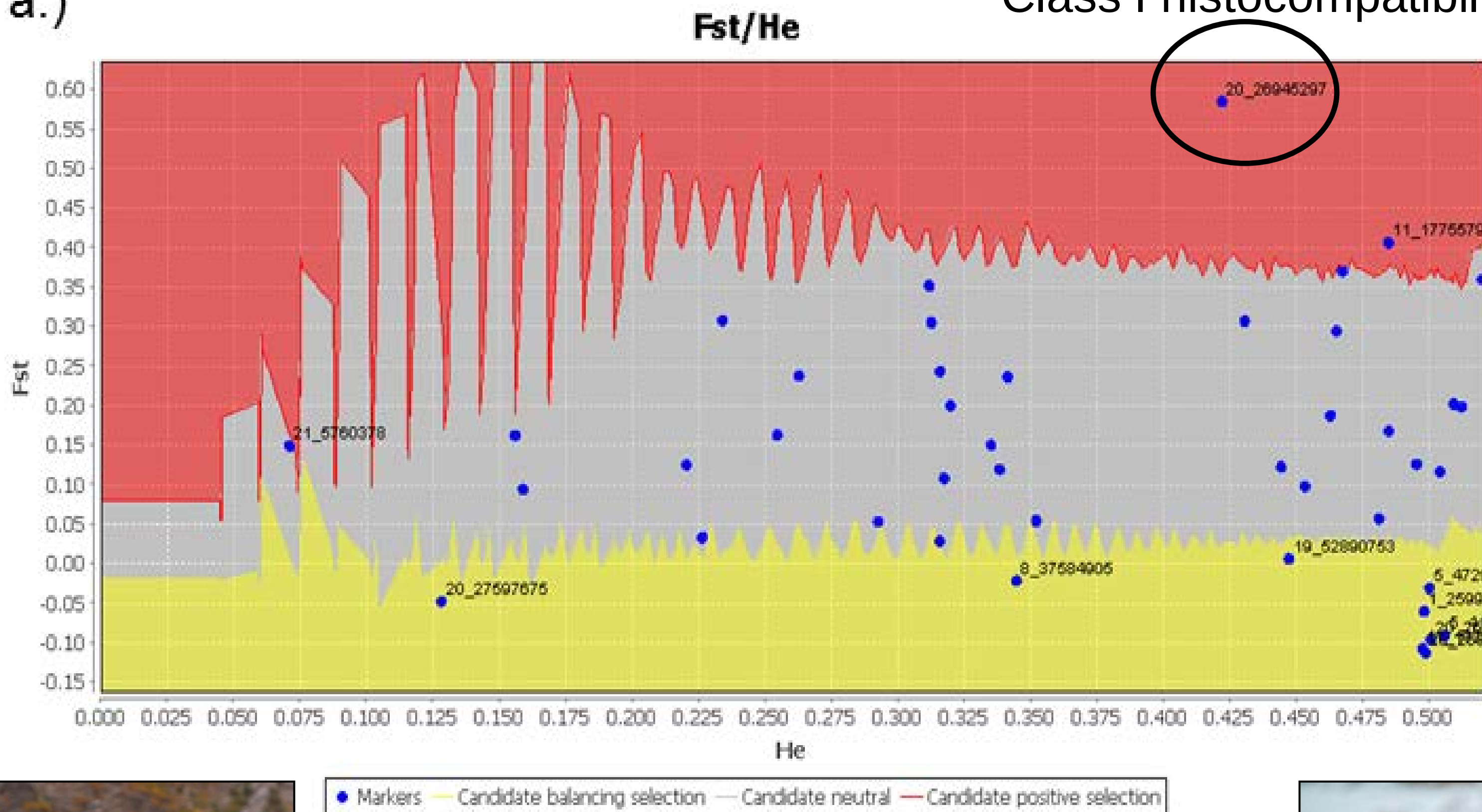
166,000 Molecular Markers

#2 Separate: Neutral vs. Adaptive Genes

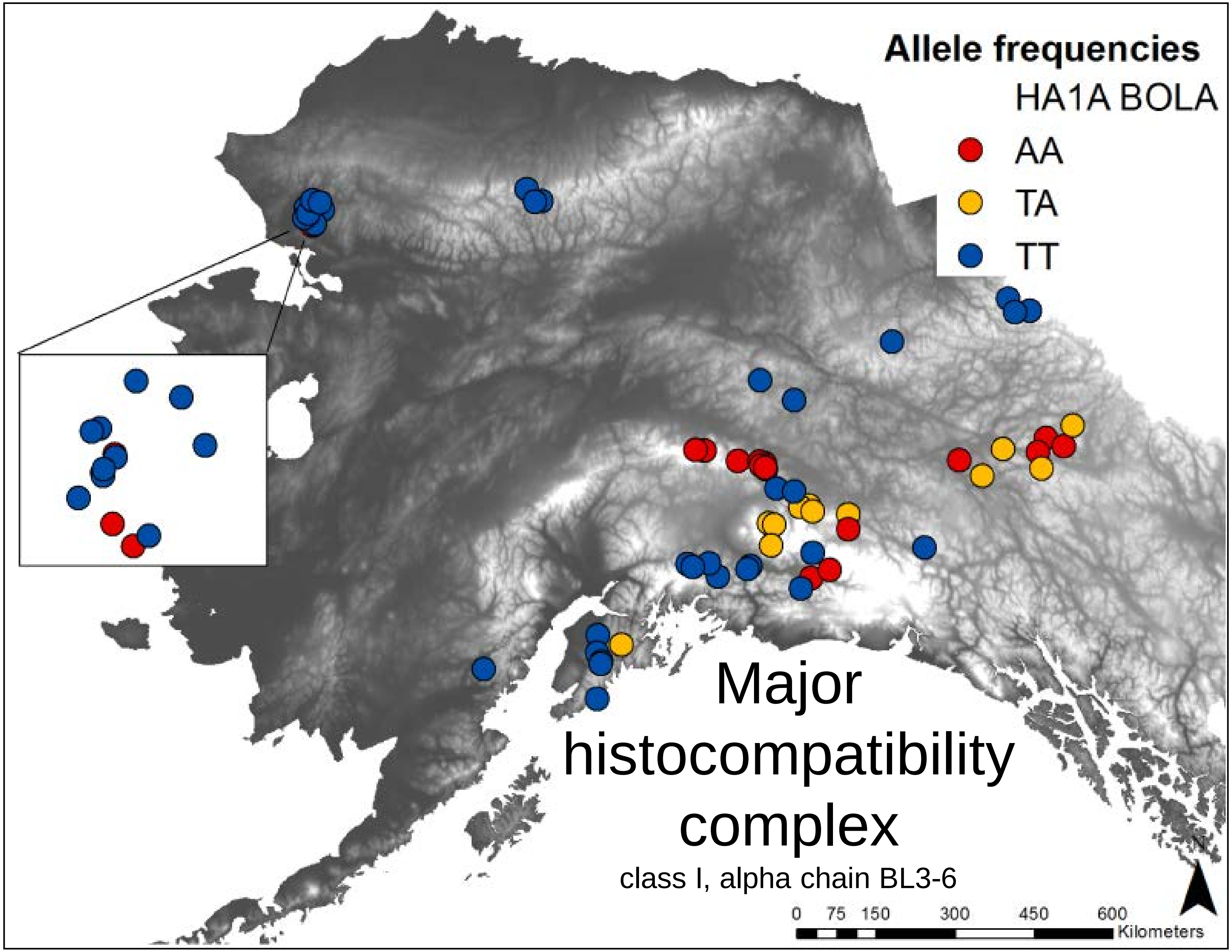
8,188 exons from >5,000 genes targeted; Roffler et al. (in prep)

a.)

Class I histocompatibility antigen



Spatial Distribution of Alleles at Locus Putatively Under Selection



Roffler et al. in prep.

Can we find genes under selection with lynx?

Leading Edge of the Range – Drift Wins, Unless Selection is Very Strong or Ne Large

Effective population size influences whether a local population can respond to selection = local adaptation

First Principles of Population Genetics: Effective Population Size

Effective population size influences whether a local population can respond to selection = local adaptation

Summary Points

- Boreal forest is almost no barrier for lynx
- Intriguing results about climate in East
- Periphery and some features = limited barrier
- Tide pool model
- When tide is out – substructure develops
- Genomics can address climate and periphery questions while also looking for genes under selection

Where do we go from here?

- Sampling (during multiple phases of cycle)
- Genomic studies to increase power
- Look for genes under selection at range margin, with focus on the NAO

What else should we do?

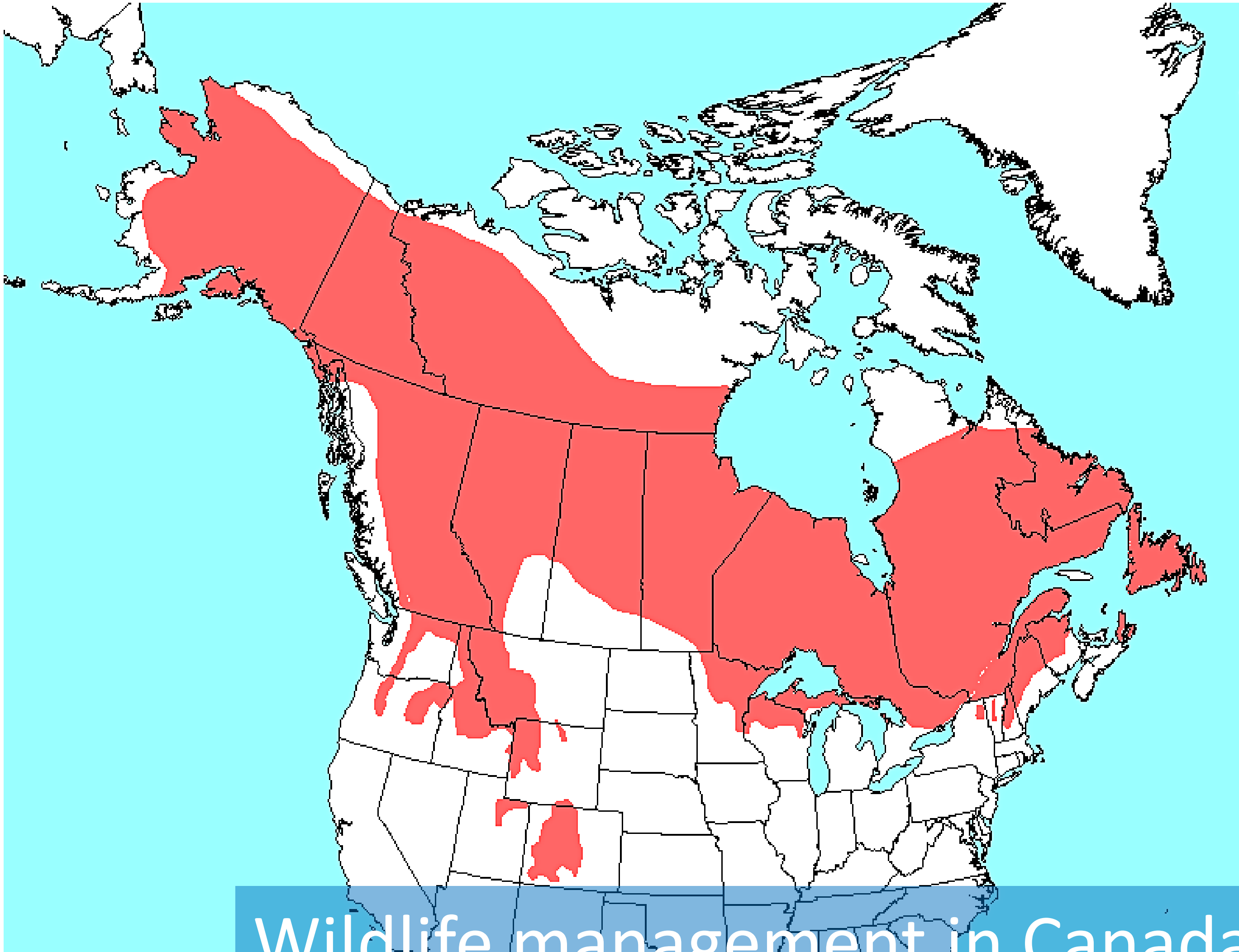
1) Conserve genetic diversity at the broad scale!!!!!!

2) Recognize that adaptive variation may = reduced gv at leading and trailing edge due to selection or drift.

3) Conserve gradients, and recognize the importance of peripheral populations (where selection occurs)

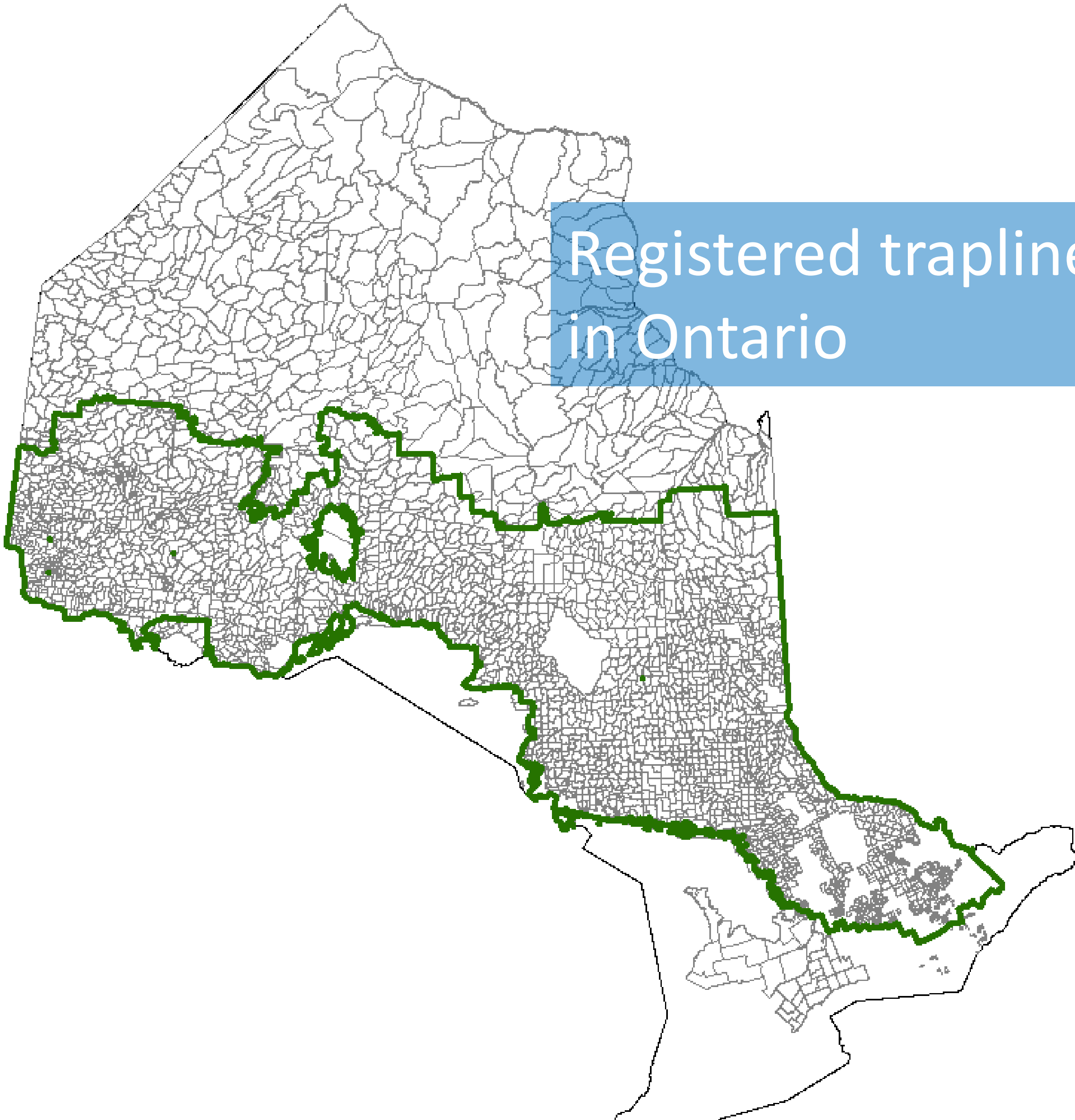
Lynx distribution, status, and management in southern Canada

Jeff Bowman
Ontario MNRF
and Trent University

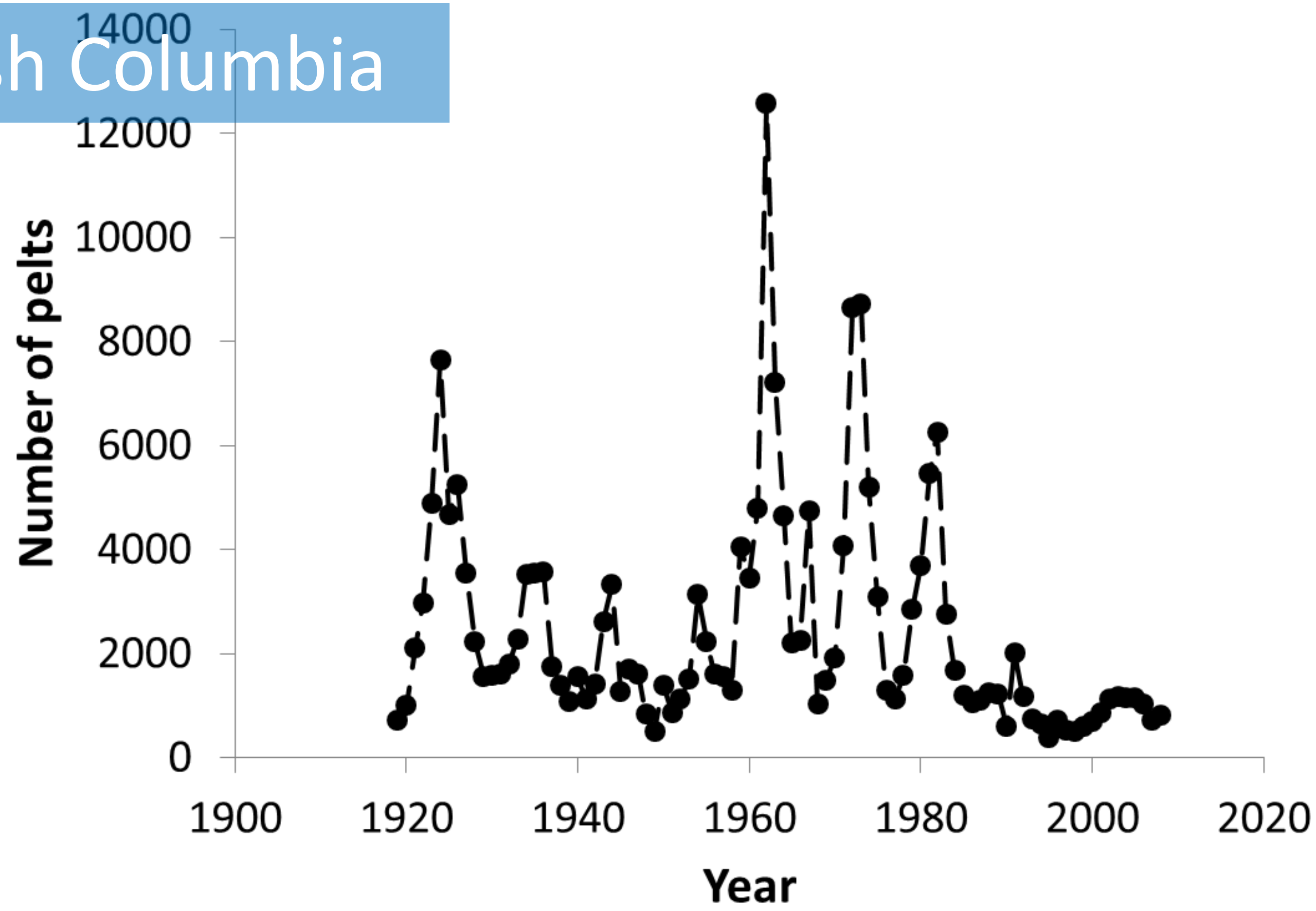


Wildlife management in Canada is largely a provincial responsibility

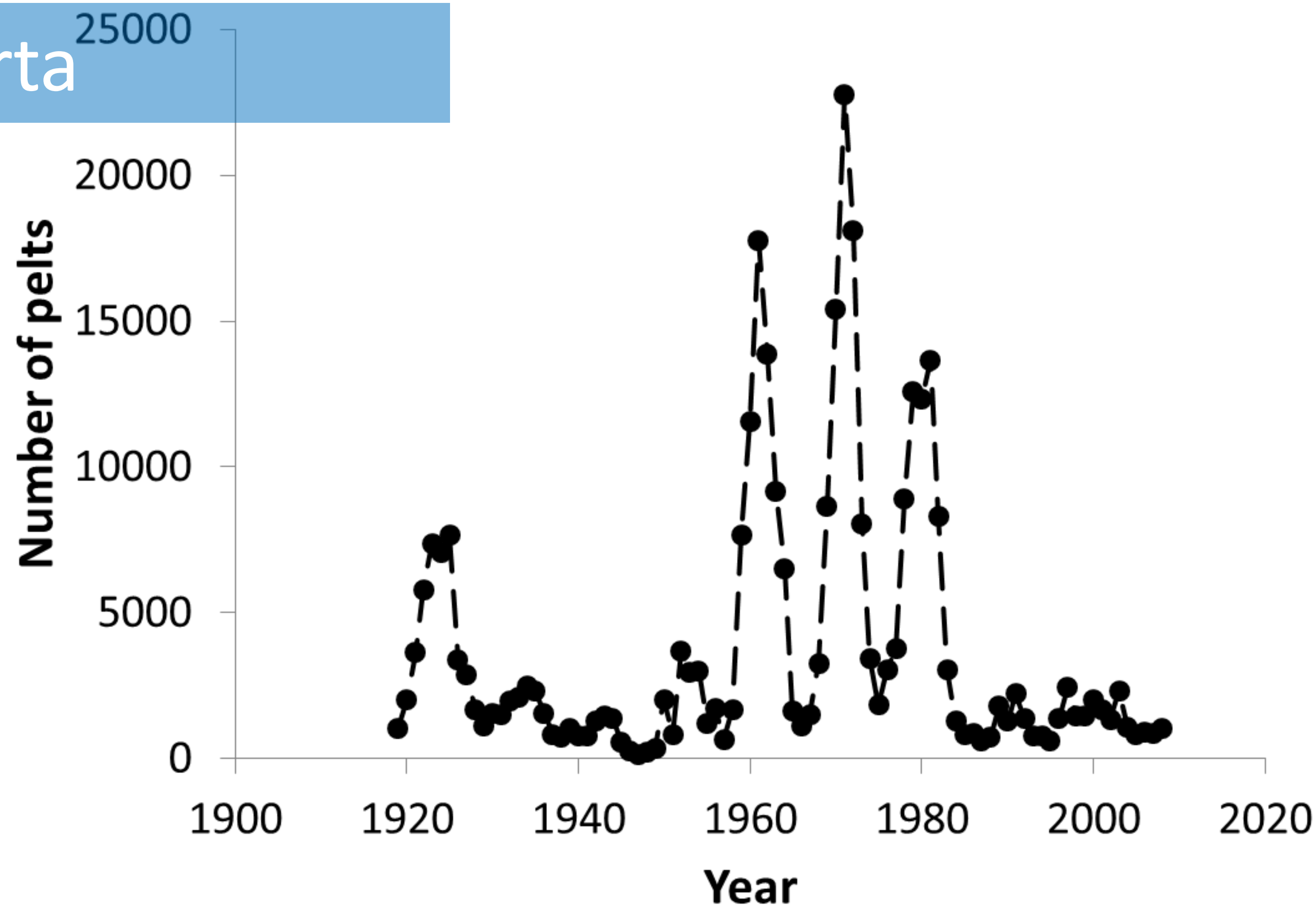
Registered traplines in Ontario



British Columbia

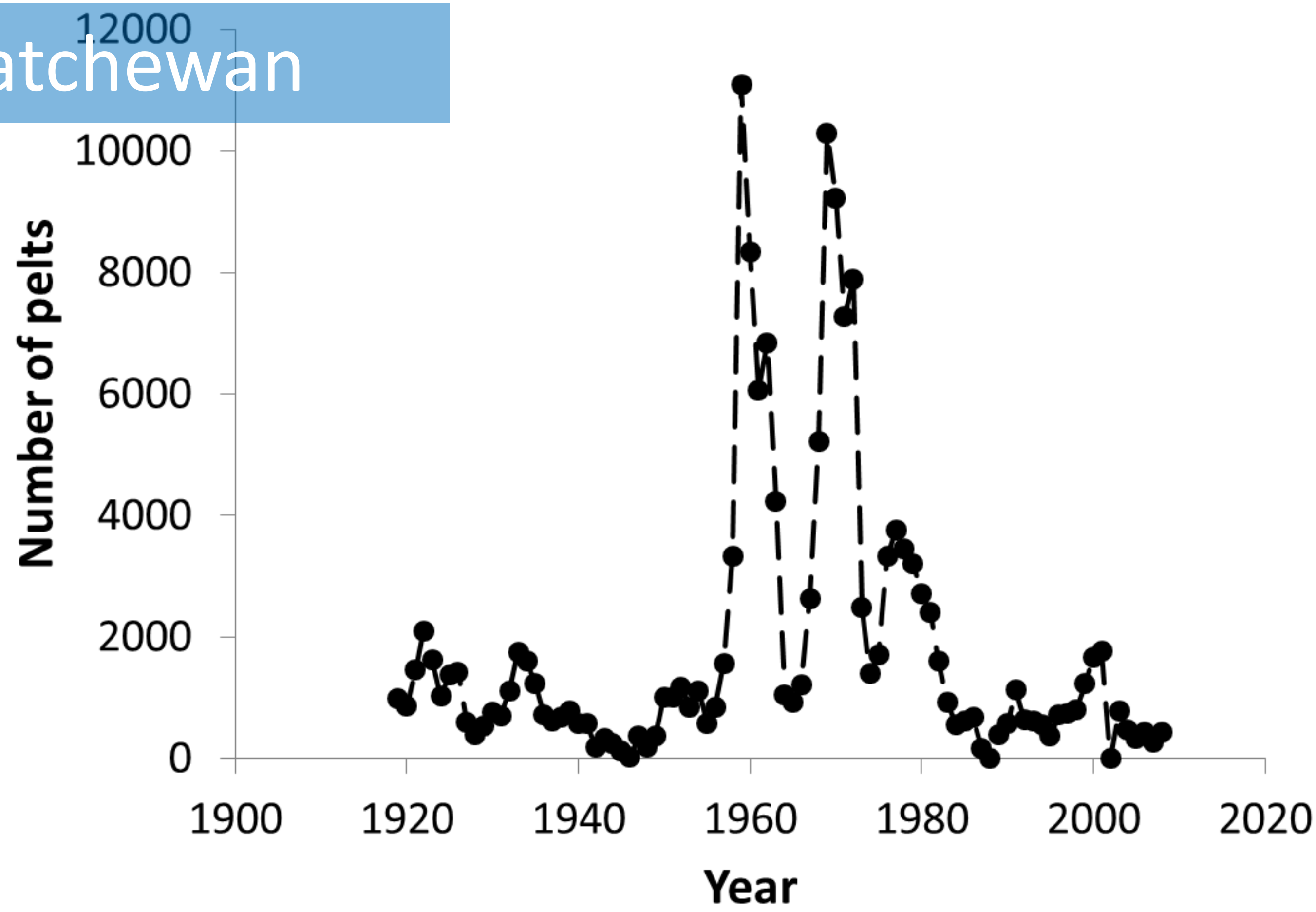


Alberta

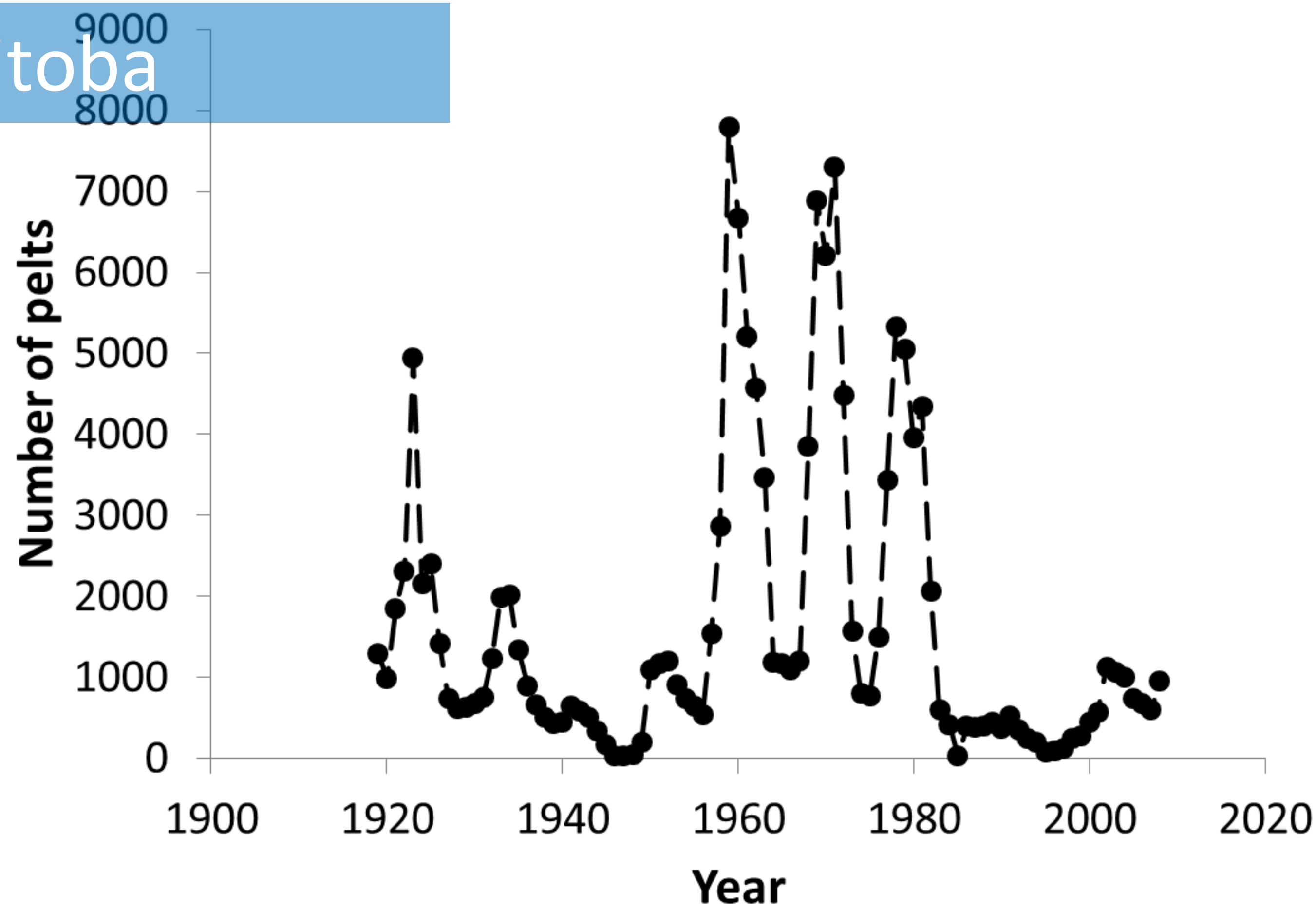


25000
20000
15000
10000
5000
0
Number of pelts
1900
1920
1940
1960
1980
2000
2020
Year

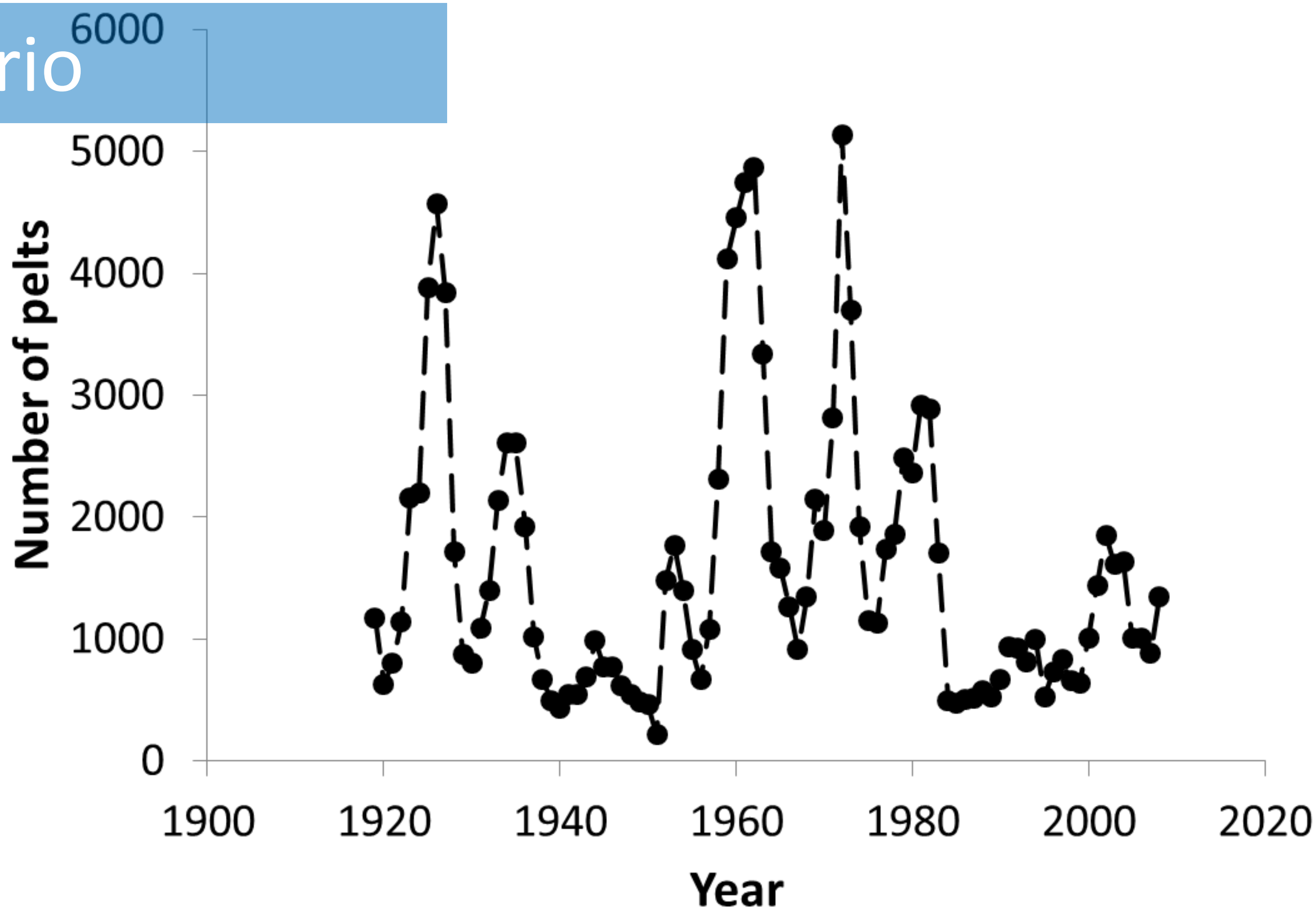
Saskatchewan



Manitoba

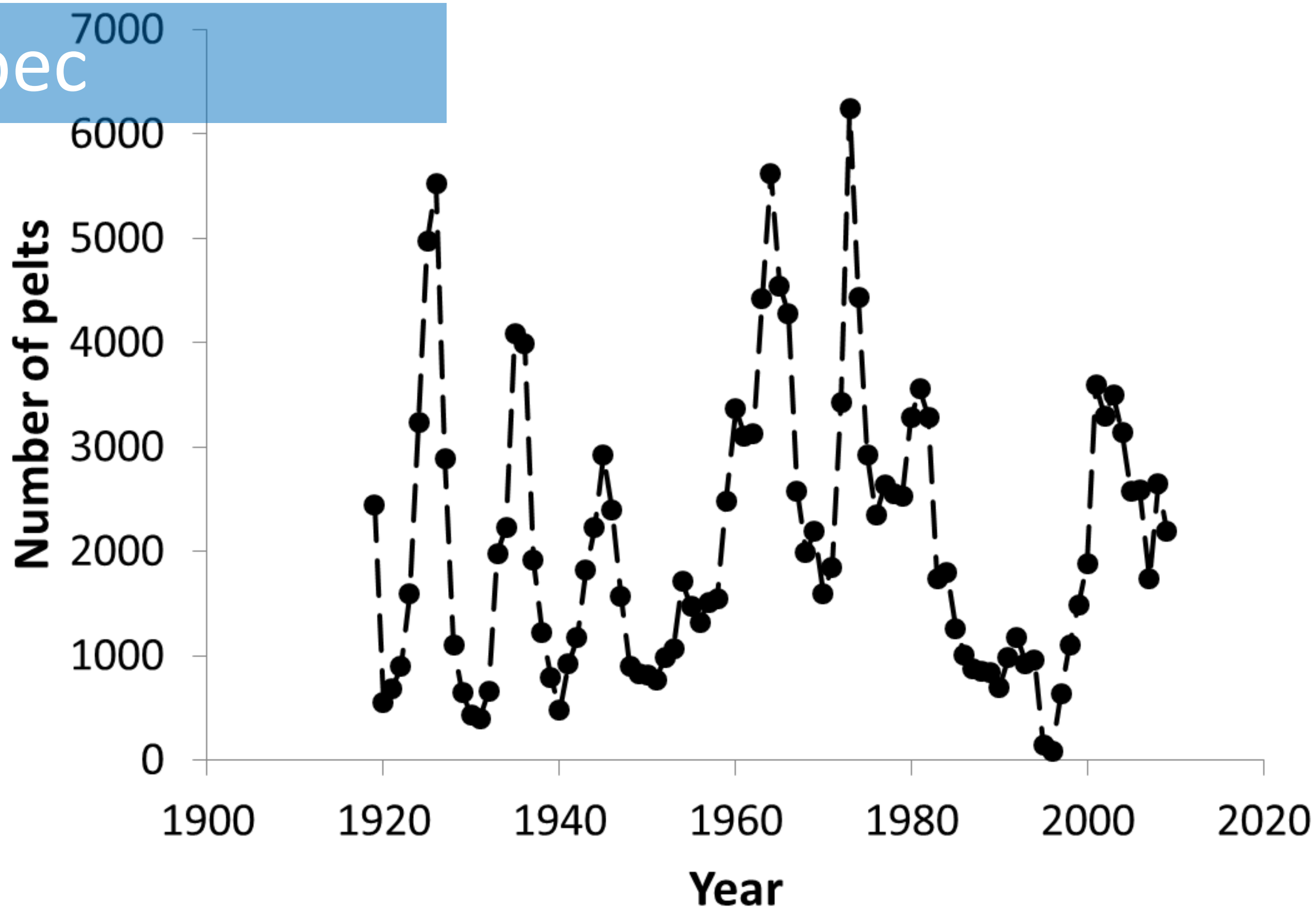

9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Number of pelts
1900
1920
1940
1960
1980
2000
2020
Year

Ontario



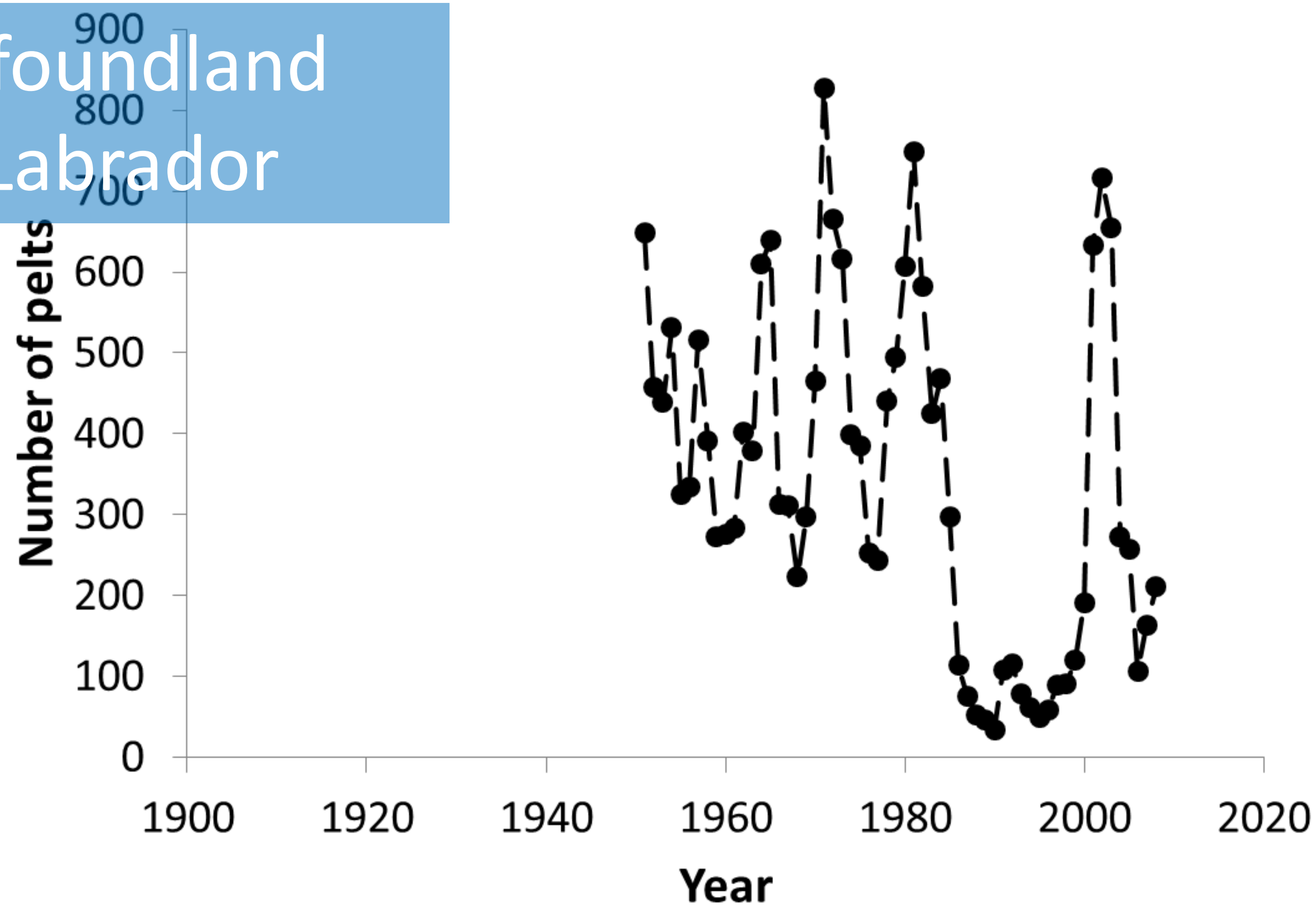
6000
5000
4000
3000
2000
1000
0
Number of pelts
1900
1920
1940
1960
1980
2000
2020
Year

Quebec

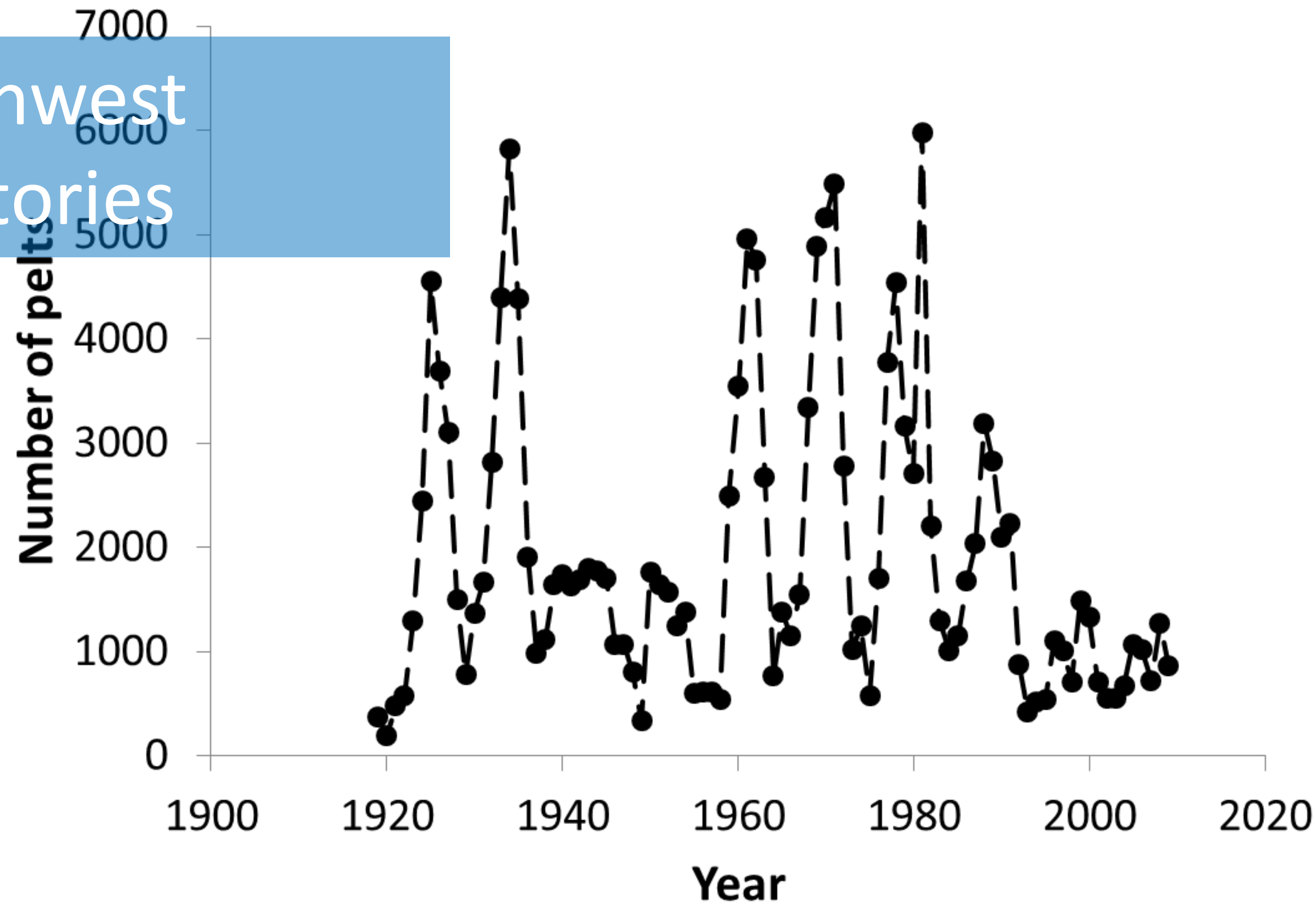


7000
6000
5000
4000
3000
2000
1000
0
Number of pelts
1900
1920
1940
1960
1980
2000
2020
Year

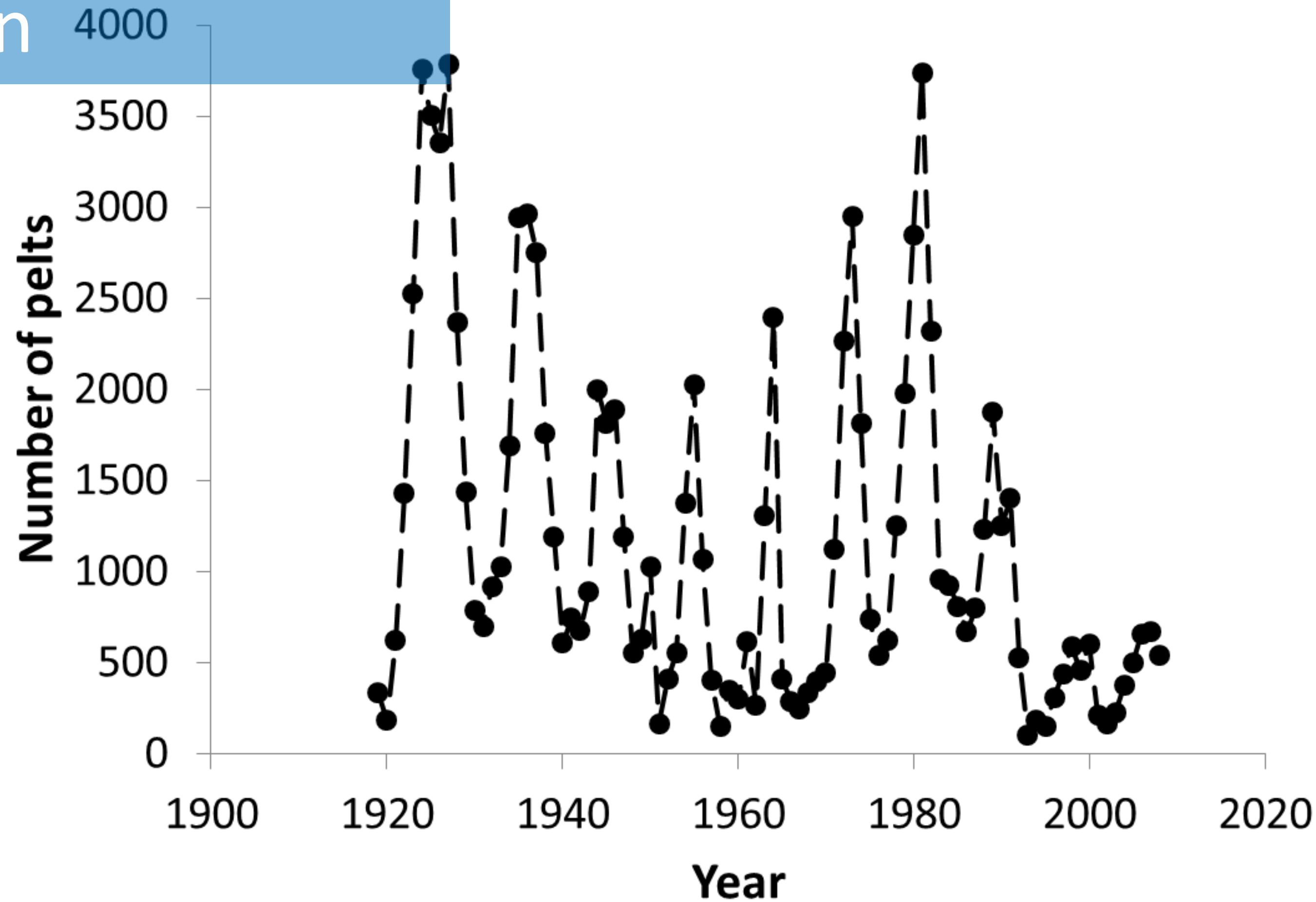
Newfoundland and Labrador



Northwest Territories

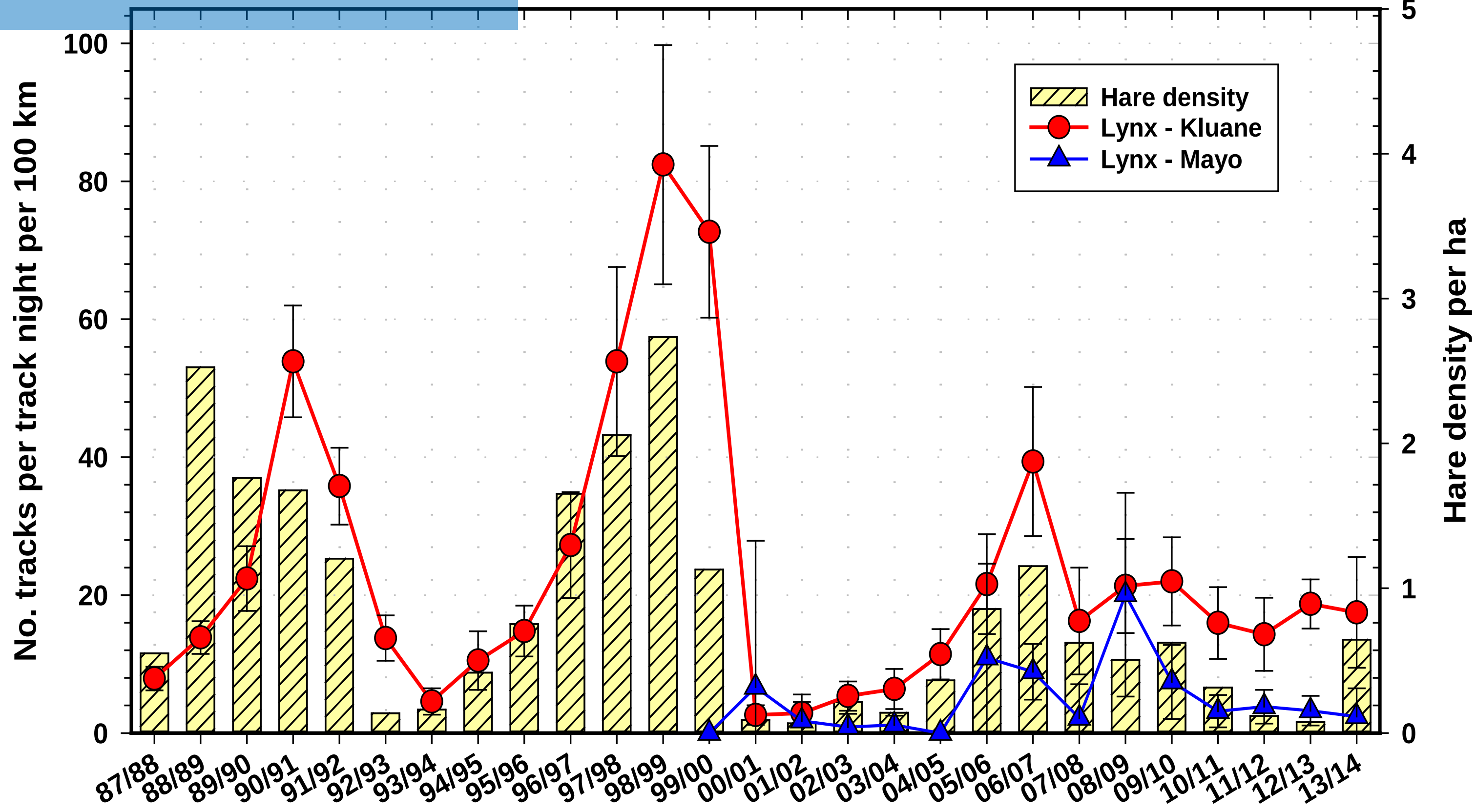


Yukon

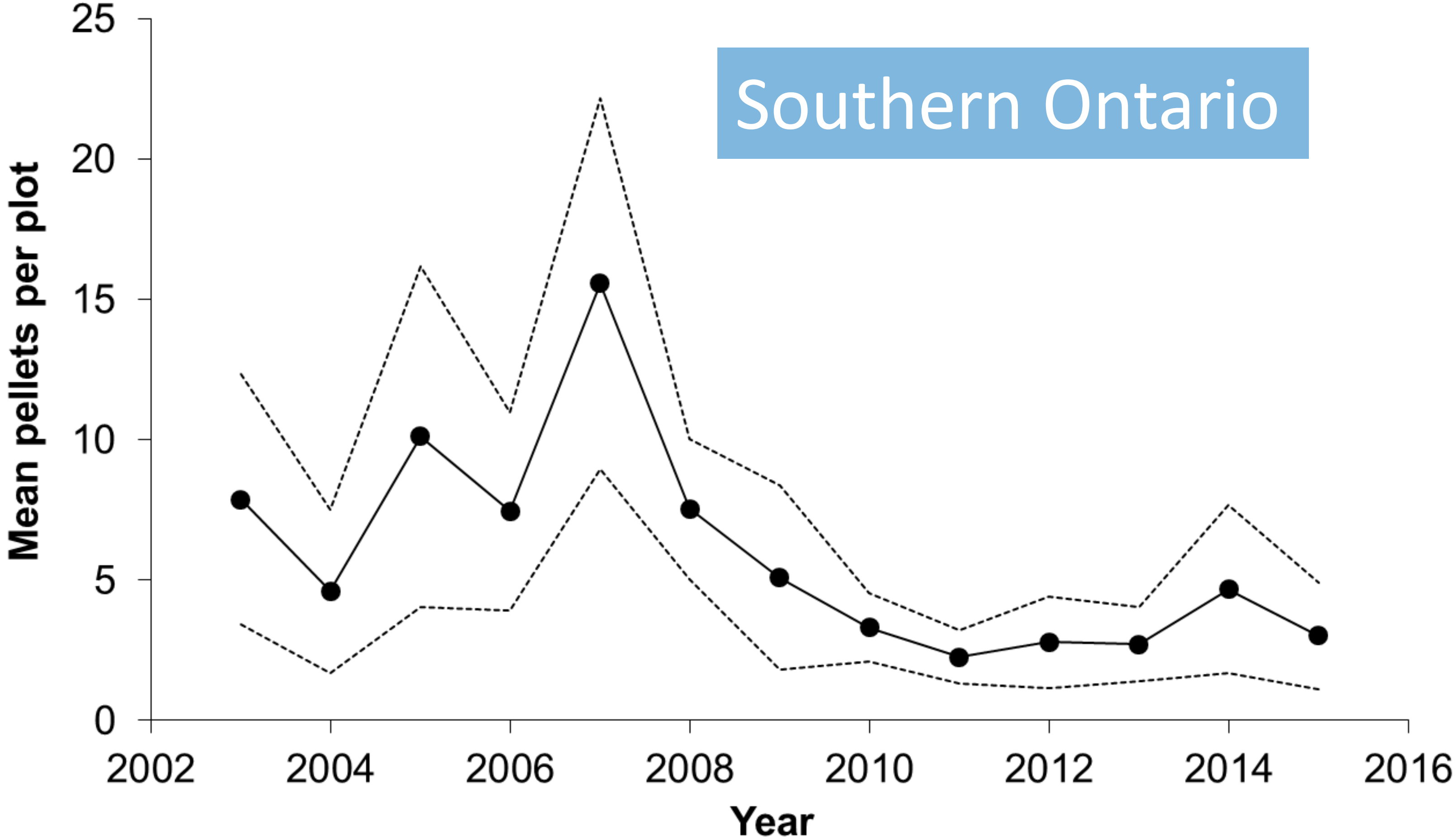


Number of pelts
4000
3500
3000
2500
2000
1500
1000
500
0
1900
1920
1940
1960
1980
2000
2020
Year

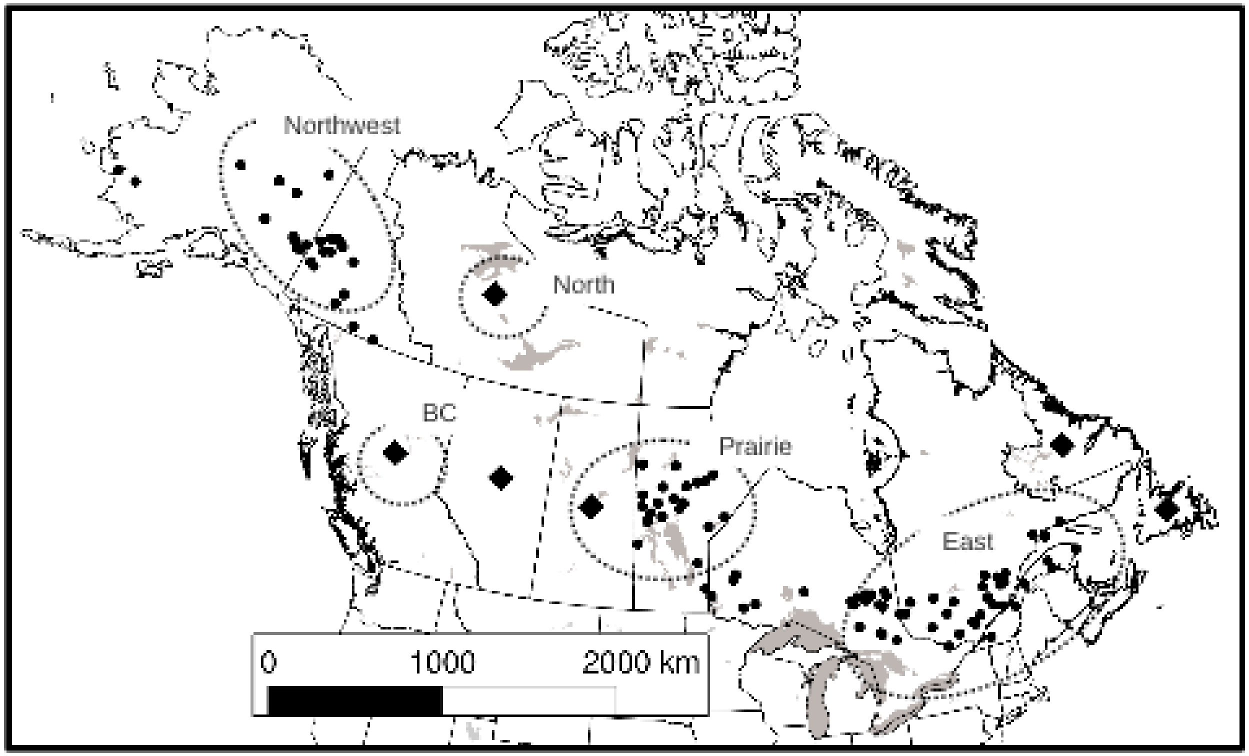
Yukon



Powell et al. 2014. CEMP Annual Report.

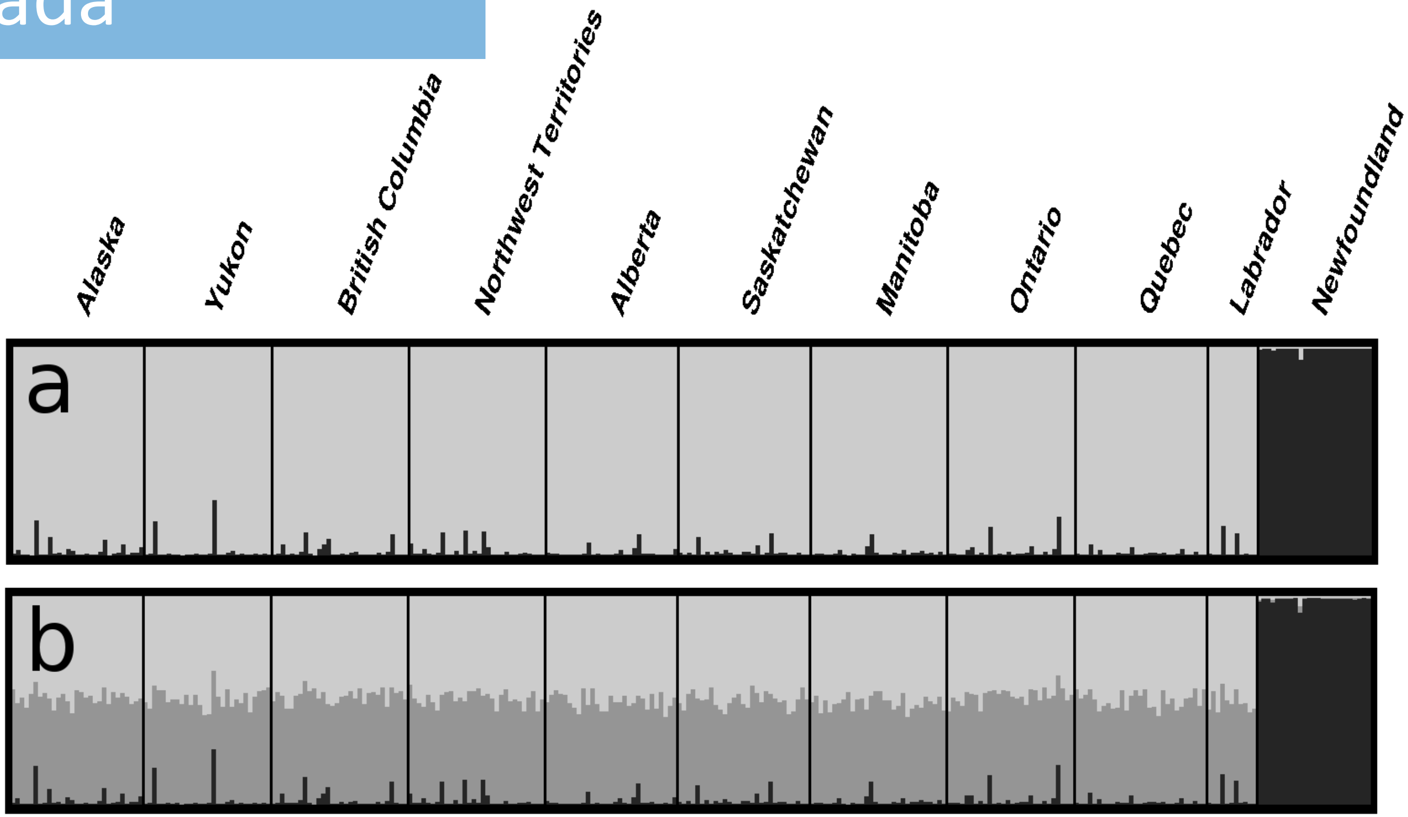

Southern Ontario
Mean pellets per plot
Year
0
5
10
15
20
25
2002
2004
2006
2008
2010
2012
2014
2016

Gene flow across Canada



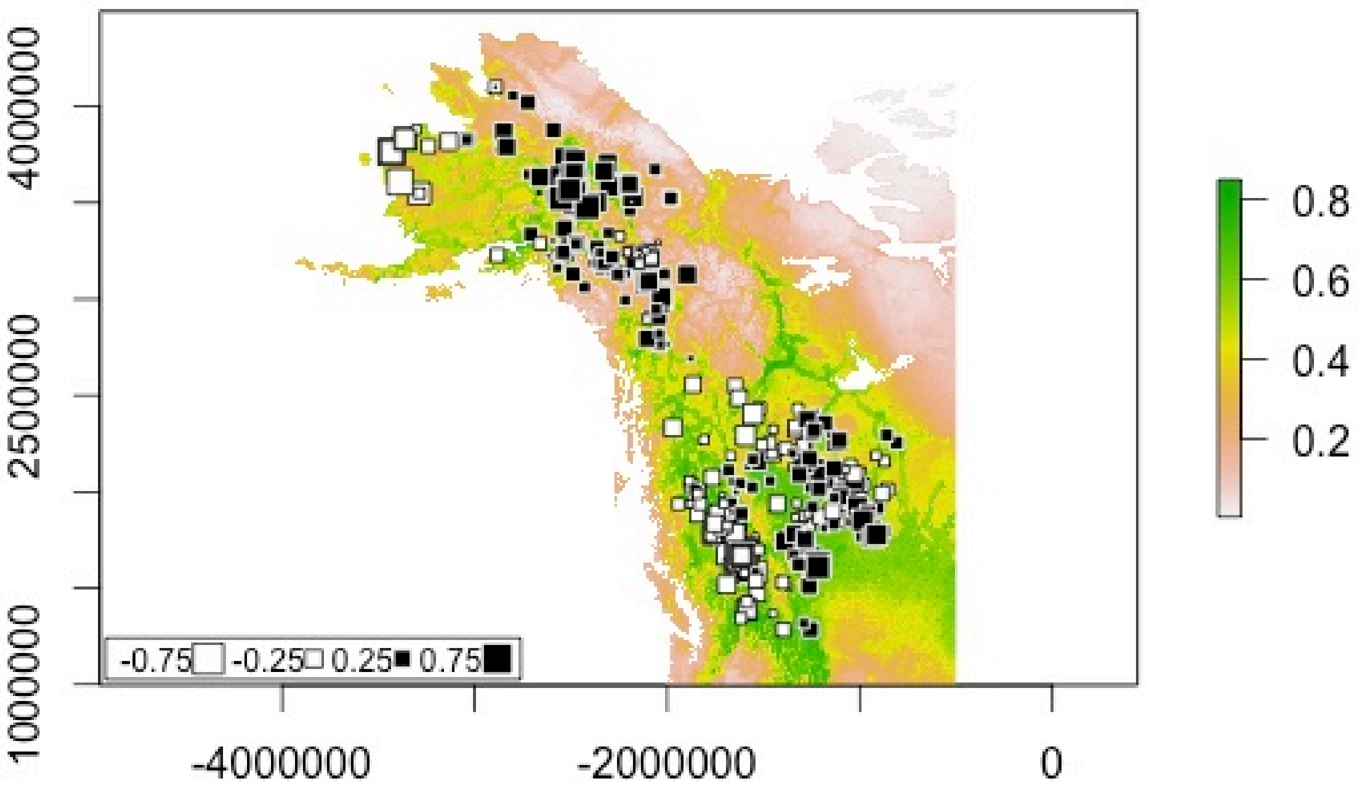
Row et al. 2012. Conservation Genetics 13: 1259-1268.

Gene flow across Canada



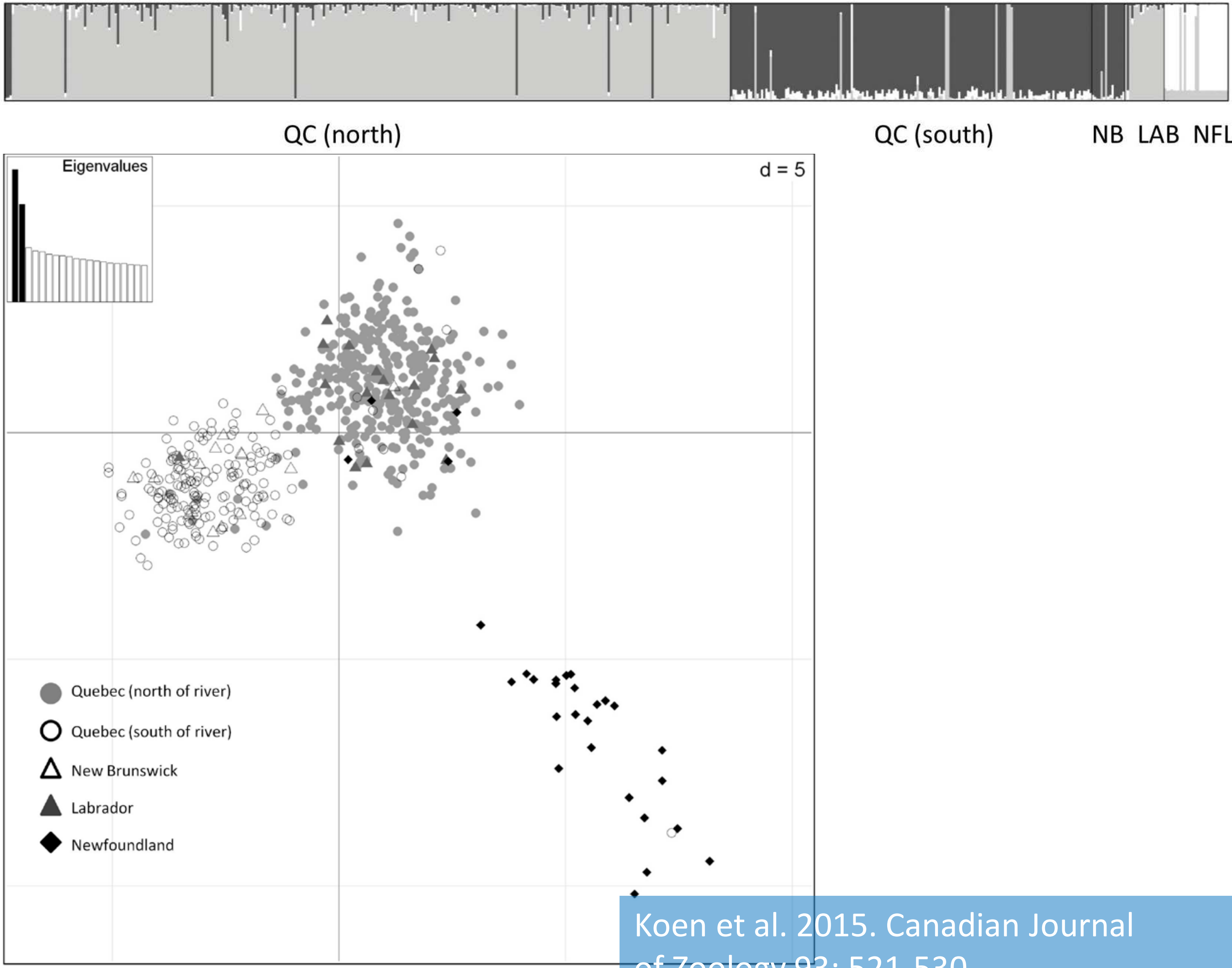
Row et al. 2012. Conservation Genetics 13: 1259-1268.

Subtle genetic structure

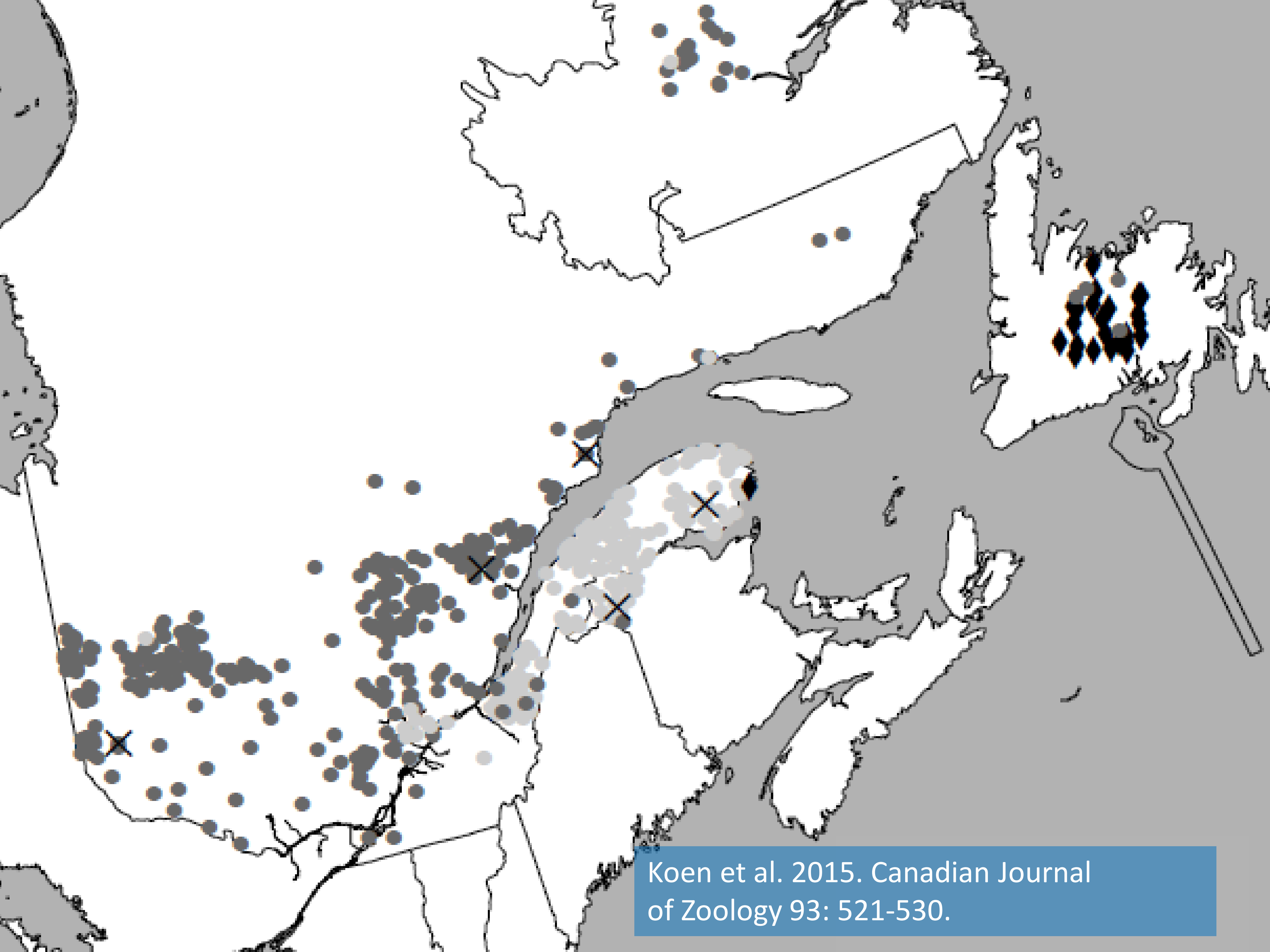


Cristen Watt, Trent University, ongoing thesis work.

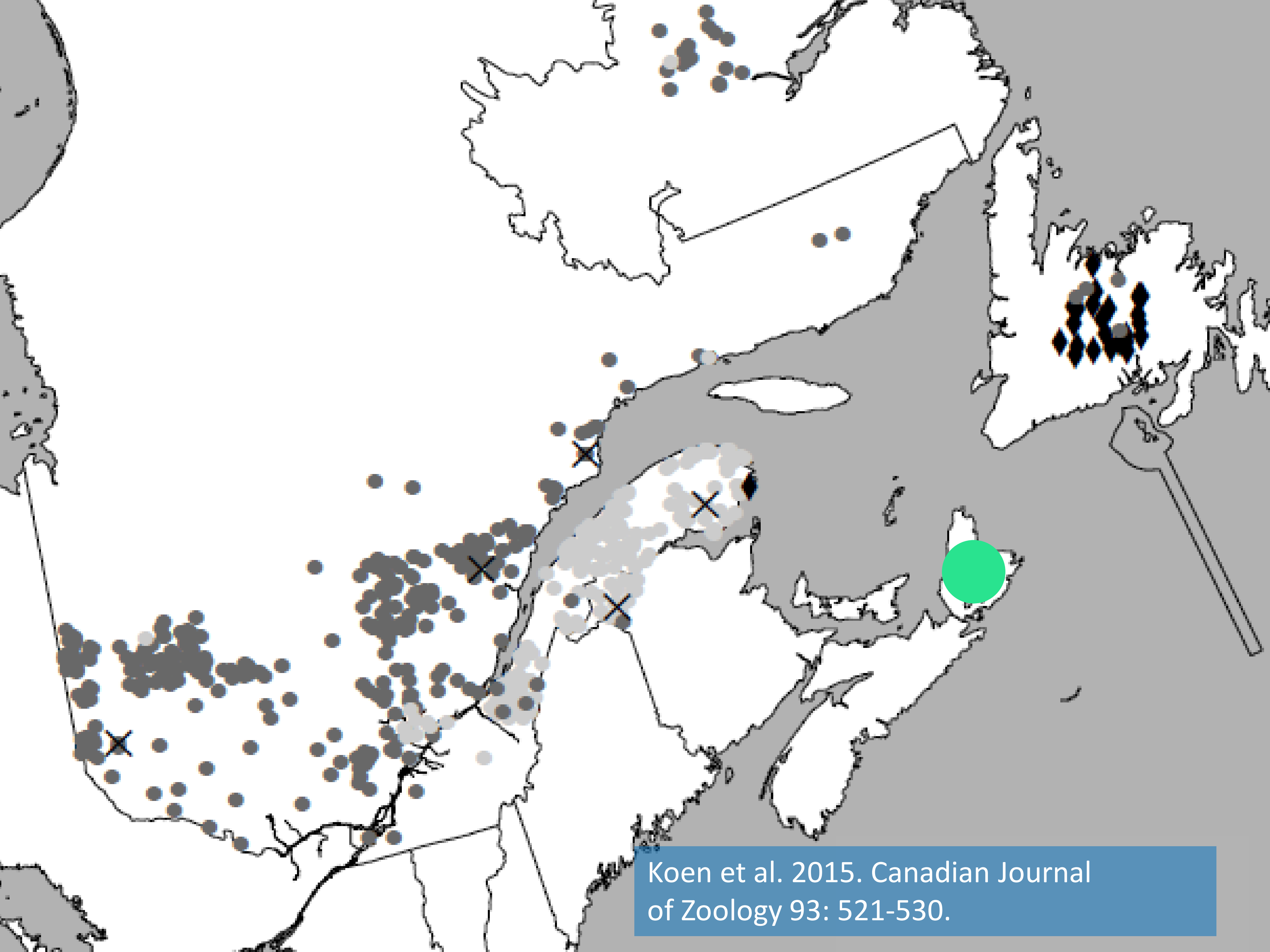

Barrier effect of
St. Lawrence River



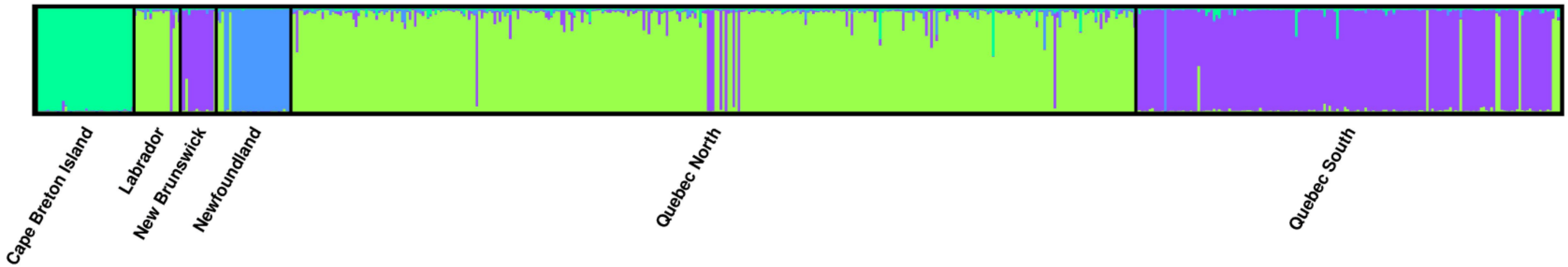
Koen et al. 2015. Canadian Journal of Zoology 93: 521-530.



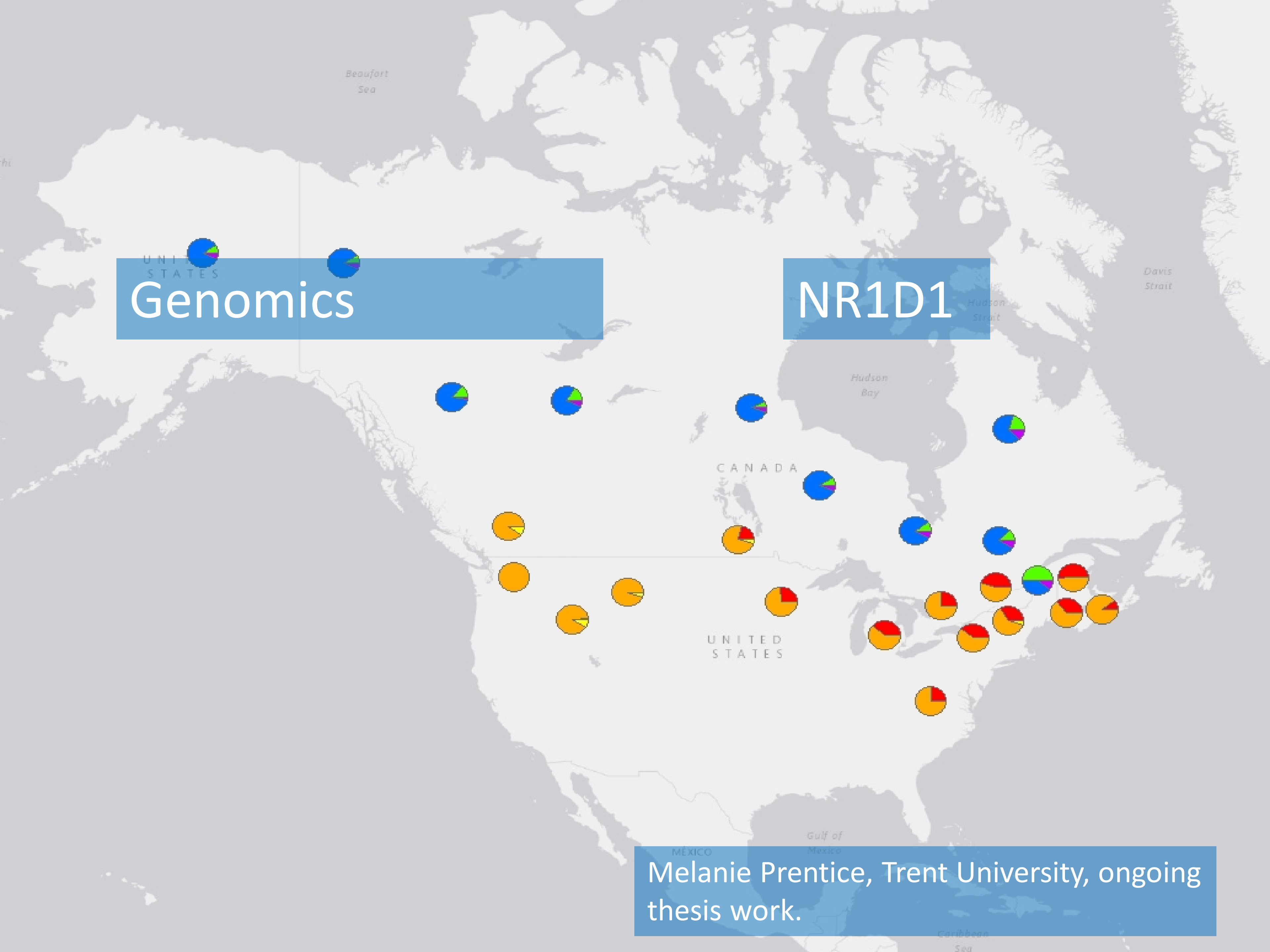
Koen et al. 2015. Canadian Journal of Zoology 93: 521-530.

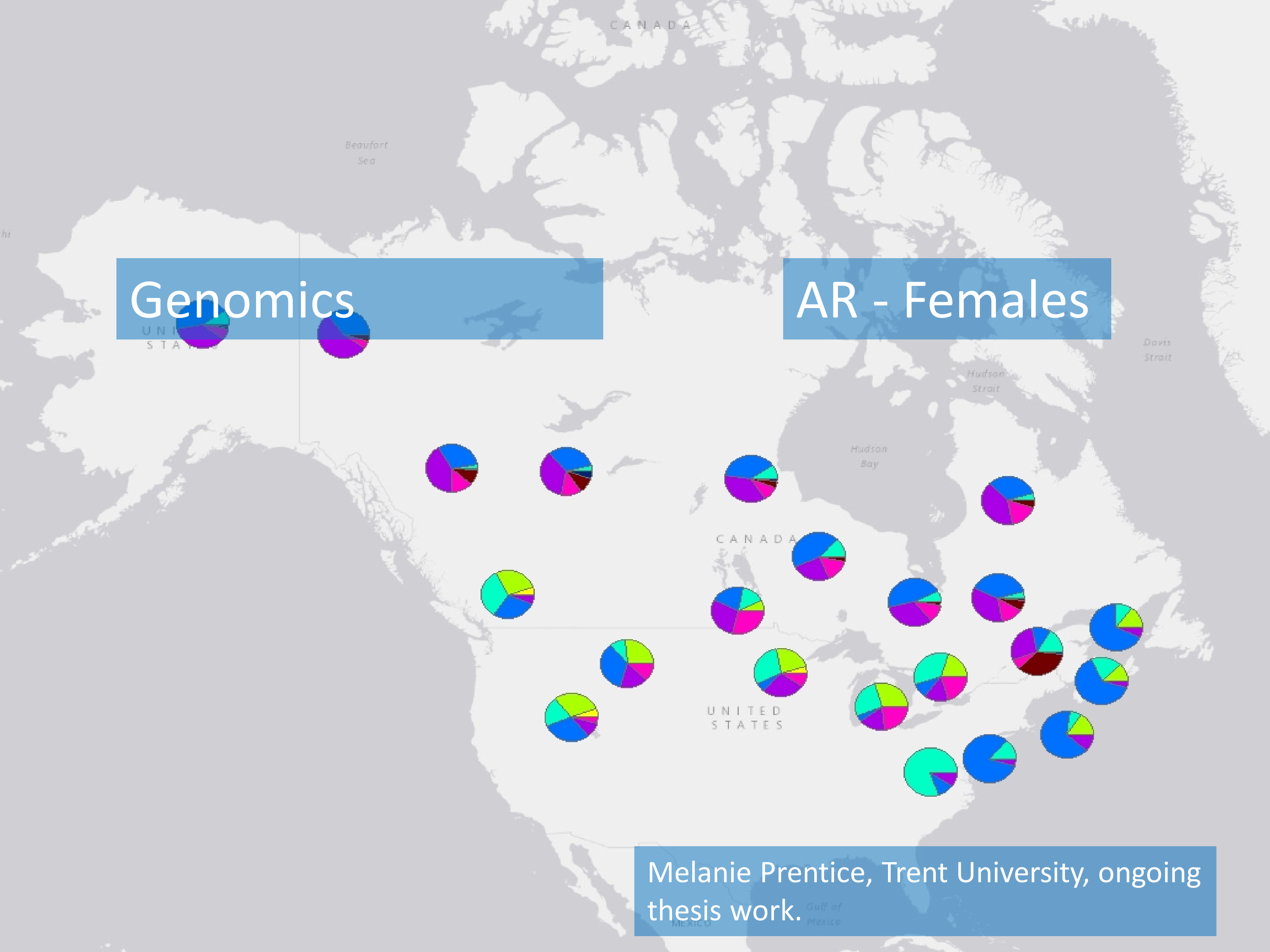


Koen et al. 2015. Canadian Journal of Zoology 93: 521-530.



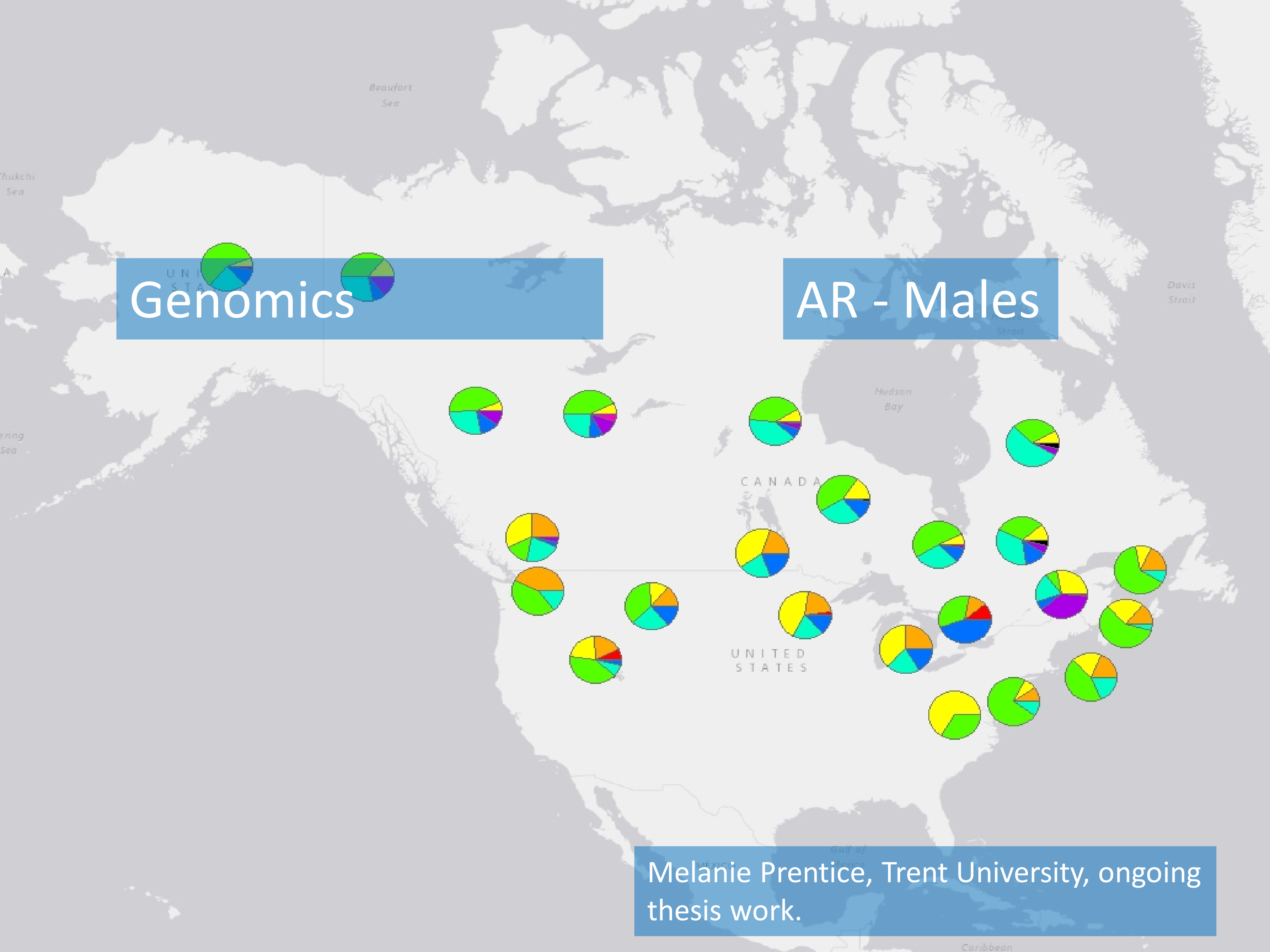
Melanie Prentice, Trent University, ongoing thesis work.


Genomics
NR1D1
Melanie Prentice, Trent University, ongoing thesis work.
Beaufort Sea
Davis Strait
Hudson Strait
Hudson Bay
CANADA
UNITED STATES
UNITED STATES
MEXICO
Gulf of Mexico


Genomics
AR - Females
Melanie Prentice, Trent University, ongoing thesis work.
CANADA
Beaufort Sea
Hudson Strait
Davis Strait
Hudson Bay
CANADA
UNITED STATES

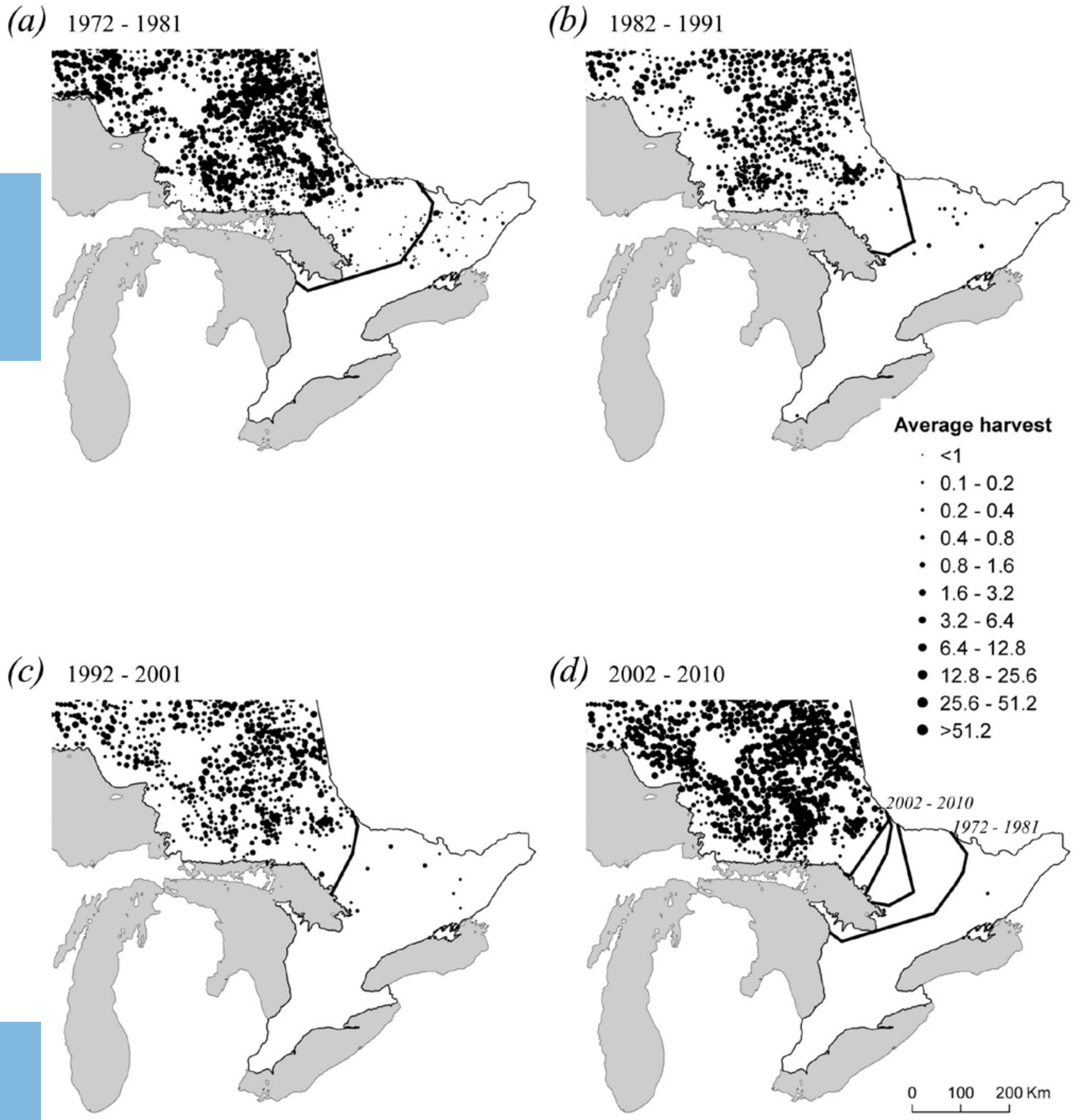
Genomics

AR - Males



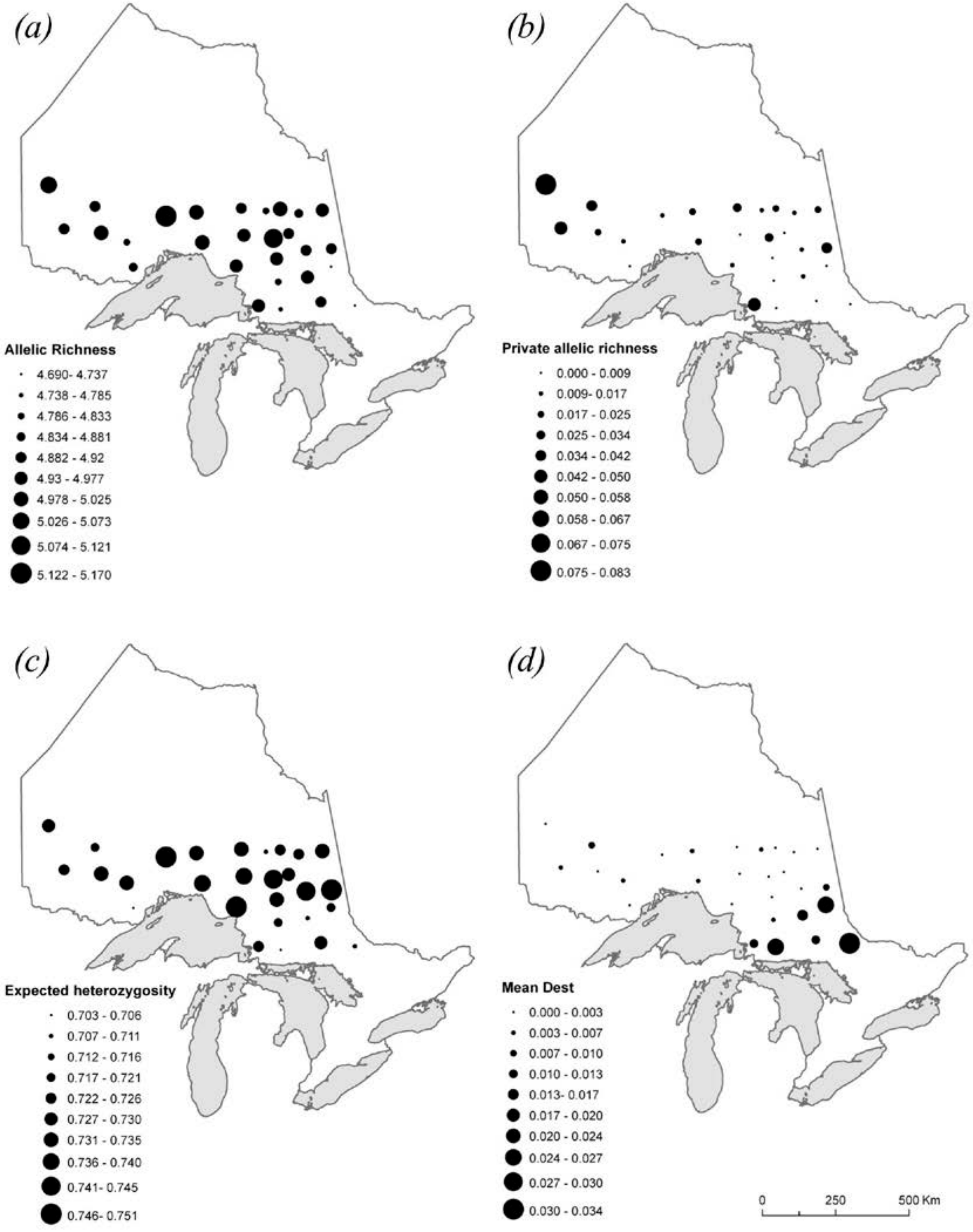
Melanie Prentice, Trent University, ongoing thesis work.

Range contraction



Koen et al. 2014. Ecography 37: 754-762.

Range contraction



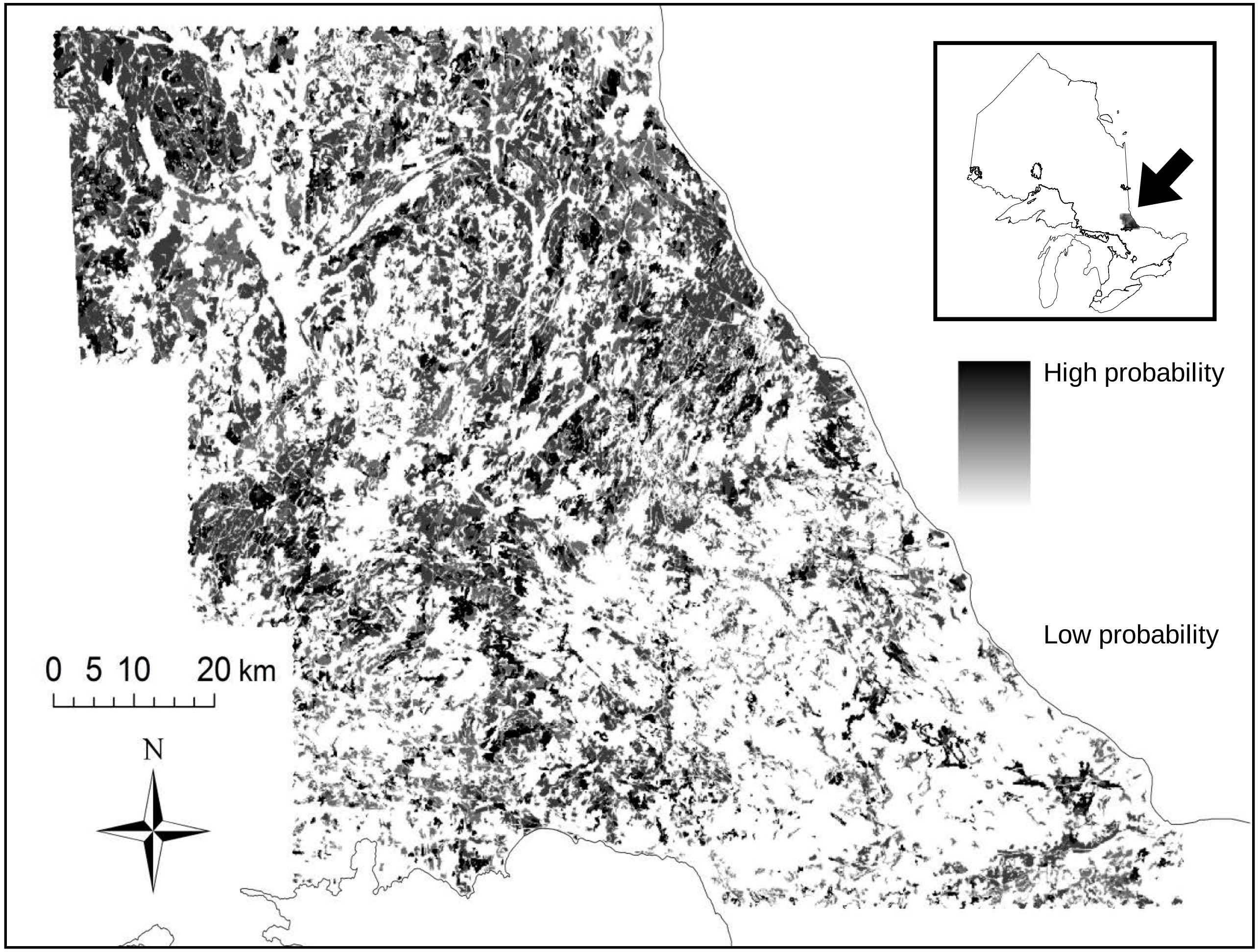
Koen et al. 2014. Ecography 37: 754-762.

Table 2. Top models (Δ AICc < 2) predicting the effect of land cover and climate on genetic structure of Canada lynx *Lynx canadensis* sampled from 28 sites in Ontario, Canada.

Dependent variable	Model[1]	logLik	AICc	w_i	R^2
Allelic richness	Temp + non-forest	30.24	−50.75	0.67	0.41
Private allelic richness	Temp	76.24	−145.49	0.51	0.21
	Temp + non-forest	76.73	−143.72	0.21	0.23
Expected heterozygosity	Snow depth	86.21	−165.43	0.47	0.26
	Snow depth + non-forest	86.93	−164.12	0.25	0.30
Mean D_{est}	Temp	99.84	−192.64	0.29	0.47
	Temp + non-forest	101.2	−192.59	0.28	0.52
	Temp + non-forest + snow	102.45	−192.04	0.21	0.56
	Temp + snow depth	100.87	−191.93	0.20	0.51

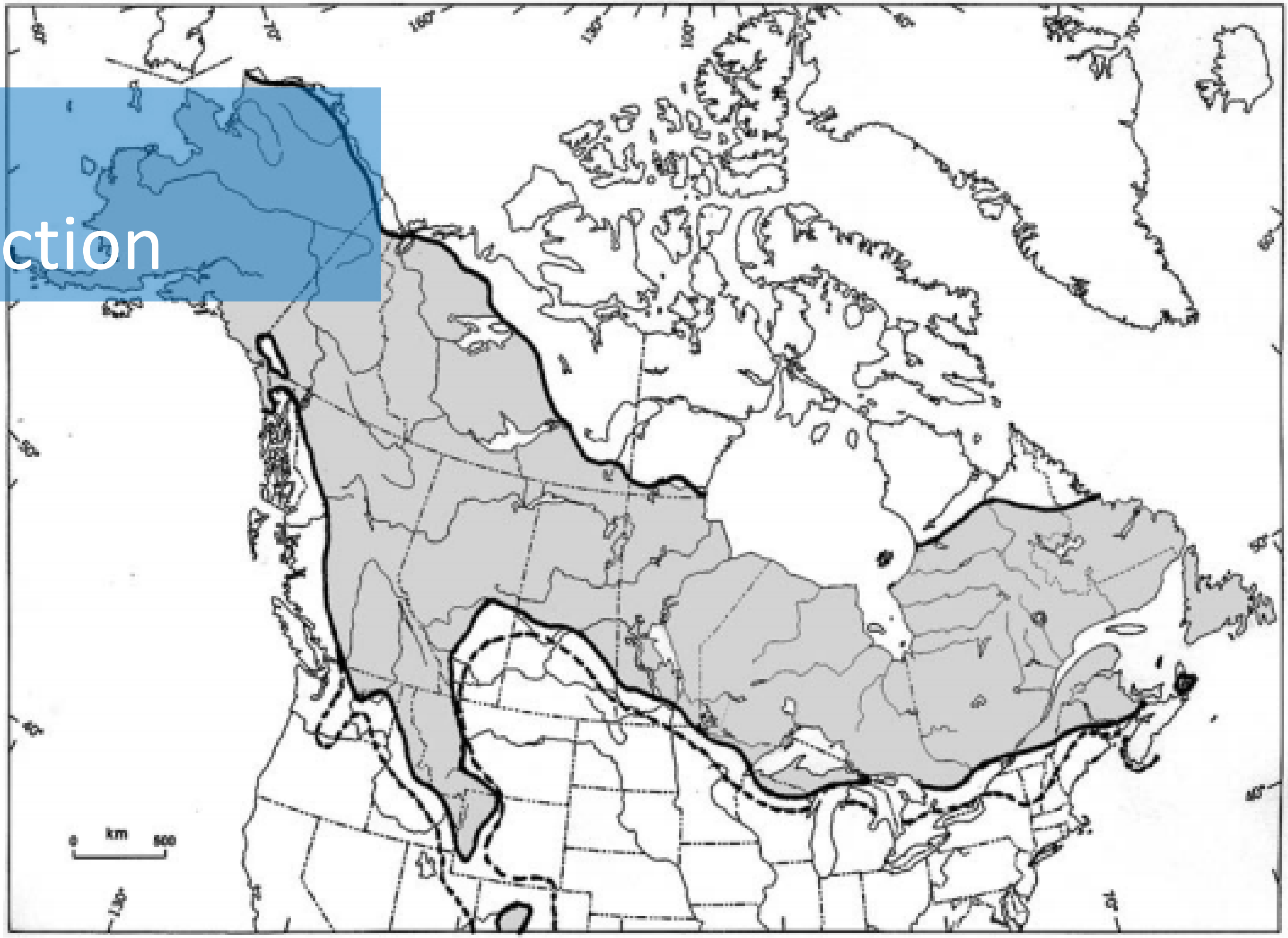
[1]Variable names are as in footnote of Table 1.

Koen et al. 2014. Ecography 37: 754-762.

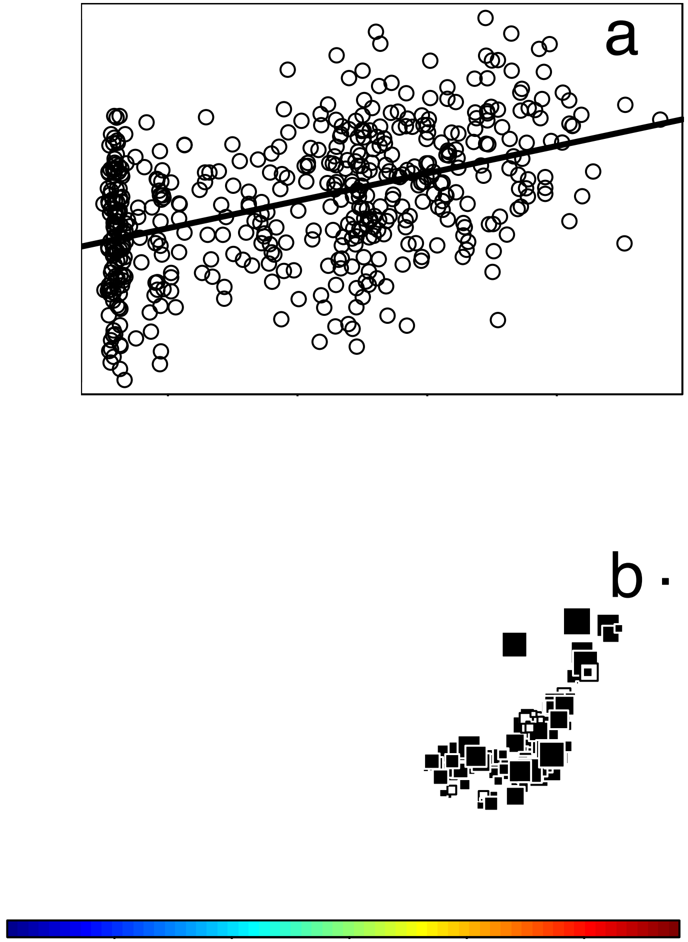


Walpole et al. 2012. Landscape Ecology 27: 761-773

Range contraction



Poole. 2003. Canadian Field-Naturalist 117: 360-376.



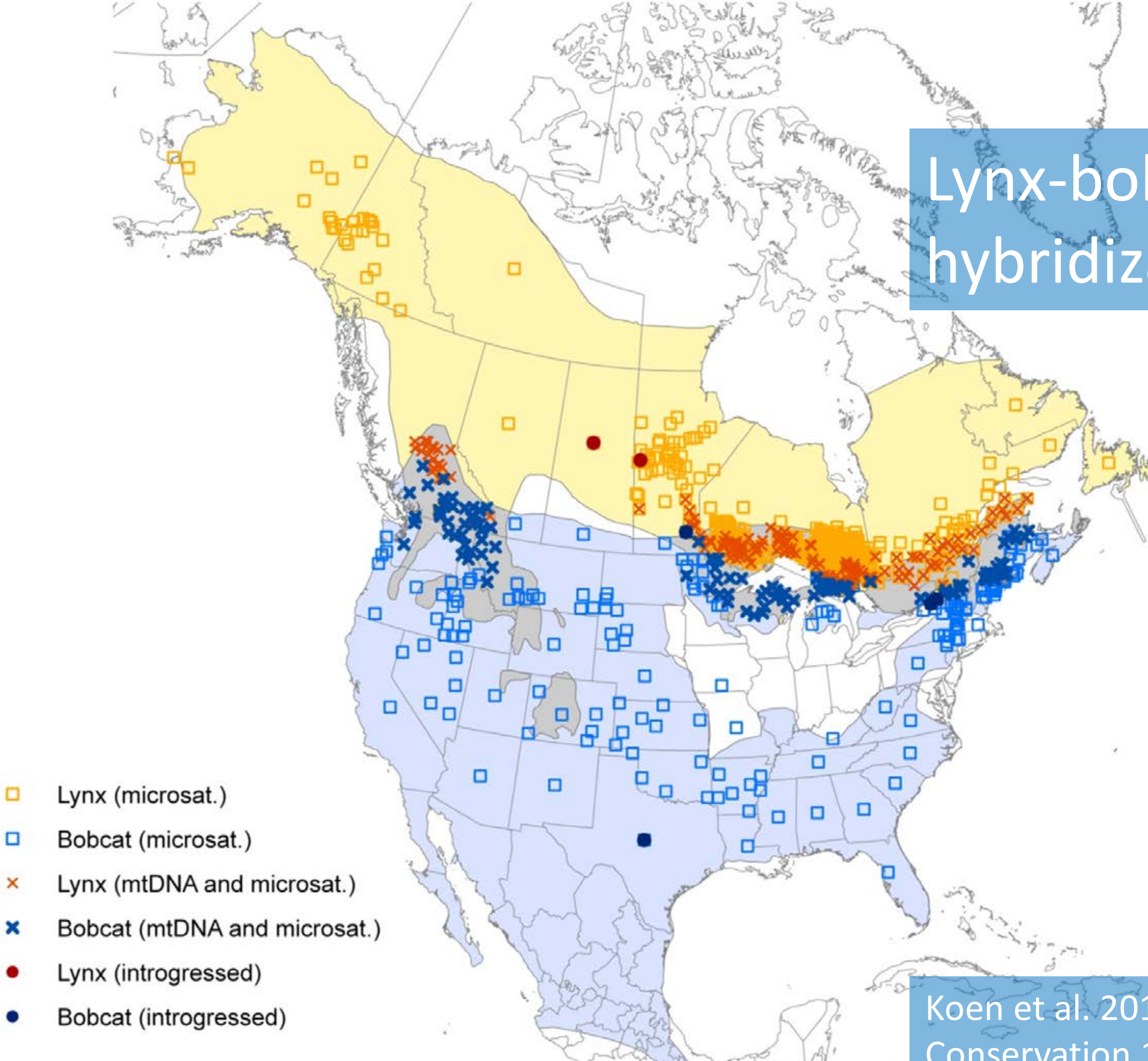
Effect of winter climate

Row et al. 2014. Global Change Biology 20: 2076-2086

Lynx-bobcat hybridization

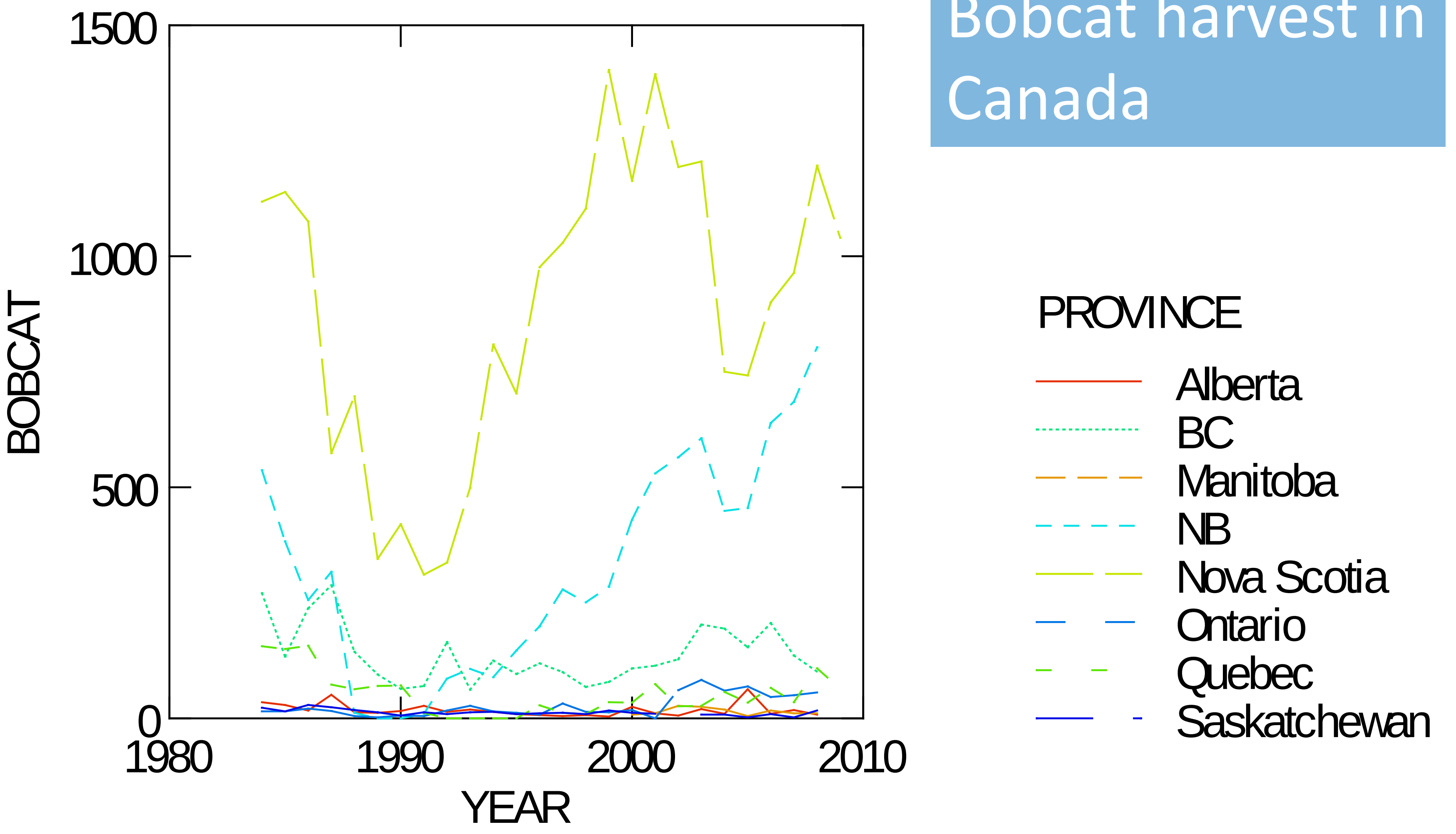

Lynx-bobcat
hybridization

Lynx-bobcat hybridization



Koen et al. 2014. Biological Conservation 178: 107-115.

Bobcat harvest in Canada



Questions?

Collaborators: Paul Wilson, Dennis Murray, Erin Koen, Melanie Prentice, Jeff Row, Cristen Watt, Aaron Walpole

More information:
people.trentu.ca/jebowman

References

Prentice, M., J. Bowman, and P. J. Wilson. A test of somatic mosaicism in the androgen receptor of Canada lynx (*Lynx canadensis*). BMC Genetics. In press.

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Hornseth, M.L., A.A. Walpole, L.R. Walton, J. Bowman, J.C. Ray, M.-J. Fortin, and D.L. Murray. 2014. Habitat loss, not fragmentation, drives occurrence patterns of Canada lynx at the southern range periphery. PLOS ONE 9(11): e113511.

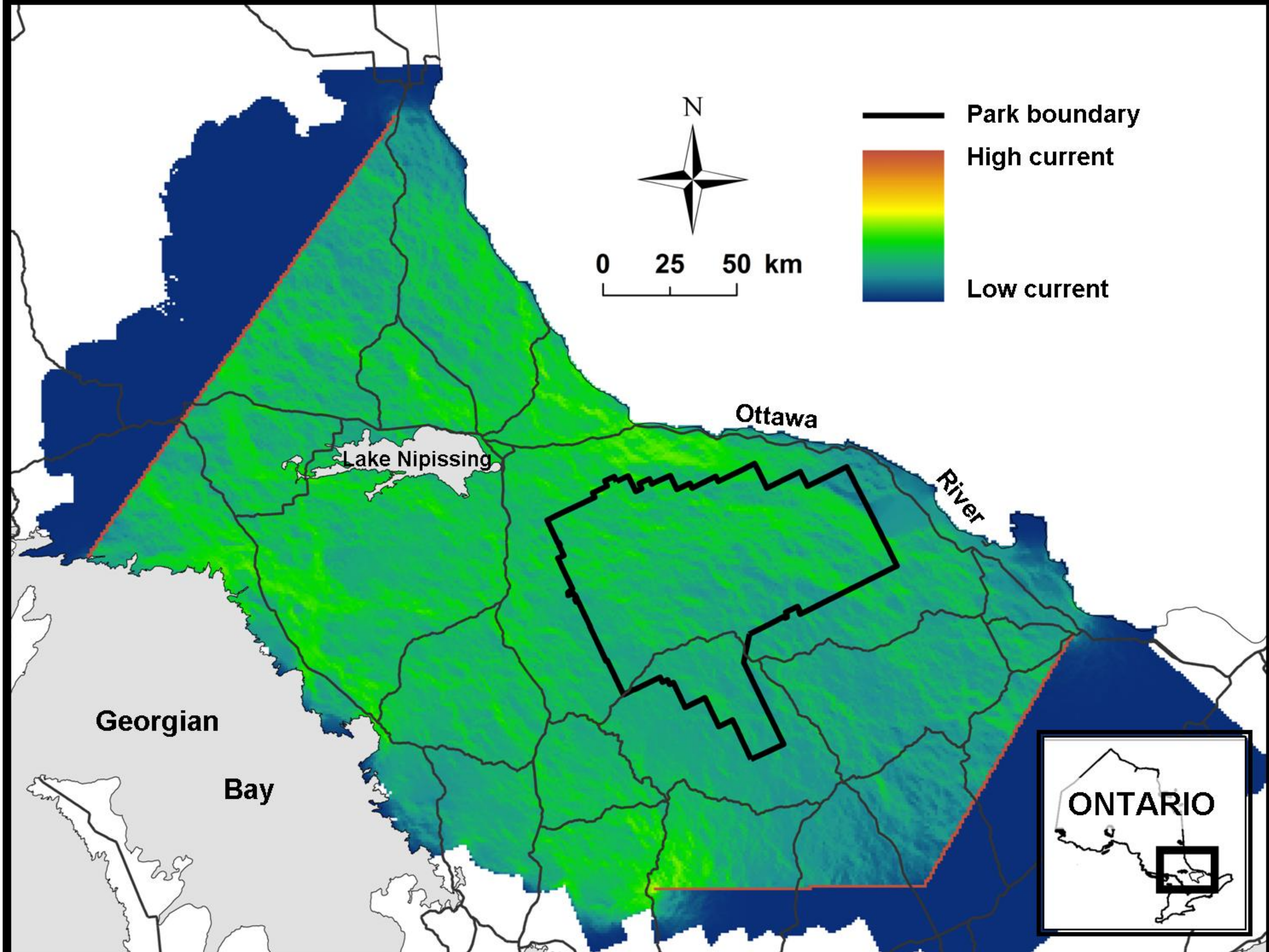
Koen, E.L., J. Bowman, J. L. Lalor, and P. J. Wilson. 2014. Continental-scale assessment of the hybrid zone between bobcat and Canada lynx. Biological Conservation. 178: 107-115.

Koen, E.L., J. Bowman, D. L. Murray, and P. J. Wilson. 2014. Climate change reduces genetic diversity of Canada lynx at the trailing range edge. Ecography 37: 754-762.
.

Row, J.R., P. J. Wilson, C. Gomez, E. L. Koen, J. Bowman, D. H. Thornton, and D. L. Murray. 2014. The subtle role of climate change on population genetic structure in Canada lynx. Global Change Biology 20: 2076-2086.

Row, J.R., C. Gomez, E.L. Koen, J. Bowman, D.L. Murray, and P.J. Wilson. 2012. Dispersal promotes high gene flow among Canada lynx populations across mainland North America. Conservation Genetics 13: 1259-1268.

Walpole, A.A., J. Bowman, D. L. Murray, and P. J. Wilson. 2012. Functional connectivity of Canada lynx at their southern range boundary. Landscape Ecology 27: 761-773.



N
0 25 50 km
Park boundary
High current
Low current
Ottawa
River
Lake Nipissing
Georgian
Bay
ONTARIO

Seven ways a warming climate can kill the boreal forest

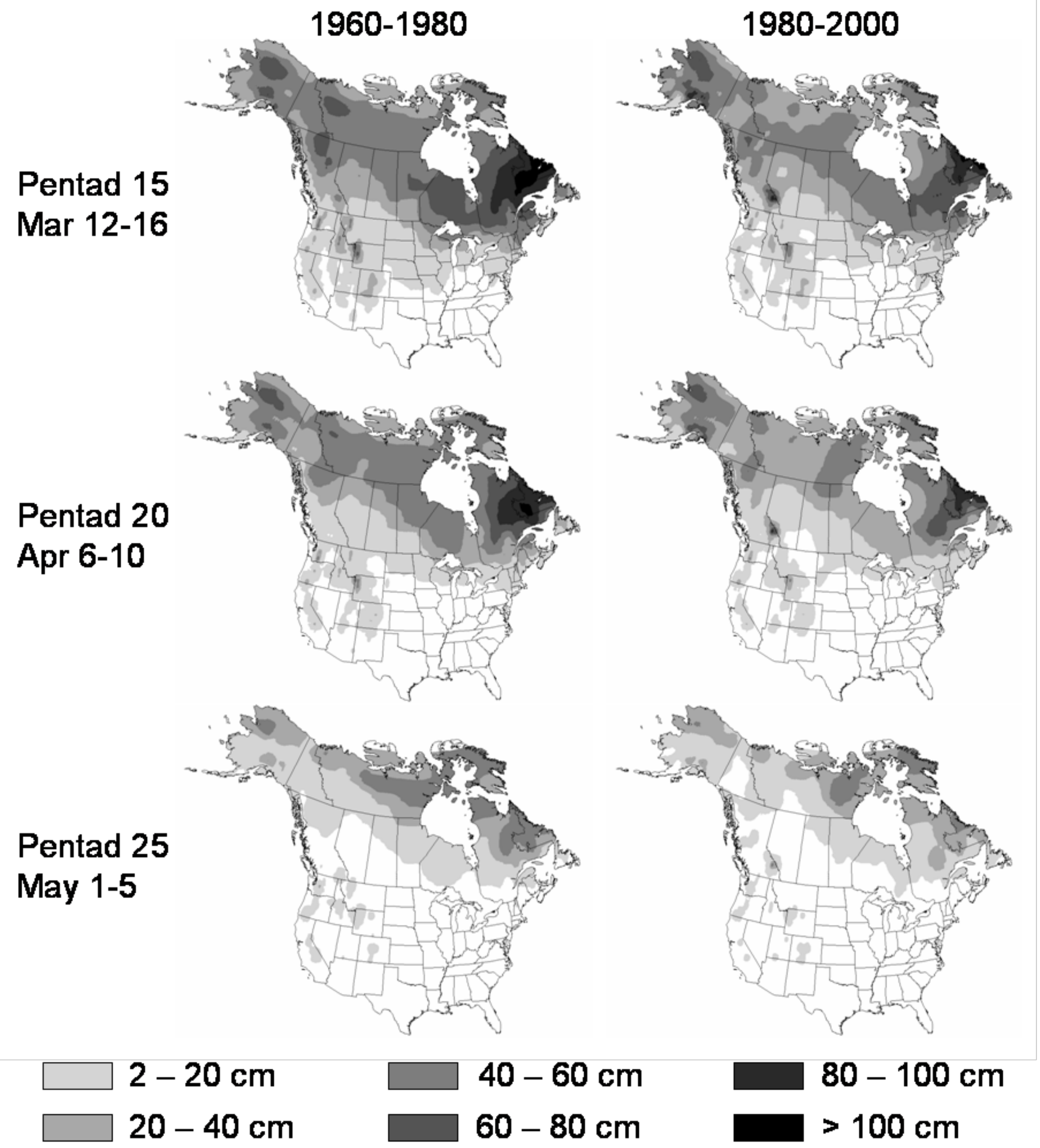
Lee E. Frelich
Director, The University of Minnesota Center for Forest Ecology

Contact: freli001@umn.edu

With unmitigated climate change, Minnesota is likely to lose the boreal biome and ca 1/3 of our native species

Biome map of Minnesota by MNDOT

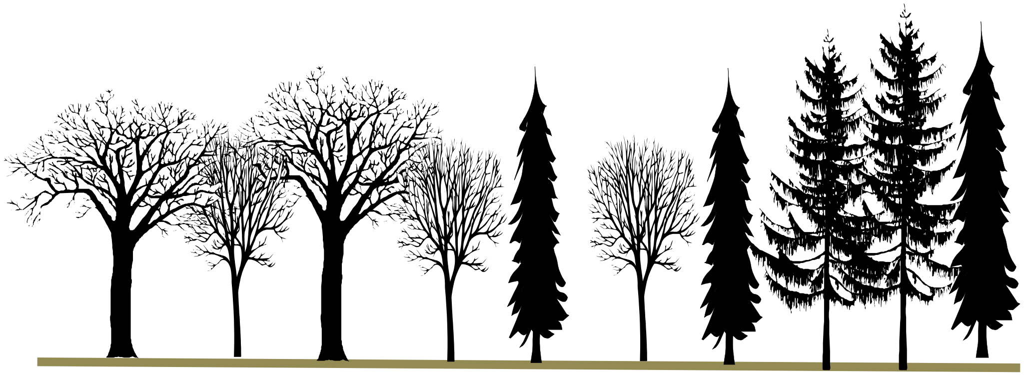
- Northern conifer (boreal) in NE MN
- Temperate forest (oak and maple), stripes from NW to SE
- Grasslands and savanna, solid beige in W and SW



Snow cover and depth in North America: 1960-1980 compared with 1980-2000.

From, J.L, Dyer and T.L. Mote. 2006. Spatial variability and trends in observed snow depth over North America. Geophysical Research Letters 33: L16503.

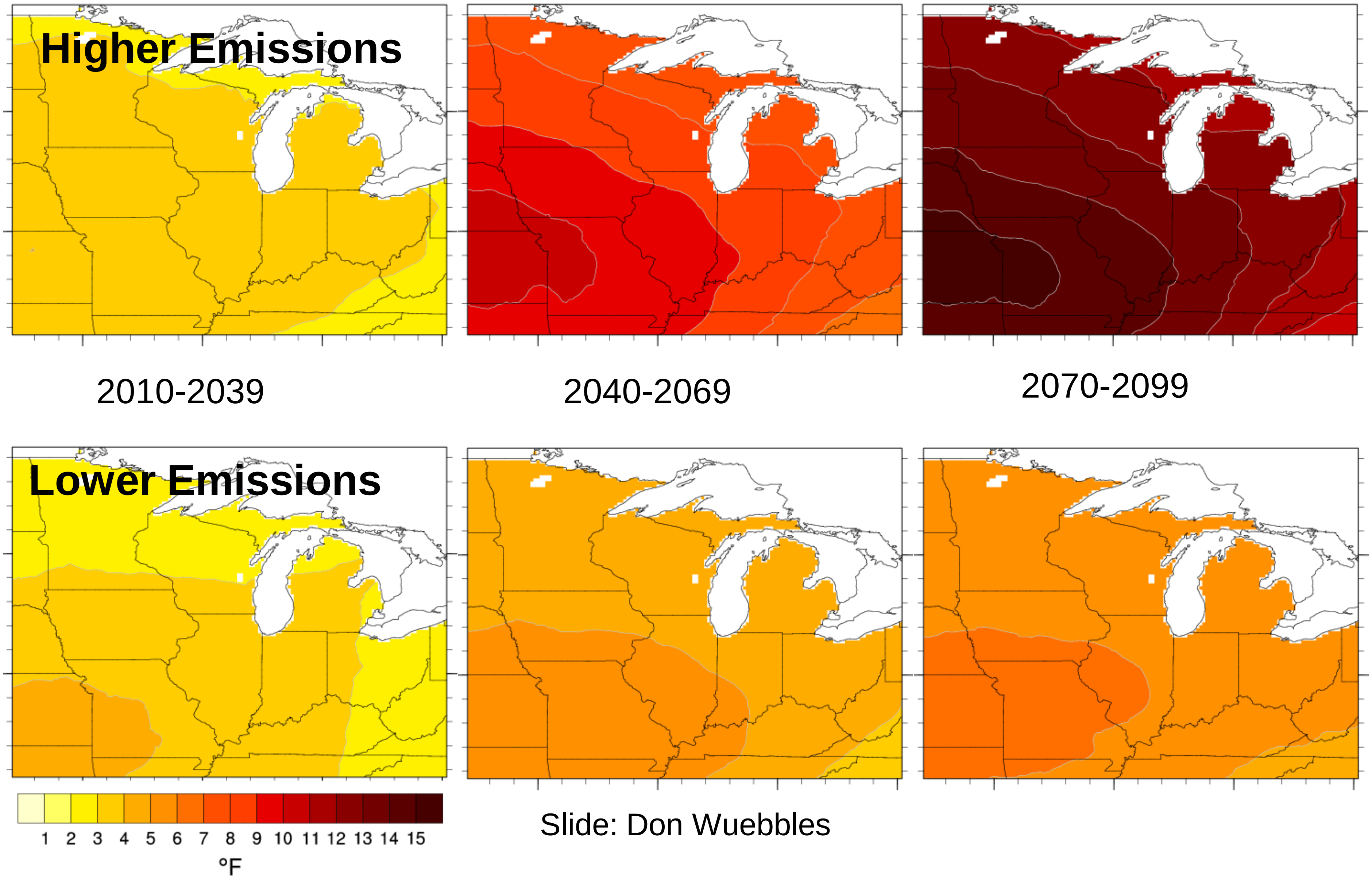
Local transitions in warm and cool summer climates



Temperate tree species are invading boreal forests, but have not had time to replace boreal species and it is not yet warm enough to kill boreal forest—therefore mixed forest or ecotone is becoming wider

Fisichelli, Frelich and Reich. 2014.
Ecography 37: 152-161. Photo, Duluth News Tribune

Change in summer (JJA) temperature



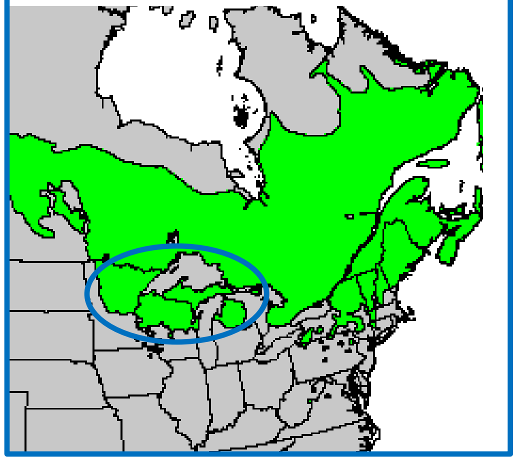
Slide: Don Wuebbles

Range Distributions of Temperate and Boreal Species

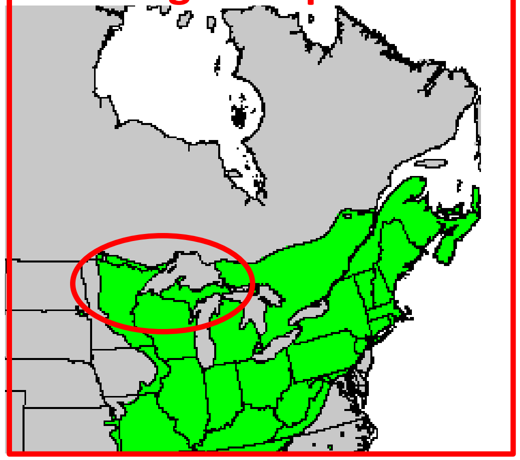
Boreal Trees

Temperate Trees

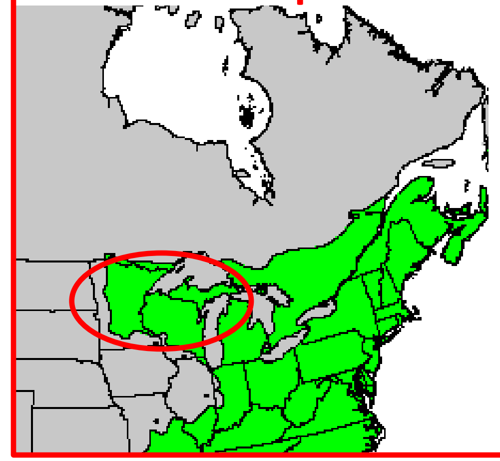
Balsam fir



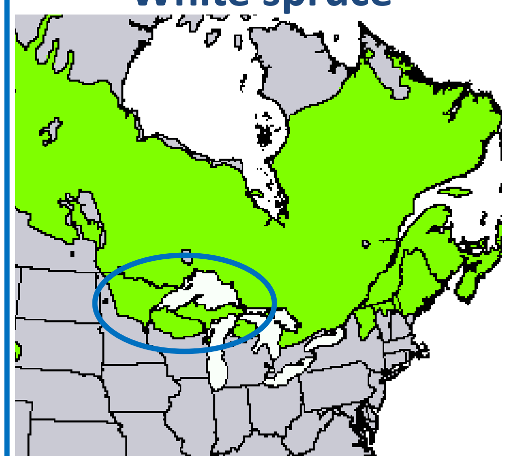
Sugar maple



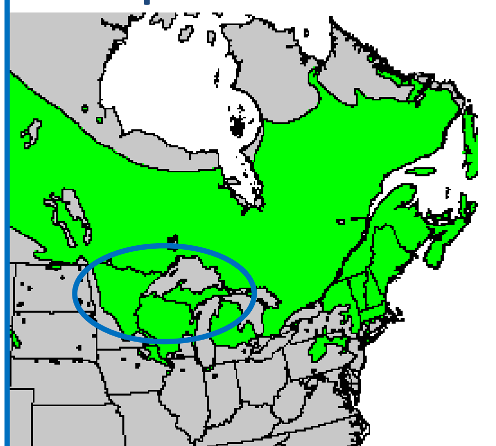
Red maple



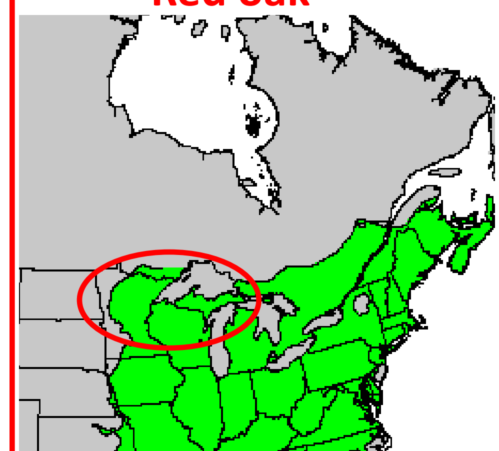
White spruce

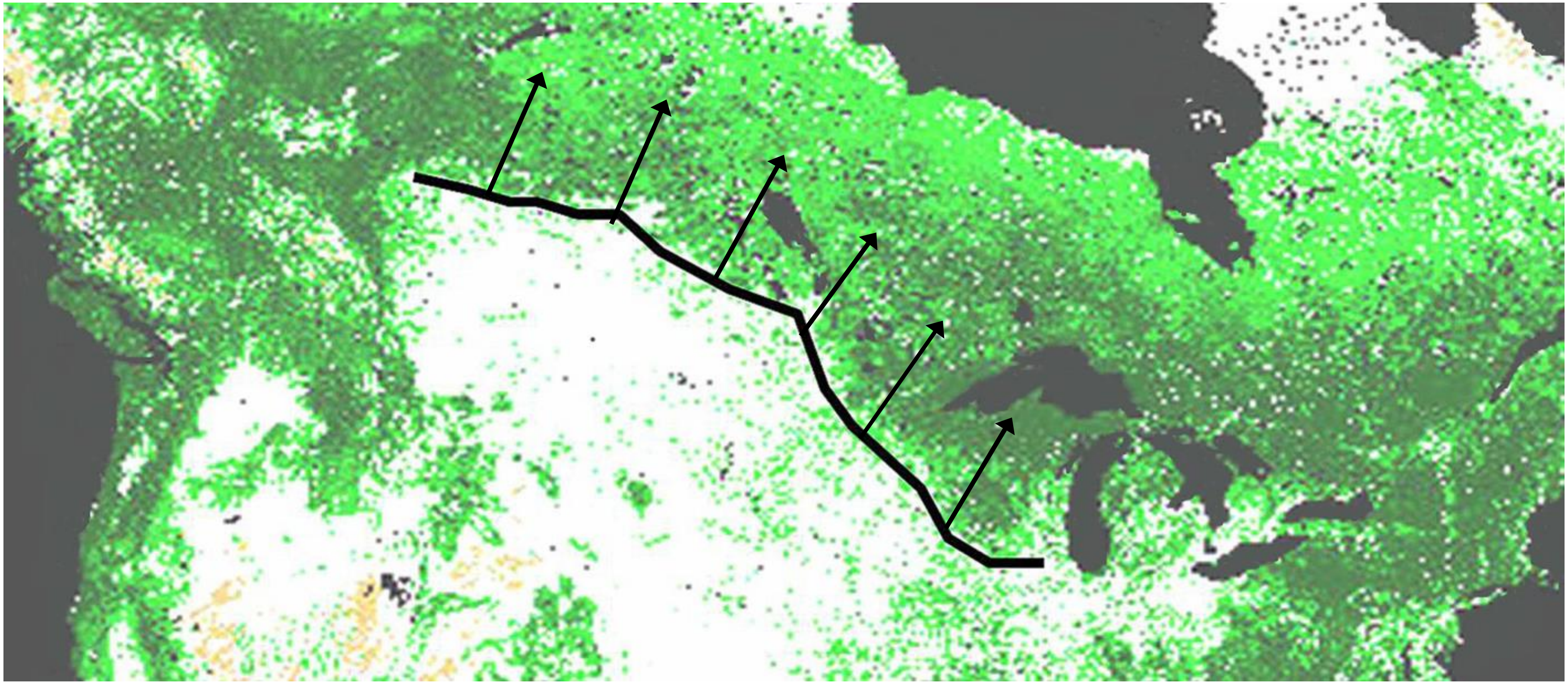


Paper birch



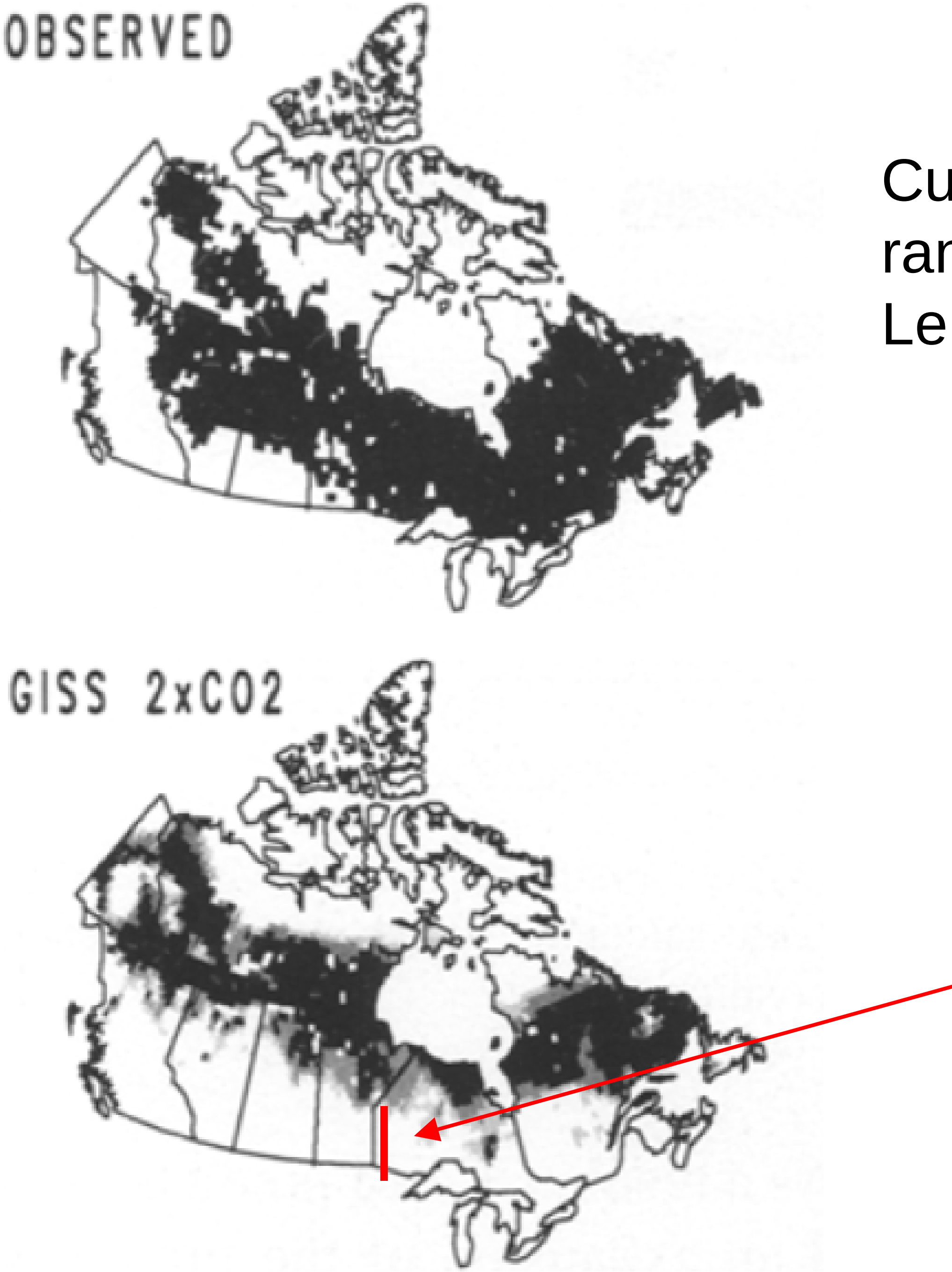
Red oak





Forest cover of central North America (green). Prairie-forest border (black line), and arrows showing the border moving 300 miles to the northeast by 2100 for a business as usual climate change scenario.
Modified from Frelich and Reich 2010, *Frontiers in Ecology and the Environment*

The BWCAW will be at the prairie-forest border!

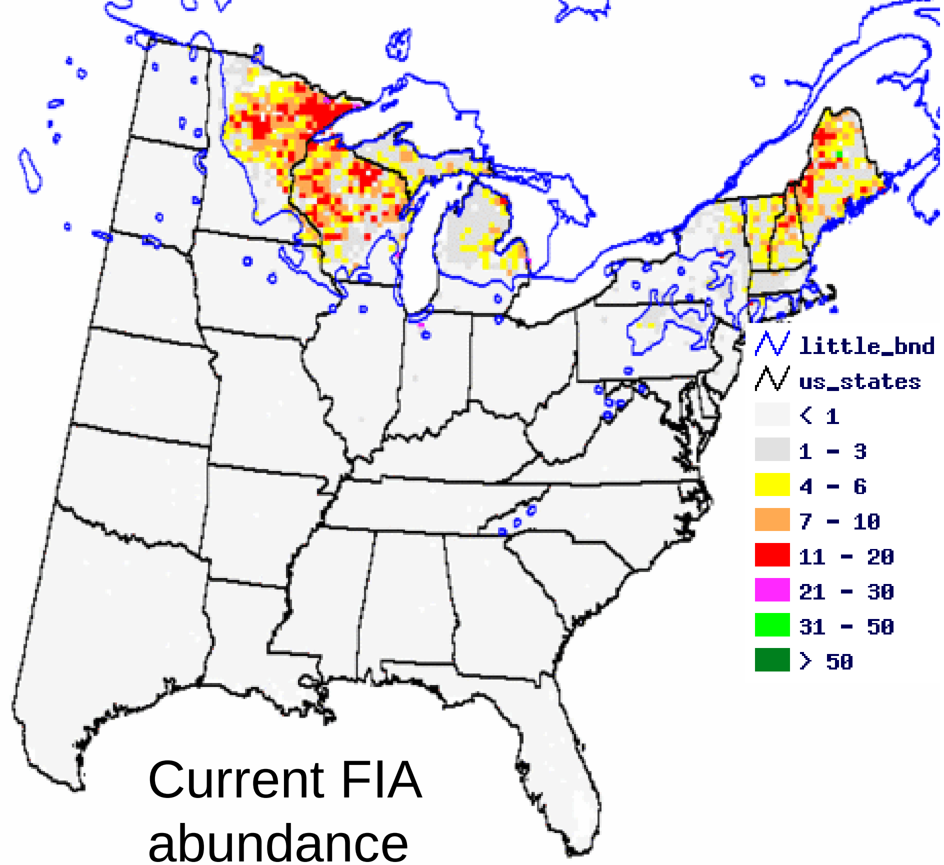


Current and simulated future range of black spruce, from Lenihan and Neilson 1995.

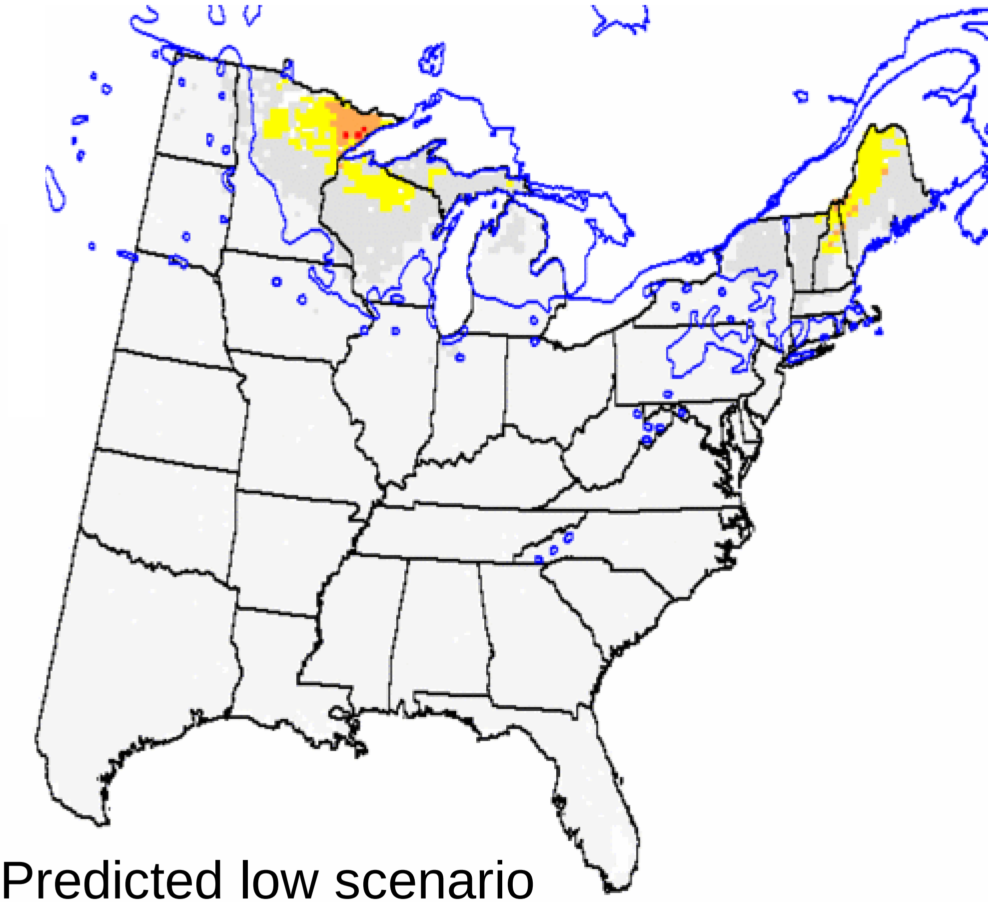
300 mile shift is equal to distance moved in ~ 2000 years in paleorecord

Paper birch abundance: Current FIA compared to predictions for low emissions scenario

Source: USDA Climate and Tree Atlas



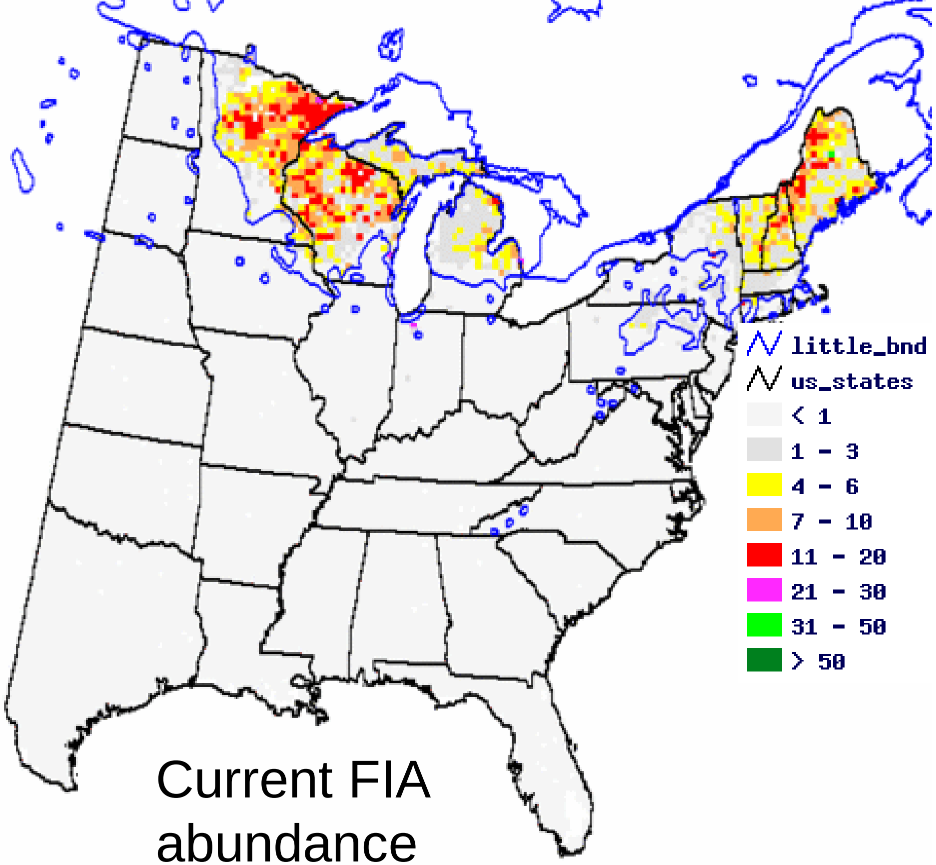
Current FIA abundance



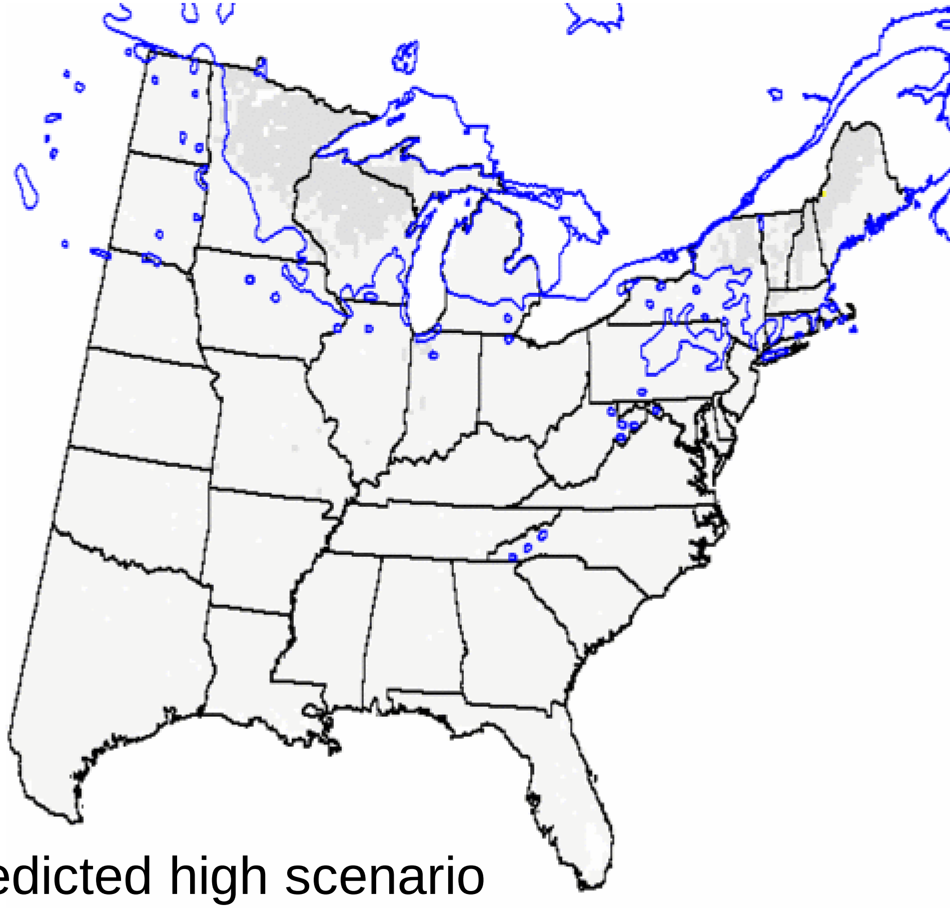
Predicted low scenario

Paper birch abundance: Current FIA compared to predictions for high emissions scenario

Source: USDA Climate and Tree Atlas



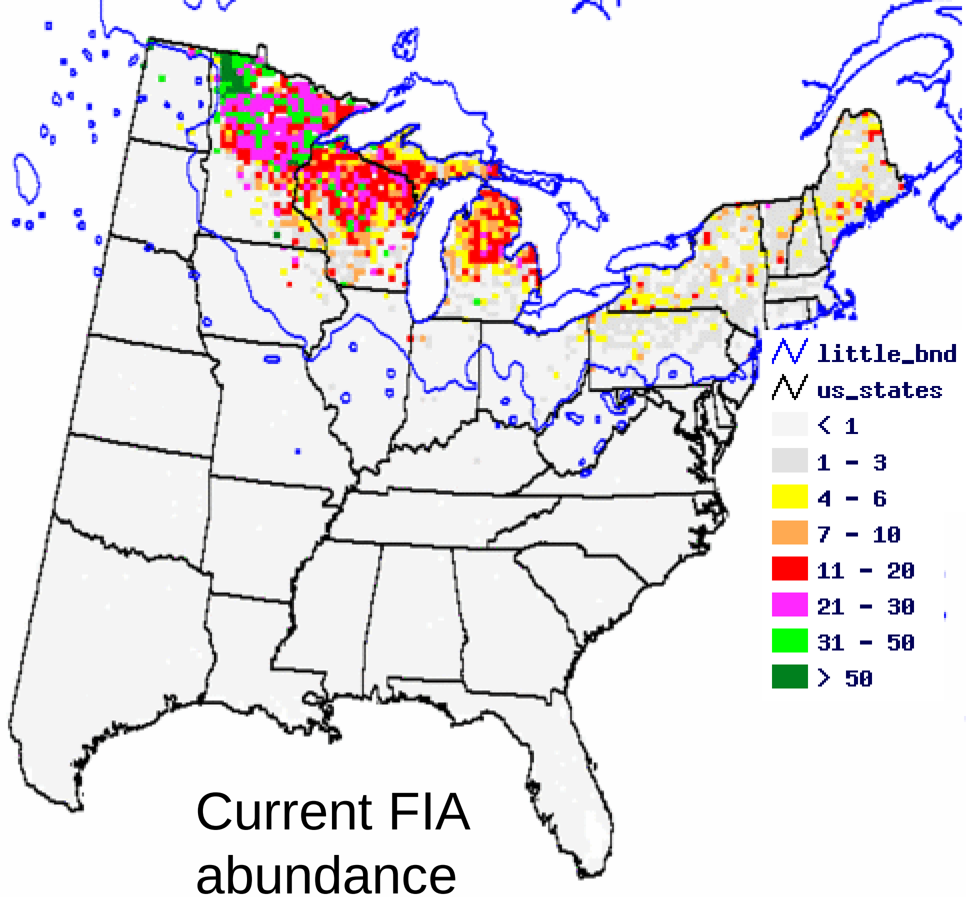
Current FIA abundance



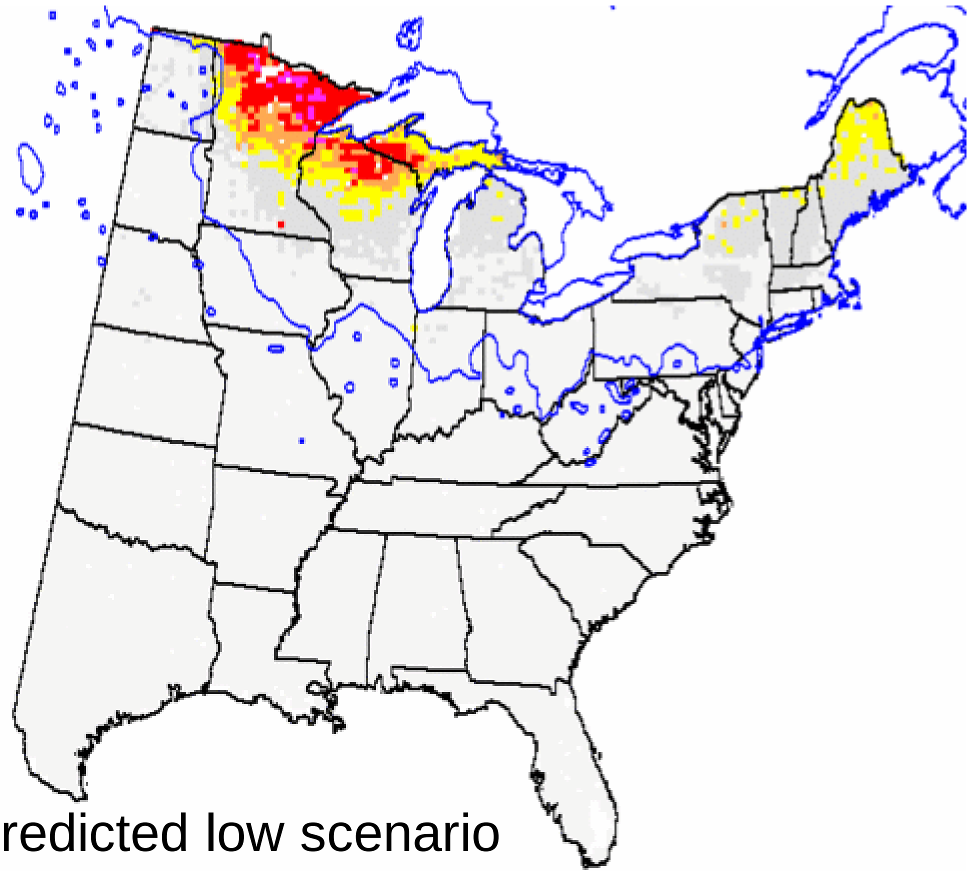
Predicted high scenario

Quaking aspen abundance: Current FIA compared to predictions for low emissions scenario

Source: USDA Climate and Tree Atlas



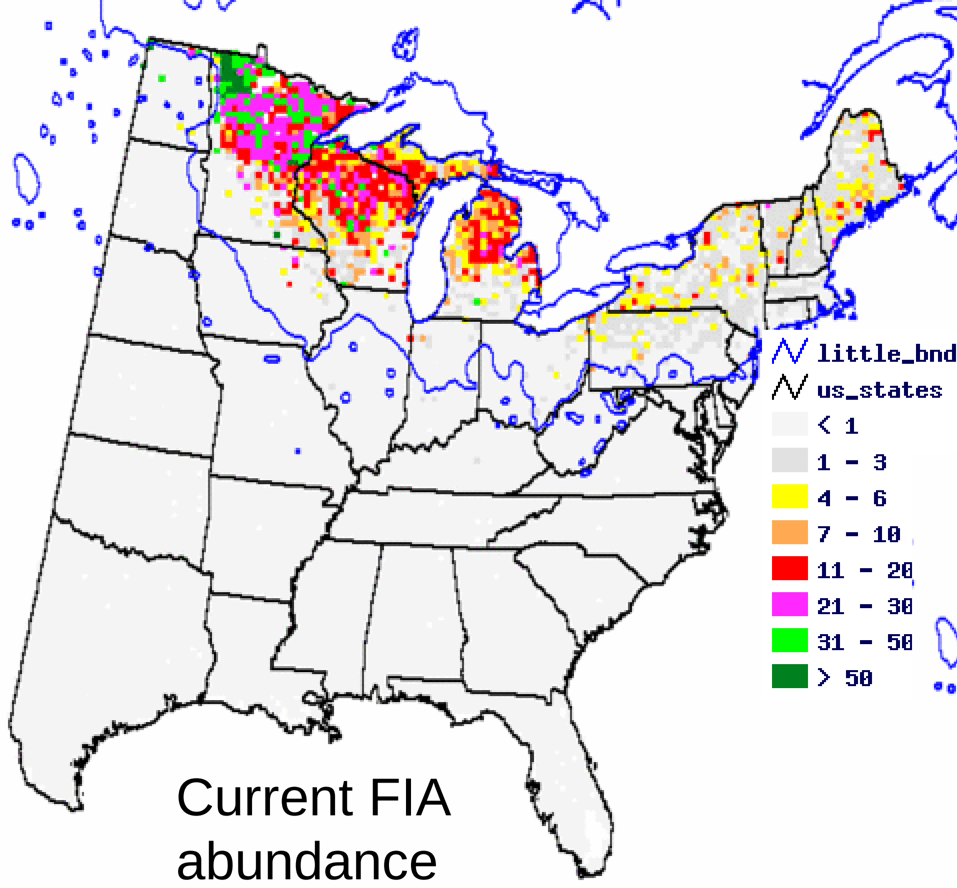
Current FIA abundance

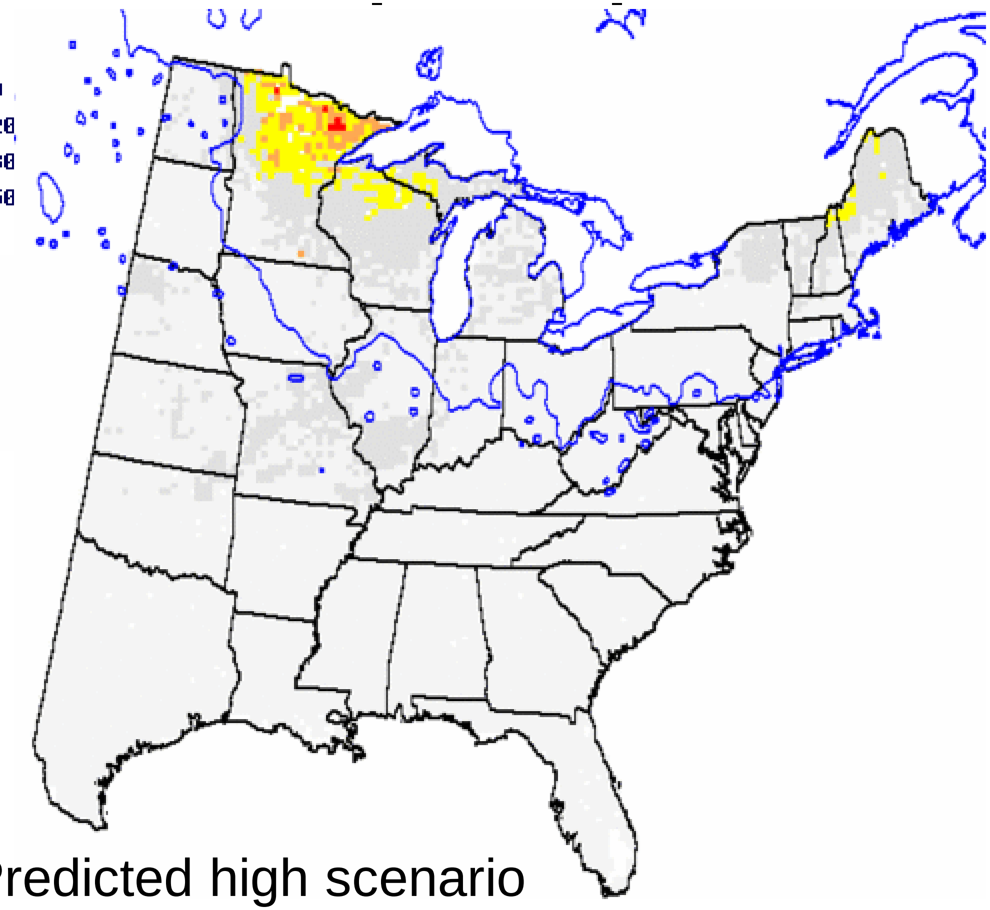


Predicted low scenario

Quaking aspen abundance: Current FIA compared to predictions for high emissions scenario

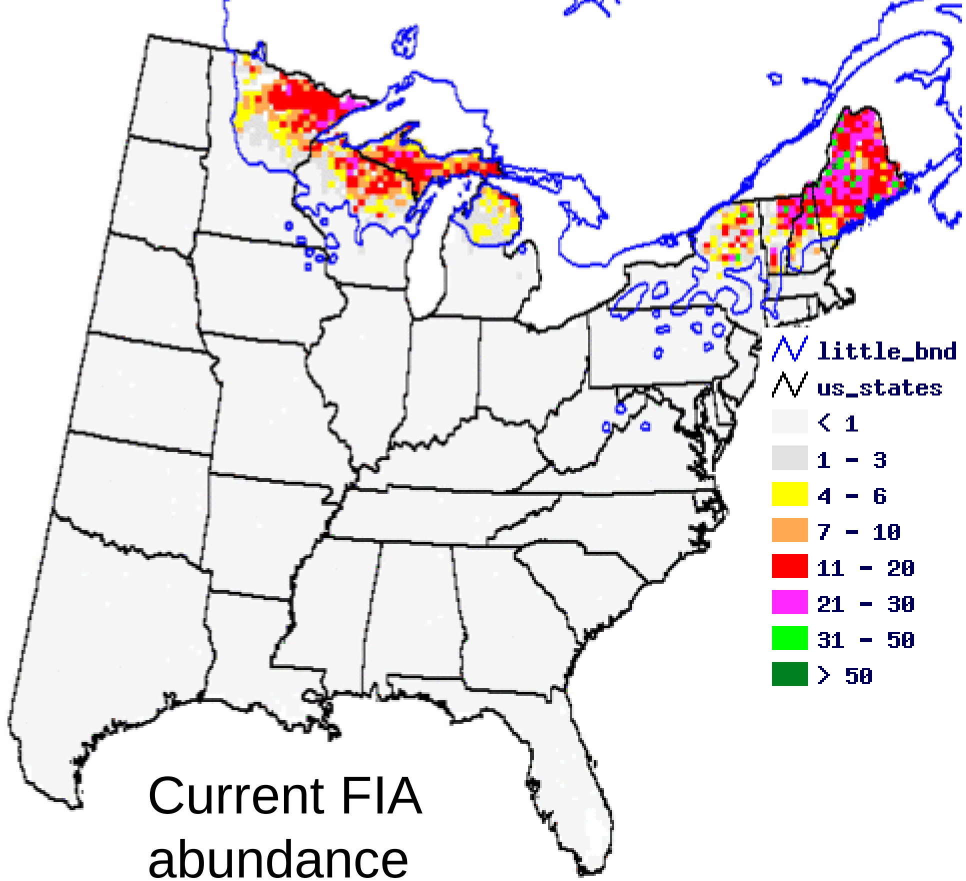
Source: USDA Climate and Tree Atlas



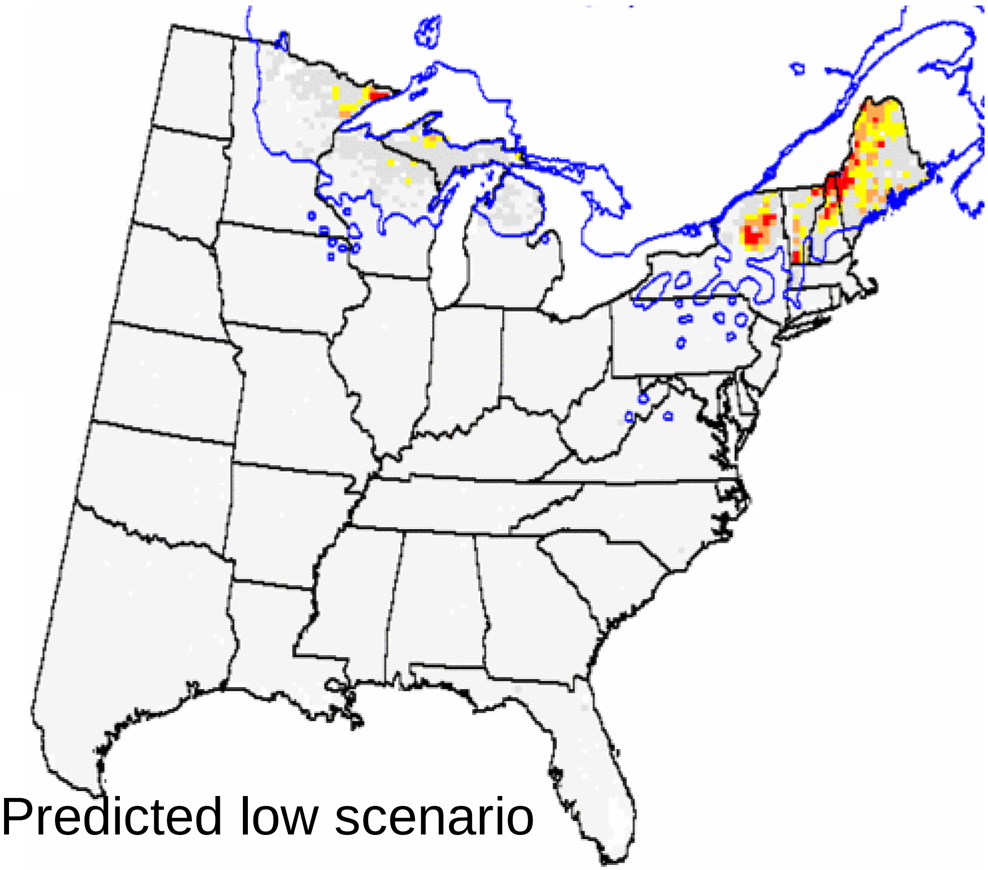


Balsam fir abundance: Current FIA compared to predictions for low emissions scenario

Source: USDA Climate and Tree Atlas



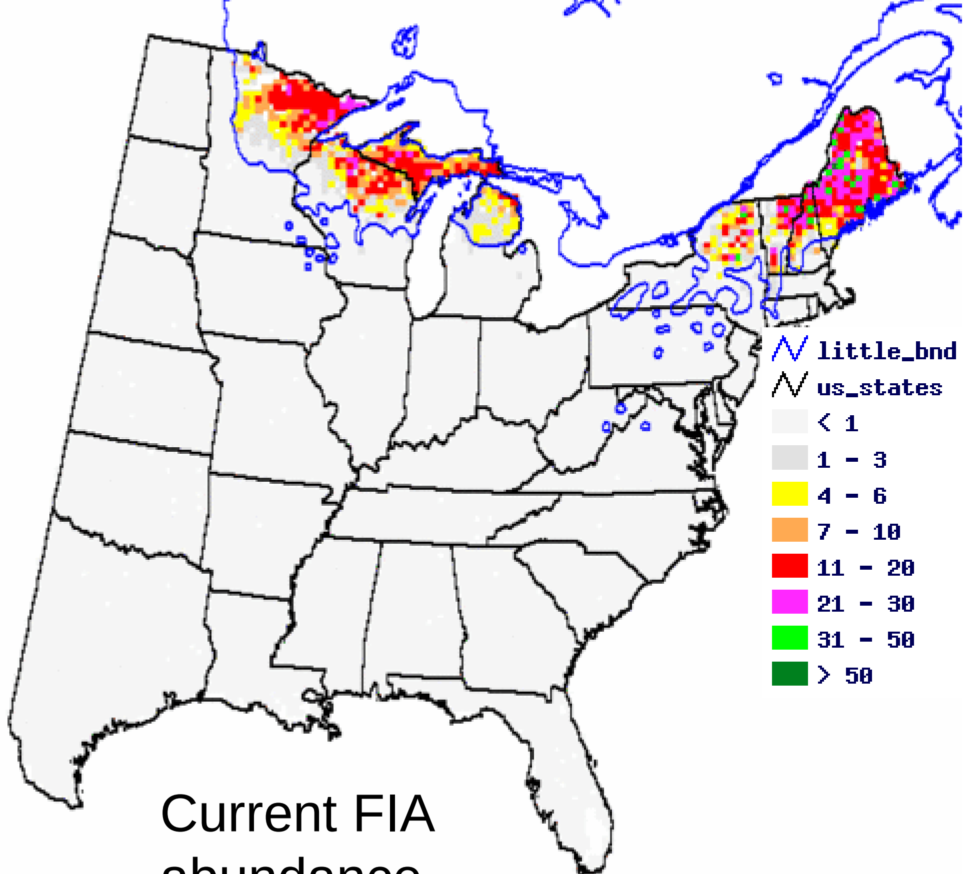
Current FIA abundance



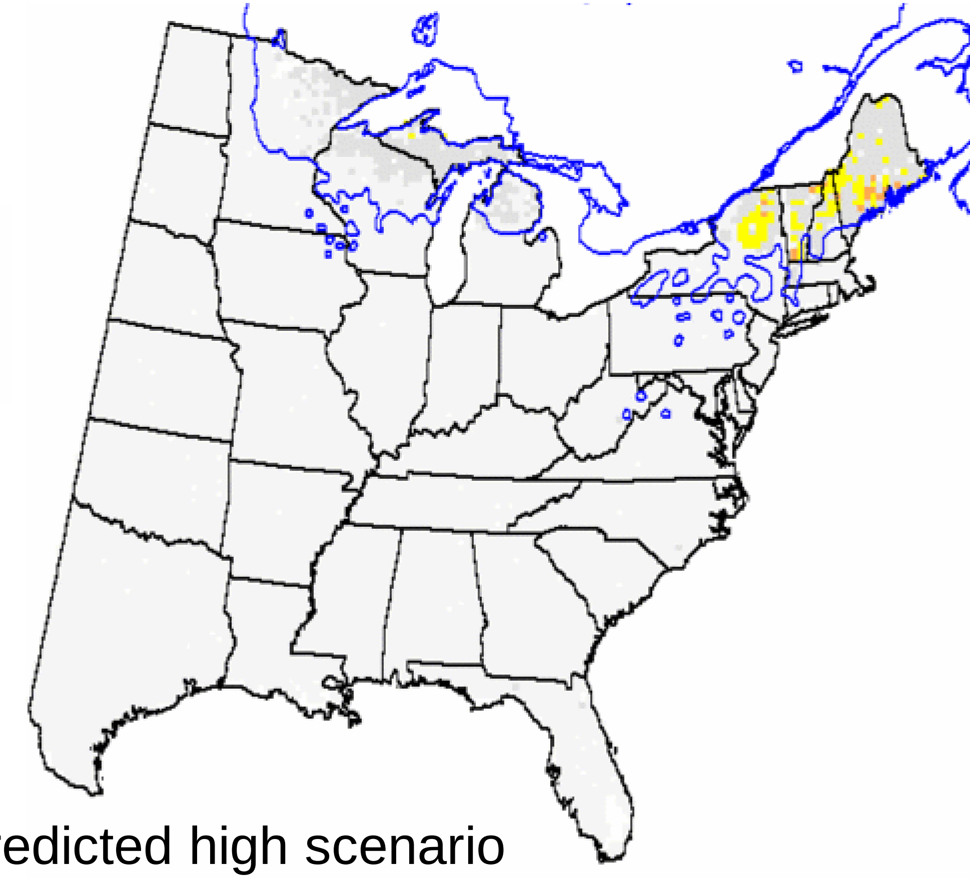
Predicted low scenario

Balsam fir abundance: Current FIA compared to predictions for high emissions scenario

Source: USDA Climate and Tree Atlas



Current FIA abundance



Predicted high scenario

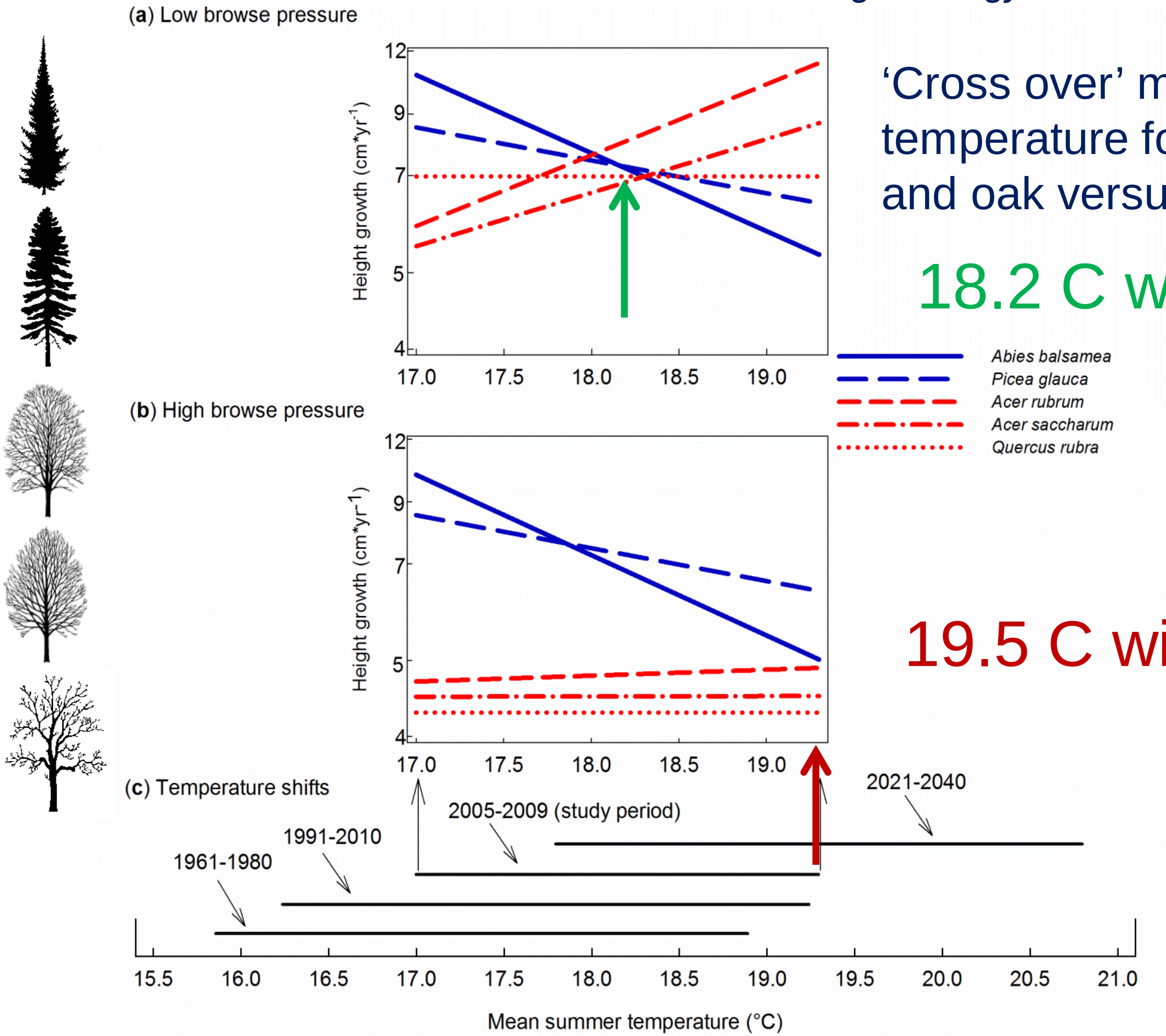
Boreal to temperate forest conversion mechanisms:

- Gap dynamics/gradual infiltration of temperate species
- Trophic cascade; delay followed by sudden change
- Wind/hail storms
- Wind + Fire
- Heat/drought stress
- Insect infestation (native and exotic) due to lack of extreme cold
- Phenological disturbance

Photo, Eli Anoszko

Temperate sapling relative performance ‘cooled’ by deer.

Fisichelli, Frelich and Reich, 2012, *Global Change Biology* 18: 3455-3463.

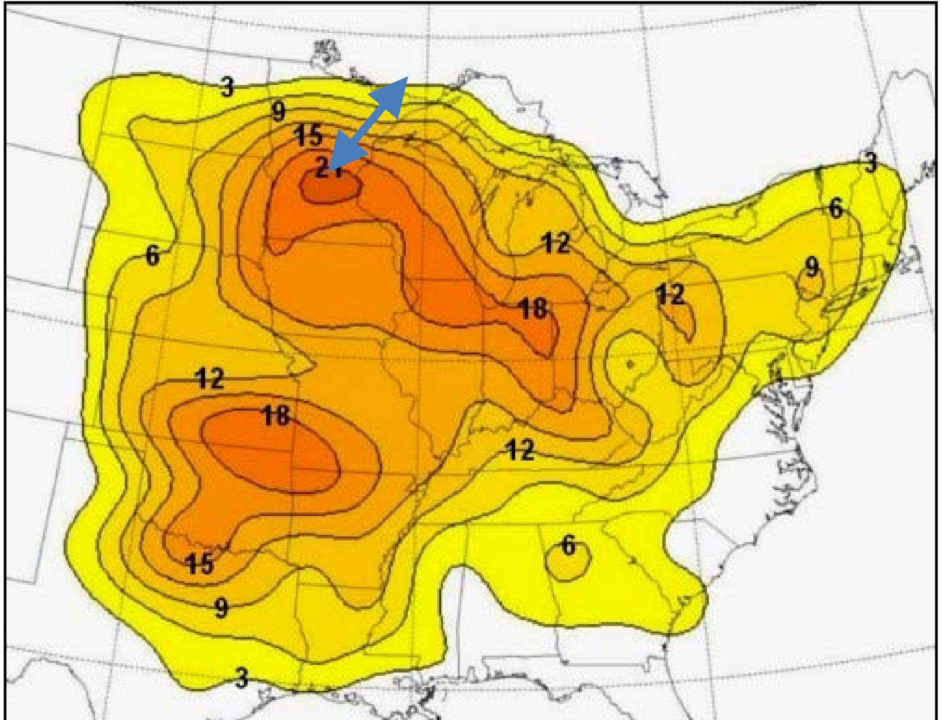


‘Cross over’ mean summer temperature for growth of maple and oak versus spruce and fir:

18.2 C with low deer

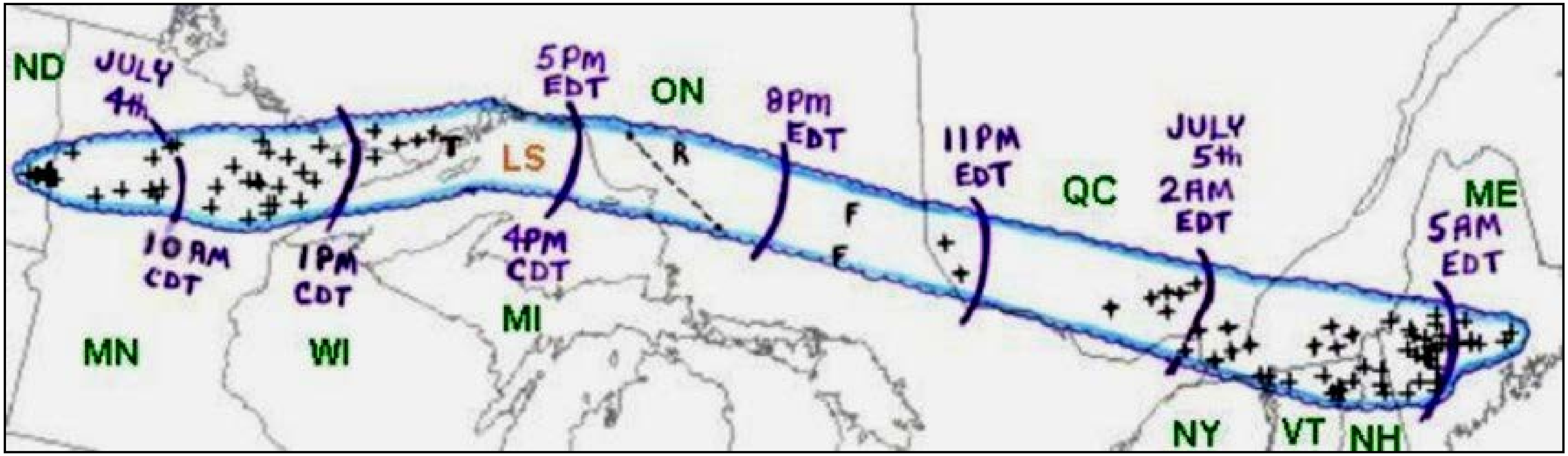
19.5 C with high deer

Derechos are severe thunderstorms that can level large swaths of boreal forest (10-1000s km^2)



From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos

Summer derecho frequency (#observed in 22 years)



From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos

The BWCAW derecho, July 4, 1999: a combination bow echo and supercell derecho that crossed half of North America

Minneapolis Star Tribune

Before and after the 1999 blowdown

90,000 red maple seedlings and saplings km^2 followed by a canopy levelling wind event equals:

Sudden transition from boreal to temperate forest by wind

Red pine bark stripped by hail during August 14, 2000 storm. Brule River State Forest, WIDNR.

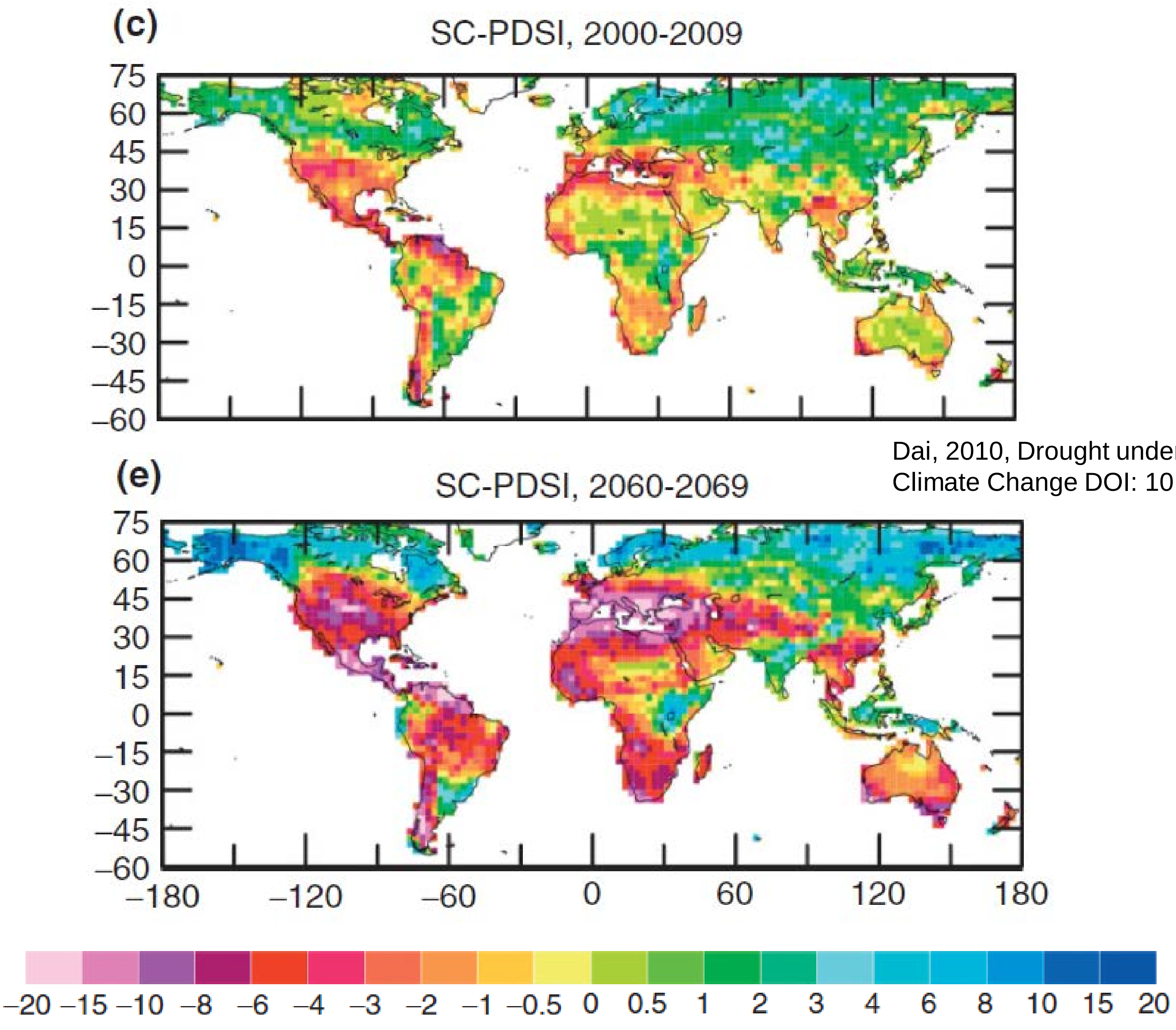
Hail damage to pine from August 14, 2000 storm. Brule River State Forest. WIDNR.

Wind plus fire = major forest transformation

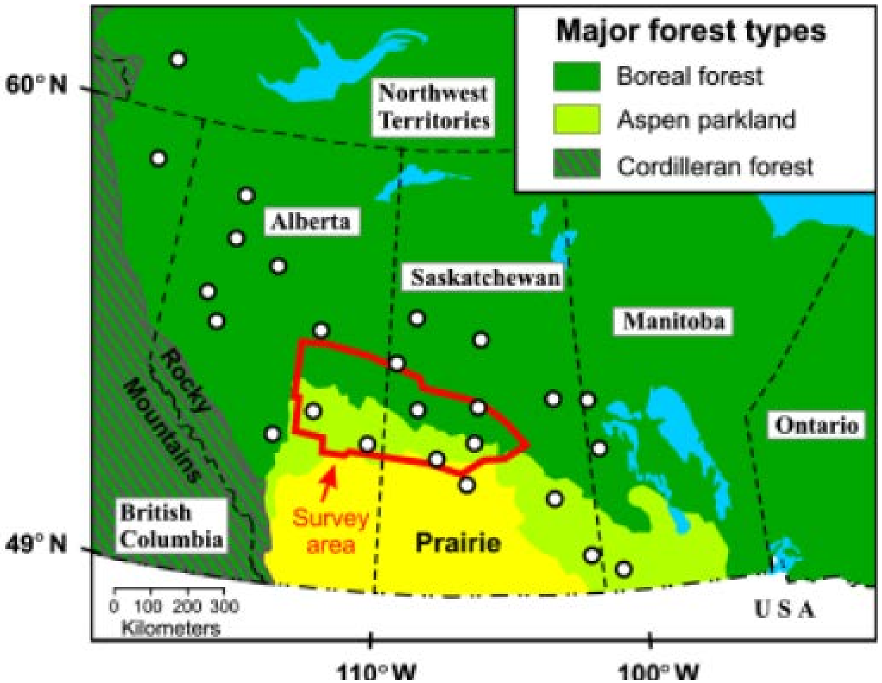
Nick Fisichelli and Roy Rich, Cavity Lake Burn, Seagull Lake, July 2007.
Photo: Dave Hansen, University of MN

Wind+fire should facilitate conversion to oaks in a warming climate

Comparing the 2060s with current



Dai, 2010, Drought under global warming, Climate Change DOI: 10.1002/wcc.81



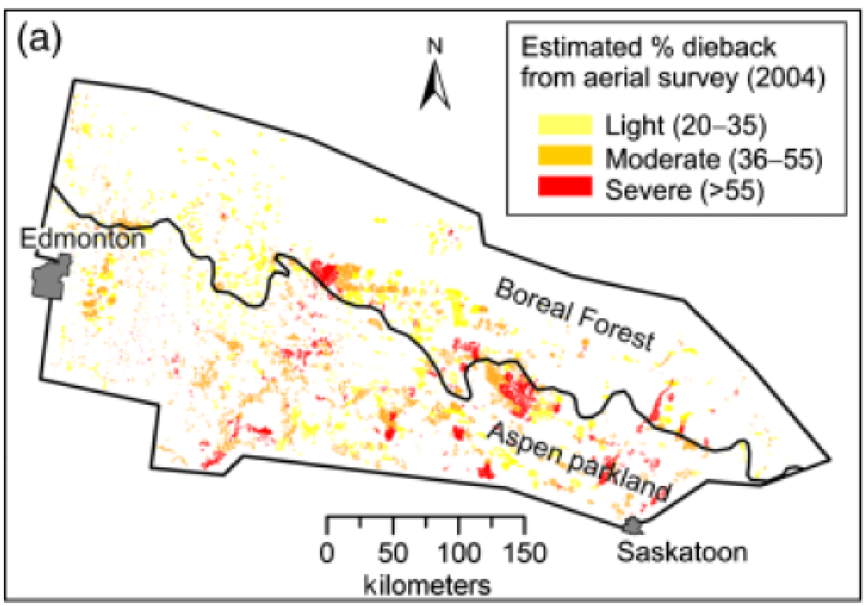
Global Change Biology

Global Change Biology (2011) 17, 2084–2094, doi: 10.1111/j.1365-2486.2010.02357.x

Massive mortality of aspen following severe drought along the southern edge of the Canadian boreal forest

MICHAEL MICHAELIAN, EDWARD H. HOGG, RONALD J. HALL and ERIC ARSENAULT

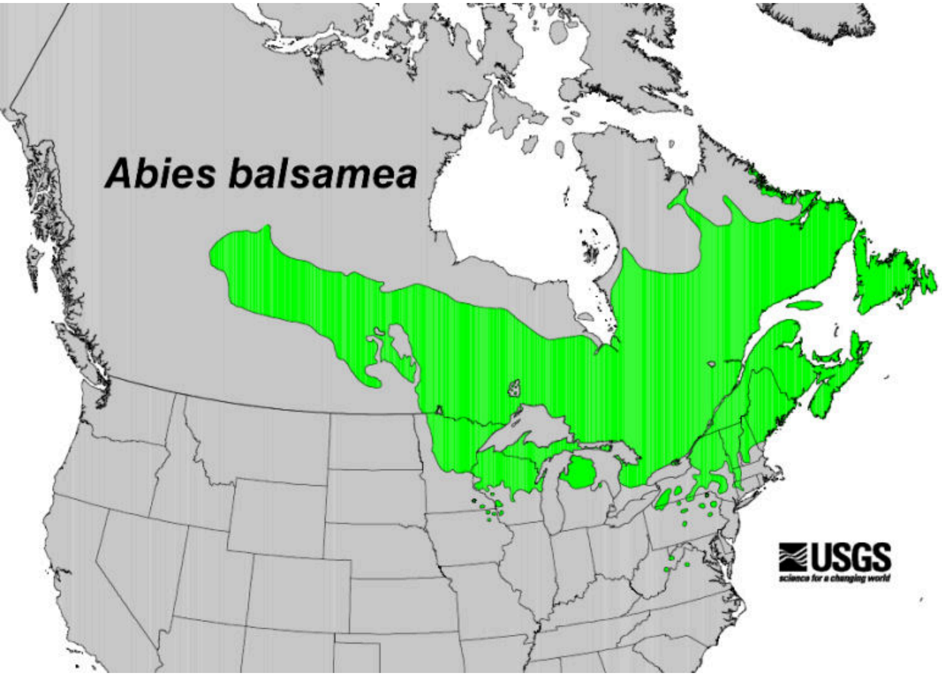
Natural Resources Canada, Canadian Forest Service, 5320-122 Street, Edmonton, AB, Canada T6H 3S5

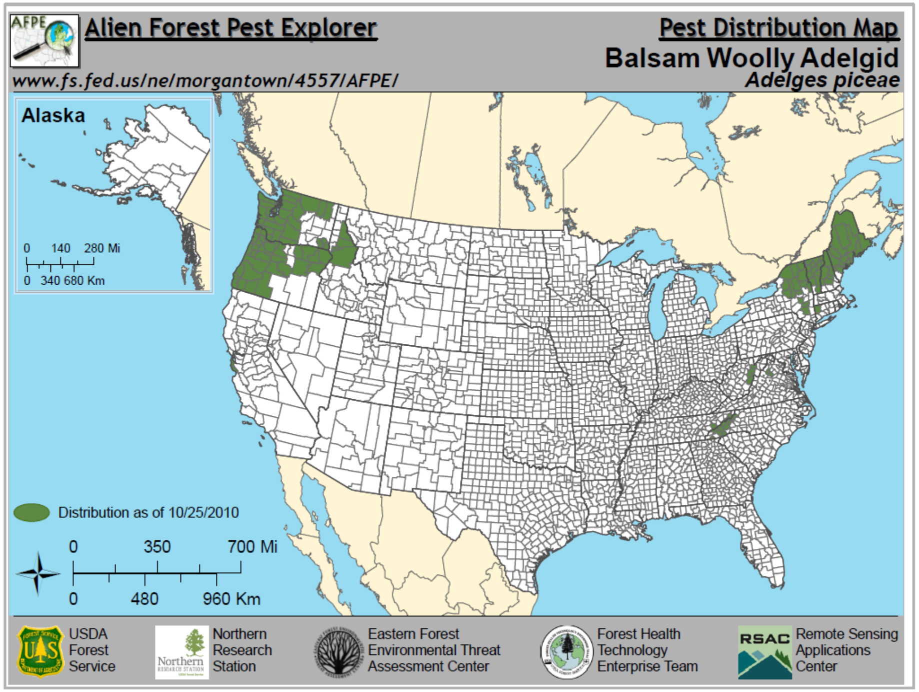


More drought = trees under stress and forest dieback
Should facilitate conversion to oaks and red maple

Native insects play a major role in forest change

Benign native insects can have outbreaks in a warmer climate. For example, mountain pine beetle in British Columbia—a native insect that caused massive tree mortality over 30 million acres of lodgepole pine forest, and could threaten jack pine in Minnesota





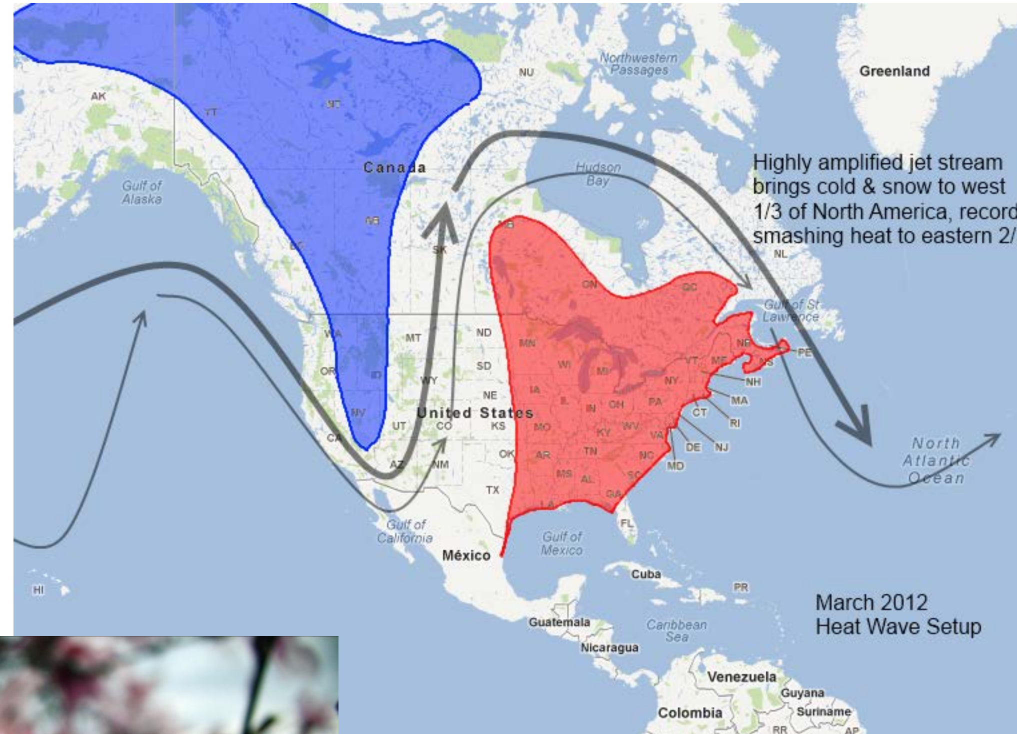
The Balsam woolly adelgid is in Maine and now has a route to get to MN—it just needs warmer winters

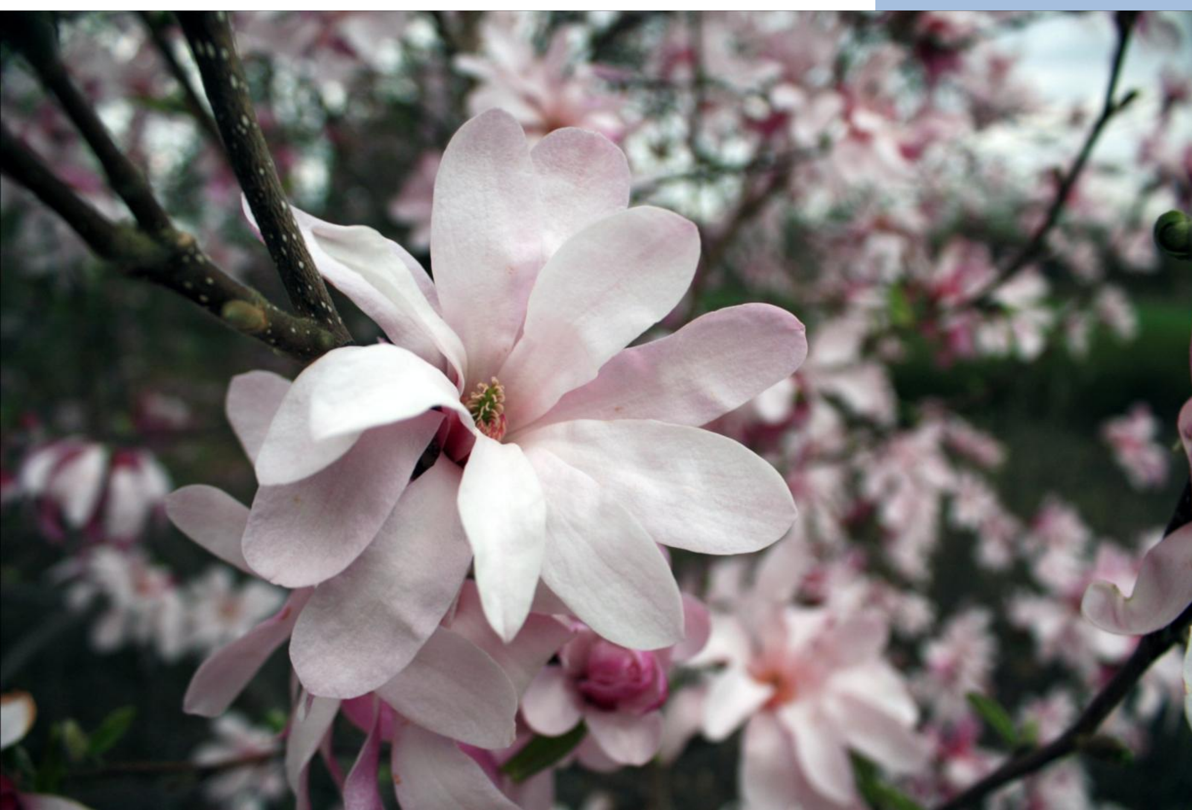
Global warming and cold/warm spells of weather:

- Warming is greater at the poles than equator
- Lesser temperature contrast between equator and poles
- Weaker westerlies
- More pronounced troughs and ridges in the jet stream
- More cold and warm temperature anomalies lasting several weeks

March 2012:

- 15,000 record highs in the U.S.
- Magnolias bloom in March in MN





Magnolia in bloom, St.Paul Campus, March 27, 2012. Photo: Jenna Williams

Phenological disturbance

Browning of post-fire regeneration, BWCAW, June 2012
Photo: Eli Anoszko

Winter browning of spruce in Ontario, May 2012. Ontario Ministry of Natural Resources

Boreal to temperate forest/savanna conversion mechanisms:

- Gap dynamics/gradual infiltration of temperate species
- Trophic cascade; delay followed by sudden change
- Wind/hail storms
- Wind + Fire
- Heat/drought stress
- Insect infestation (native and exotic) due to lack of extreme cold
- Phenological disturbance

Photo, Eli Anoszko

All mechanisms operate on large tracts of land, only 1 is gradual

Photo, Eli Anoszko

Lots of redundancy; it’s a matter of which mechanism operates first in a given location

At landscape/ecoregion scales a mosaic of conversion mechanisms and rates of change will occur


Forests of the
BWCAW today
Photo: Lee Frelich

The BWCAW tomorrow. Gniess Outcrops Scientific and Natural Area, near Granite Falls MN (orange star)—an analog for the future BWCAW (blue star) in a warmer climate, with shallow rocky soils similar to the BWCAW. Photo: Minnesota River Basin Data Center

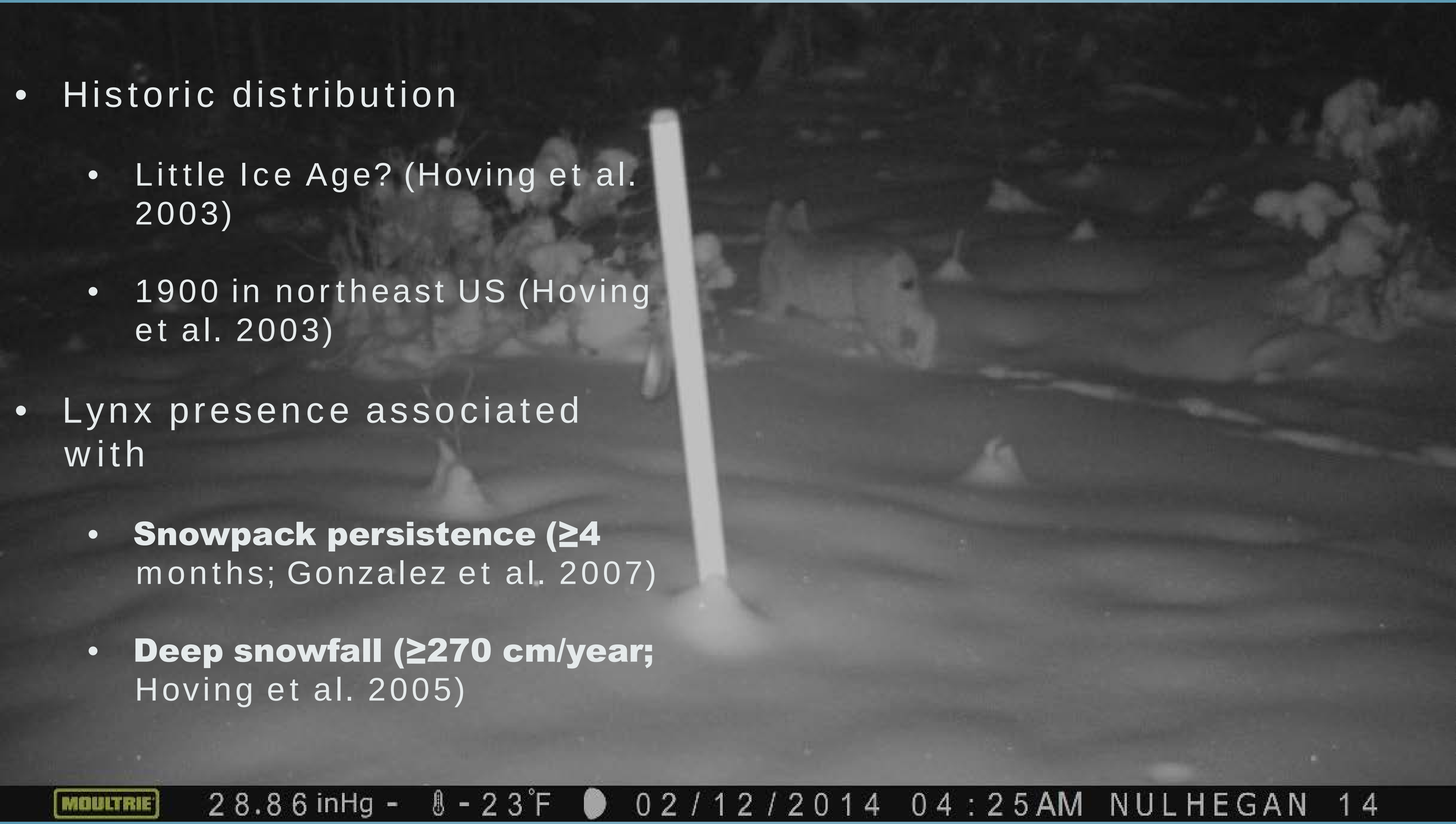

CLIMATE CHANGE AND UNCERTAINTY:
IMPLICATIONS FOR CANADA LYNX CONSERVATION
AND MANAGEMENT IN THE CONTIGUOUS US
NECSC

CLIMATE MODELING 101

Accessed from: http://www.vets.ucar.edu/vg/T341/index.shtml

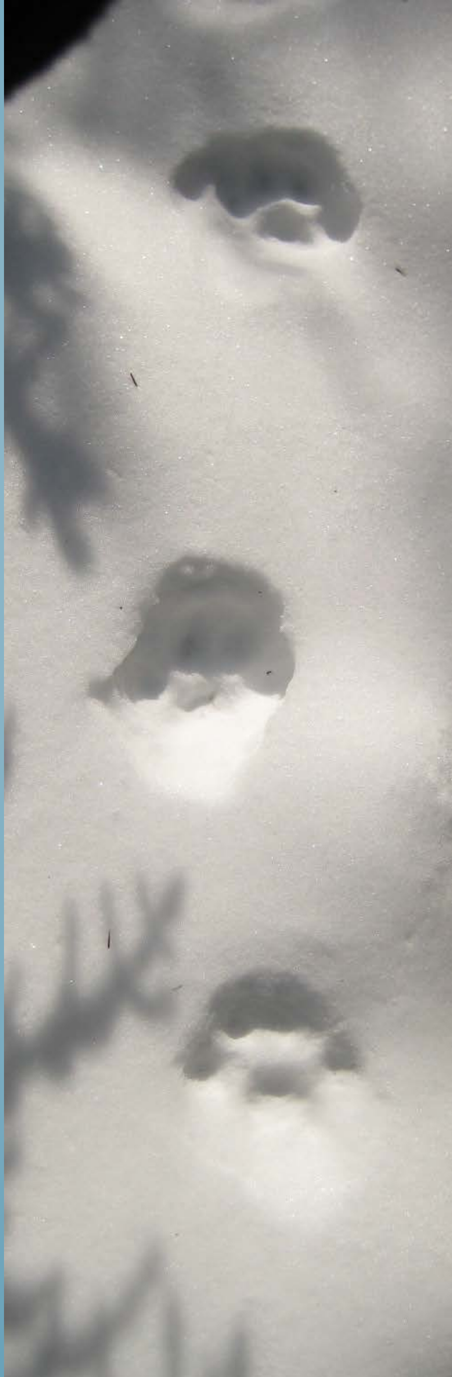
Lynx distribution and climate

- Historic distribution
  - Little Ice Age? (Hoving et al. 2003)
  - 1900 in northeast US (Hoving et al. 2003)
- Lynx presence associated with
  - **Snowpack persistence (≥4** months; Gonzalez et al. 2007)
  - **Deep snowfall (≥270 cm/year;** Hoving et al. 2005)



How else may climate influence lynx?

- Population cycles (Hone et al. 2011) and declines (Yan et al. 2013)
- Population viability (Carroll 2007)
- Increased competition with sympatric carnivores (Parker et al. 1983, Peers et al. 2013)
- Reduced genetic diversity (Koen et al. 2014)
- Access to hares (Watt 1973, Stenseth et al. 2004)
- Coat color mismatch (Mills et al. 2013, 2014)



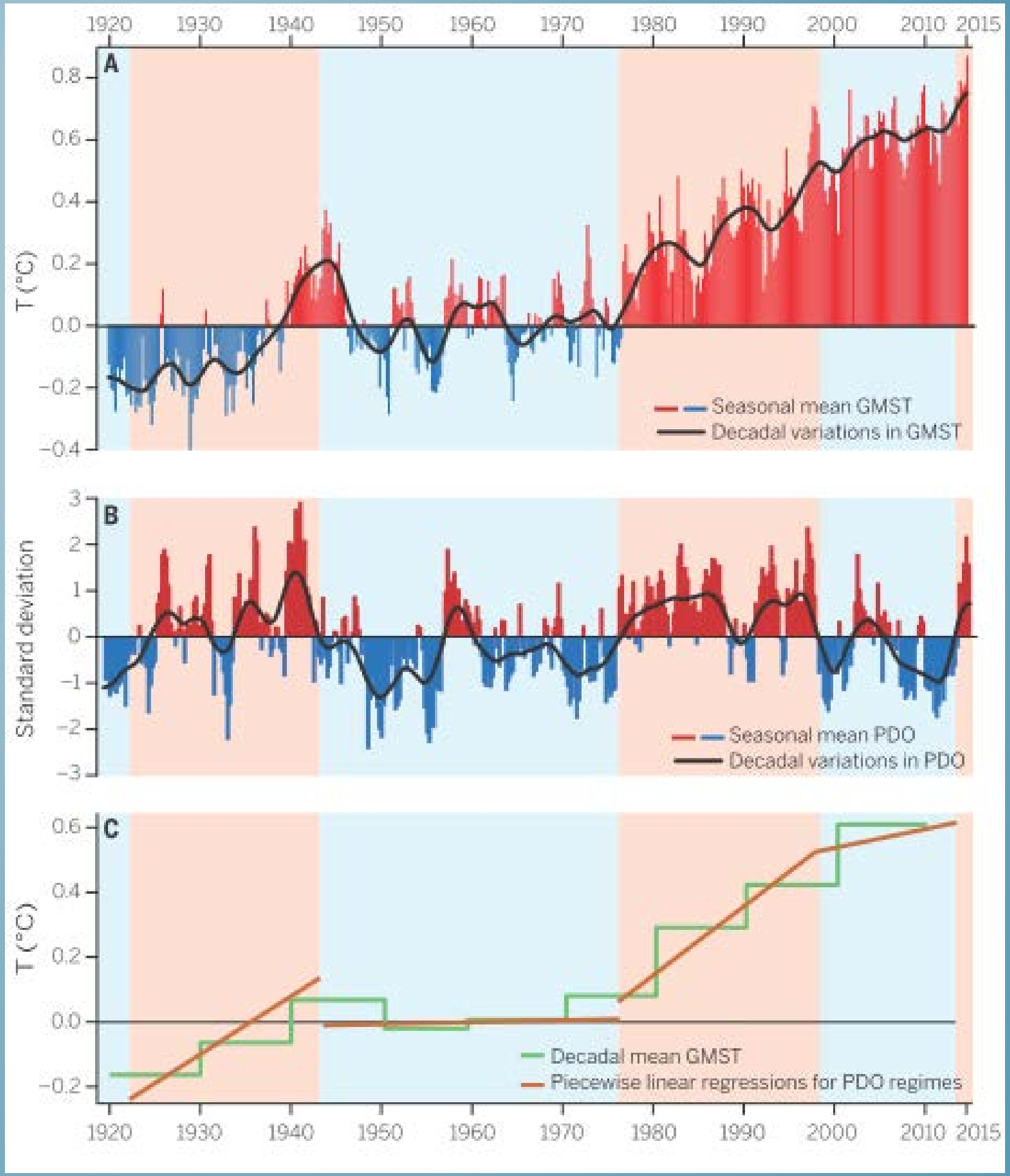
Increase in global mean surface temperature (GMST)

-Natural variation can mask change, especially short-term

-Attributed to the recent "climate hiatus" (15 yrs)

-Overall trend is towards increased global temps especially after mid-1970s

-GMST may be increasing due to latest El Nino event

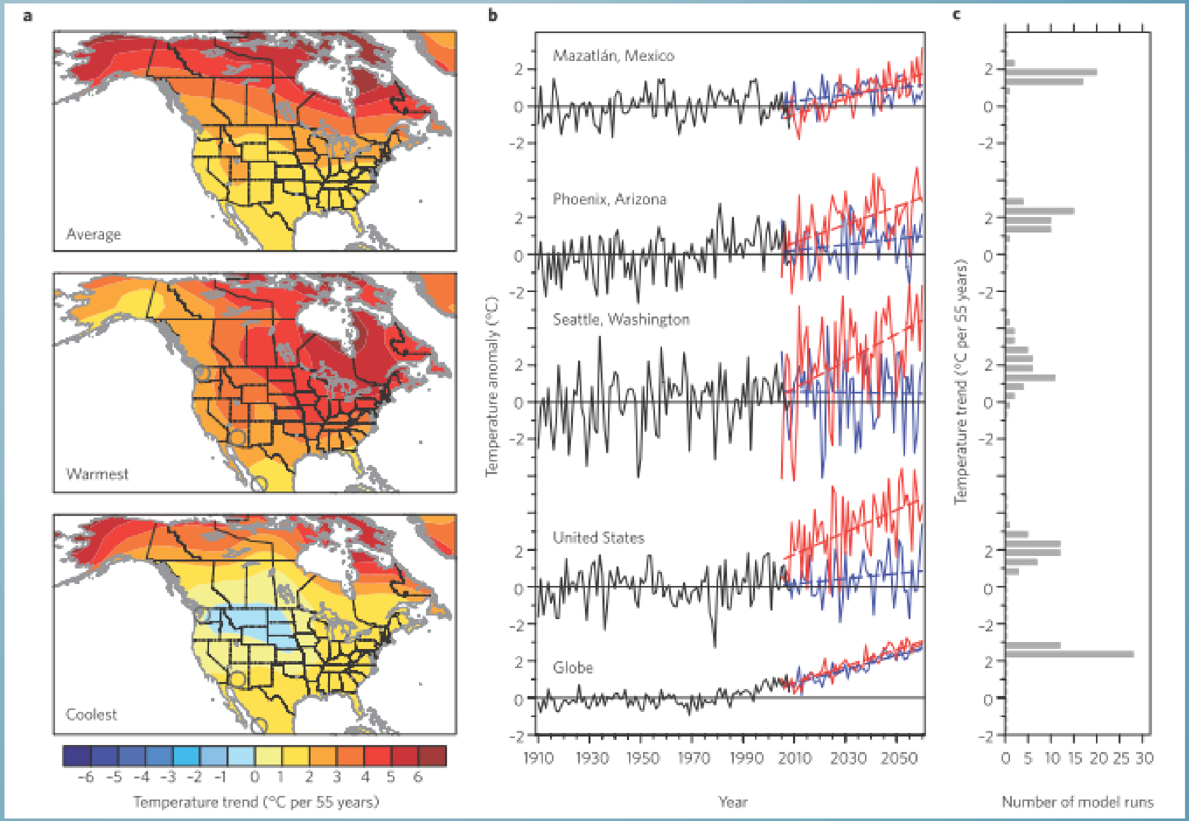


Seasonal GMST temperature trends compared to century mean (Trenberth 2015)

NECSC Northeast Climate Science Center

Climate change and uncertainty in North America

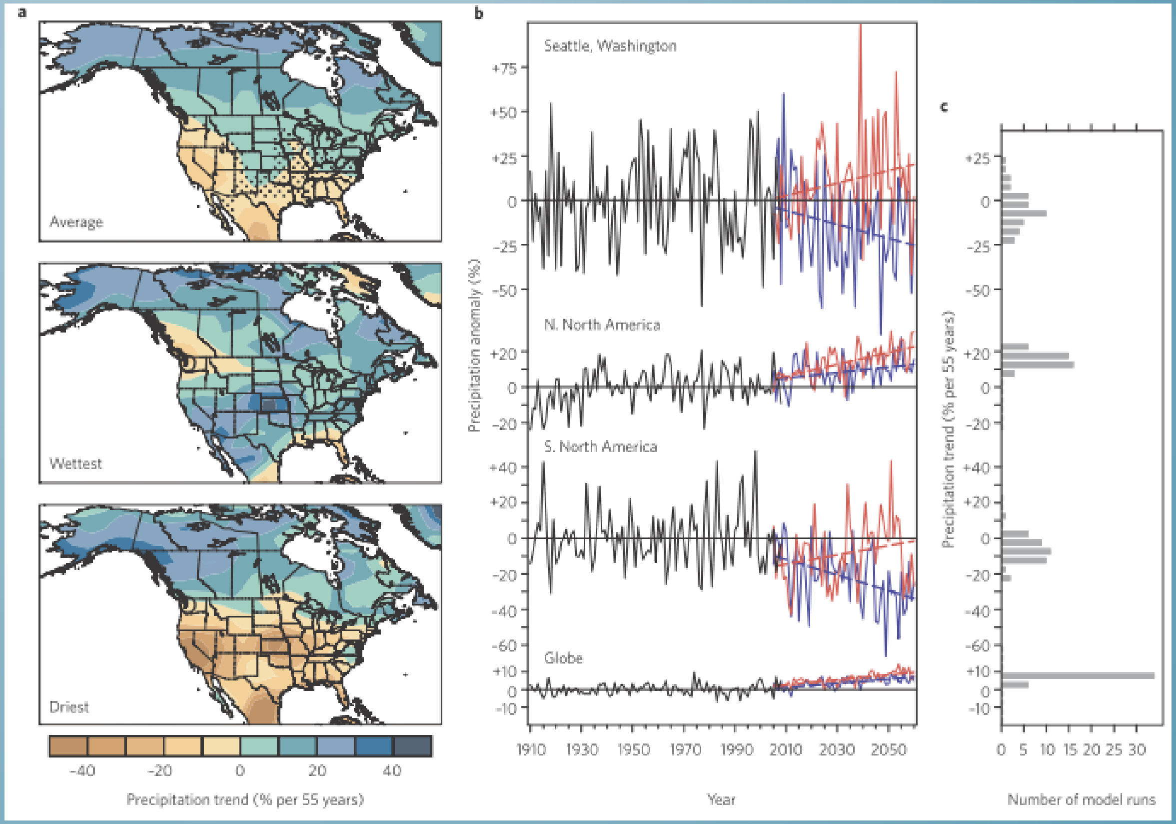
- Winter temperature projections
  - Average of 40 model runs and warmest and coolest scenarios
  - Overall increase in winter temperature with greatest increase in northeast US
  - Uncertainty given emission scenarios



Observed winter temperature and predictions based on common record (Deser et al. 2013)

Climate change and uncertainty in North America

- Winter precipitation projections
  - Average of 40 model runs and wettest and driest scenarios
  - Increase in precipitation in eastern US and
  - Drier in the Northwest US
  - Uncertainty given emission scenarios and spatial formation of clouds



Observed winter precipitation and predictions based on common record (Deser et al. 2013)

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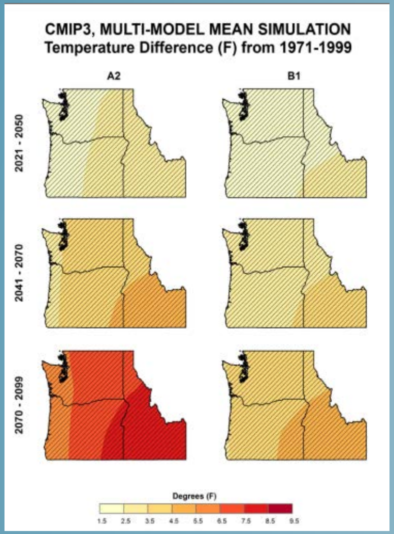
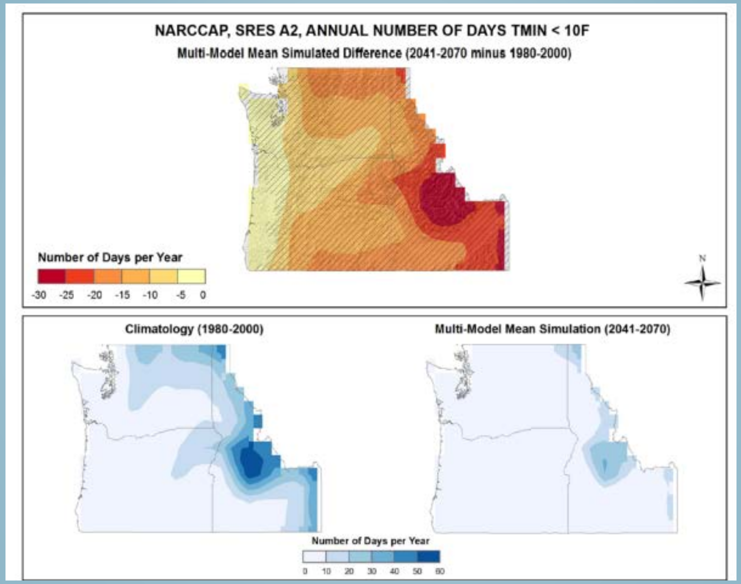
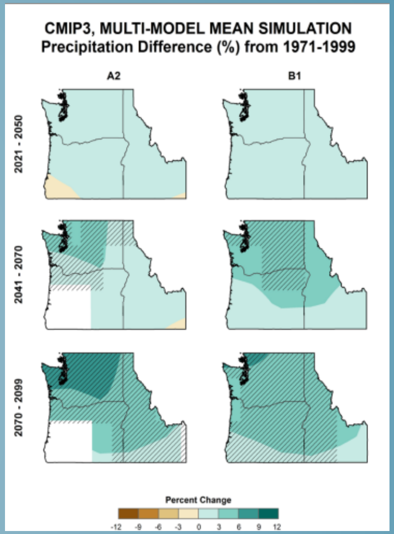
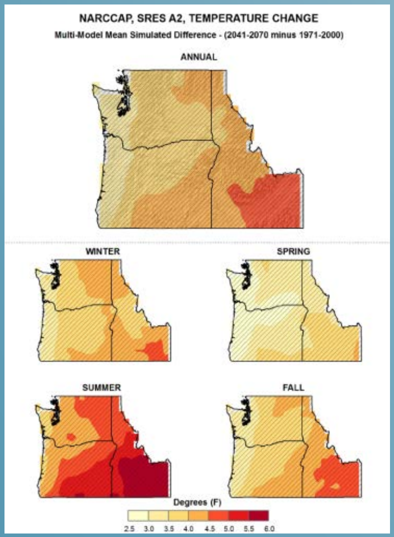
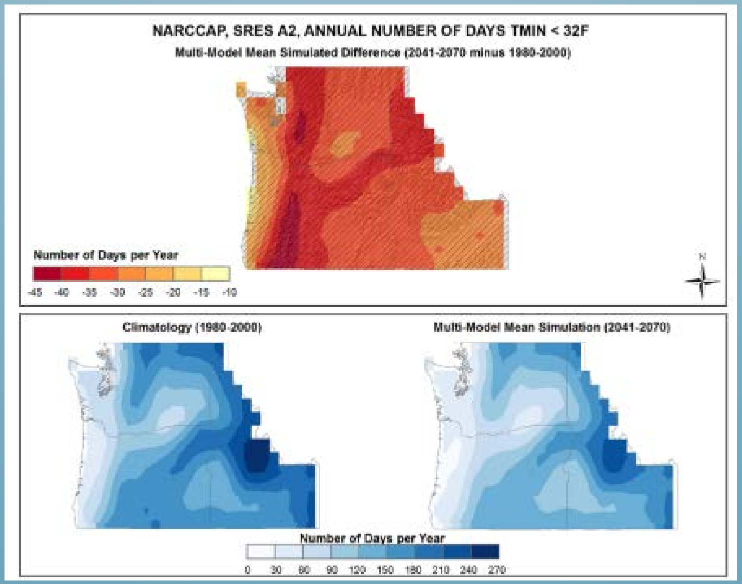
Northwestern US: Predicted climate change

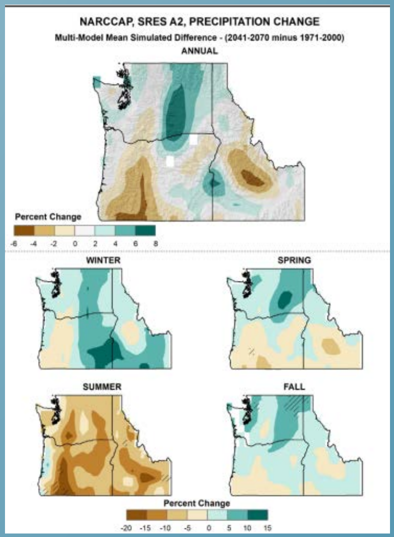












Figures from Kunkel et al. (2013)

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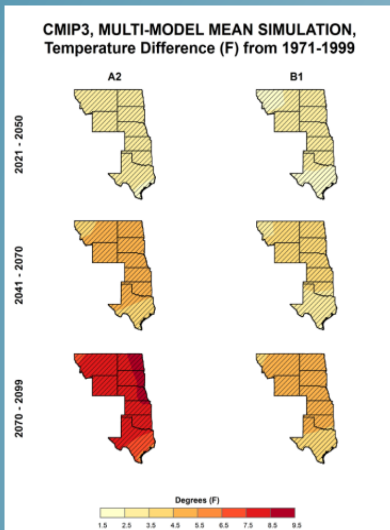
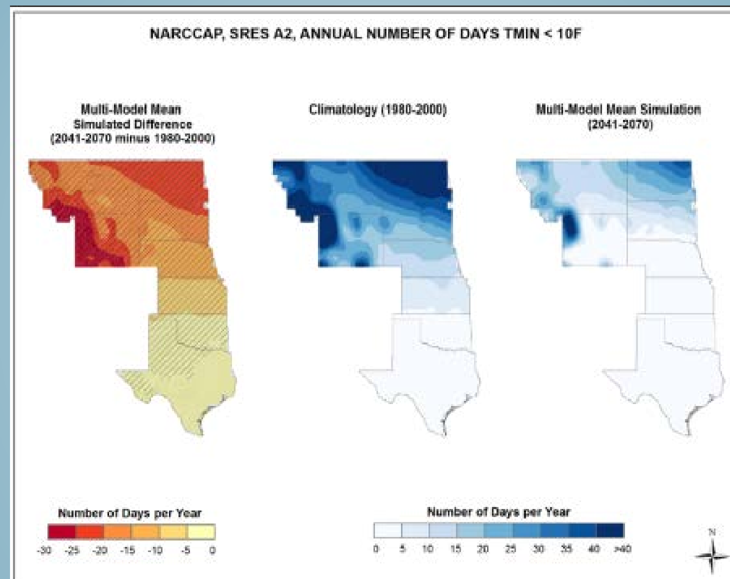
Northwestern US: Snowpack trends and projections

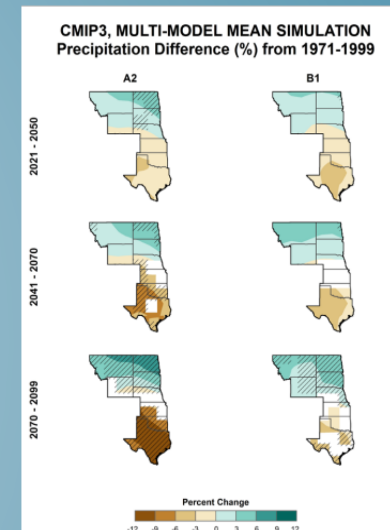
- Recent trends
  - Decrease in spring snowpack at lower elevations but unequivocal at high elevation (Mote et al. 2008)
  - Overall decline in snowpack the latter half of the 20th century (Mote et al. 2005; Pierce et al. 2008)
  - Decrease in overall snowpack (Pierce and Cayan 2013; Knowles 2015)
  - Lower proportion of winter precipitation occurring as snow (Knowles et al. 2006)
- Projections
  - Lower proportion of winter precipitation occurring as snow and reduced number of snowfall days (Pierce and Cayan 2013; Lute et al. 2015)
  - Decrease in snowfall season and snowfall (Pierce and Cayan 2013).

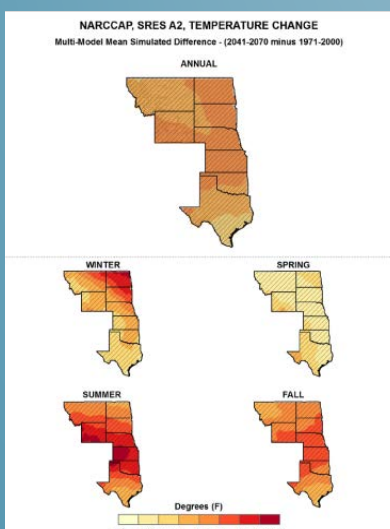
NECSC Northeast Climate Science Center

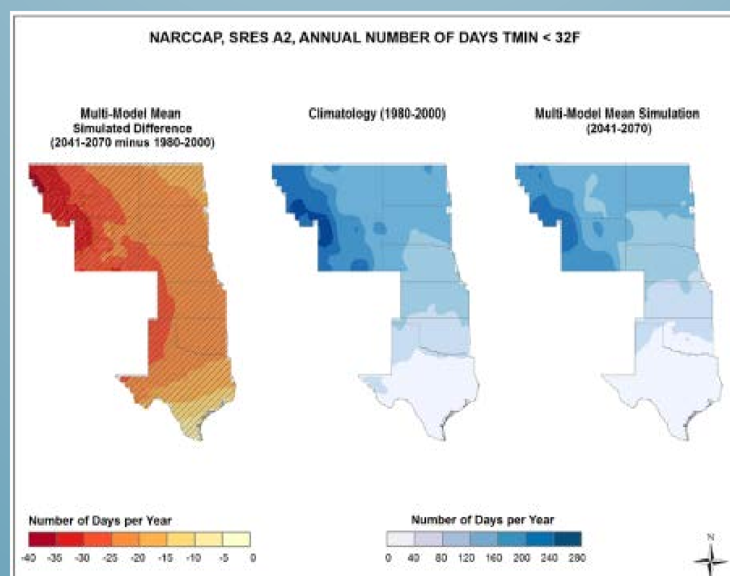
Northern Rockies: Predicted Climate Change

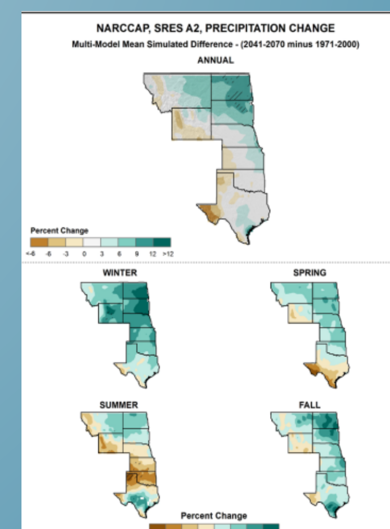






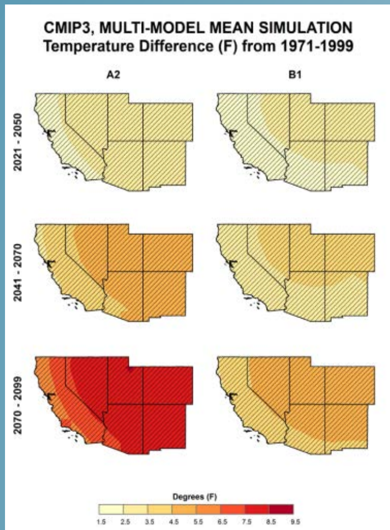


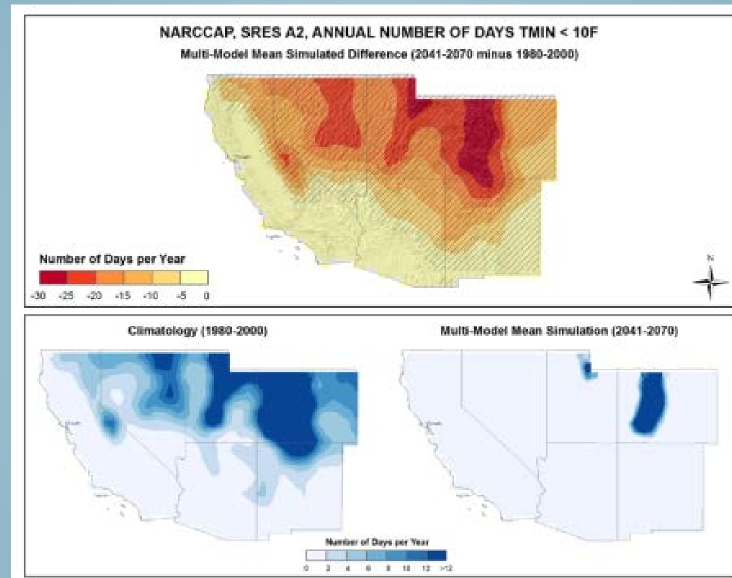


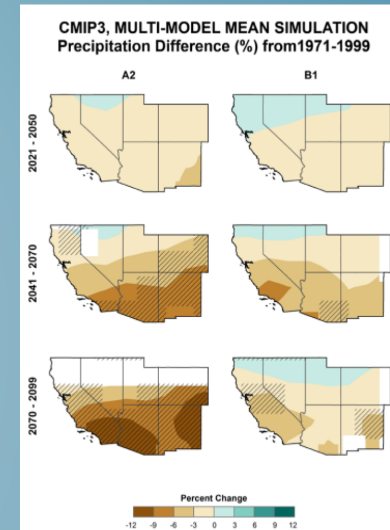


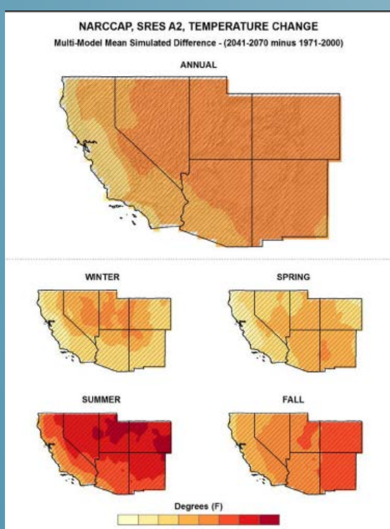
Figures from Kunkel et al. (2013)

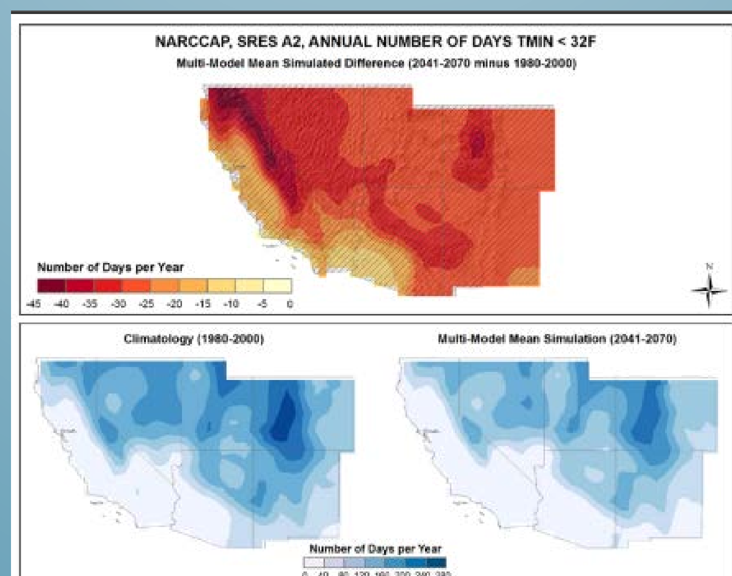
Southern Rockies: Predicted climate change

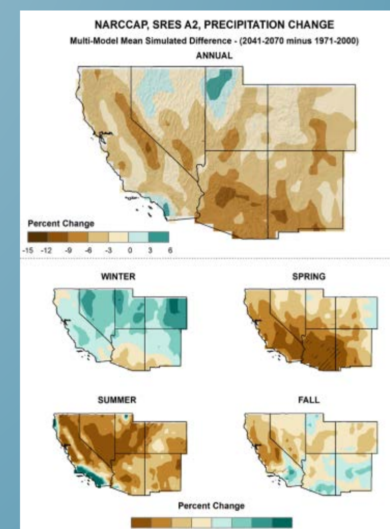












Figures from Kunkel et al. (2013)

Northern & Southern Rockies: Snowpack trends and projections

- Recent trends
  - Overall decline in snowpack the latter half of the 20th century (Pierce et al. 2008).
  - Decrease in overall snowpack (Knowles 2015).
  - Lower proportion of winter precipitation occurring as snow (Knowles et al. 2006; Pierce and Cayan 2015).
- Projections
  - Lower proportion of winter precipitation occurring as snow and reduced number of number of snowfall days (Pierce and Cayan 2013; Lute et al. 2015)
  - Decrease in snowfall season and snowfall (Pierce and Cayan 2013).

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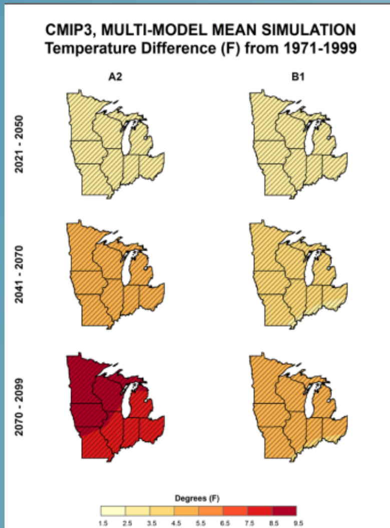
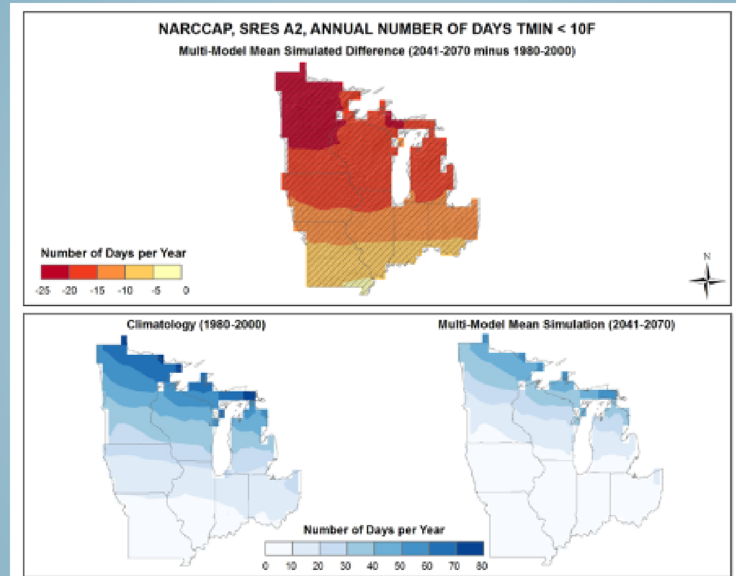
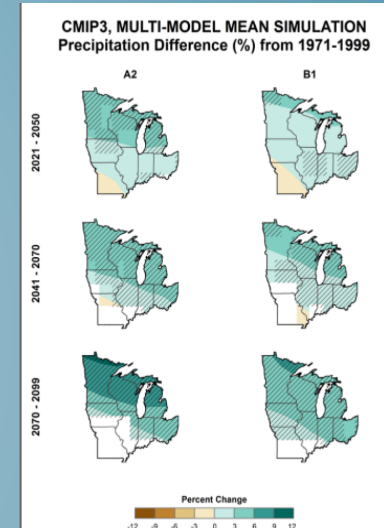
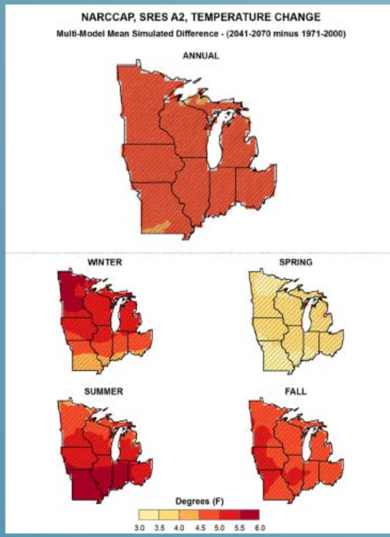
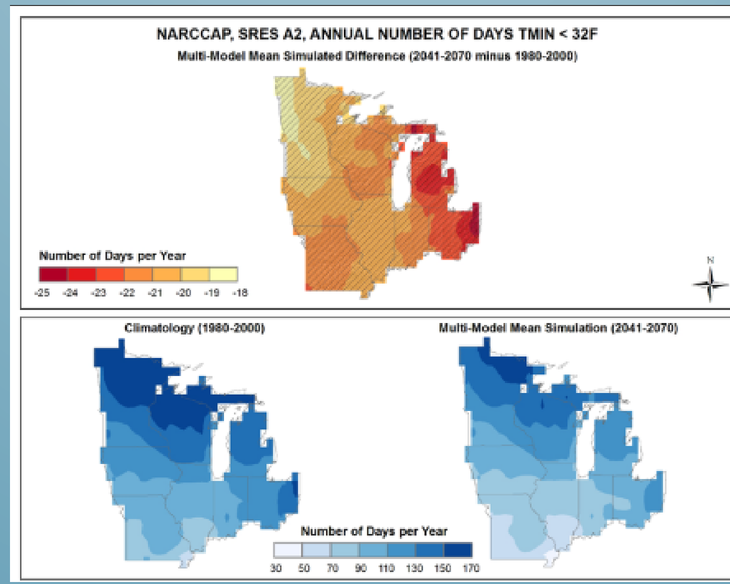
Great Lakes: Predicted Climate Change

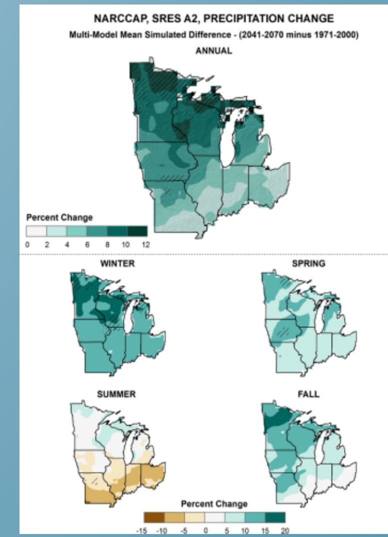












Figures from Kunkel et al. (2013)

Great Lakes: Snowpack trends and projections

- Recent trends
  - Increase in lake effect snow (Andresen et al. 2012) and longer snow seasons (Kunkel et al. 2007; Knowles 2015) to the north.
- Projections
  - Increased winter precipitation throughout Midwest, but lower proportion occurring as snow (Notaro et al. 2014; Suriano and Leathers 2015).
  - Increased lake effect snow around Lake Superior with eventual decline towards end of century (Notaro et al. 2015).
  - Increased lake effect snow north of eastern Great Lakes then gradual decline (Suriano and Leathers 2015)
  - Decline in snowfall and length of snowpack coverage (Notaro et al. 2014; Notaro et al. 2015)

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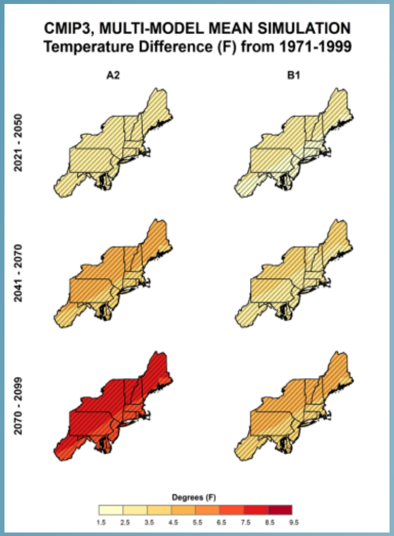
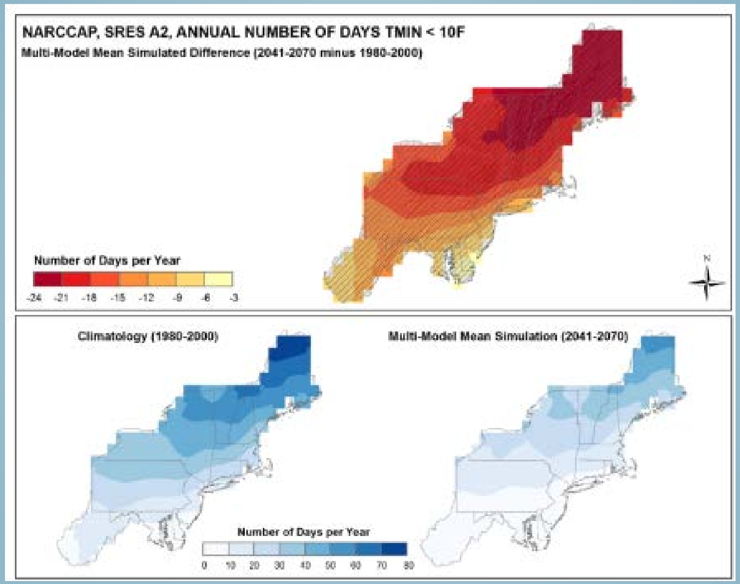
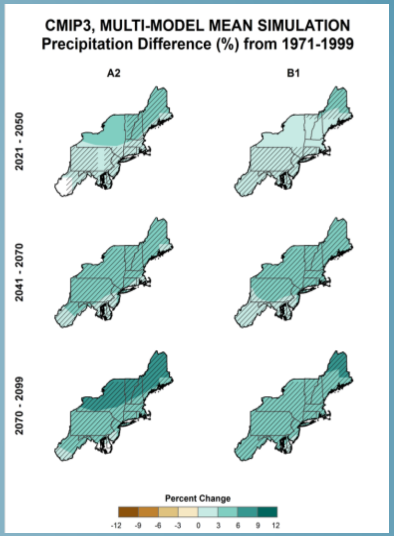
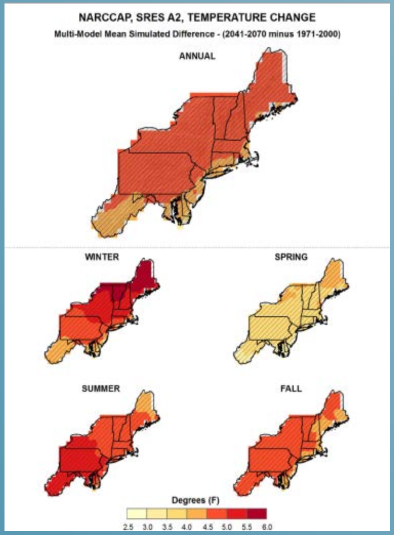
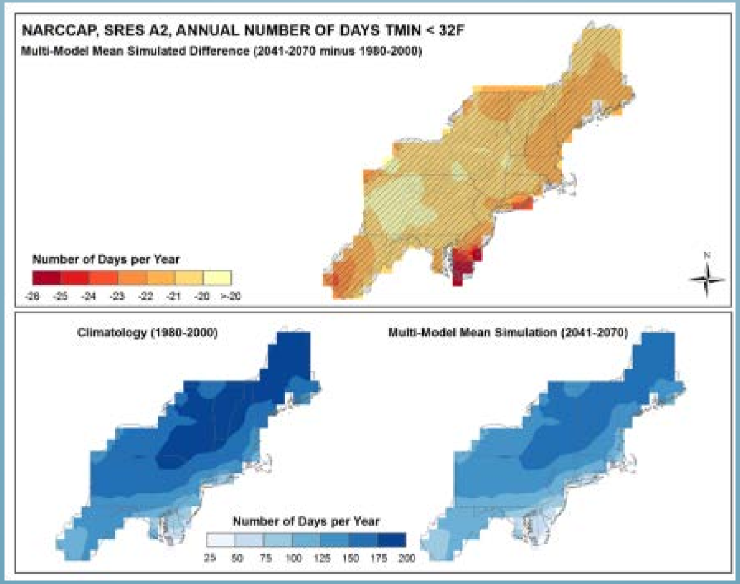
Northeast: Predicted Climate Change

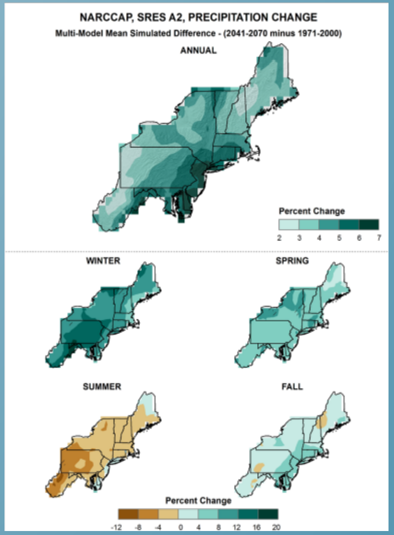












Figures from Kunkel et al. (2013)

Northeast: Snowpack trends and projections

- Recent trends
  - Reduction in number of snow covered days (Burakowski et al. 2008; Campbell et al. 2010; Bryan et al. 2015) and snowfall
  - Lower proportion of winter precipitation occurring as snow (Huntington et al. 2003; Brian et al. 2015)
- Projections
  - Increased winter precipitation (Rawlings et al. 2012; Notaro et al. 2014), but lower proportion occurring as snow
  - Decline in snowfall and length of snowpack coverage (Notaro et al. 2014)

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Acknowledgements

-Toni Lyn Morelli, PhD (USGS, NE CSC)

-Mary Ratnaswamy, PhD (USGS, NE CSC)

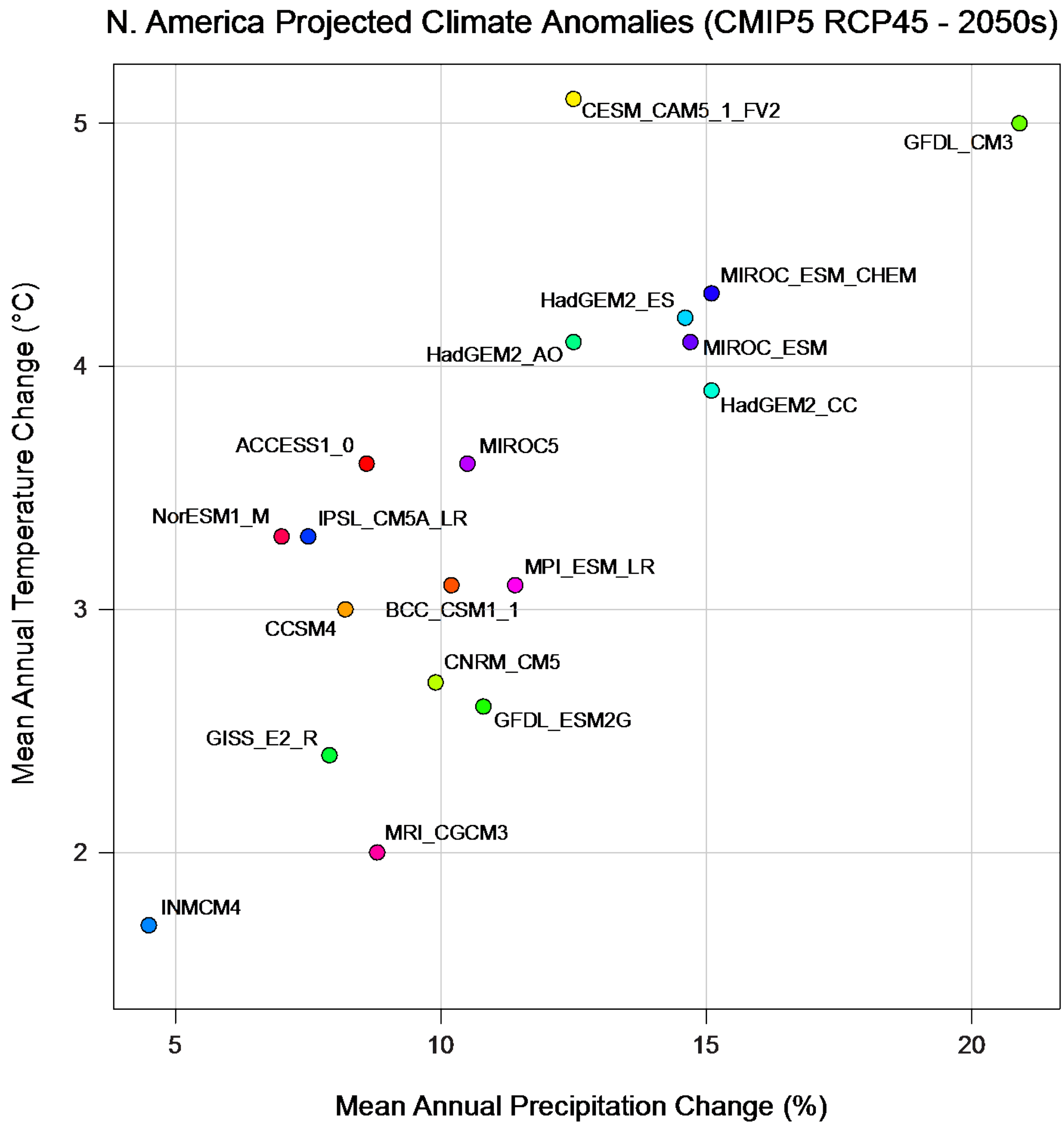
-Ambarish Karmalkar, PhD (NE CSC)

-Alexander Bryan, PhD (NE CSC)

NE CSC
Northeast Climate Science Center

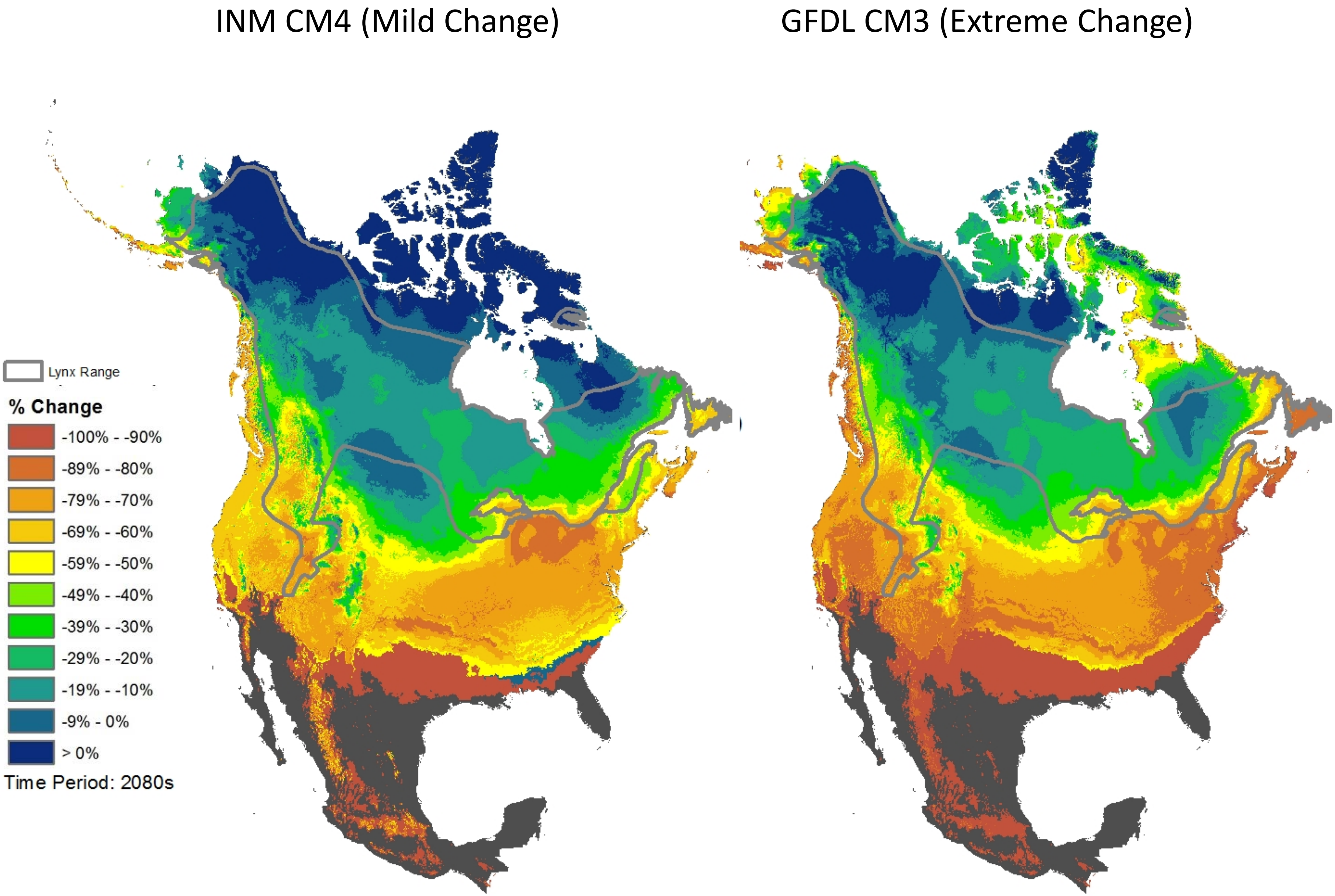
Projected climate-change impacts on snow, vegetation, and lynx populations in the western U.S.

Josh Lawler, University of Washington
Chad Wilsey, National Audubon Society



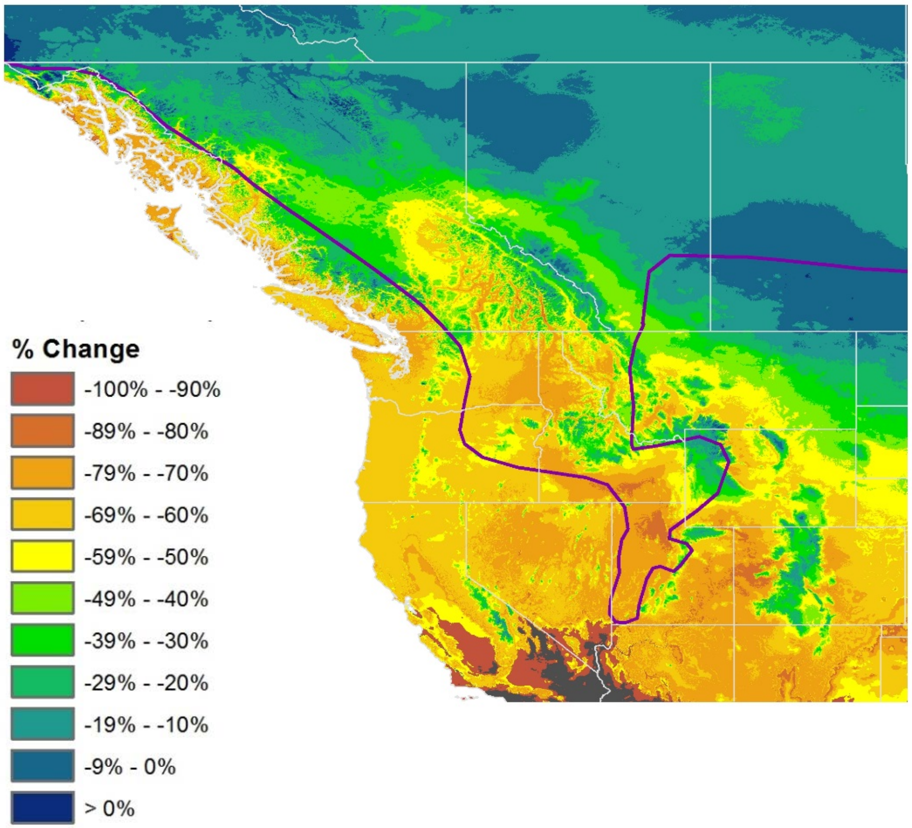
N. America Projected Climate Anomalies (CMIP5 RCP45 - 2050s)
CESM_CAM5_1_FV2
GFDL_CM3
MIROC_ESM_CHEM
HadGEM2_ES
HadGEM2_AO
MIROC_ESM
HadGEM2_CC
ACCESS1_0
MIROC5
NorESM1_M
IPSL_CM5A_LR
MPI_ESM_LR
BCC_CSM1_1
CCSM4
CNRM_CM5
GFDL_ESM2G
GISS_E2_R
MRI_CGCM3
INMCM4
Mean Annual Temperature Change (°C)
Mean Annual Precipitation Change (%)
5
4
3
2
5
10
15
20

Precipitation falling as snow

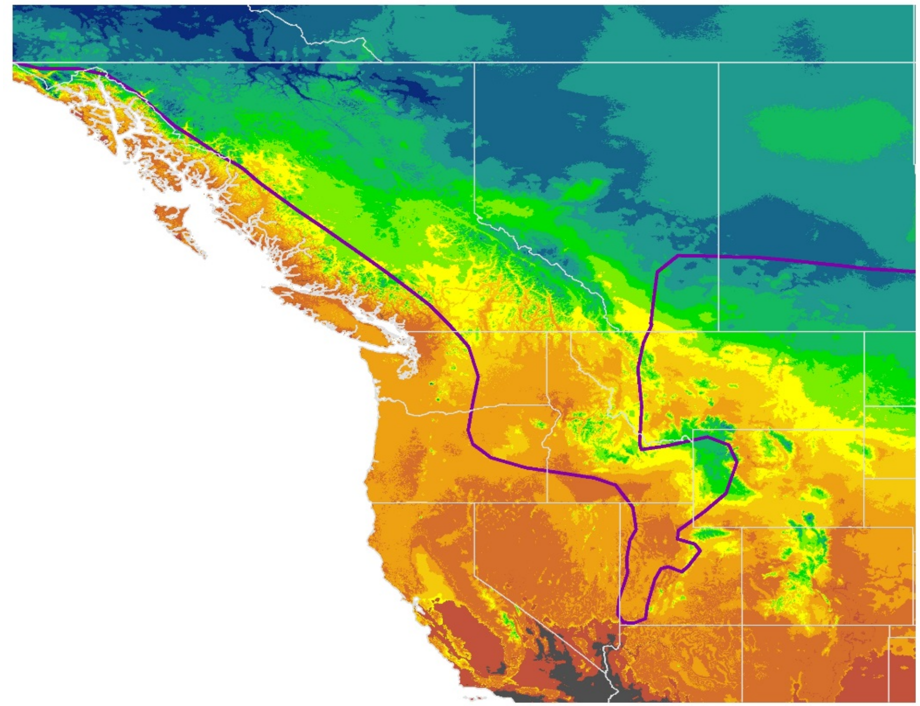


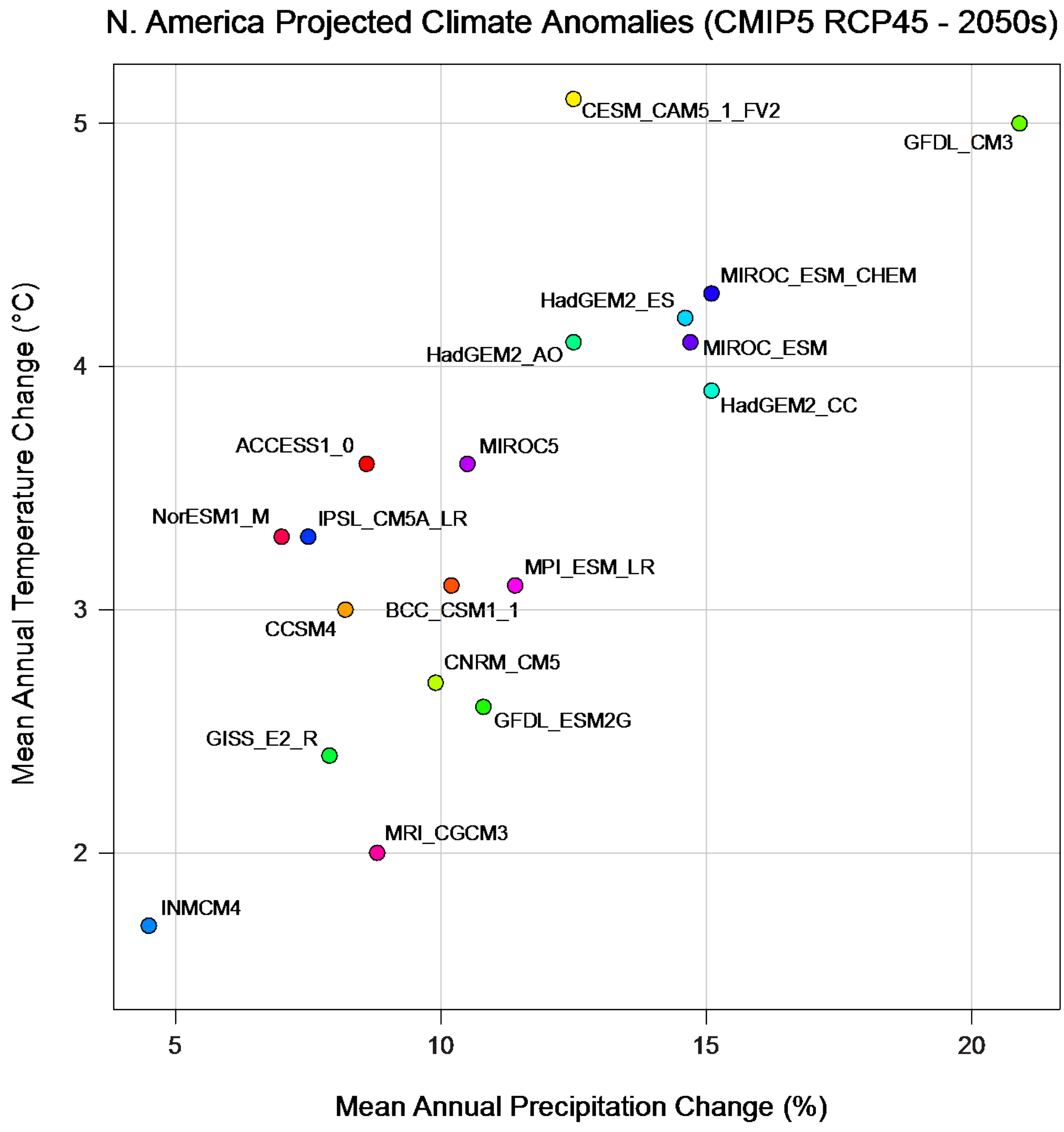
Precipitation falling as snow

INM CM4 (Mild Change)



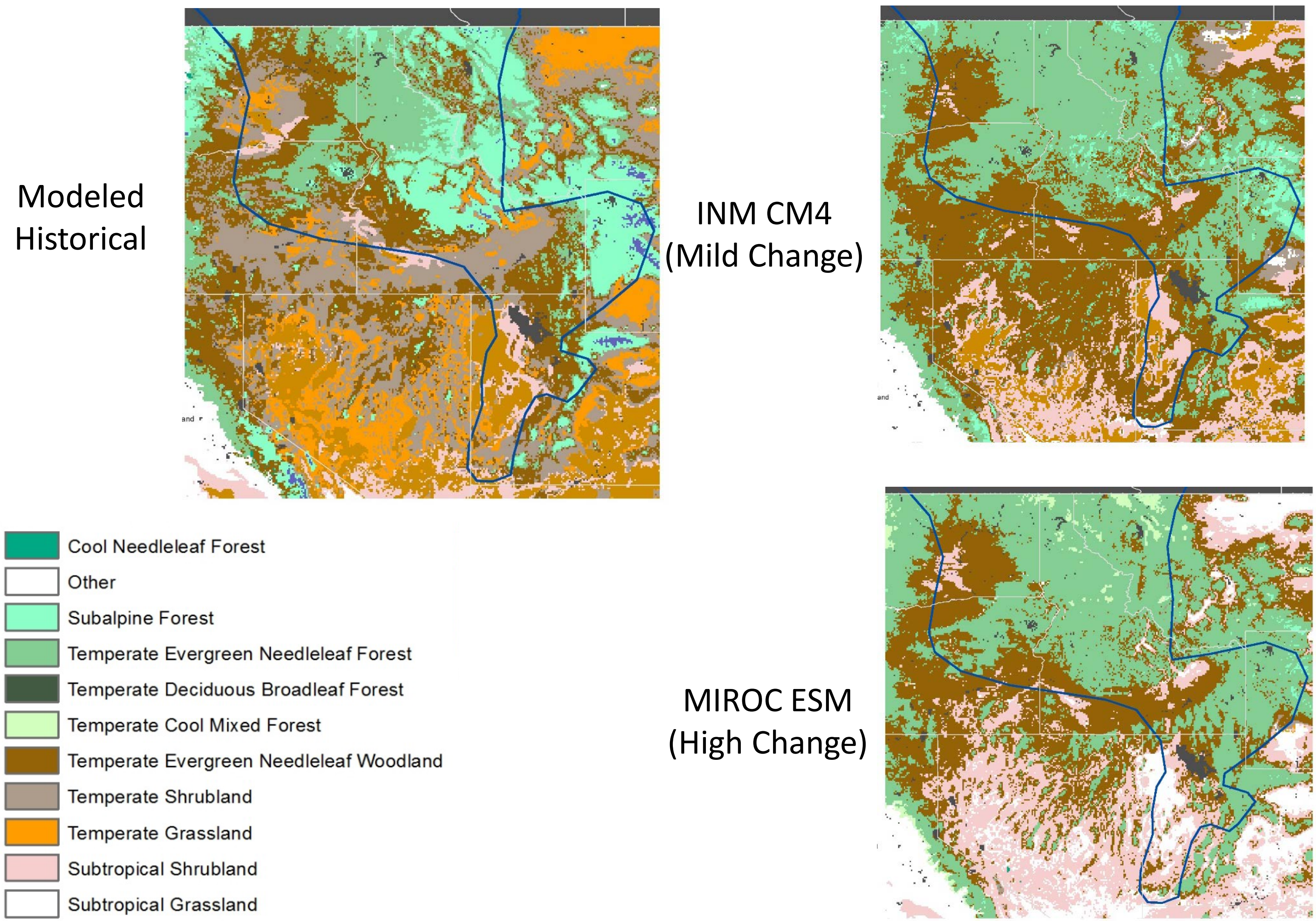
GFDL CM3 (Extreme Change)



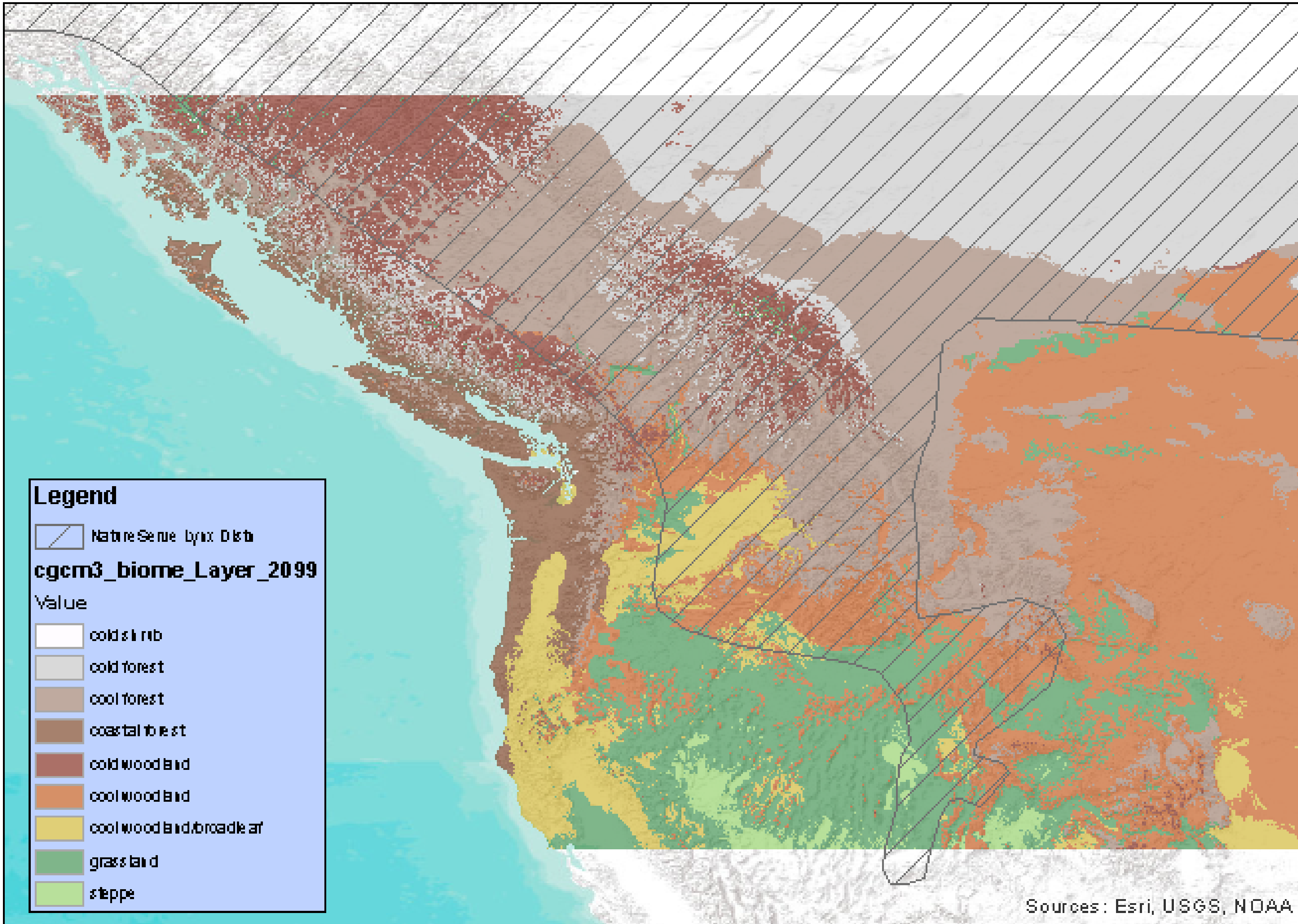


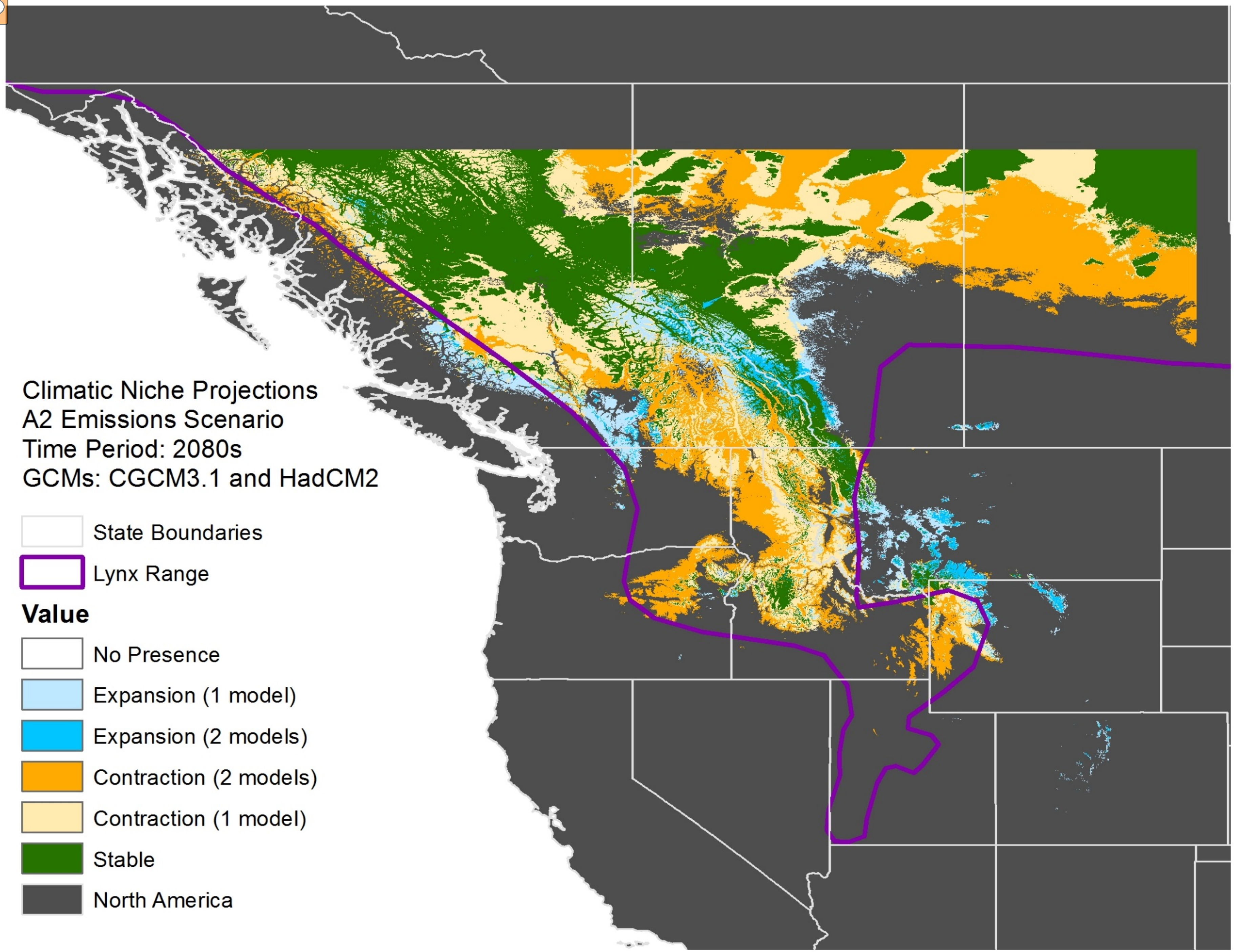
N. America Projected Climate Anomalies (CMIP5 RCP45 - 2050s)
Mean Annual Temperature Change (°C)
Mean Annual Precipitation Change (%)
5
4
3
2
5
10
15
20
CESM_CAM5_1_FV2
GFDL_CM3
MIROC_ESM_CHEM
HadGEM2_ES
HadGEM2_AO
MIROC_ESM
HadGEM2_CC
ACCESS1_0
MIROC5
NorESM1_M
IPSL_CM5A_LR
MPI_ESM_LR
BCC_CSM1_1
CCSM4
CNRM_CM5
GFDL_ESM2G
GISS_E2_R
MRI_CGCM3
INMCM4

MC2, 2080s, RCP8.5



LPJ, 2080s, A2 (CMIP3 data)




Climatic Niche Projections
A2 Emissions Scenario
Time Period: 2080s
GCMs: CGCM3.1 and HadCM2
State Boundaries
Lynx Range
Value
No Presence
Expansion (1 model)
Expansion (2 models)
Contraction (2 models)
Contraction (1 model)
Stable
North America

Canada lynx

- Long-distance dispersal
- Mid and high elevation forests
- Avoid humans
- Snowshoe hare specialists

A mechanistic approach

- Statistically downscaled GCM output

Applying anomalies to observed climate (DELTA method)
30 arc second, ~1km grid
5 GCMs, CMIP 3
A2 emission scenario

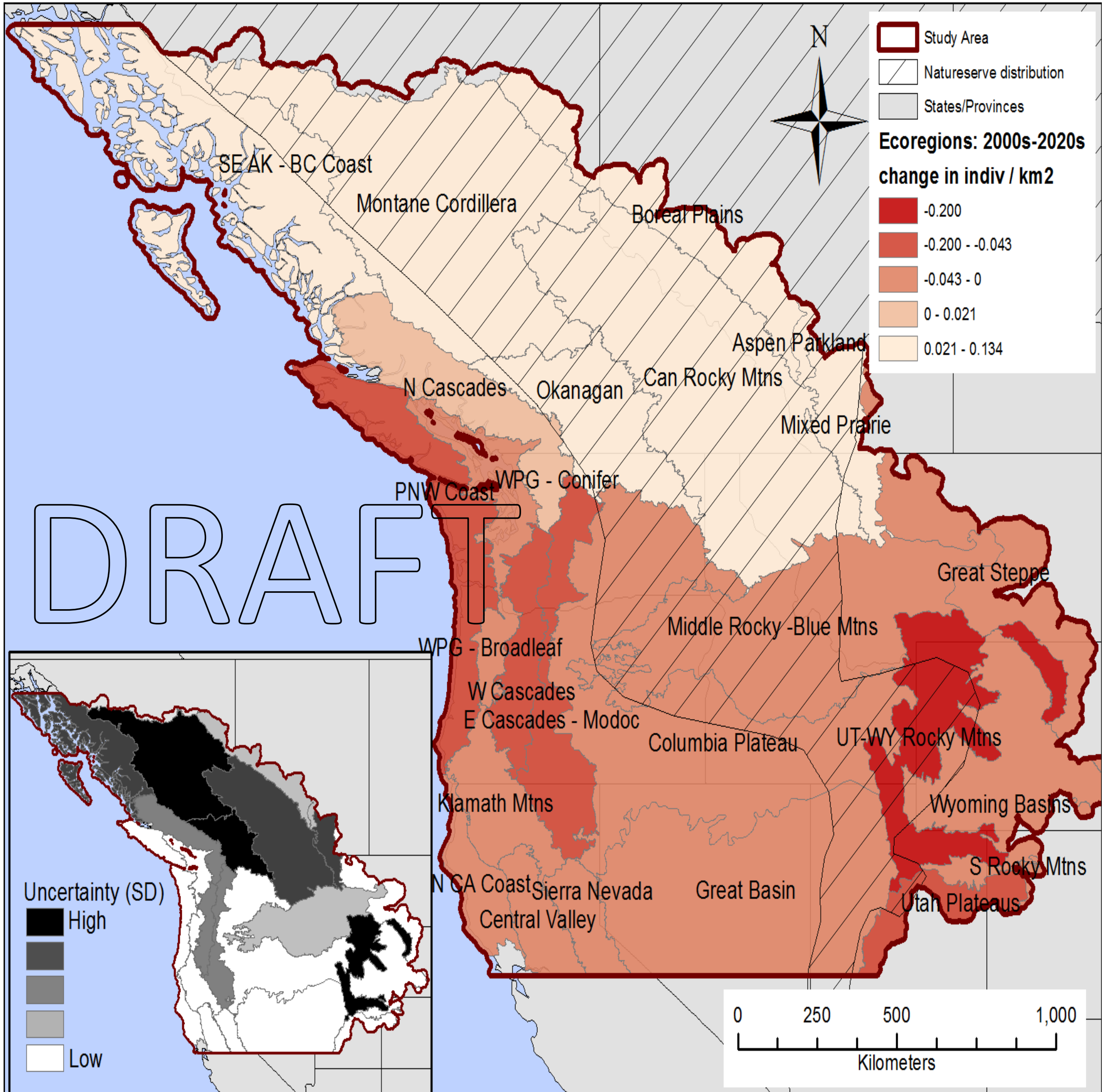
Dynamic vegetation simulations

LPJ DGVM (Sitch 2003)
8 plant function types
Processes…
CO_2 fertilization, fire, competition

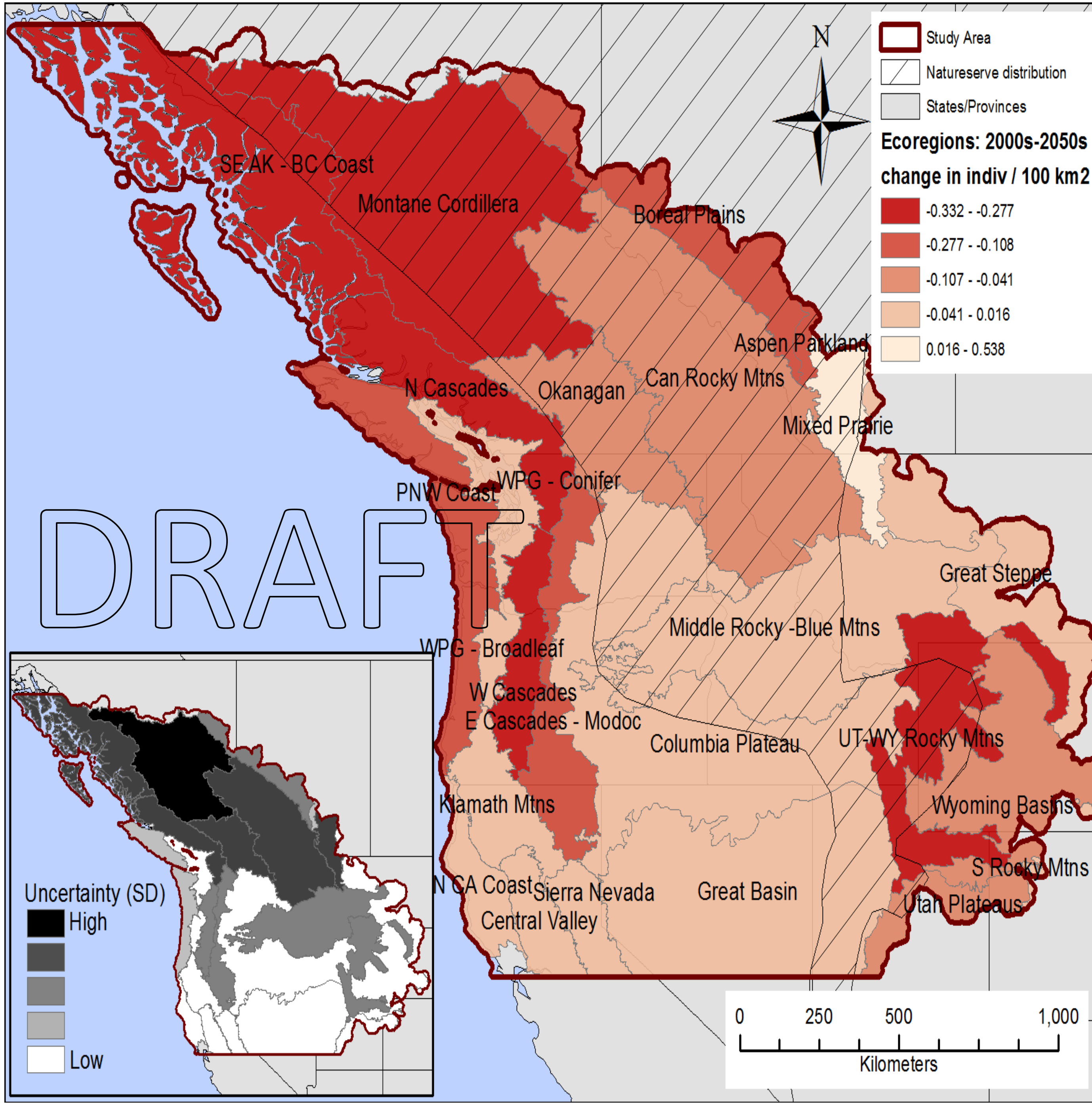
Spatially explicit population modeling

HexSim modeling framework
Individual-based model
Processes…
Survival, reproduction, dispersal

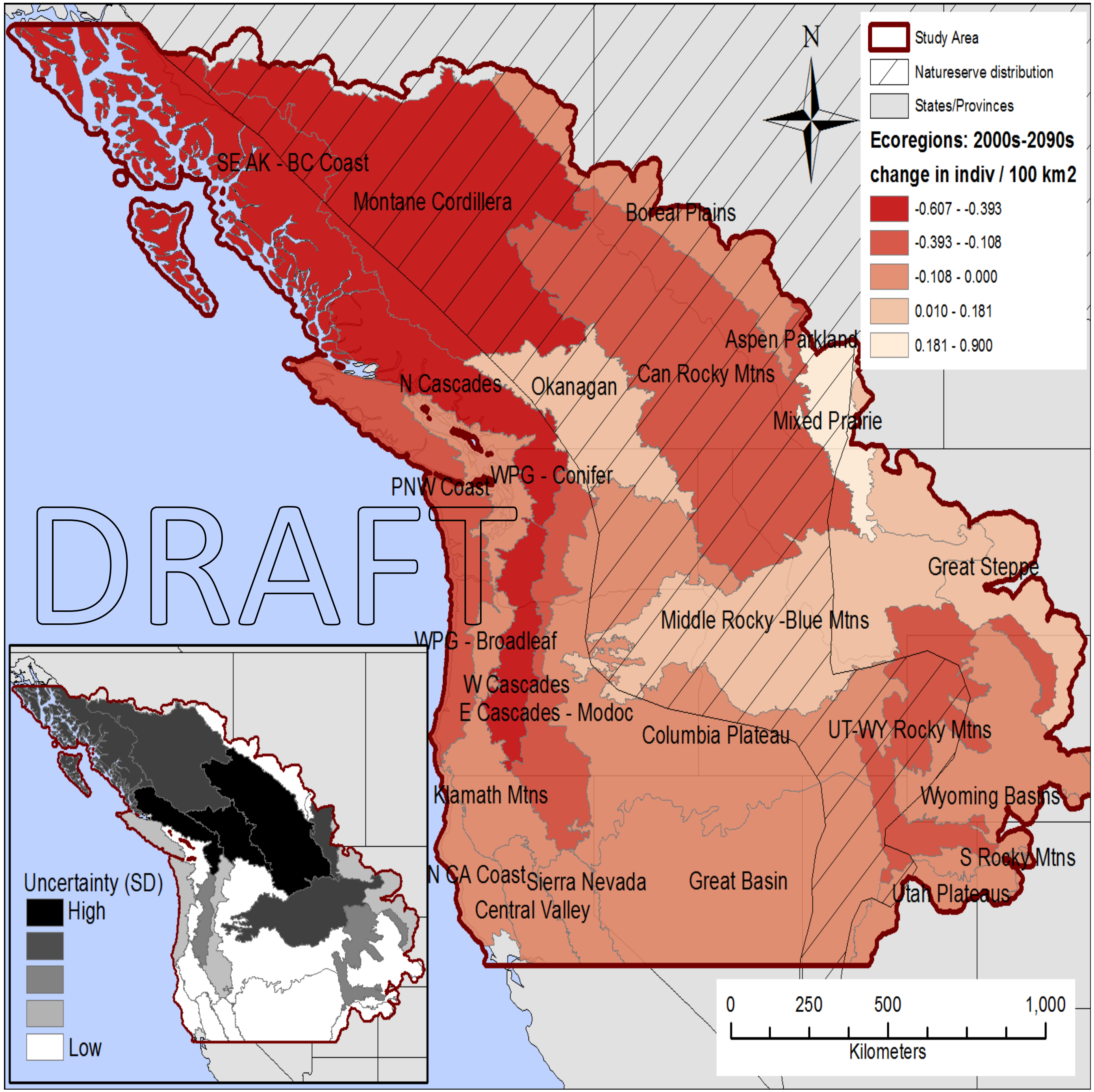
Simulated change in density 2020s



Simulated change in density 2050s

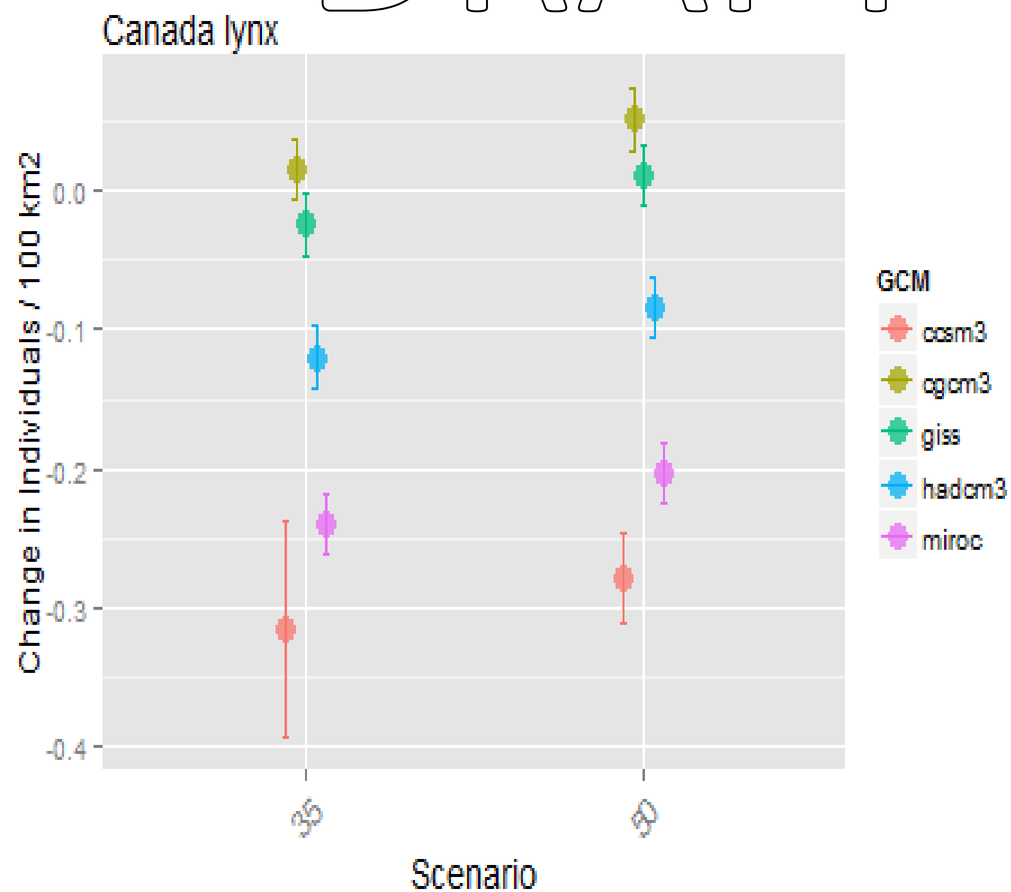


Simulated change in density 2090s



Effect of population cycling

- Simulated declines differed more due to GCM model used than due to population cycling
- Differences among GCMs generated more variability in predictions



Conclusions

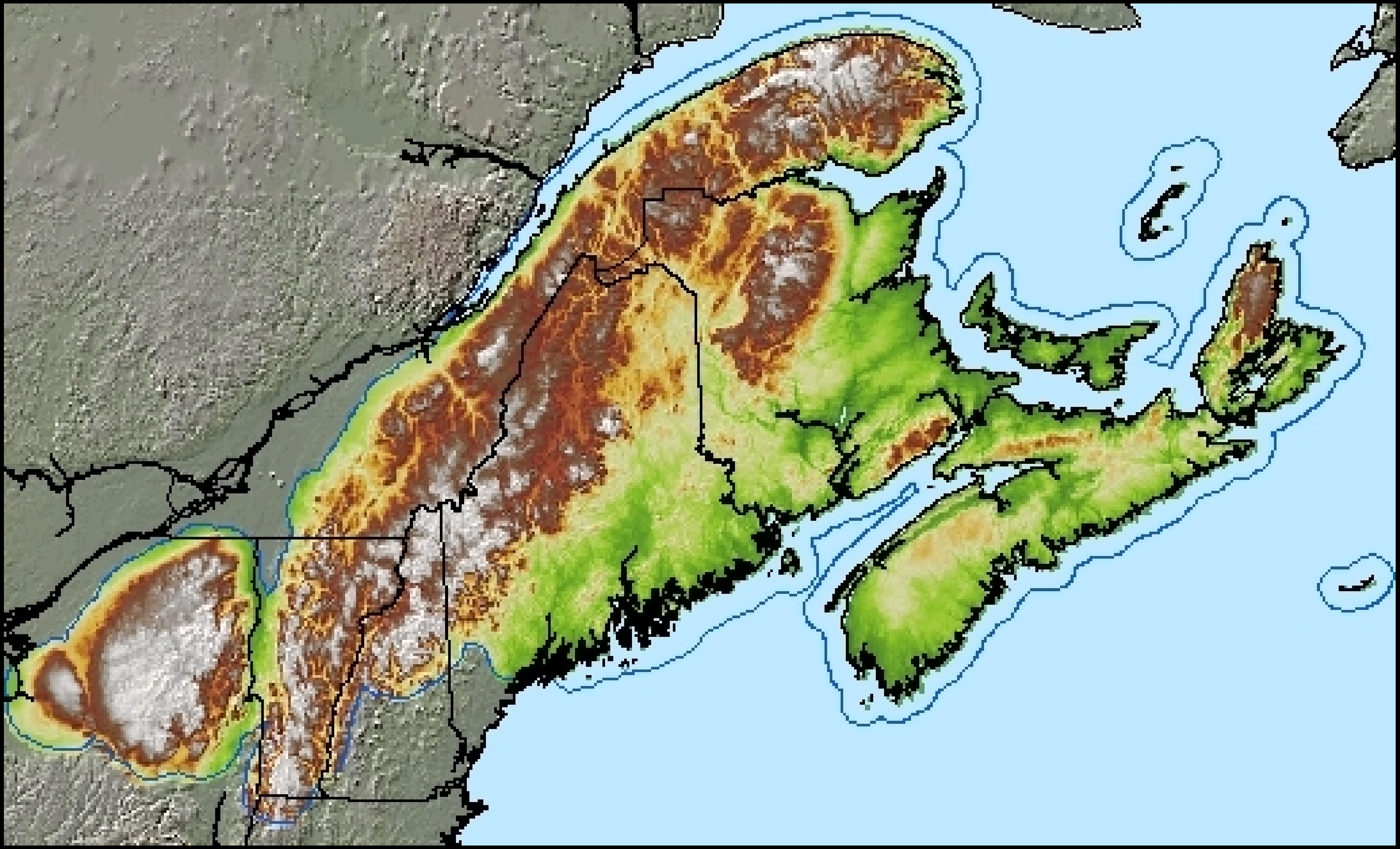
- On average simulated moderate declines in Canada lynx
  - Growing populations: Fescue-Mixed Grass Prairie, Middle Rocky-Blue Mountains, and Great Steppe
  - Declines occurred in: West Cascades, PNW Coast, N Cascades, East Cascades – Modoc, and Aspen Parkland
- Results robust to assumptions of population cycling

Forest Management & Lynx Habitat Trends

Erin Simons-Legaard

Collaborators: Kasey Legaard, Dan Harrison, Mark McCollough, Aaron Weiskittel, Caitlin Andrews

Northern Appalachian/Acadian Ecoregion



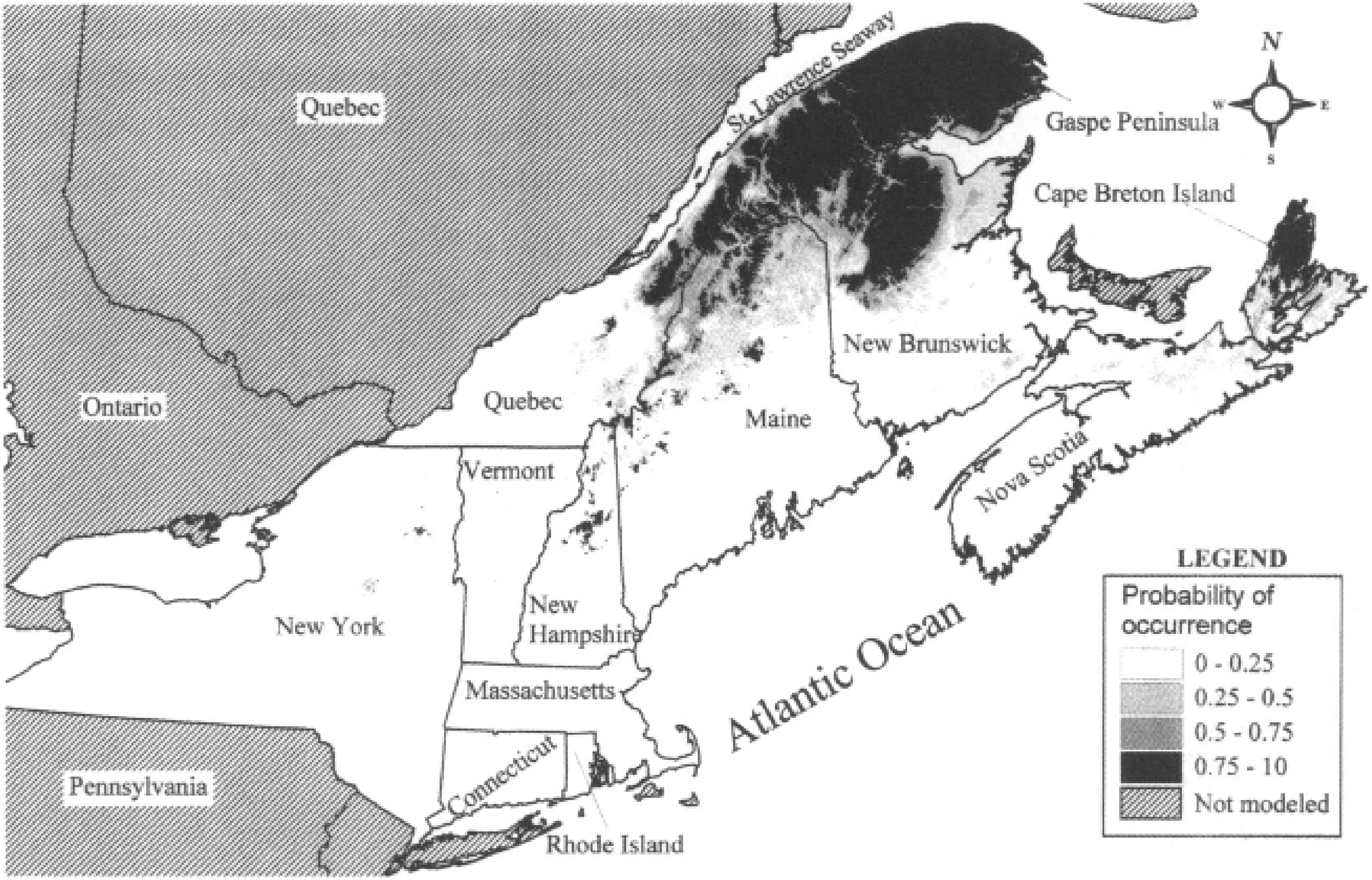


Fig. 2. Relative probability of Canada lynx occurrence based on snowfall and extent of deciduous cover throughout northeastern North America, south of the St. Lawrence Seaway, as determined from logistic regression modeling.

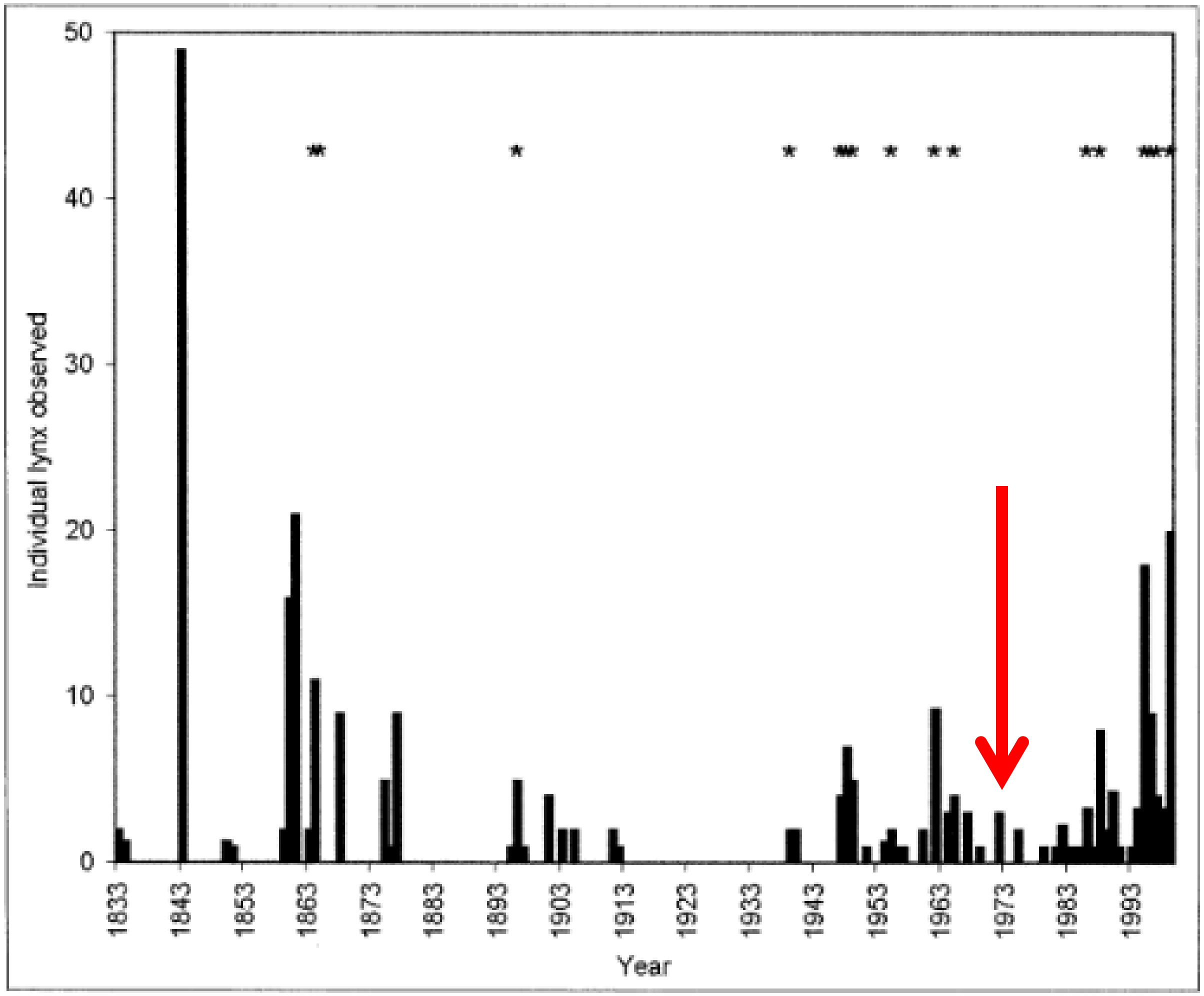
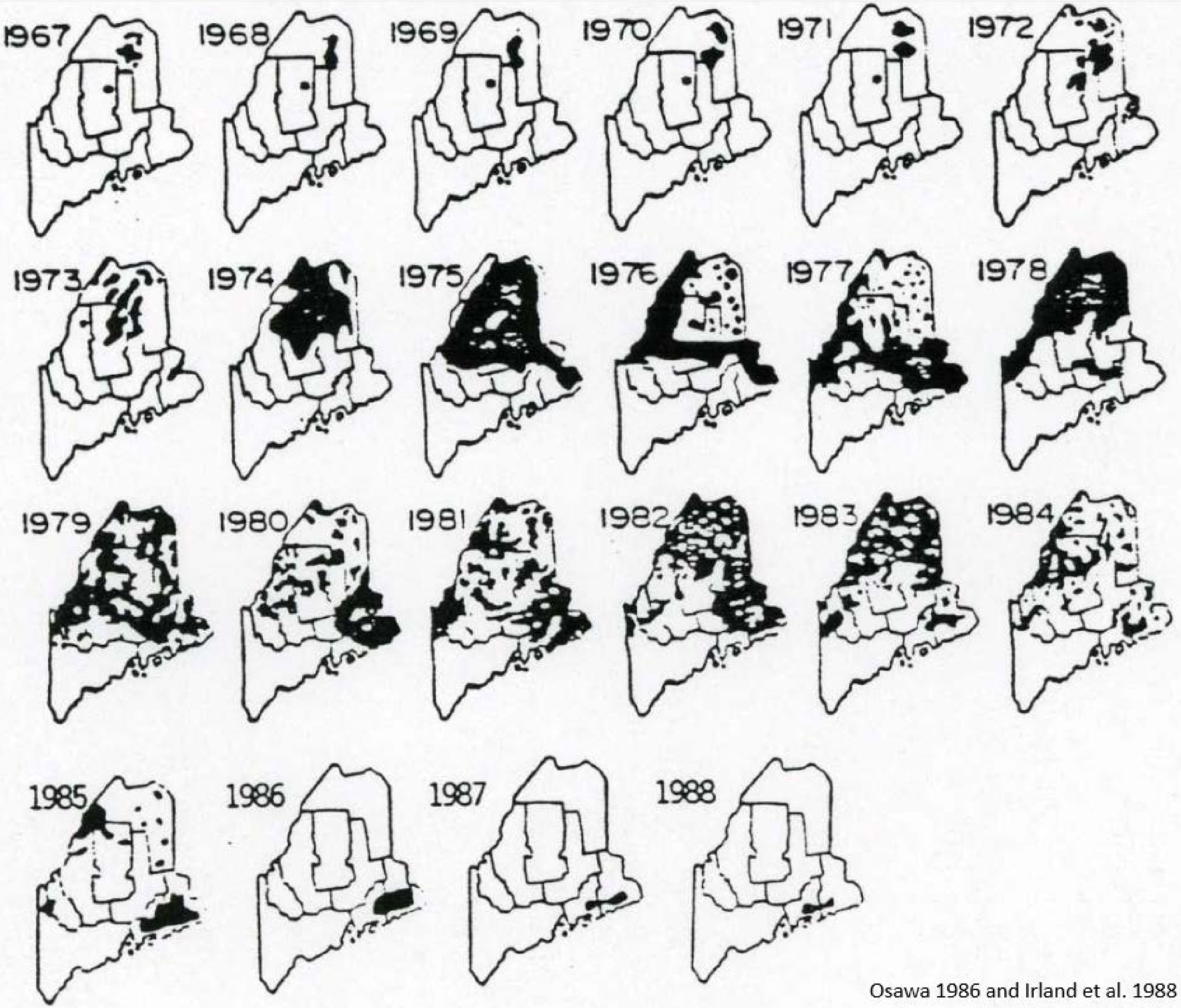


Figure 4. Canada lynx observations in Maine per year, 1833–1999, which were specific township or region. Asterisk indicate records of one or more kittens.

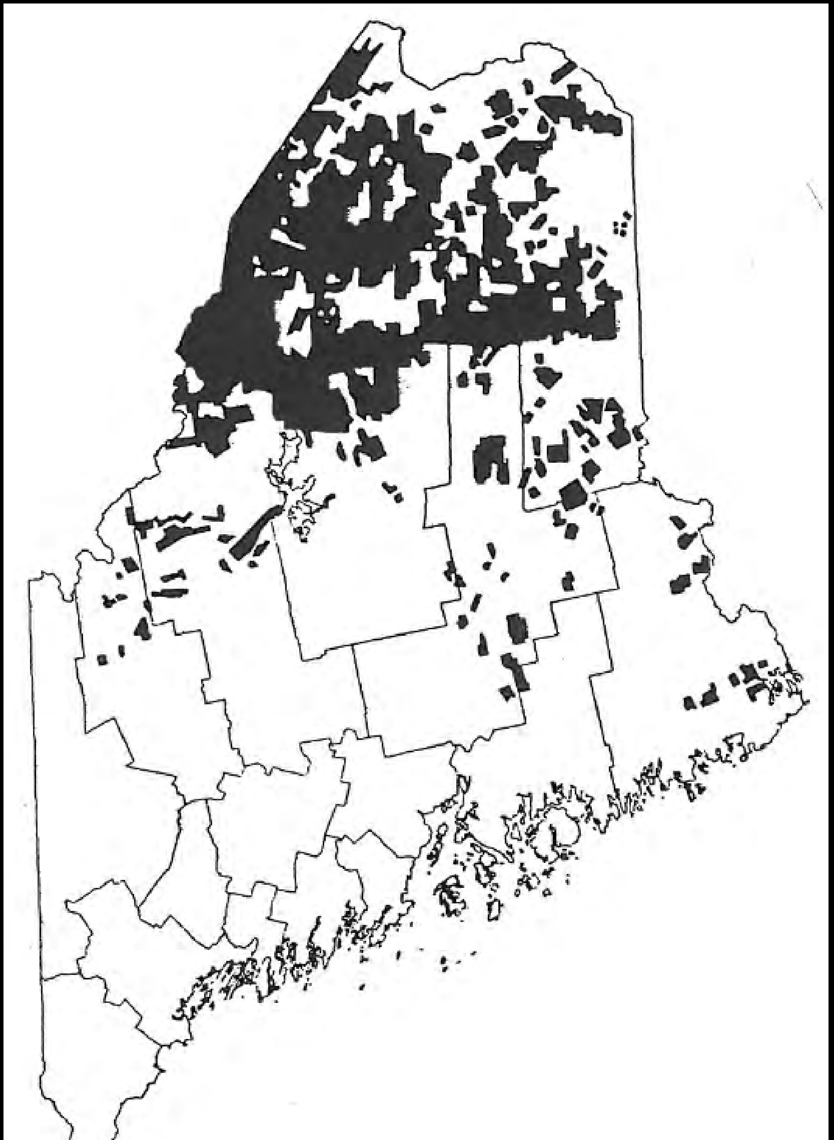
Hoving et al. 2003

Eastern spruce budworm (*Choristoneura fumiferana* Clem.)



Osawa 1986 and Irland et al. 1988

State-run spray protection program, treating several million acres annually at its peak



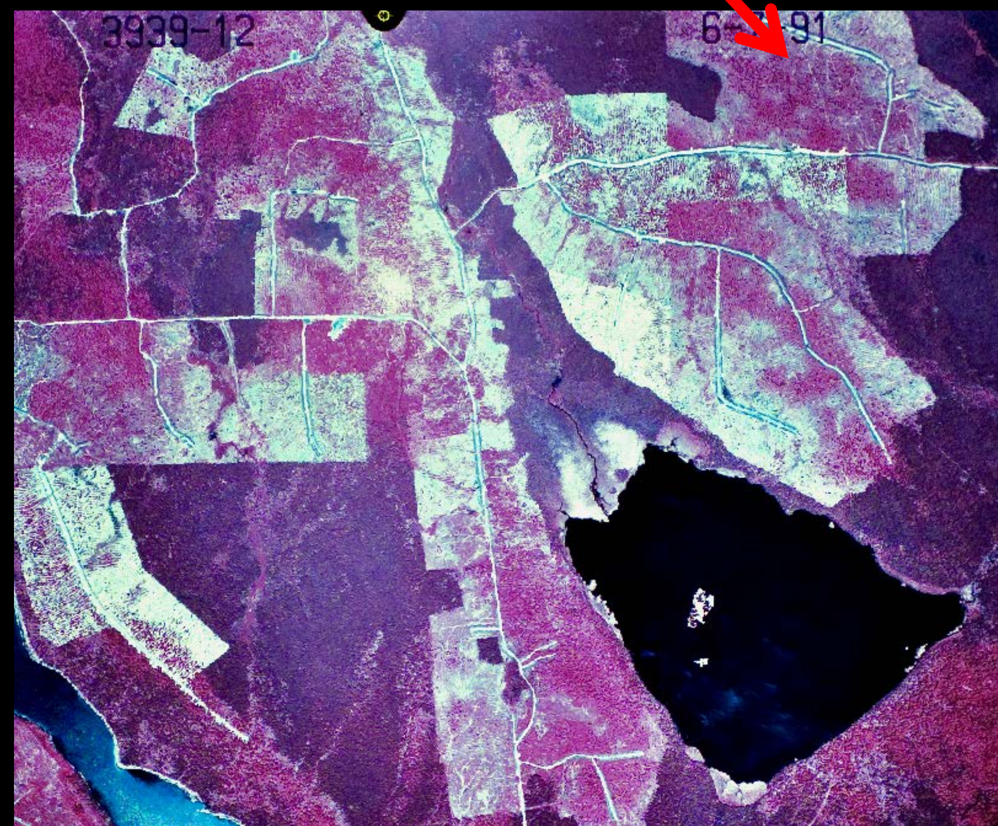
Proposed spray blocks, 1979

Irland et al. 1988

Severe mortality
- 20-25 million cords of spruce and fir killed

Salvage logging by commercial clearcut

Approx. 1500 ac salvage harvest block



Maine Forest Practices Act, 1989

Forest Practices Act (FPA)

Introduction
This rule regulates the size, arrangement, regeneration and management of clearcuts.

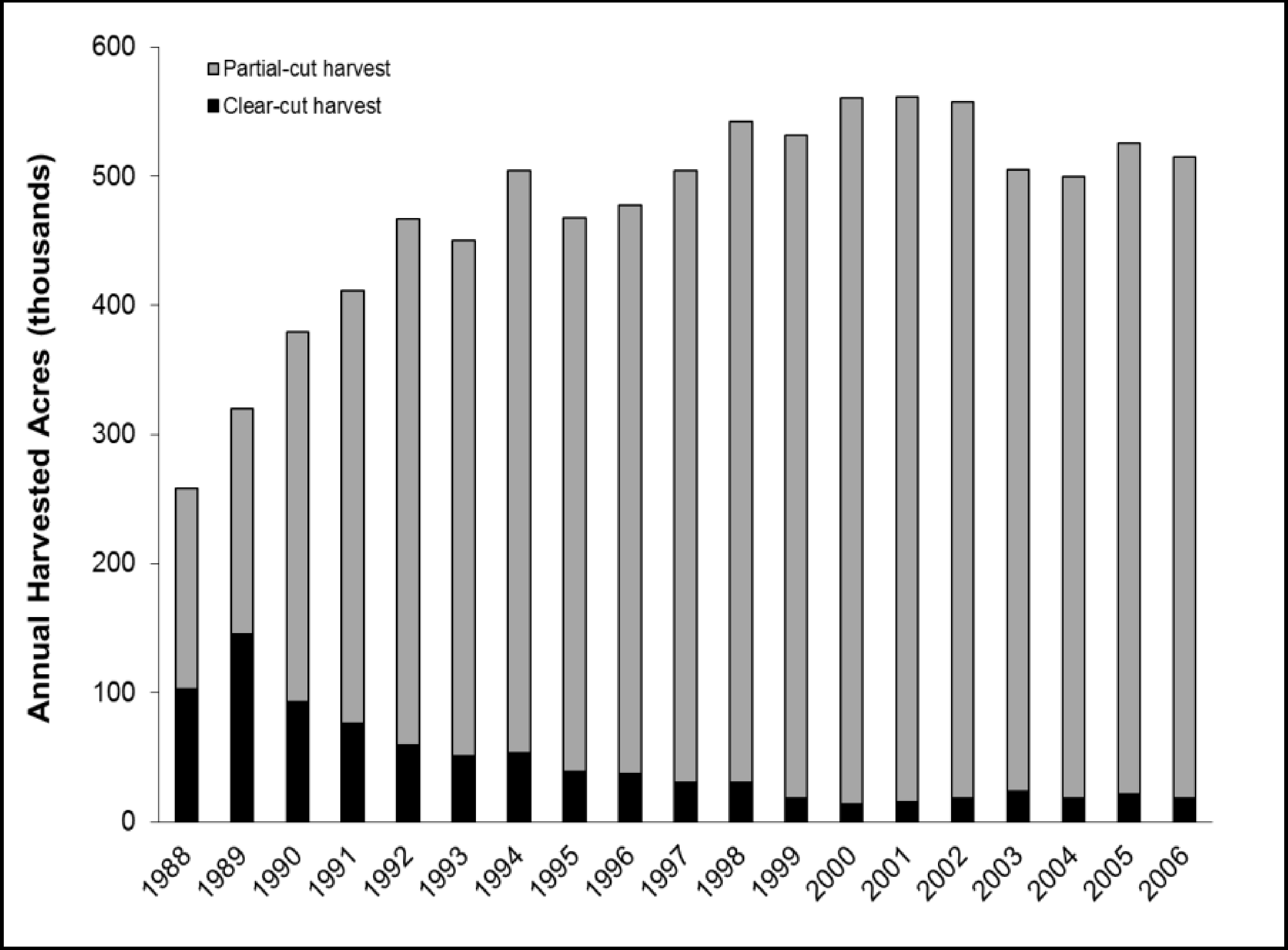
Photo: Maine Forest Service

Proper Name of the Rule
Maine Forest Service – Chapter 20
Forest Regeneration & Clearcutting Standards – Forest Practices Act

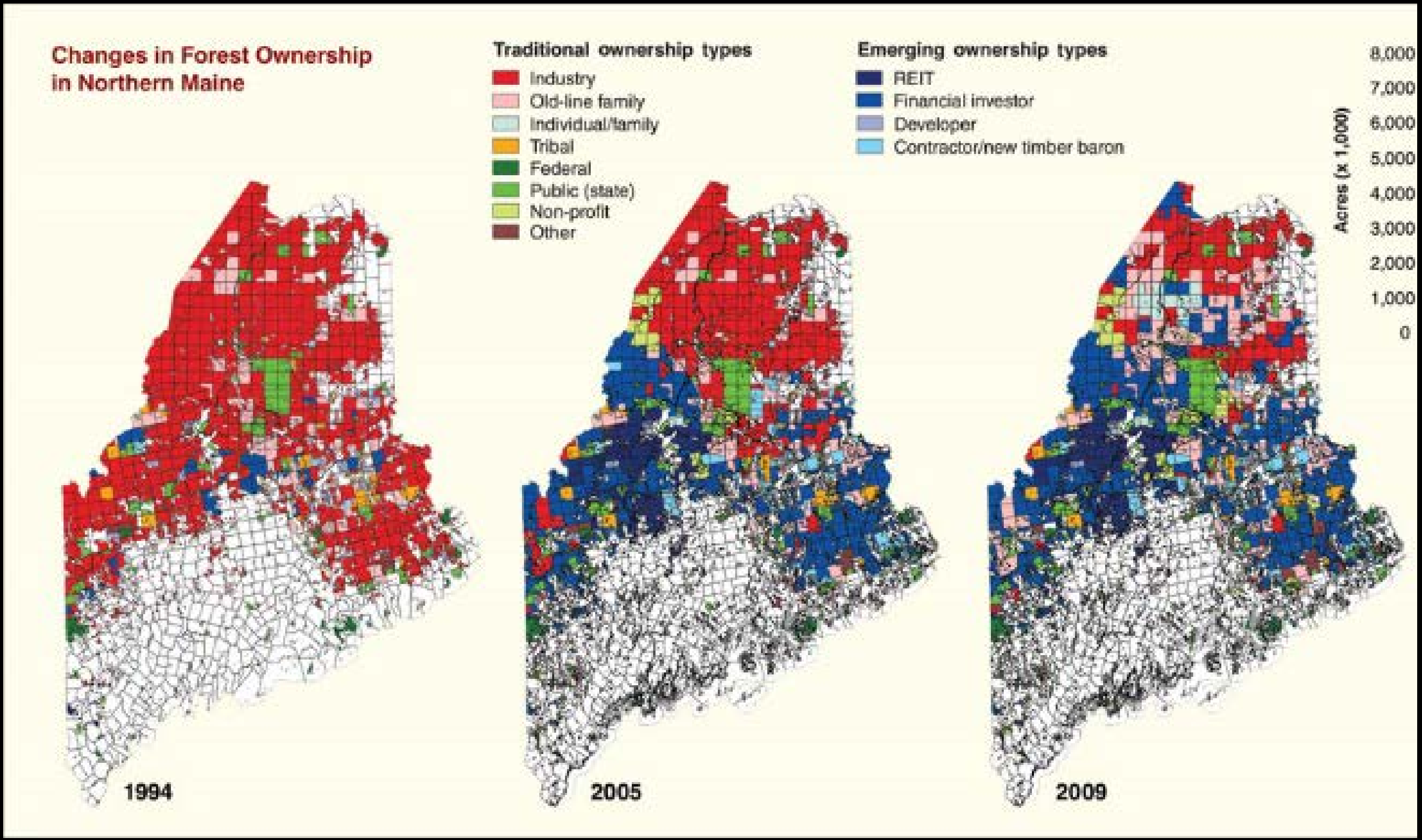
- First legal definition of a clearcut
- Regulation of clearcut size, configuration, regeneration

Maine Forest Practices Act, 1989

Annual statewide harvest

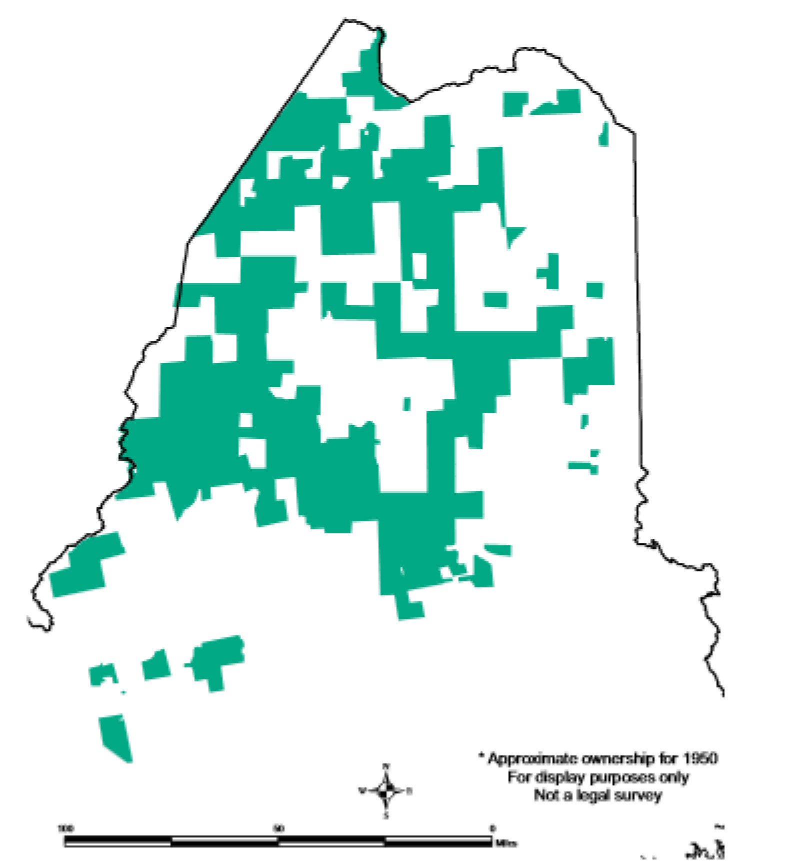


Ownership change

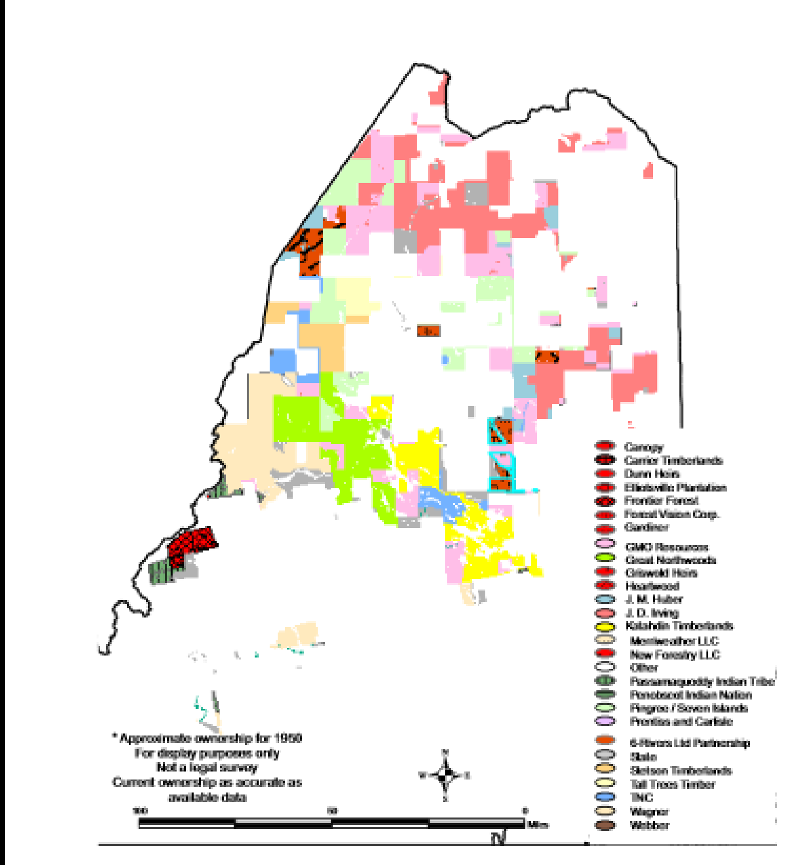


Lilliholm et al. 2010

Ownership change



Great Northern Paper 1950 Land Ownership Map*
Figure 3 Source: Maine Forest Service, used with permission



Great Northern Paper 1950 Land Ownership Today*
Figure 4 Source: Maine Forest Service, used with permission

Ownership change

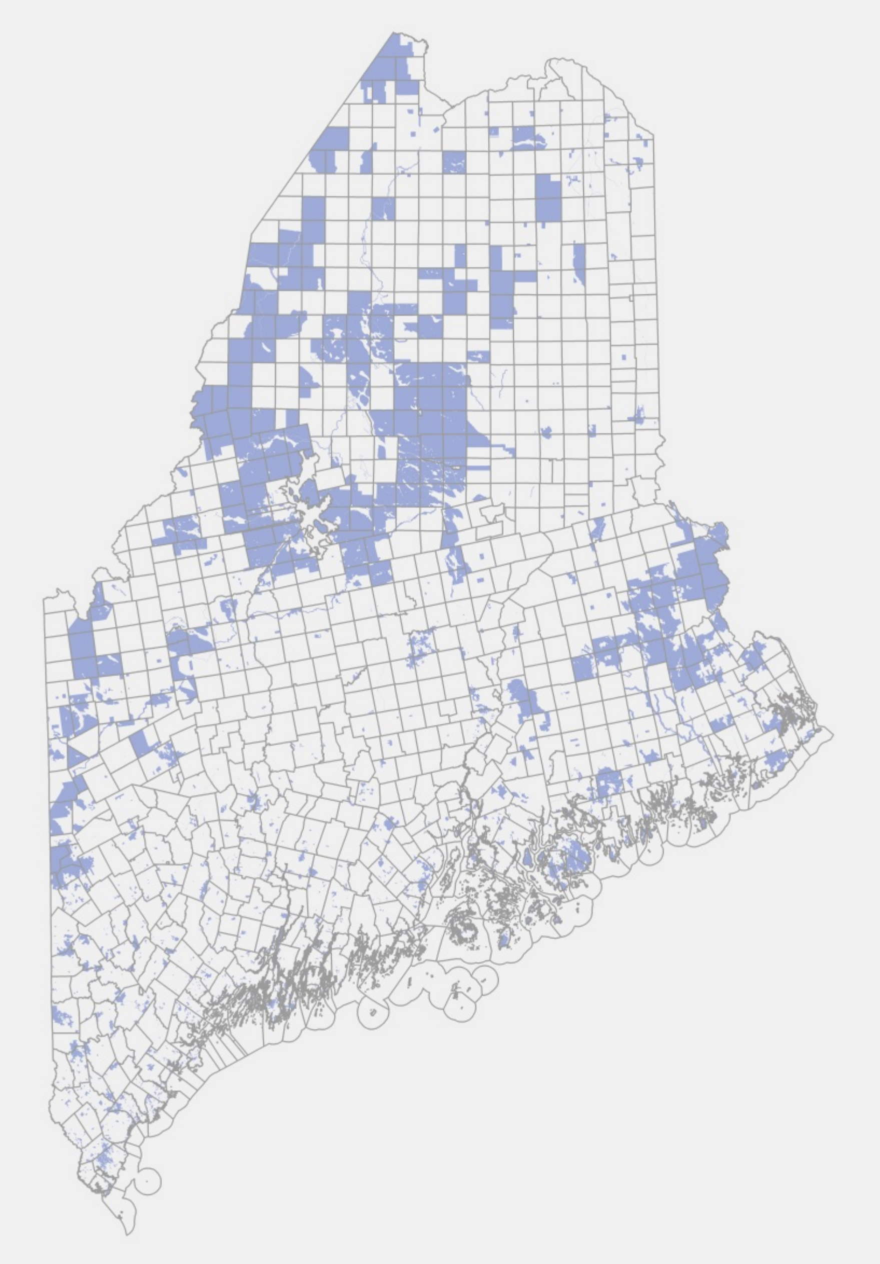
Maine's newest big-time landowner is also the nation's largest landowner

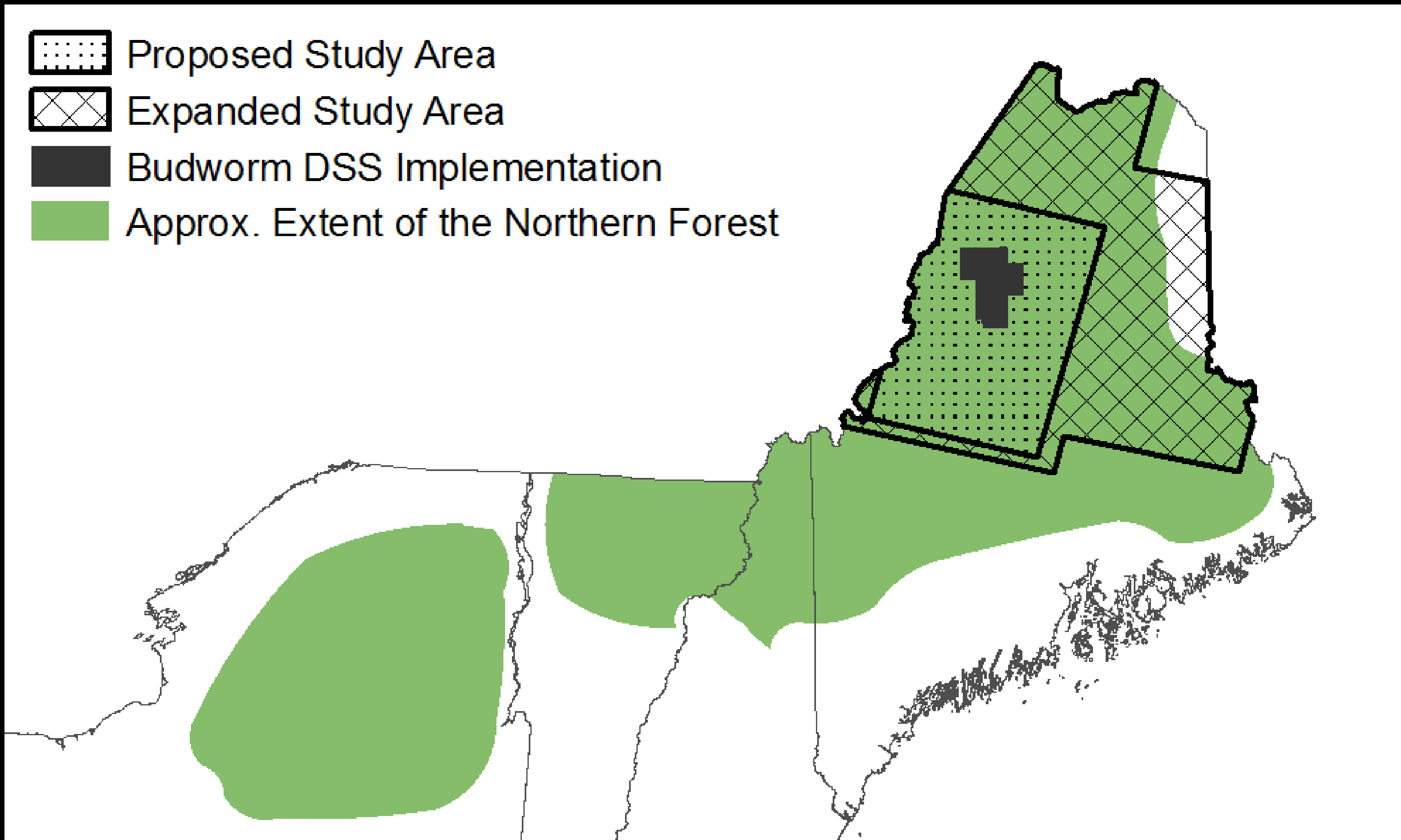
Next 1 of 2

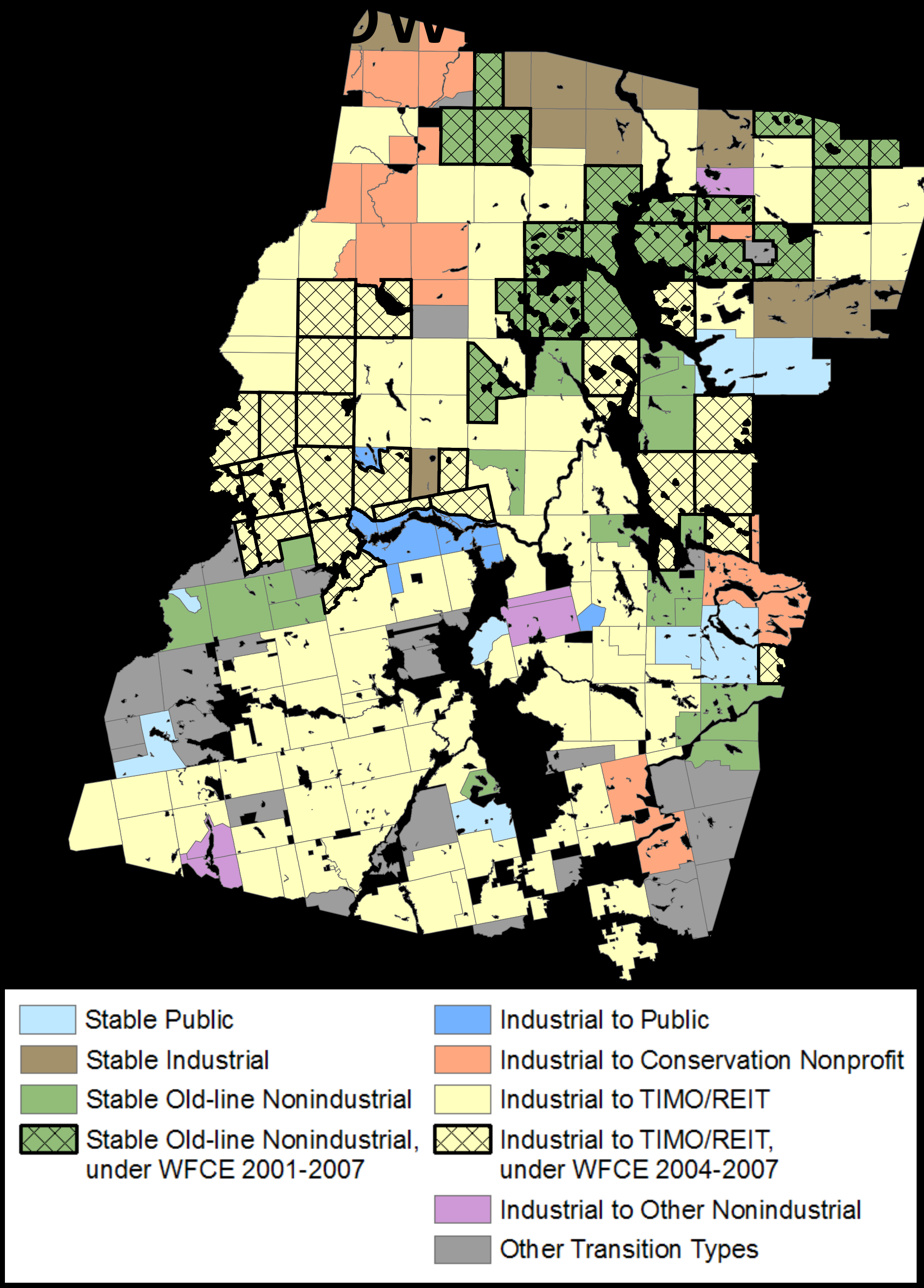
Karl Gehring | Denver Post

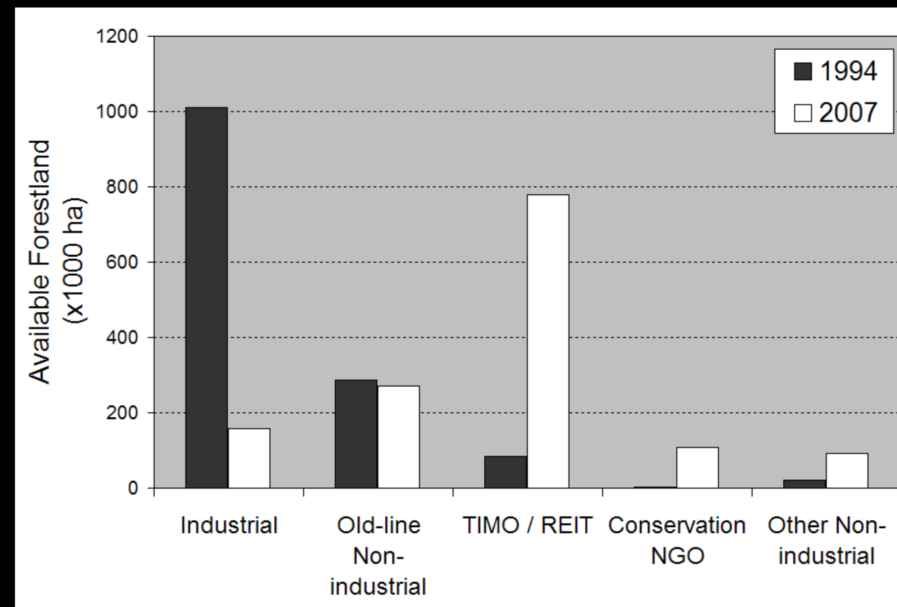
John Malone (center) is now the United States' largest landowner

Conservation easements

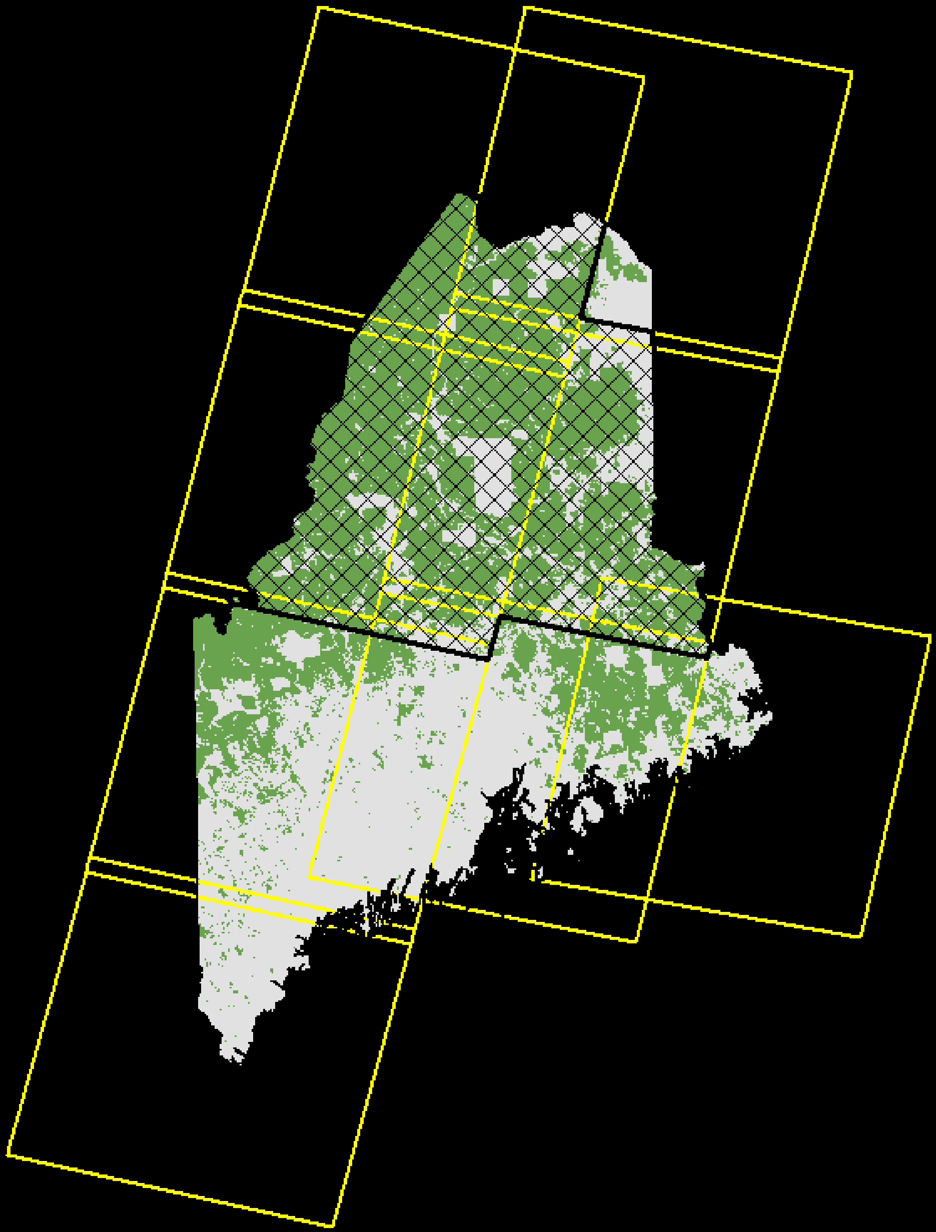



Proposed Study Area
Expanded Study Area
Budworm DSS Implementation
Approx. Extent of the Northern Forest


Stable Public
Stable Industrial
Stable Old-line Nonindustrial
Stable Old-line Nonindustrial, under WFCE 2001-2007
Industrial to Public
Industrial to Conservation Nonprofit
Industrial to TIMO/REIT
Industrial to TIMO/REIT, under WFCE 2004-2007
Industrial to Other Nonindustrial
Other Transition Types


Available Forestland (x1000 ha)
1200
1000
800
600
400
200
0
1994
2007
Industrial
Old-line Non-industrial
TIMO / REIT
Conservation NGO
Other Non-industrial

Forest disturbance, age, composition mapping



Landsat Thematic Mapper:

2010
2007
2004
2001
1998
1995
1993
1991
1988
1985

2-3 year intervals
- stand-replacing and partial canopy disturbance
- disturbance intensity (% basal area removed)

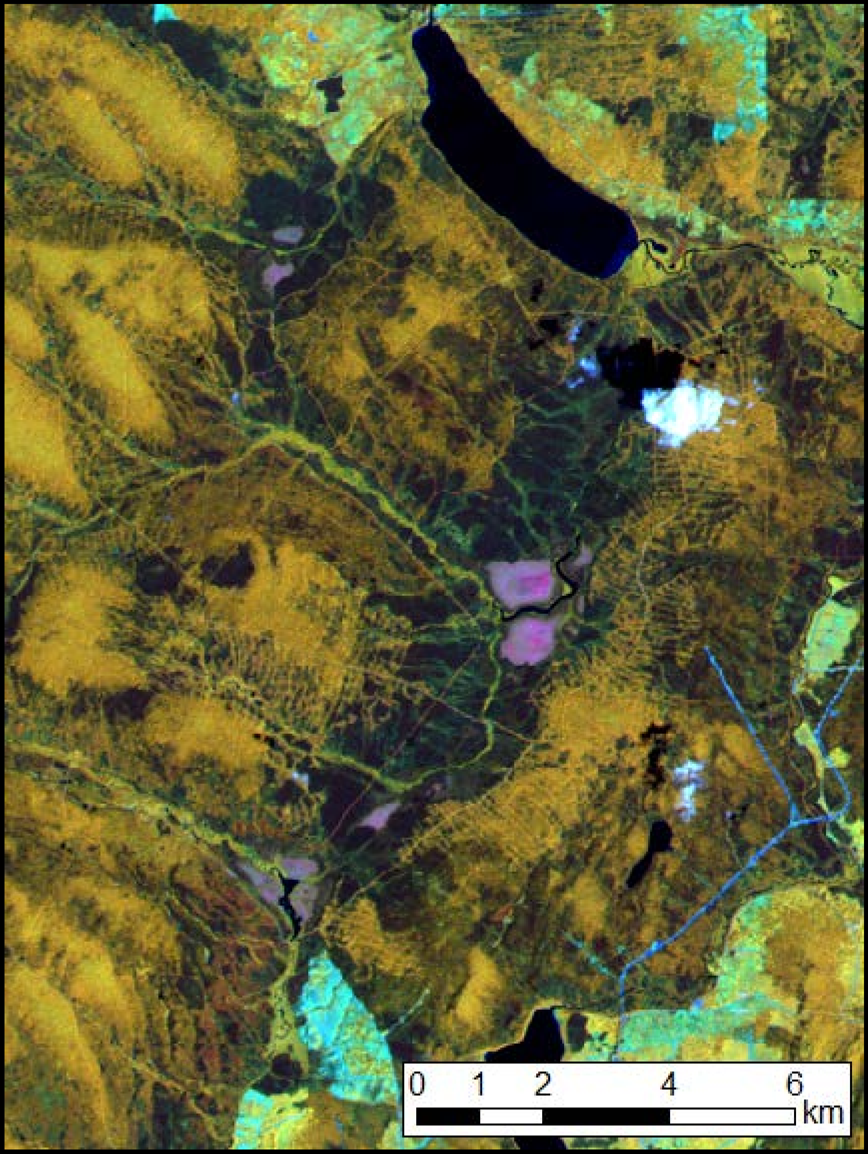
Landsat Multispectral Scanner:

1985
1982
1978
1975
1973

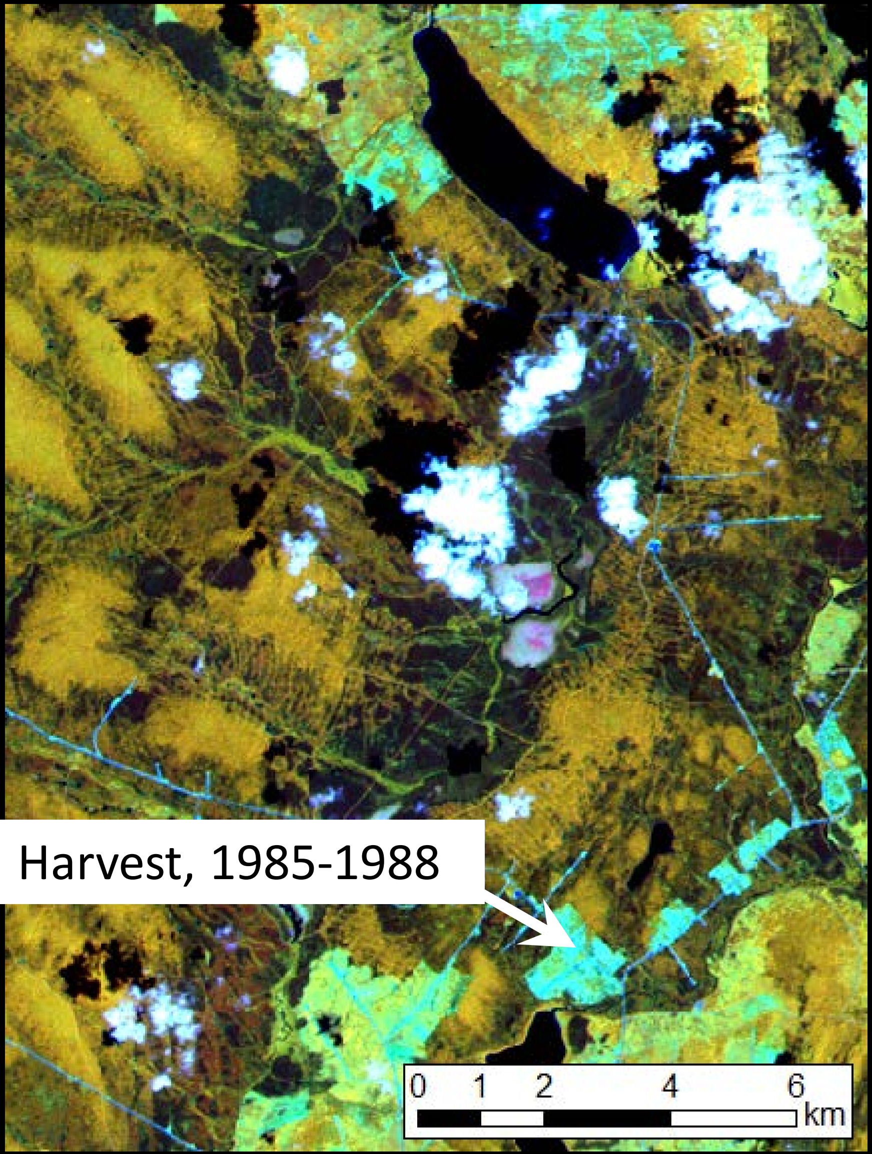
2-4 year intervals
- stand-replacing disturbance

Forest disturbance, age, composition mapping

1985 Landsat:

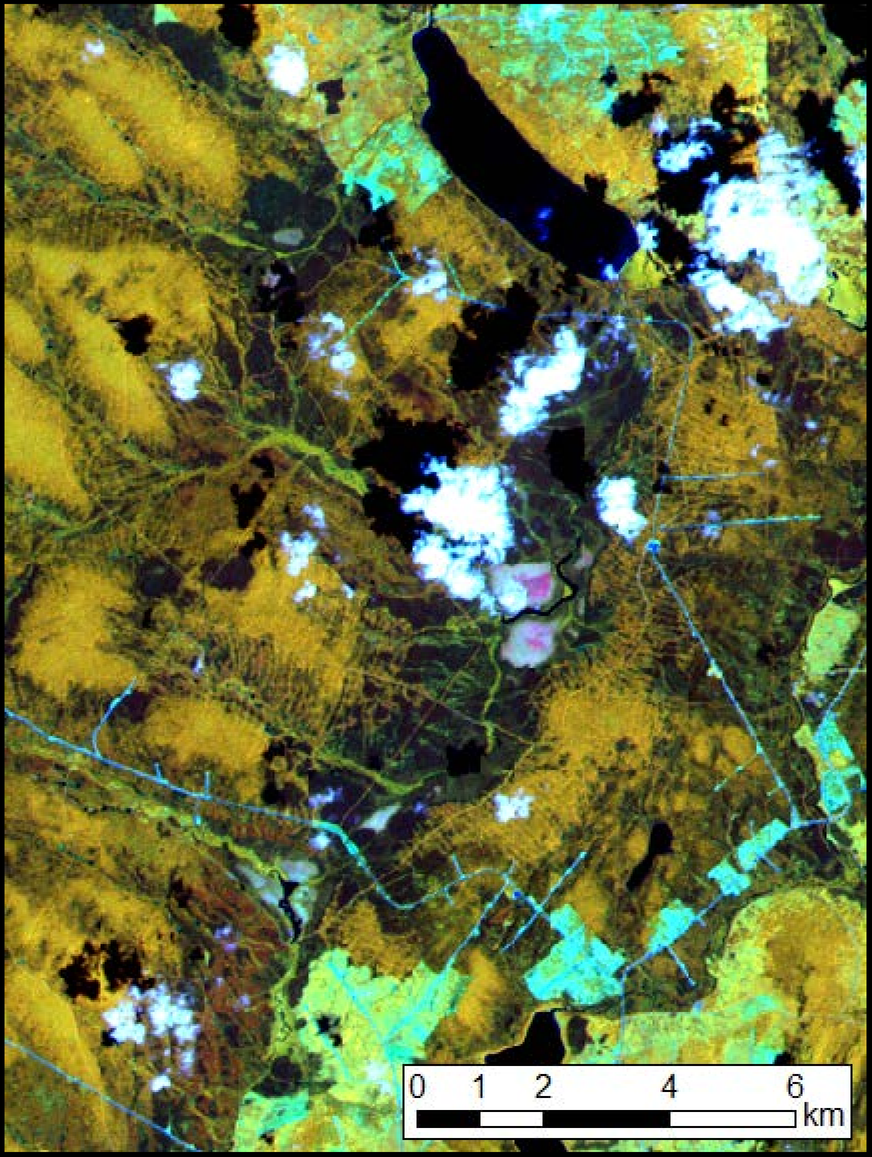


1988 Landsat:

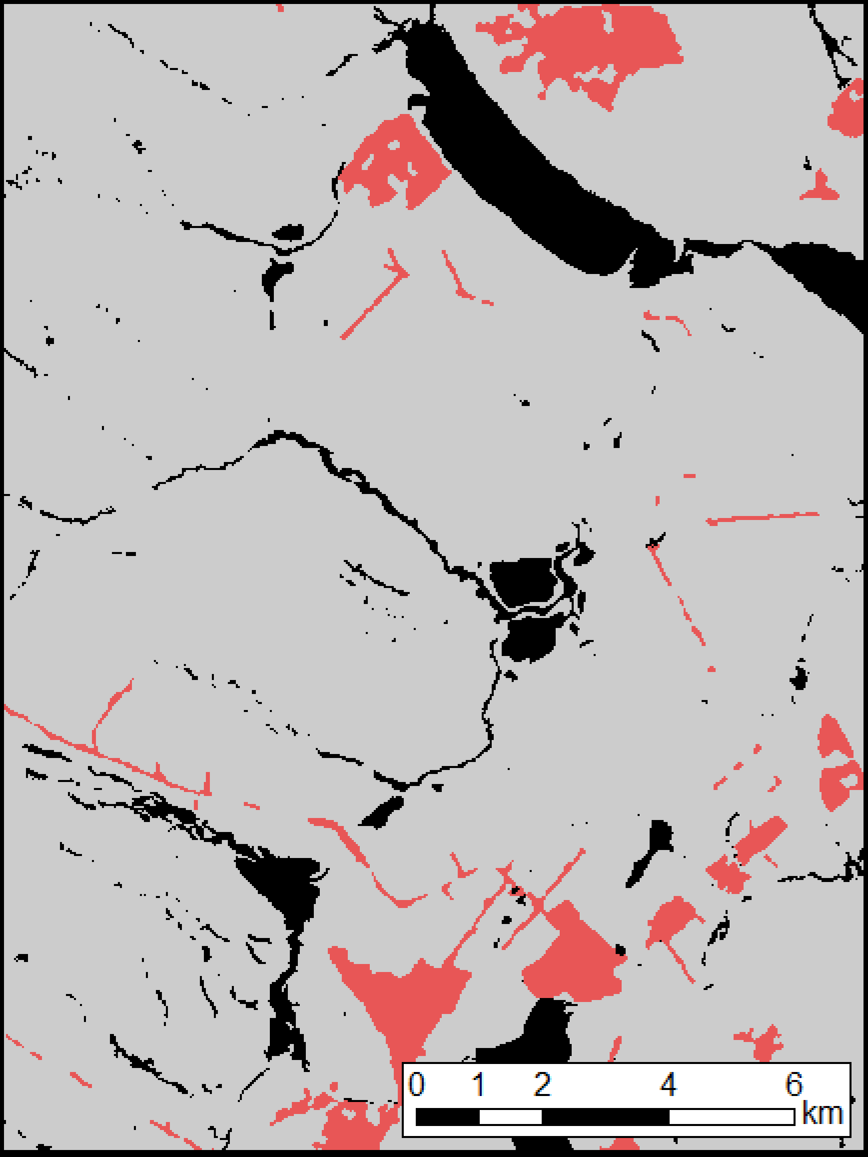


Forest disturbance, age, composition mapping

1988 Landsat:

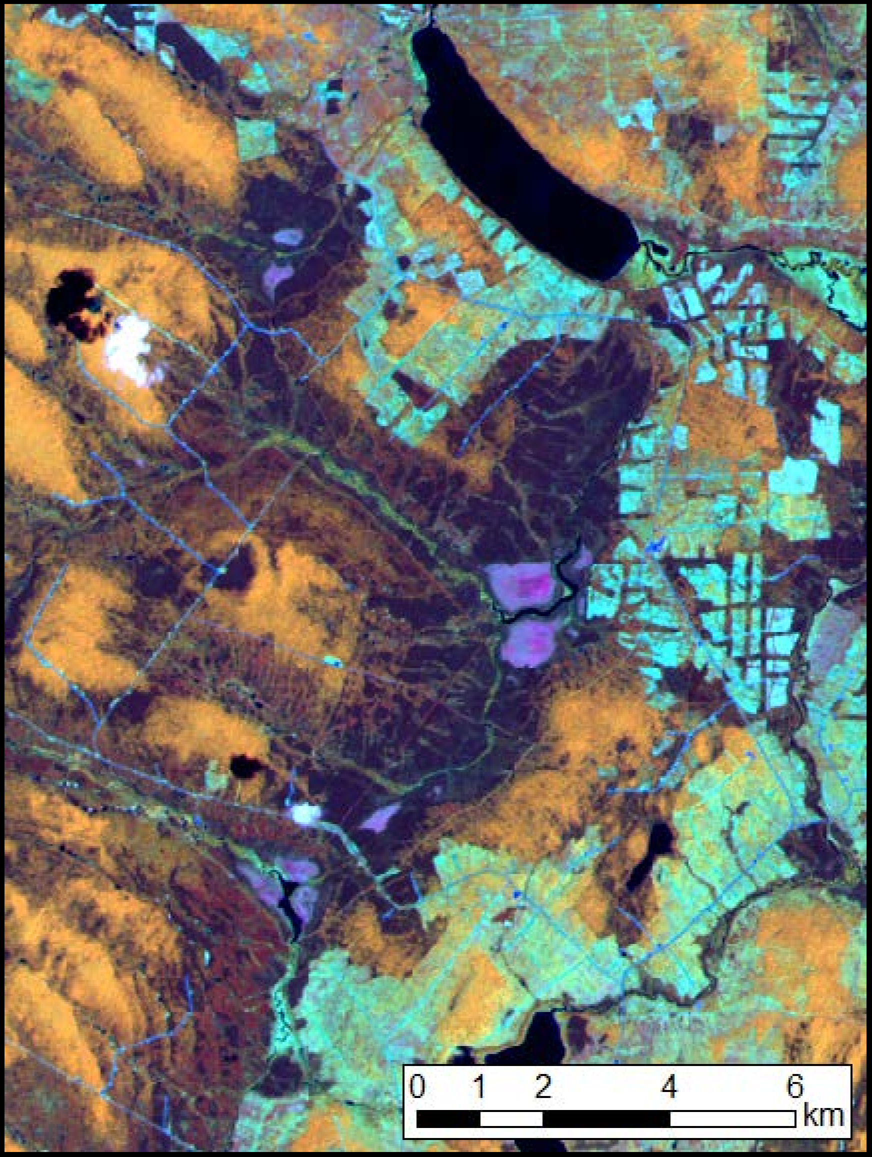


1985-1988 forest disturbance:

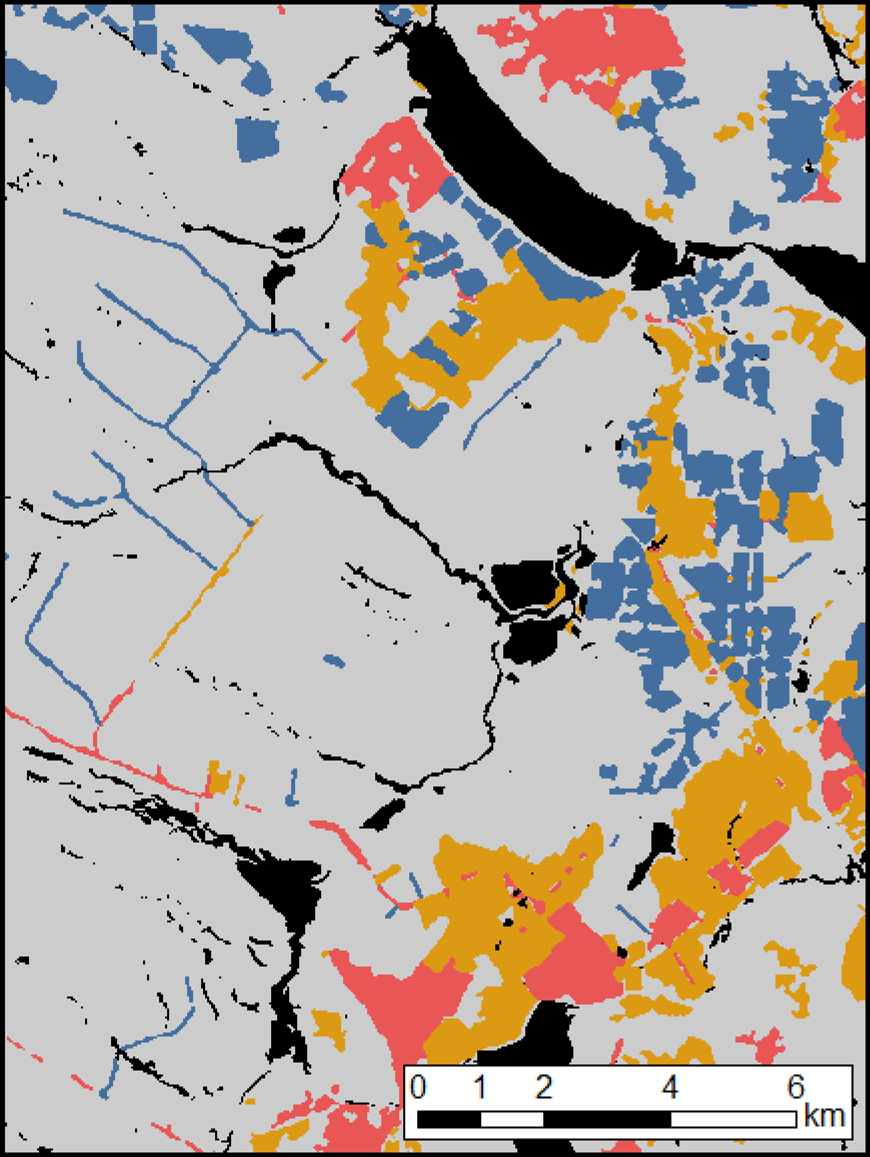


Forest disturbance, age, composition mapping

1993 Landsat:



1985-1993 forest disturbance:



The Journal of Wildlife Management 77(3):567–578; 2013; DOI: 10.1002/jwmg.508

Management and Conservation

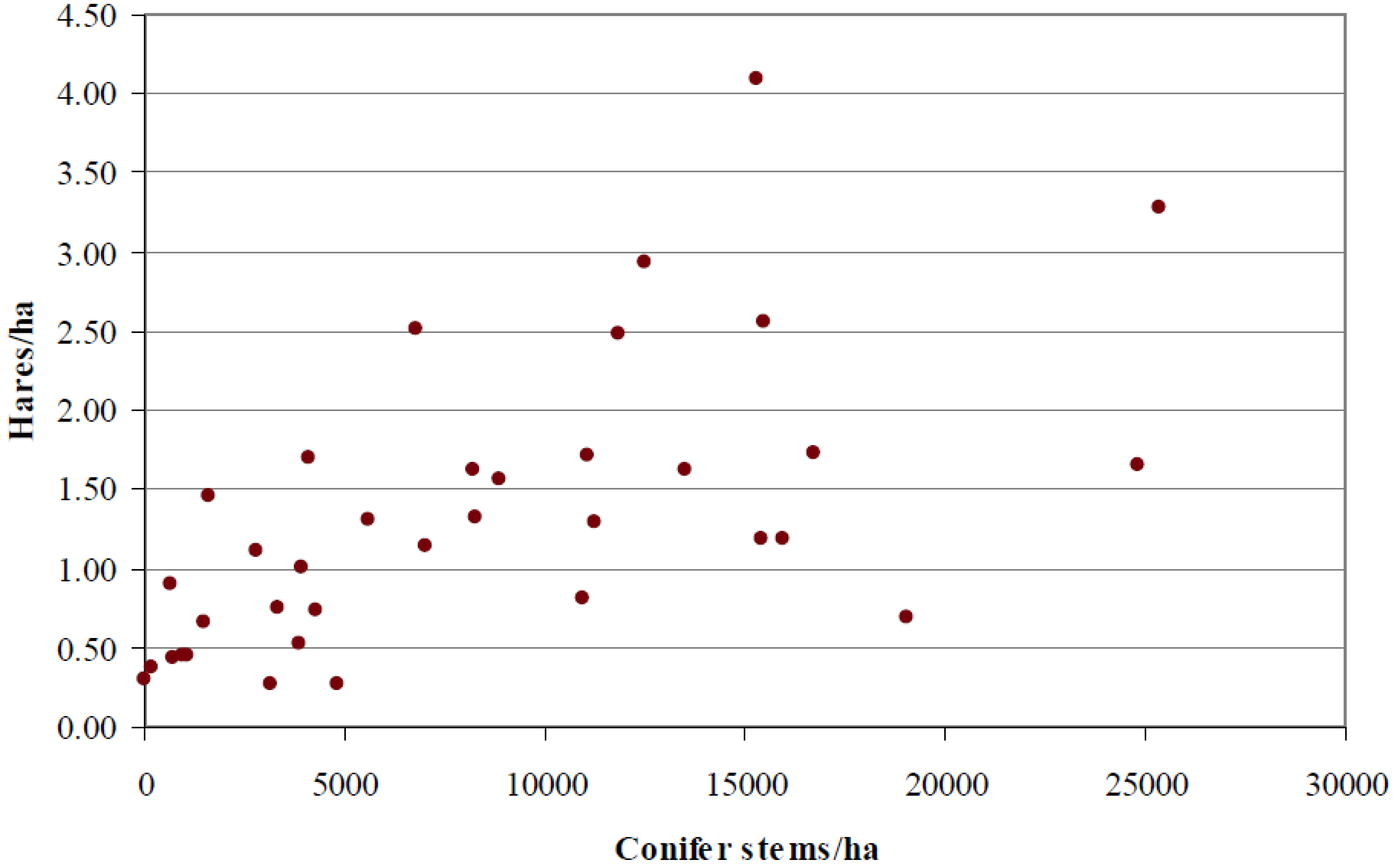
Canada Lynx Occurrence and Forest Management in the Acadian Forest

ERIN M. SIMONS-LEGAARD,[1,2] *Department of Wildlife Ecology, University of Maine, 5755 Nutting Hall, Orono, ME 04469, USA*
DANIEL J. HARRISON, *Department of Wildlife Ecology, University of Maine, 5755 Nutting Hall, Orono, ME 04469, USA*
WILLIAM B. KROHN, *Department of Wildlife Ecology, University of Maine, 5755 Nutting Hall, Orono, ME 04469, USA*
JENNIFER H. VASHON, *Maine Department of Inland Fisheries and Wildlife, 650 State Street, Bangor, ME 04401, USA*

Table 1. Forest classes mapped using a time series of Landsat satellite images, class areas circa 2004 (km^2), stand-scale snowshoe hare densities, and references for hare densities used to predict occurrence of Canada lynx across our 16,530-km^2 study area in the Acadian Forest of Maine, USA, 2003–2006.

Class	Years post-harvest	Area	Hares/ha	Refs.
Mature forest	>35	7,213	0.24	Fuller and Harrison (2005)
Partially harvested forest[a]				
Recent	1–10	2,151	0.80	Robinson (2006)
Established	11–16	743	0.80	Robinson (2006)
Regenerating forest[b]				
Recent clearcut	1–9	1,053	0	de Bellefeuille et al. (2001)
Coniferous or mixed	10–17	748	0.2–1.6[c]	
Coniferous or mixed	18–35	1,393	1.8	Robinson (2006) and Homyack et al. (2007)
Deciduous	10–35	1,296	0.4	Litvaitis et al. (1985)
Non-forestland[d]		1,933		

[a] Recent and established partially harvested forest defined based on Fuller et al. (2007).
[b] Regenerating forest identified by heavy canopy disturbances detected 1970–2004 using Landsat satellite imagery. Evidence of intensive management in regenerating forest (e.g., precommercial thinning) detected during harvest mapping reduced respective density estimates by 50% based on Homyack et al. (2007).
[c] We assumed a linear relationship between stand age and hare density 10–18 years post-harvest, resulting in an estimated increase of 0.2 hares/ha/year.
[d] Non-forestland included water and non-forested wetland classes.


4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Hares/ha
0
5000
10000
15000
20000
25000
30000
Conifer stems/ha

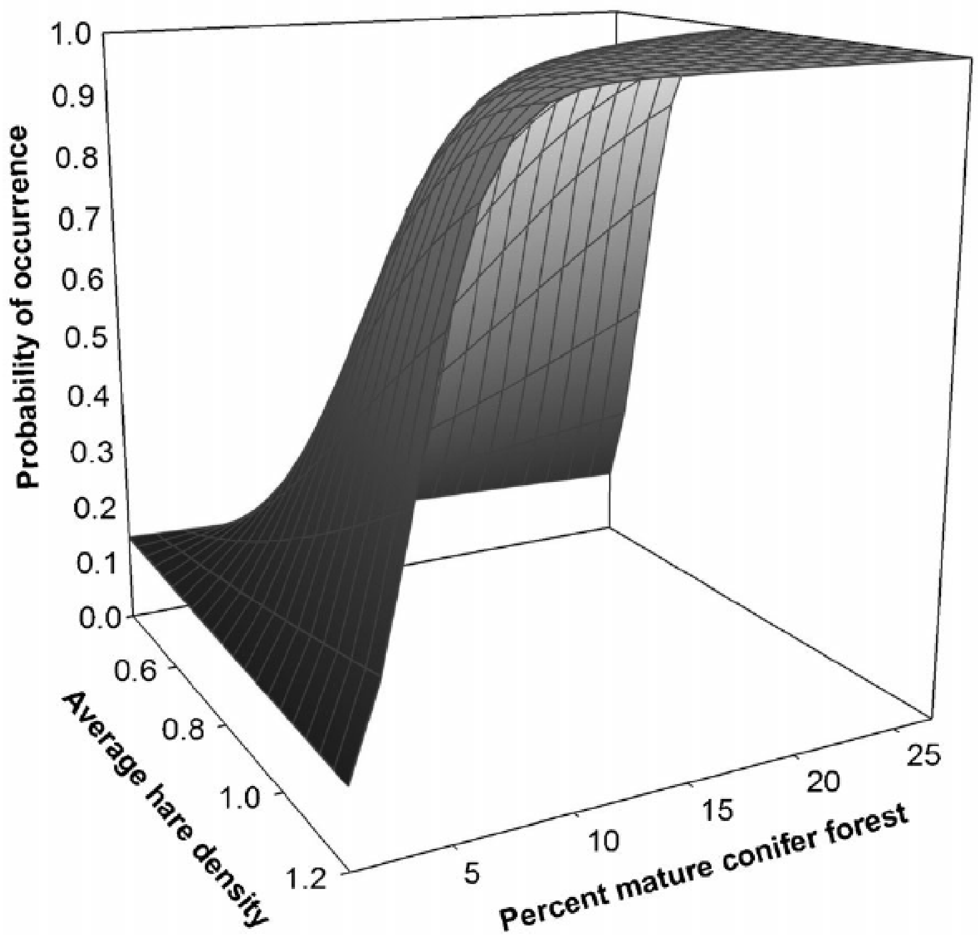
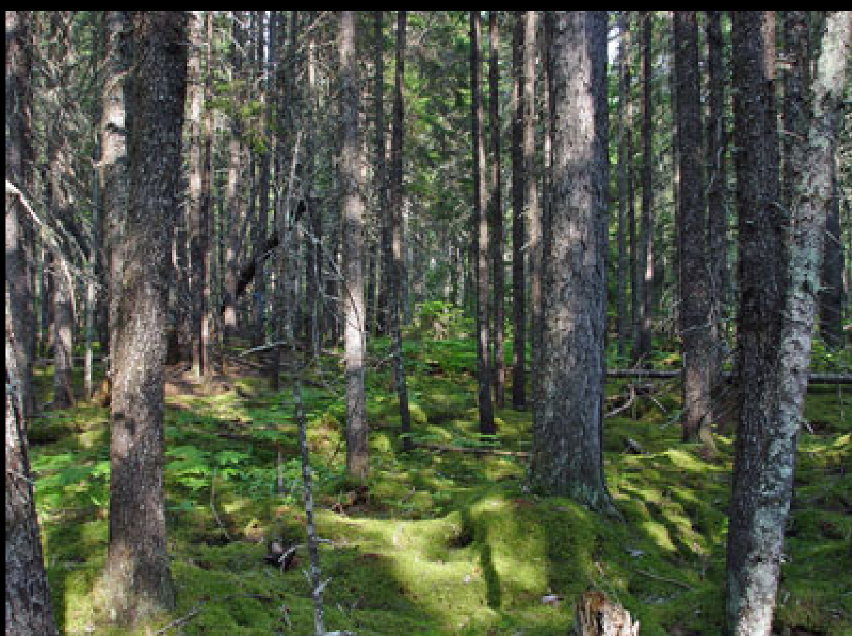
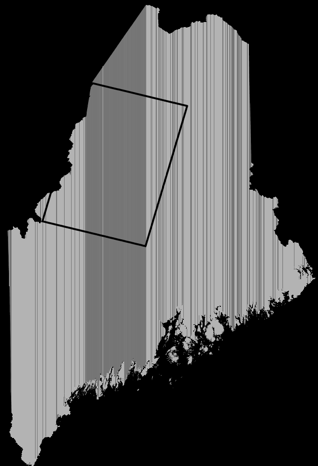
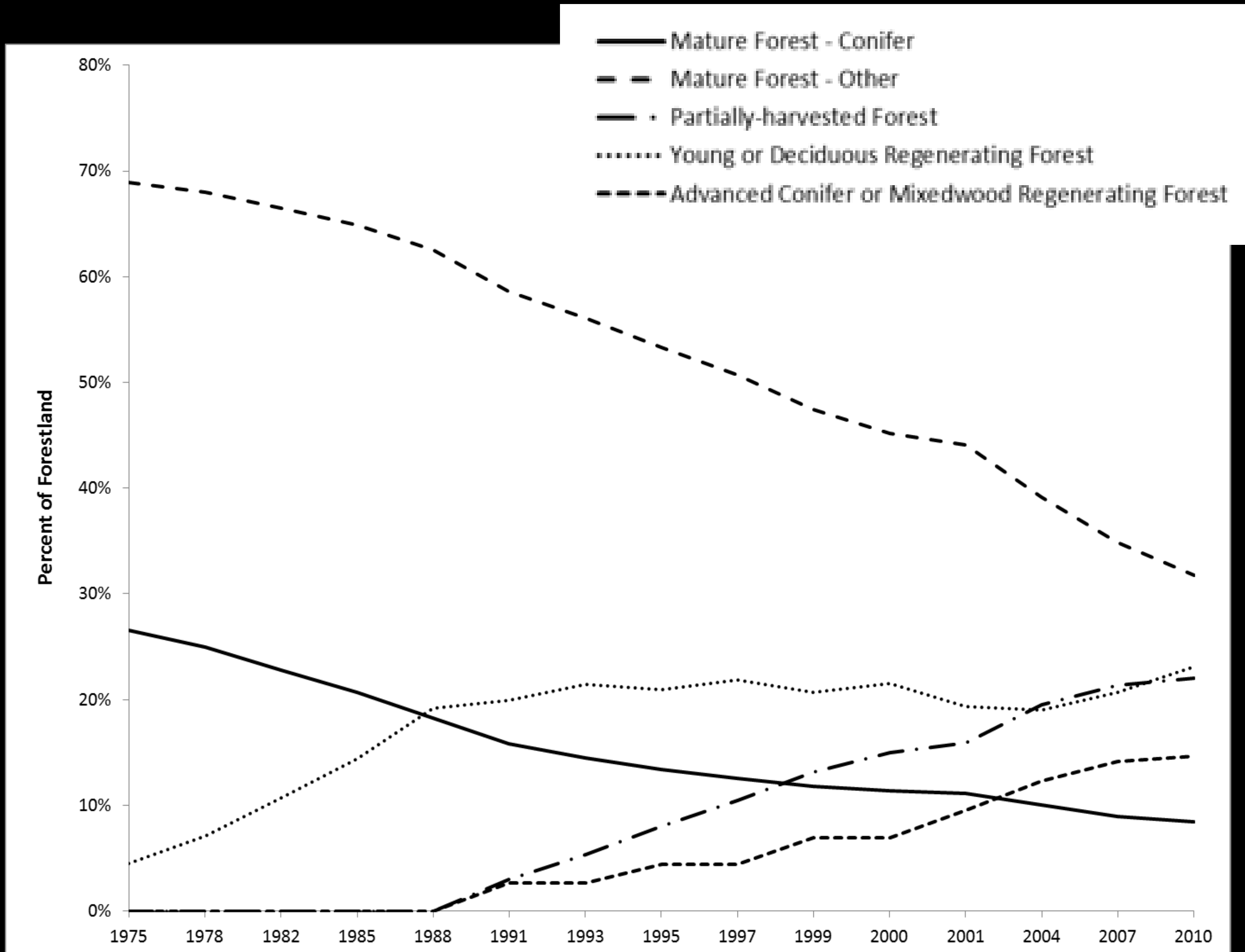


Figure 2. Predicted probability of occurrence of adult Canada lynx modeled at the landscape scale as a function of percent mature conifer and average density of snowshoe hare (hares/ha) using binary logistic regression, 2003–2006, Maine, USA.

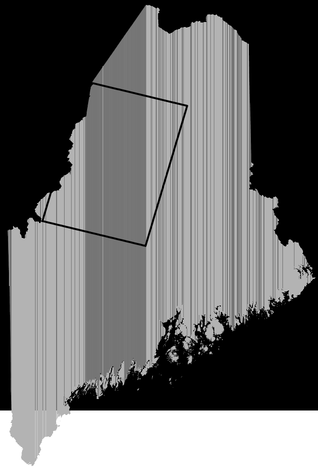


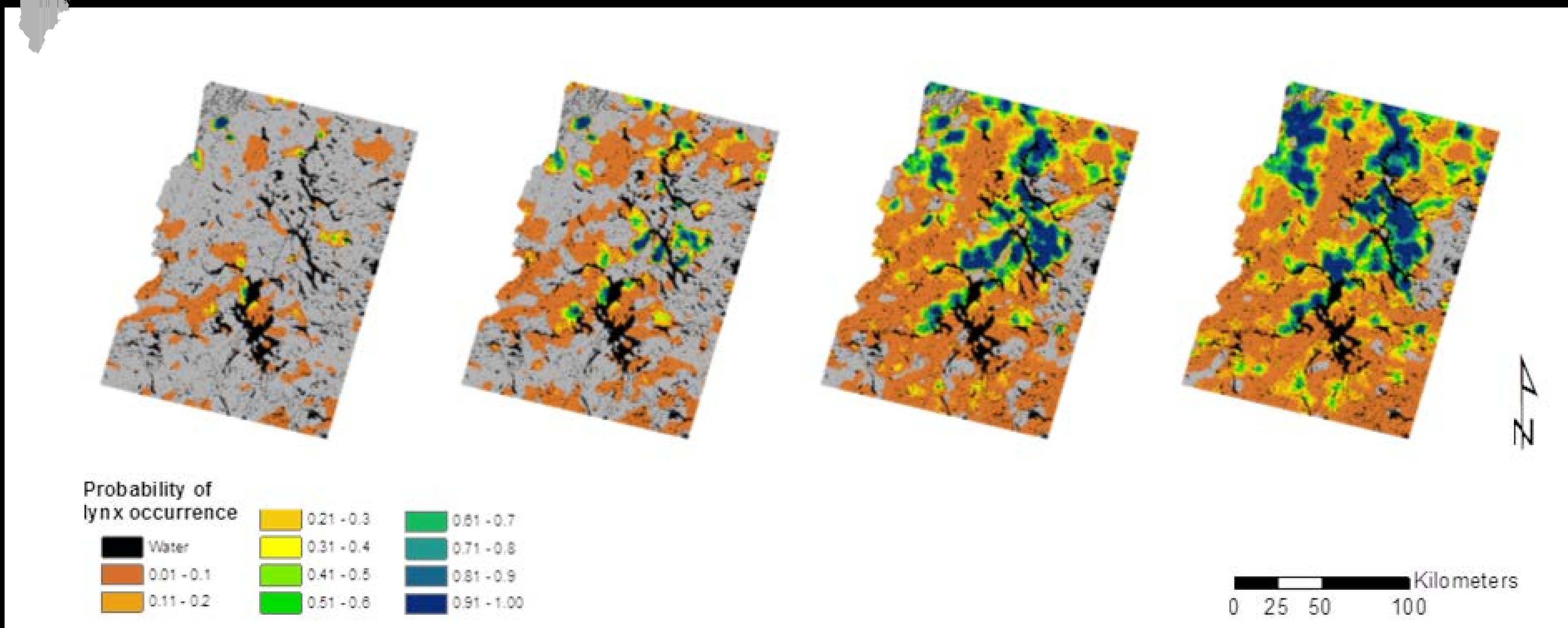


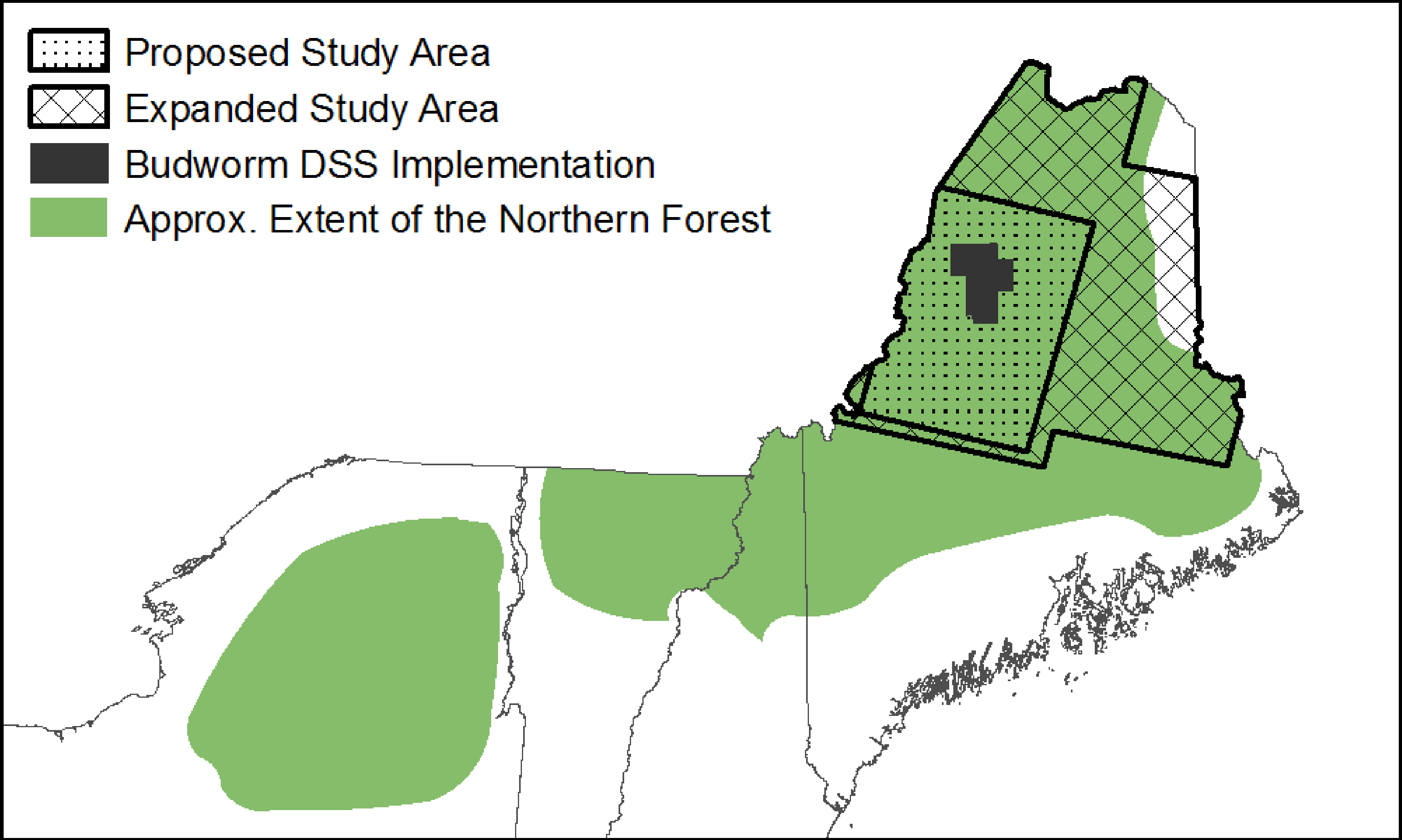


Mature Forest - Conifer
Mature Forest - Other
Partially-harvested Forest
Young or Deciduous Regenerating Forest
Advanced Conifer or Mixedwood Regenerating Forest
Percent of Forestland
80%
70%
60%
50%
40%
30%
20%
10%
0%
1975
1978
1982
1985
1988
1991
1993
1995
1997
1999
2000
2001
2004
2007
2010





Probability of lynx occurrence
Water
0.01 - 0.1
0.11 - 0.2
0.21 - 0.3
0.31 - 0.4
0.41 - 0.5
0.51 - 0.6
0.61 - 0.7
0.71 - 0.8
0.81 - 0.9
0.91 - 1.00
N
Kilometers
0 25 50 100

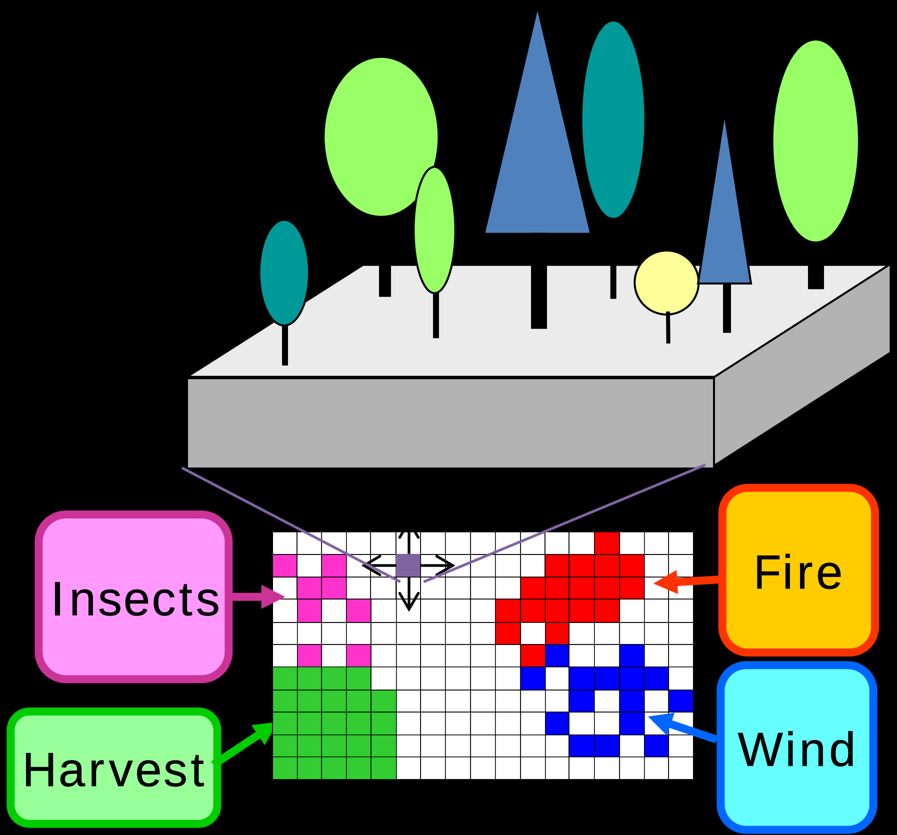

Proposed Study Area
Expanded Study Area
Budworm DSS Implementation
Approx. Extent of the Northern Forest

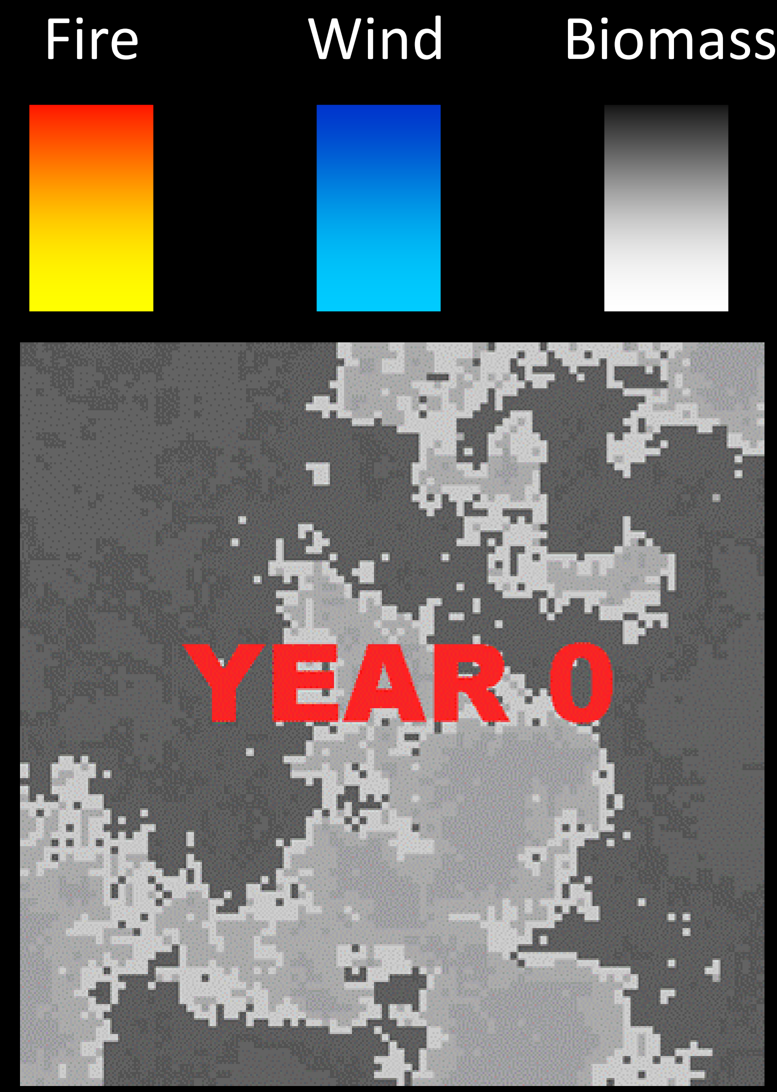
LANDIS-II

sponsored by

THE UNIVERSITY WISCONSIN MADISON

Portland State UNIVERSITY



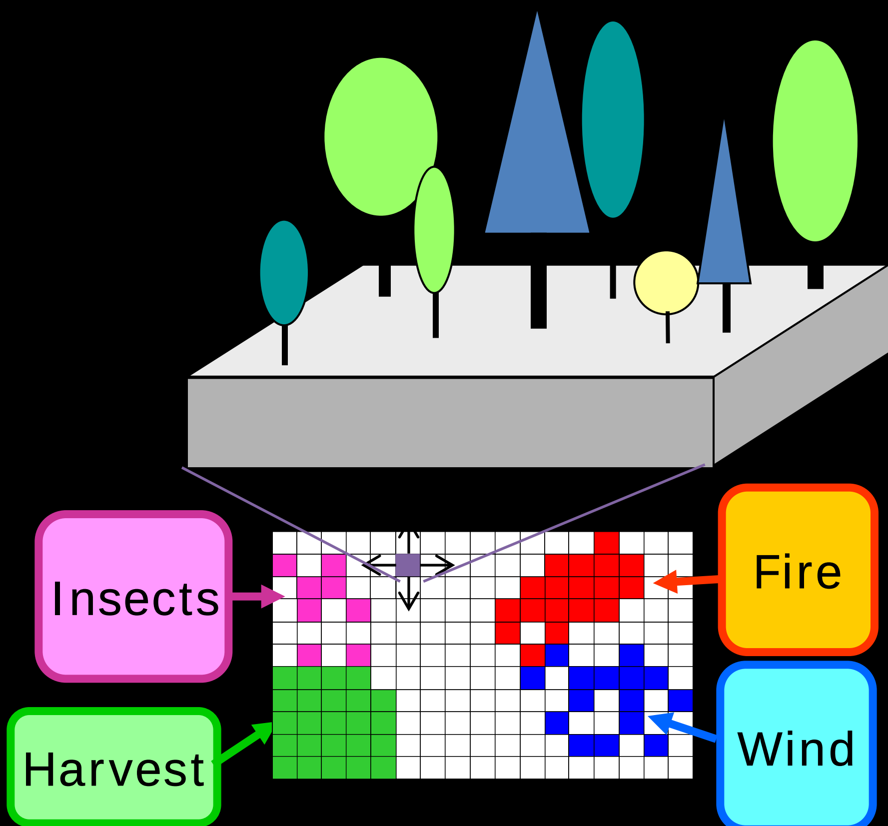


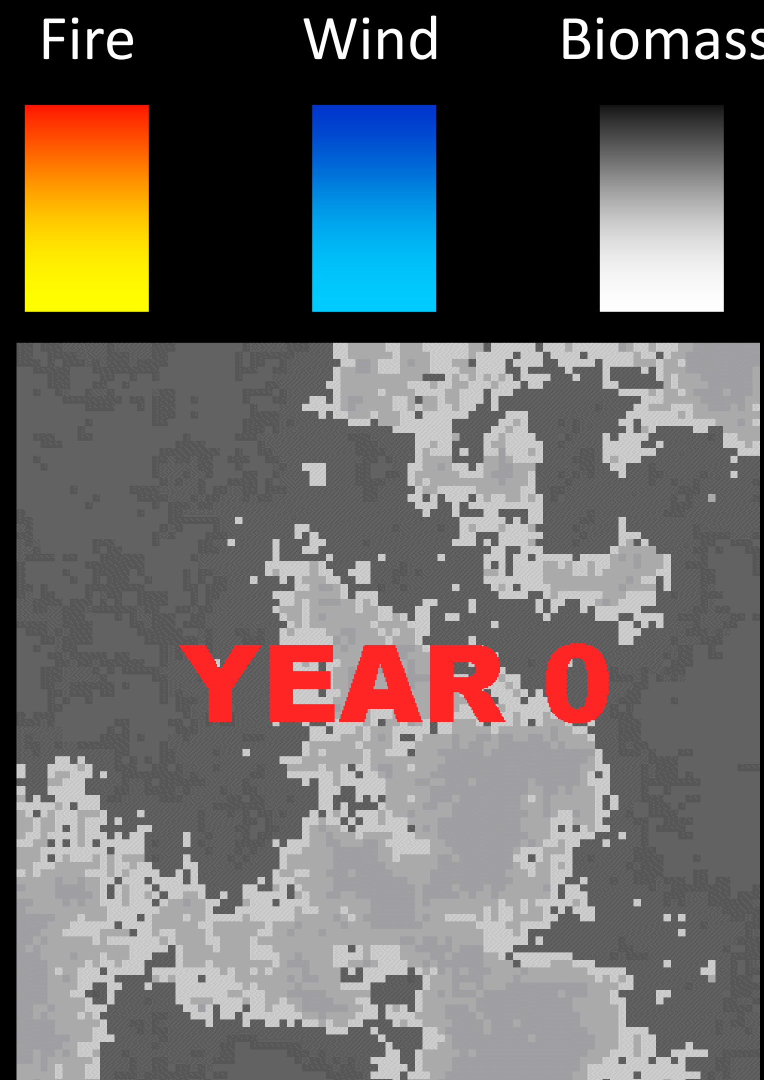
LANDIS-II

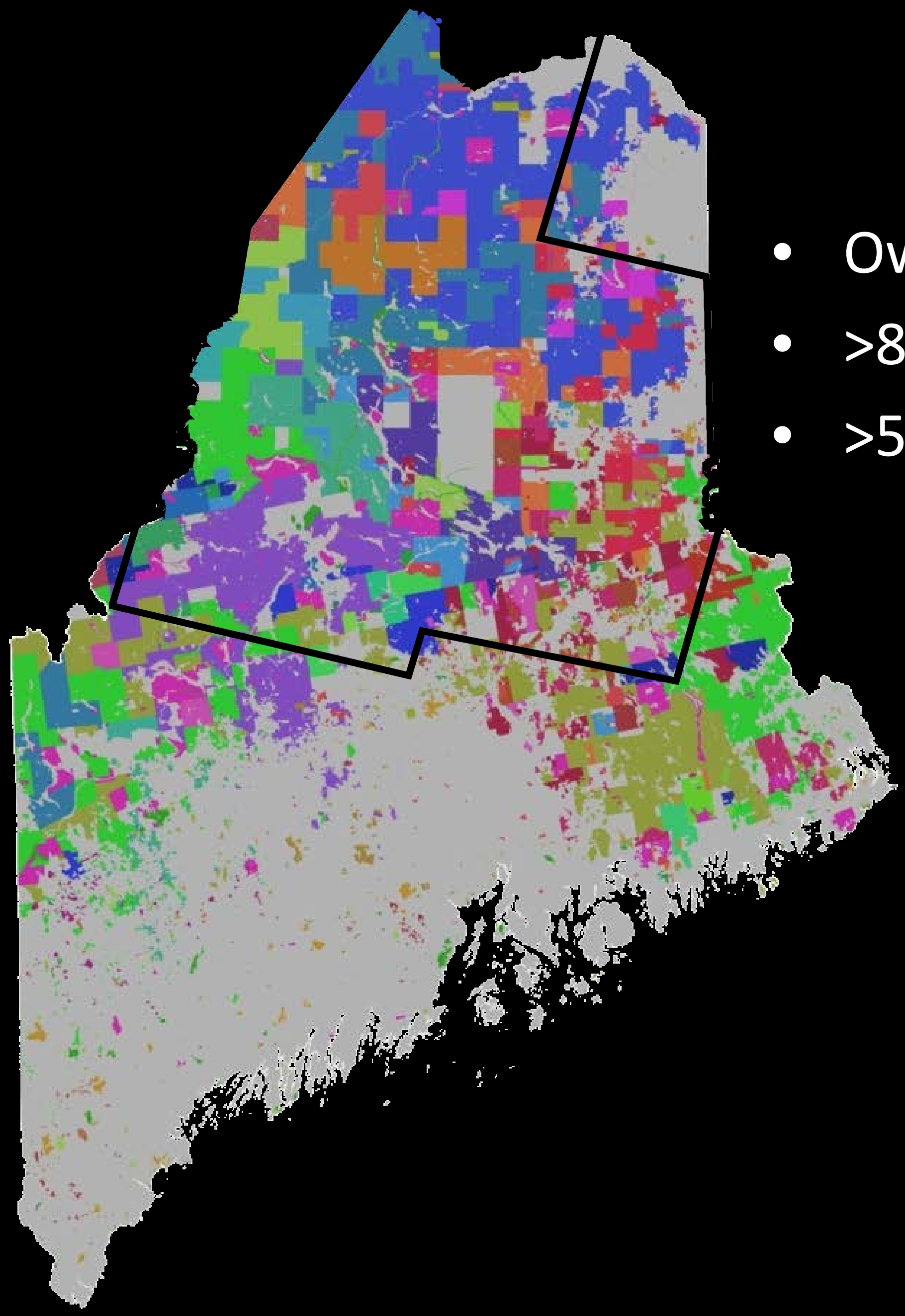
sponsored by

THE UNIVERSITY of WISCONSIN MADISON

Portland State UNIVERSITY

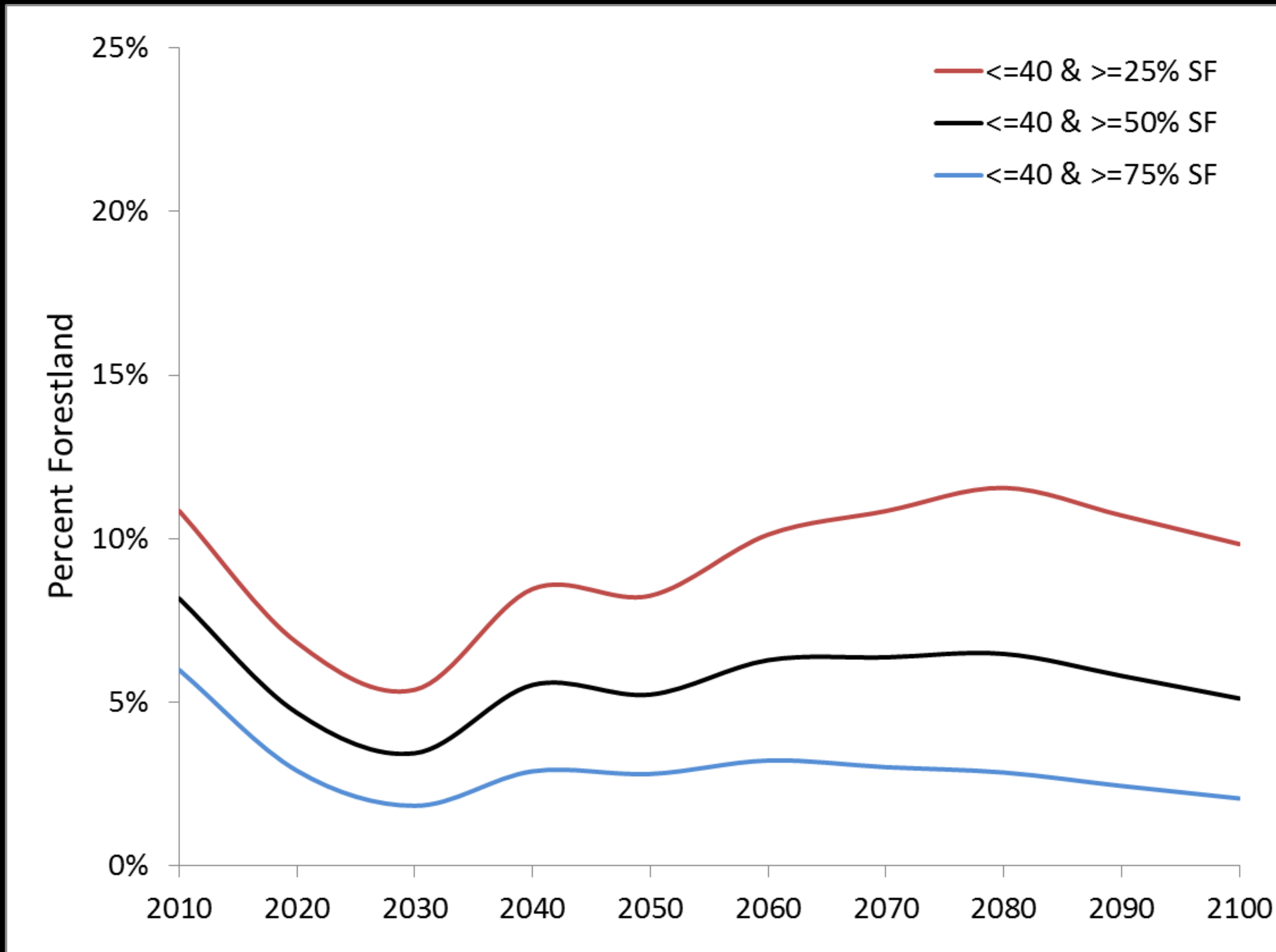


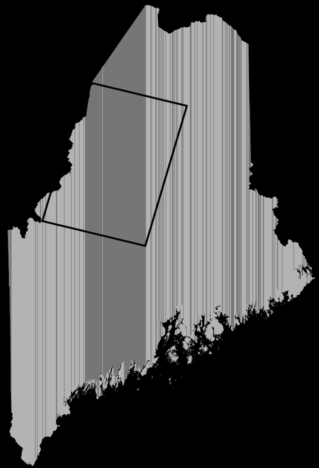


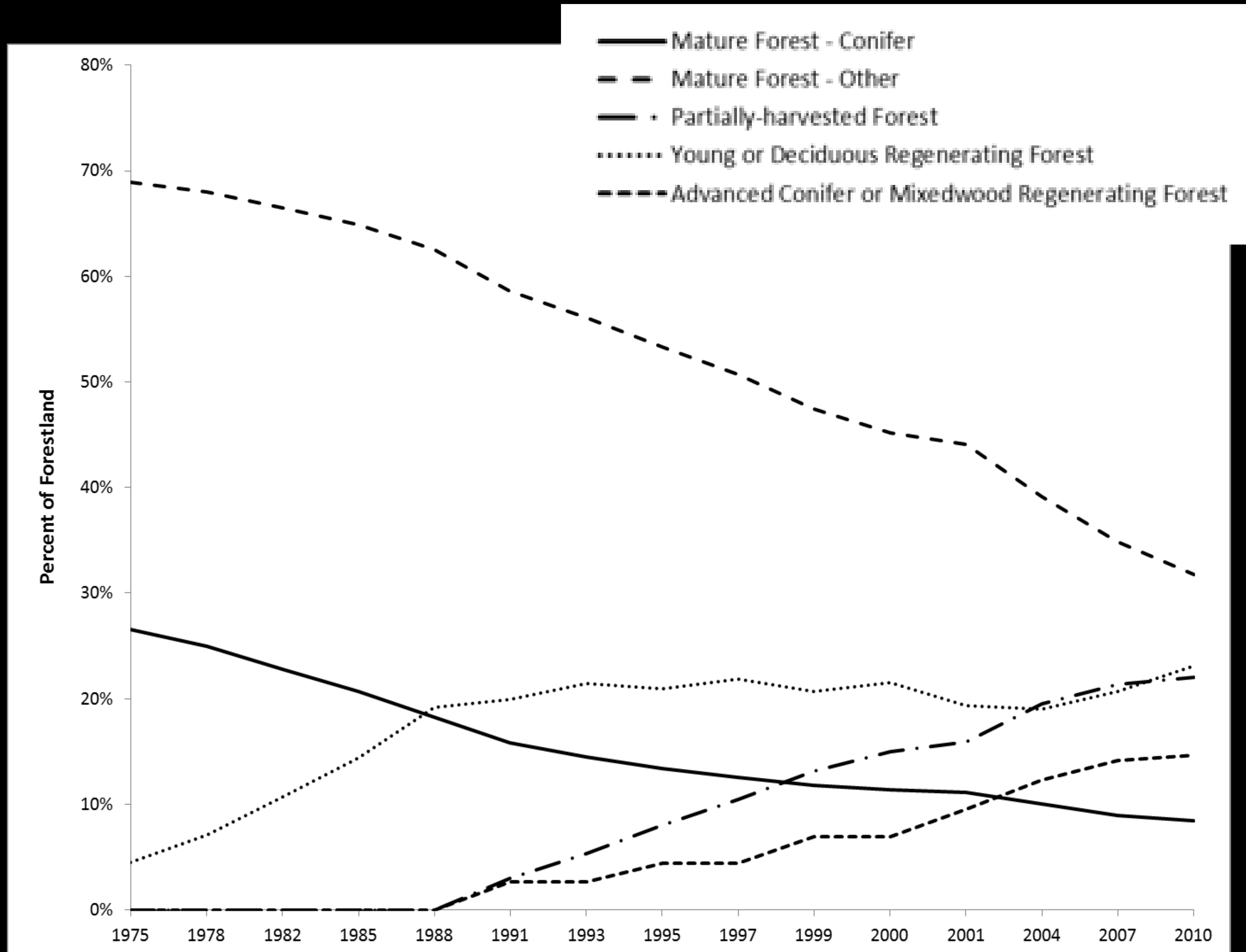


- Ownership ca. 2010
- >80 owners
- >500 parcels

Snowshoe hare/Lynx foraging habitat







Mature Forest - Conifer
Mature Forest - Other
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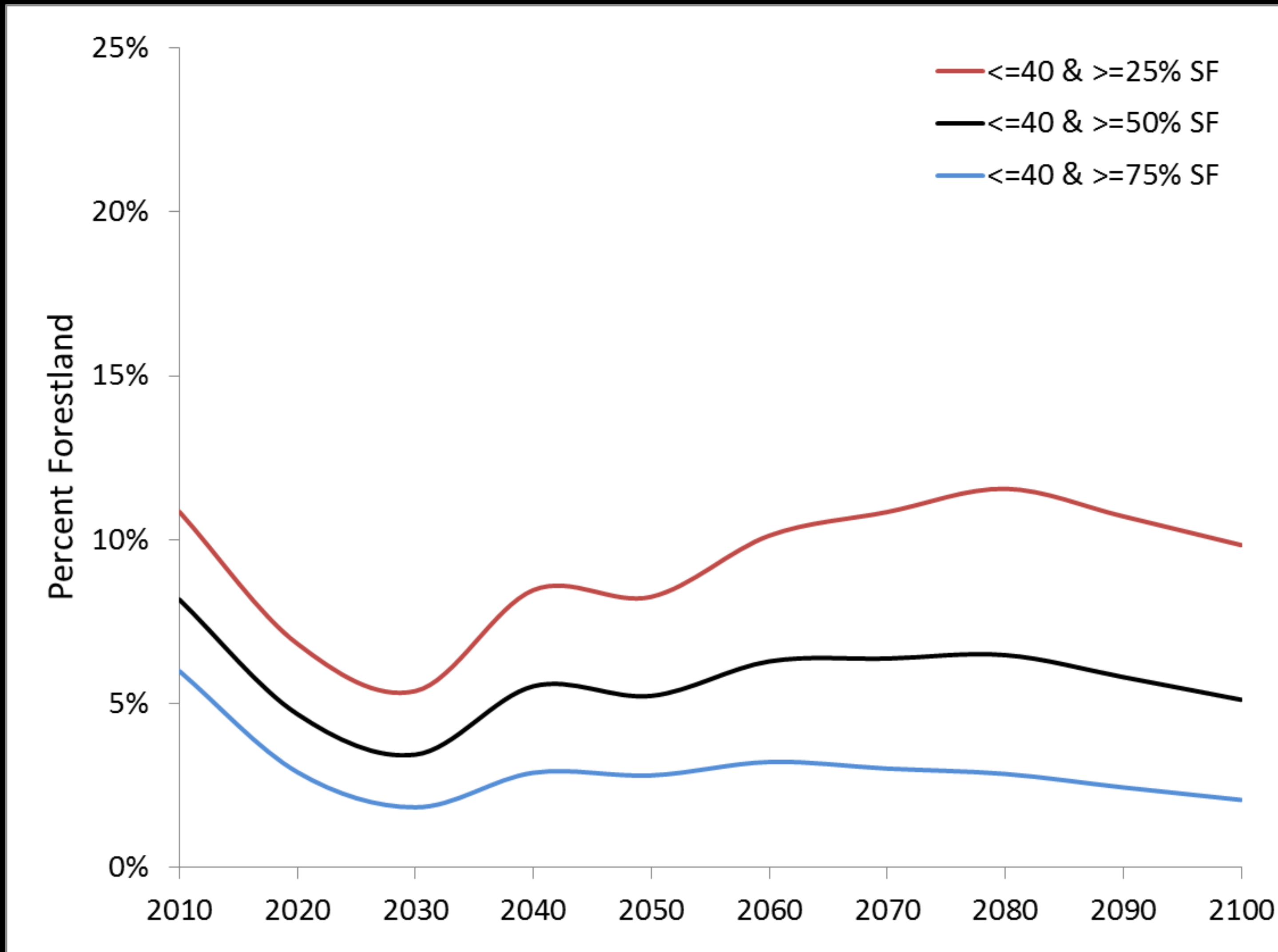
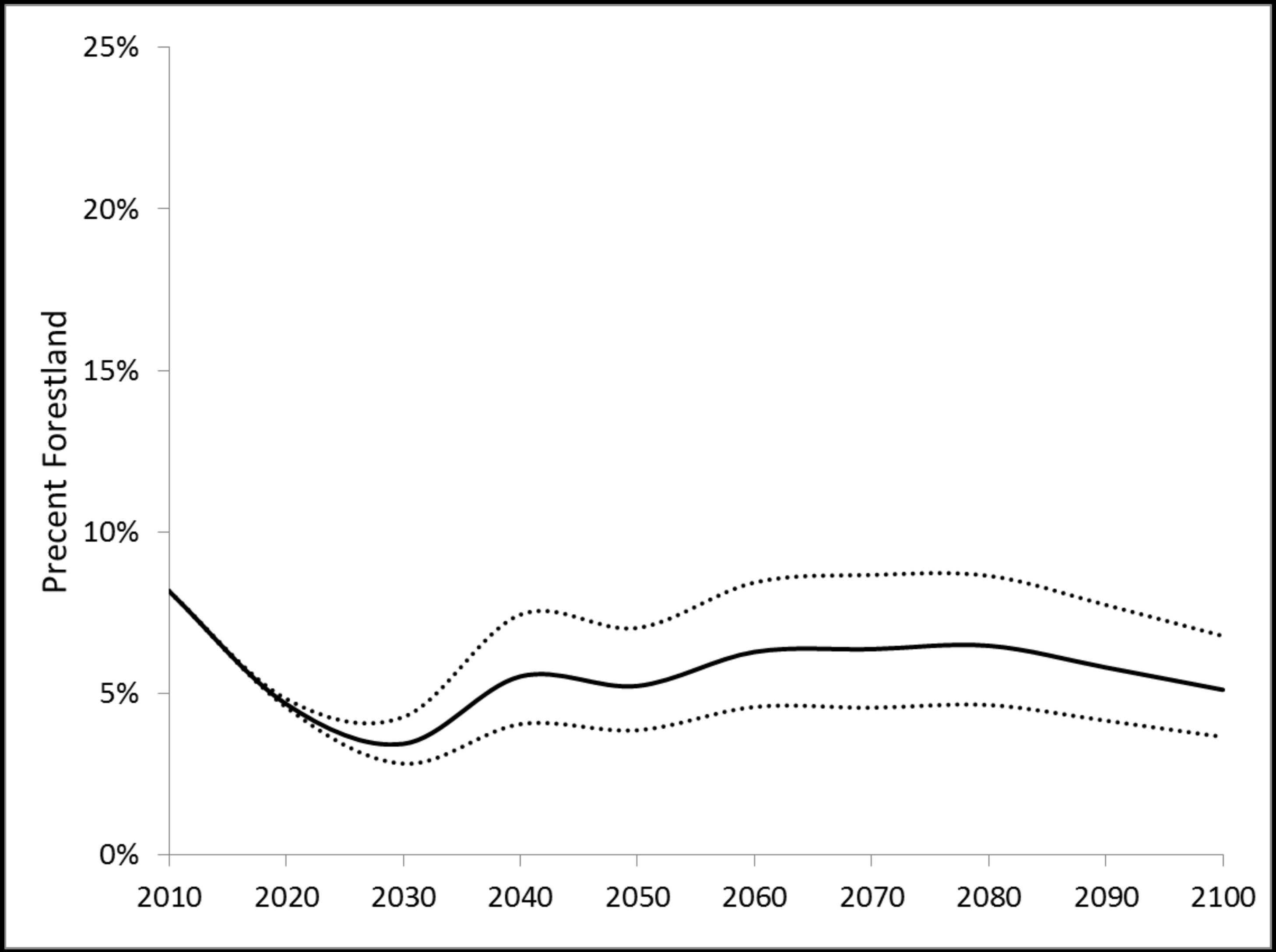
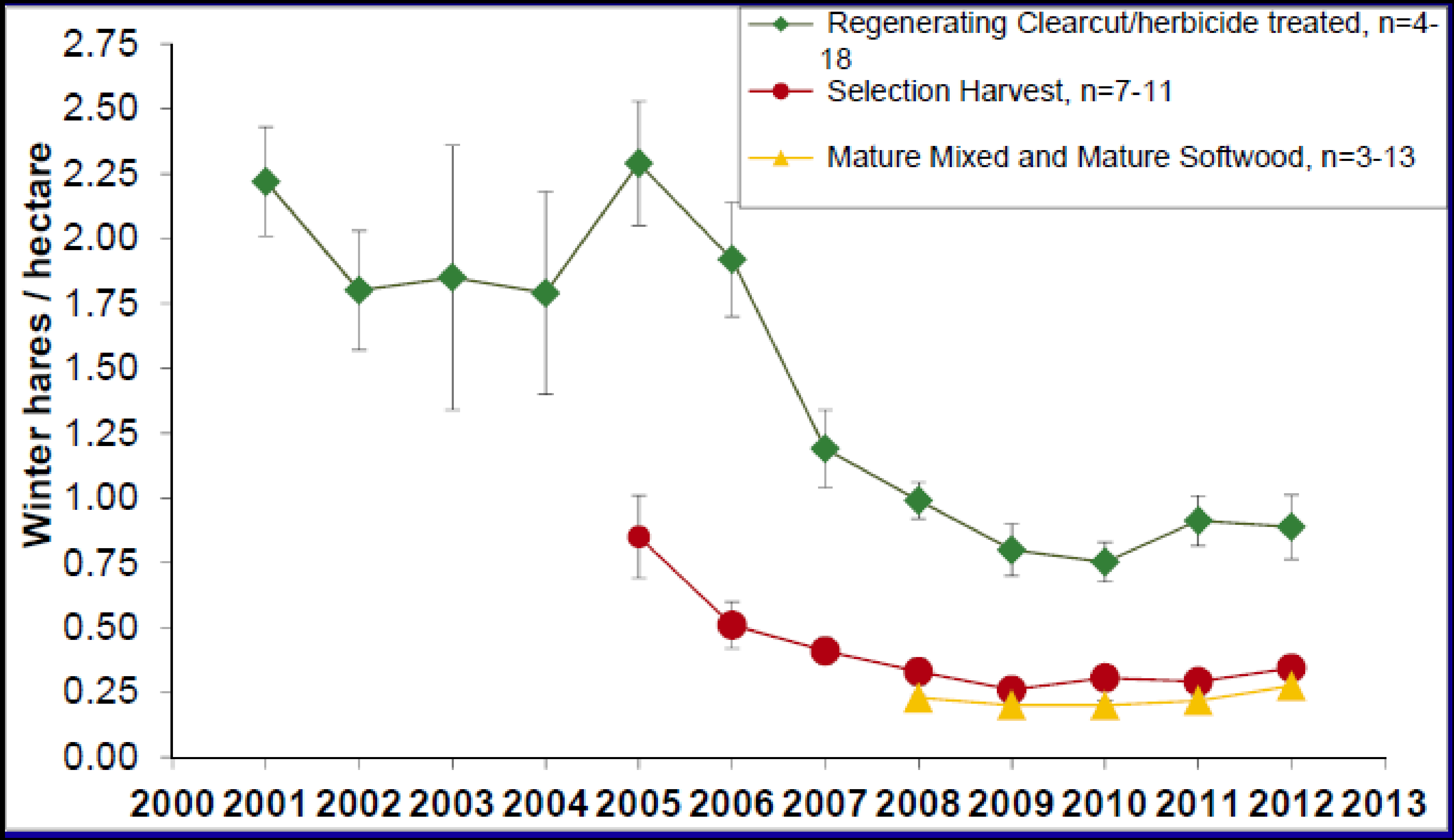
Young or Deciduous Regenerating Forest
Advanced Conifer or Mixedwood Regenerating Forest
Percent of Forestland
80%
70%
60%
50%
40%
30%
20%
10%
0%
1975
1978
1982
1985
1988
1991
1993
1995
1997
1999
2000
2001
2004
2007
2010

Snowshoe hare/Lynx foraging habitat



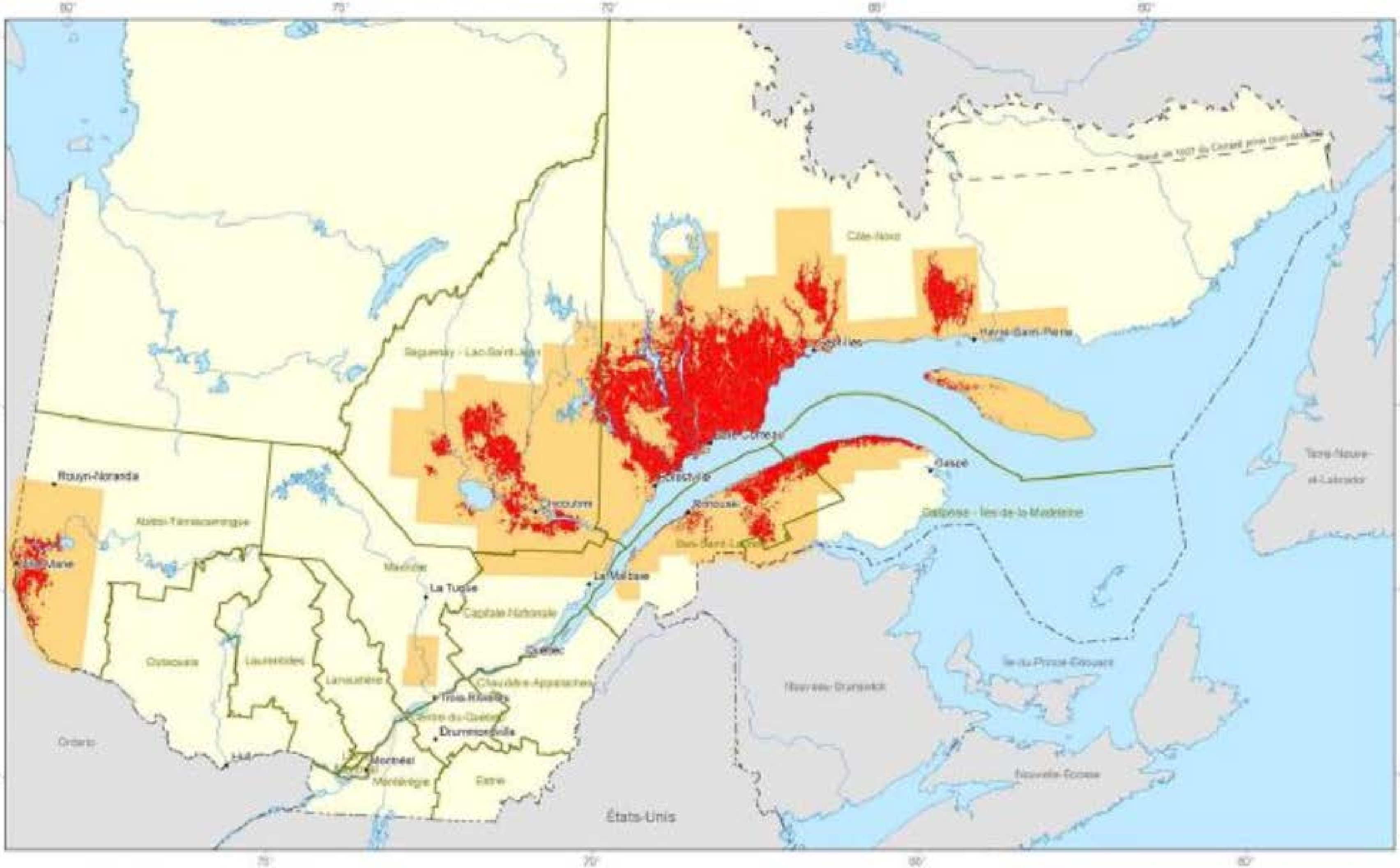
Snowshoe hare/Lynx foraging habitat





Regenerating Clearcut/herbicide treated, n=4-18
Selection Harvest, n=7-11
Mature Mixed and Mature Softwood, n=3-13
Winter hares / hectare
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013

S. Olsen 2014



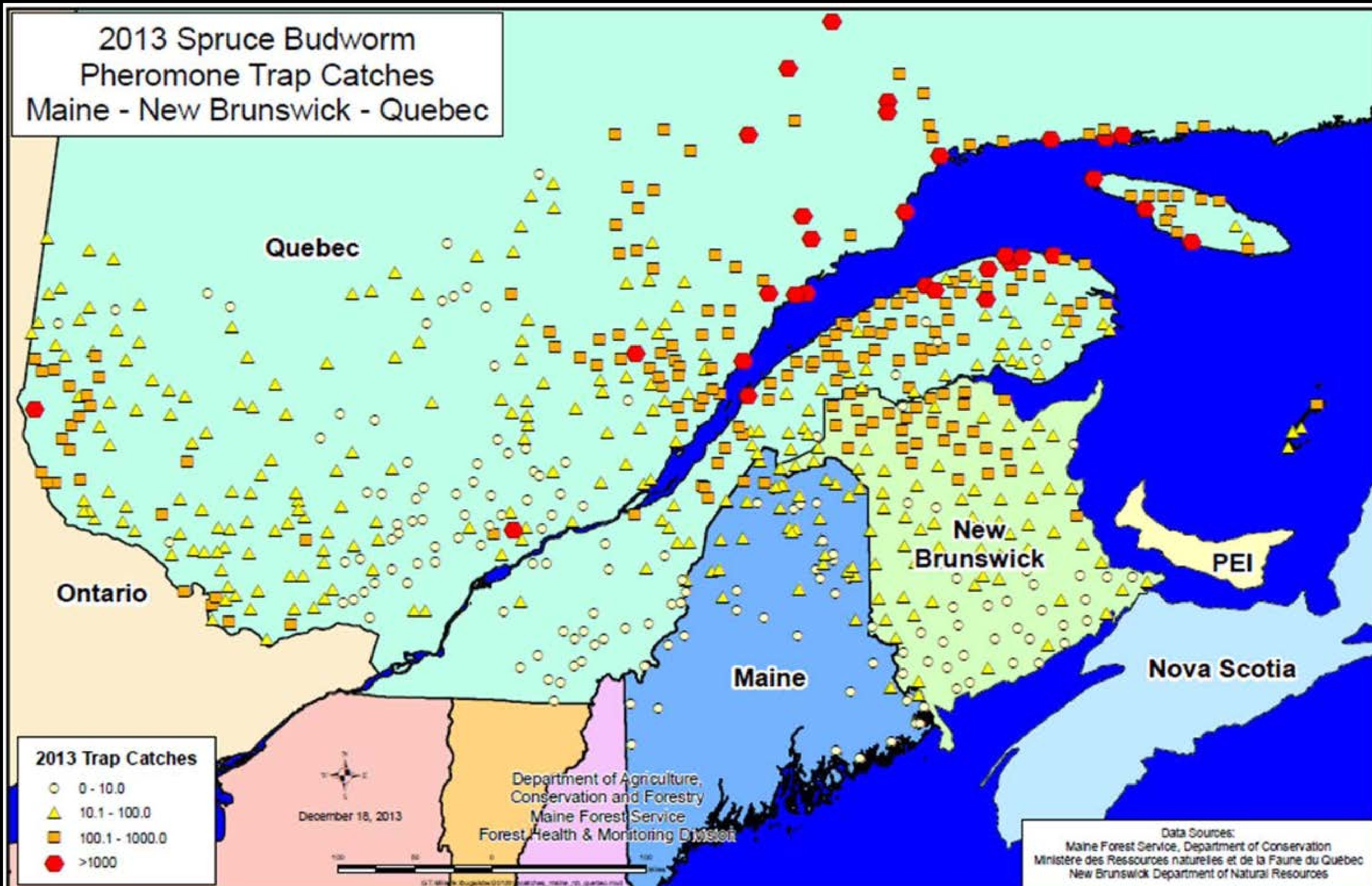
Québec méridional

Relevé aérien des dommages causés par la tordeuse des bourgeons de l'épinette
Territoire survolé

Source : Direction de la protection des forêts

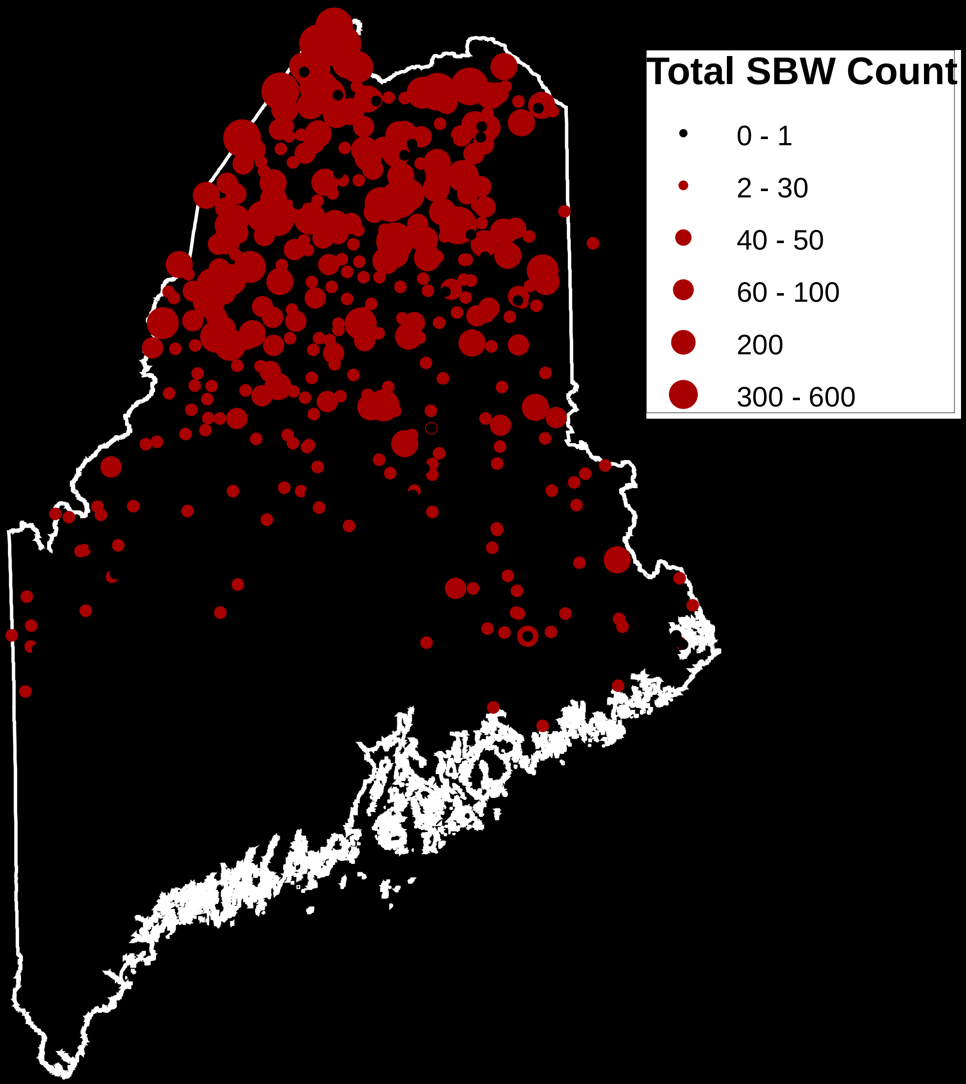
- Limite de survol
- Défoliation 2014
- Limite de région administrative

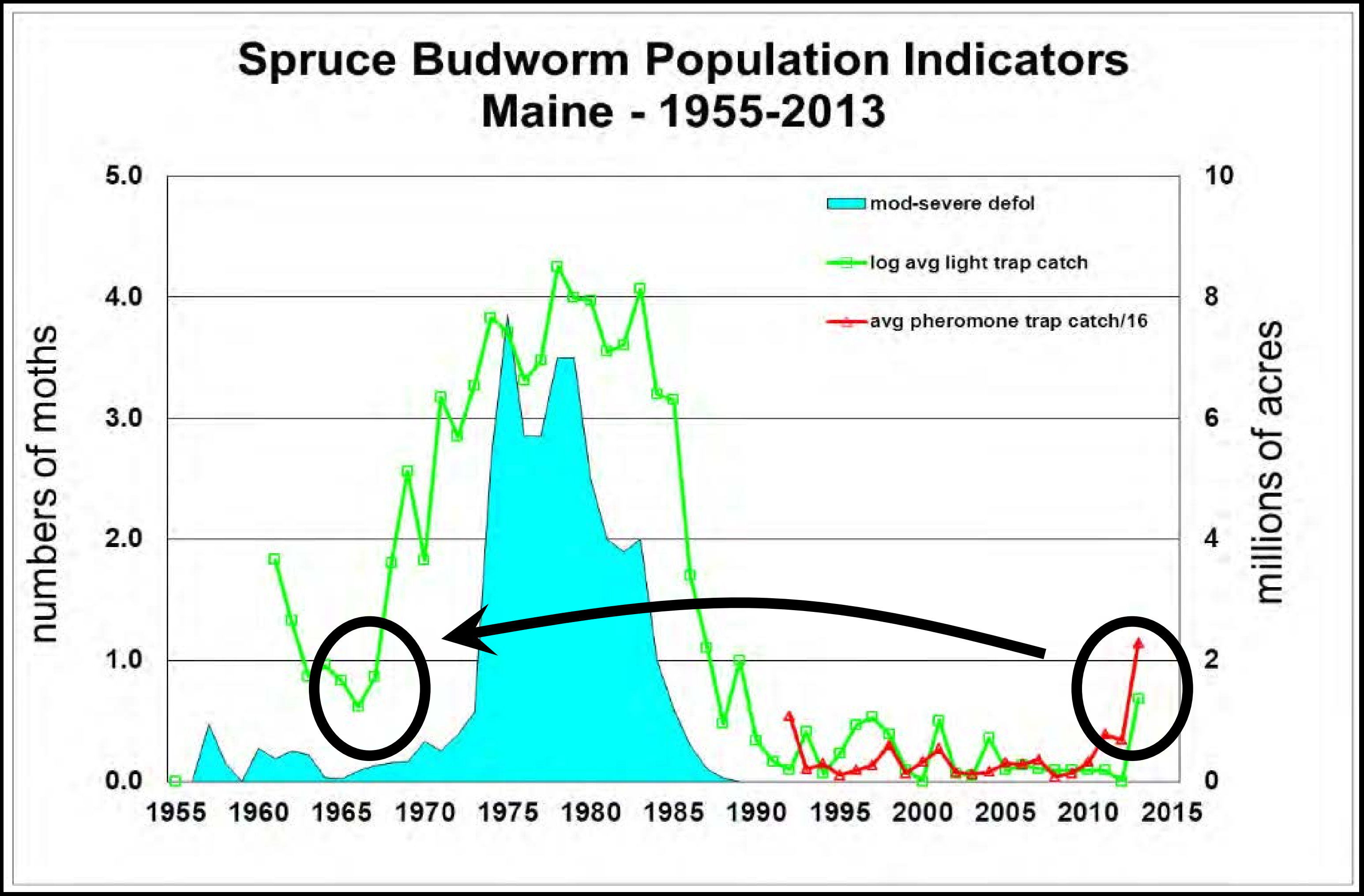
Forêts, Faune et Parcs
Québec



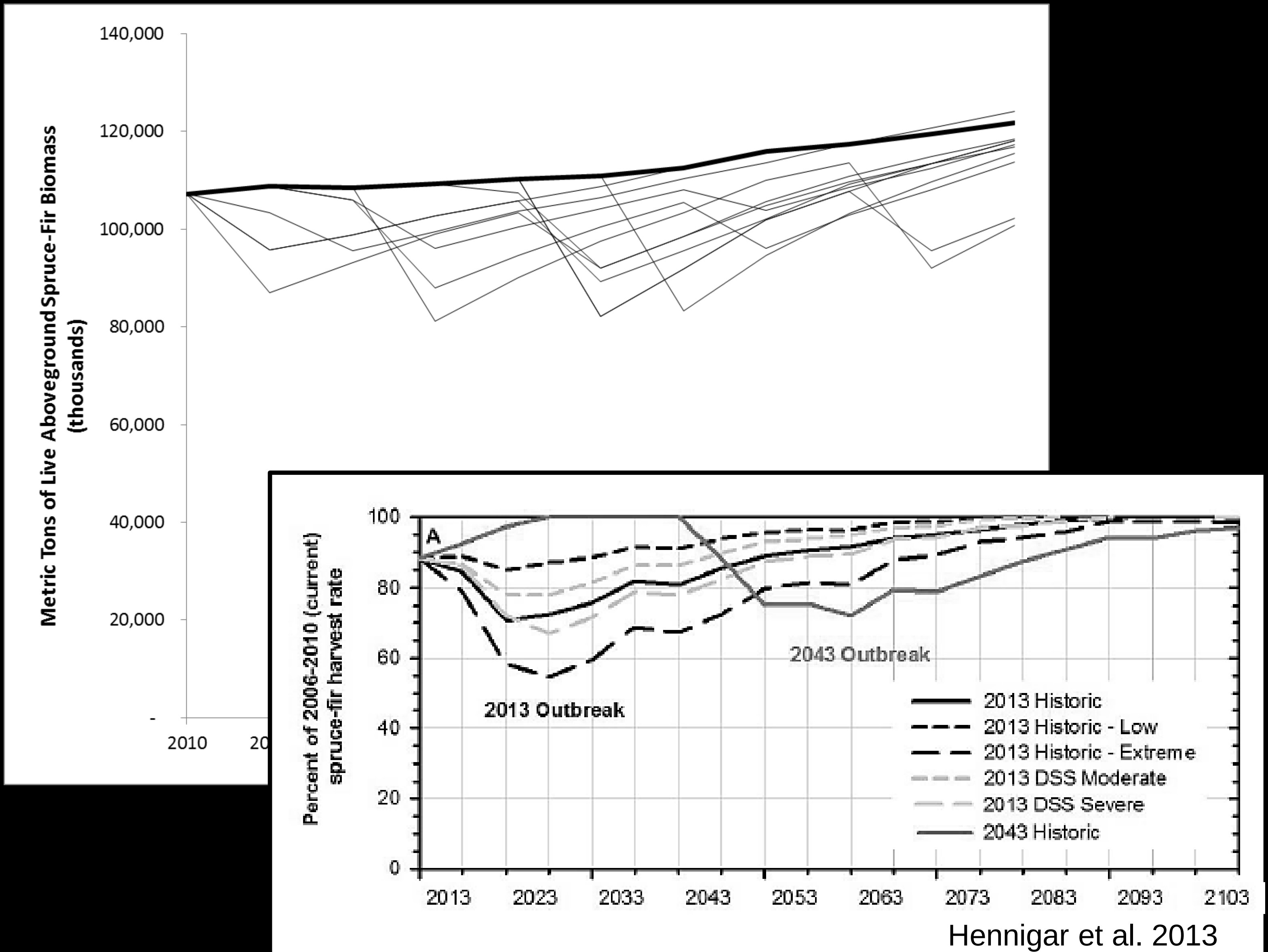
Maine Forest Service

2014 trap counts



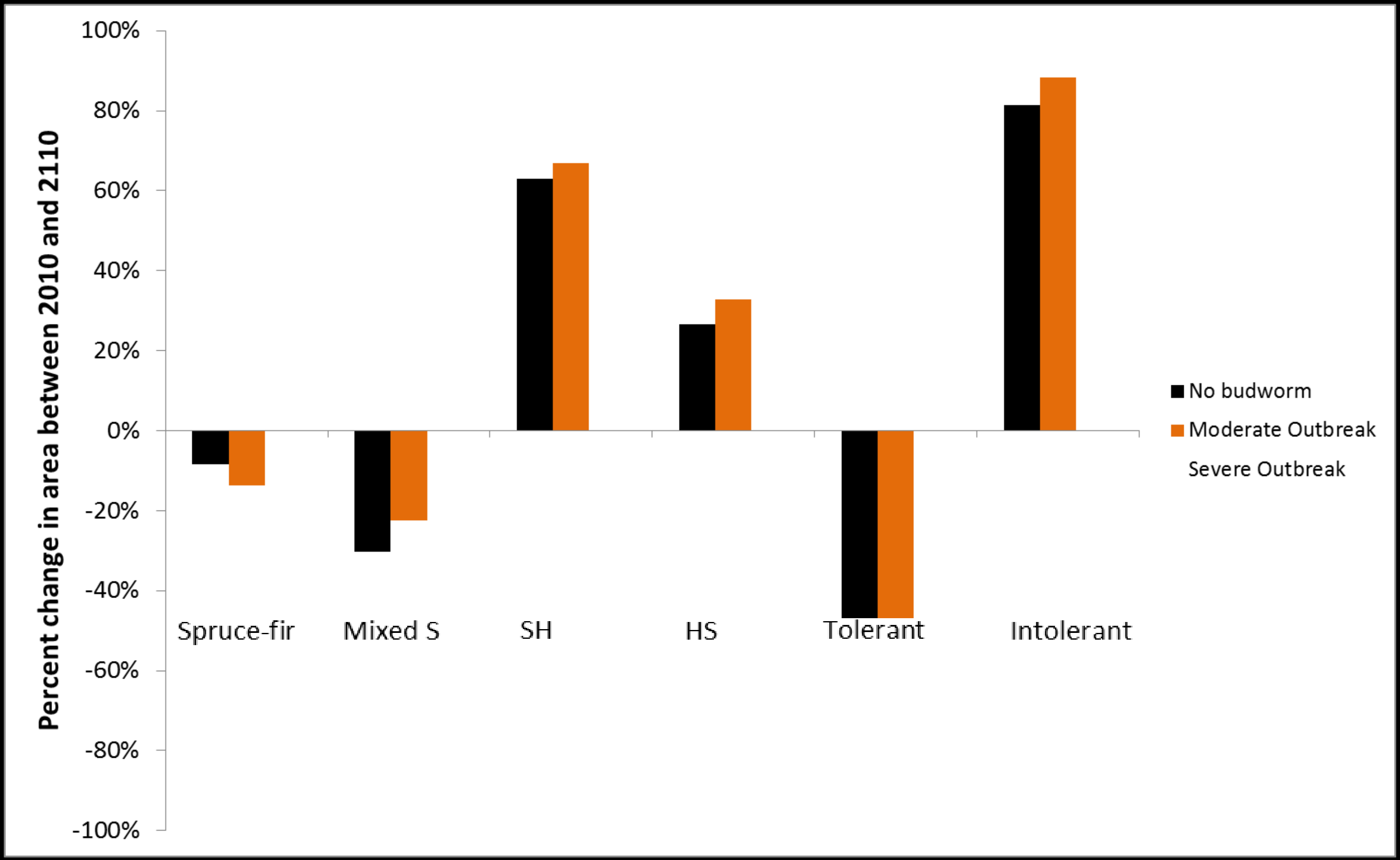

Spruce Budworm Population Indicators
Maine - 1955-2013
numbers of moths
millions of acres
mod-severe defol
log avg light trap catch
avg pheromone trap catch/16
5.0
4.0
3.0
2.0
1.0
0.0
10
8
6
4
2
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

Spruce-fir Live Biomass

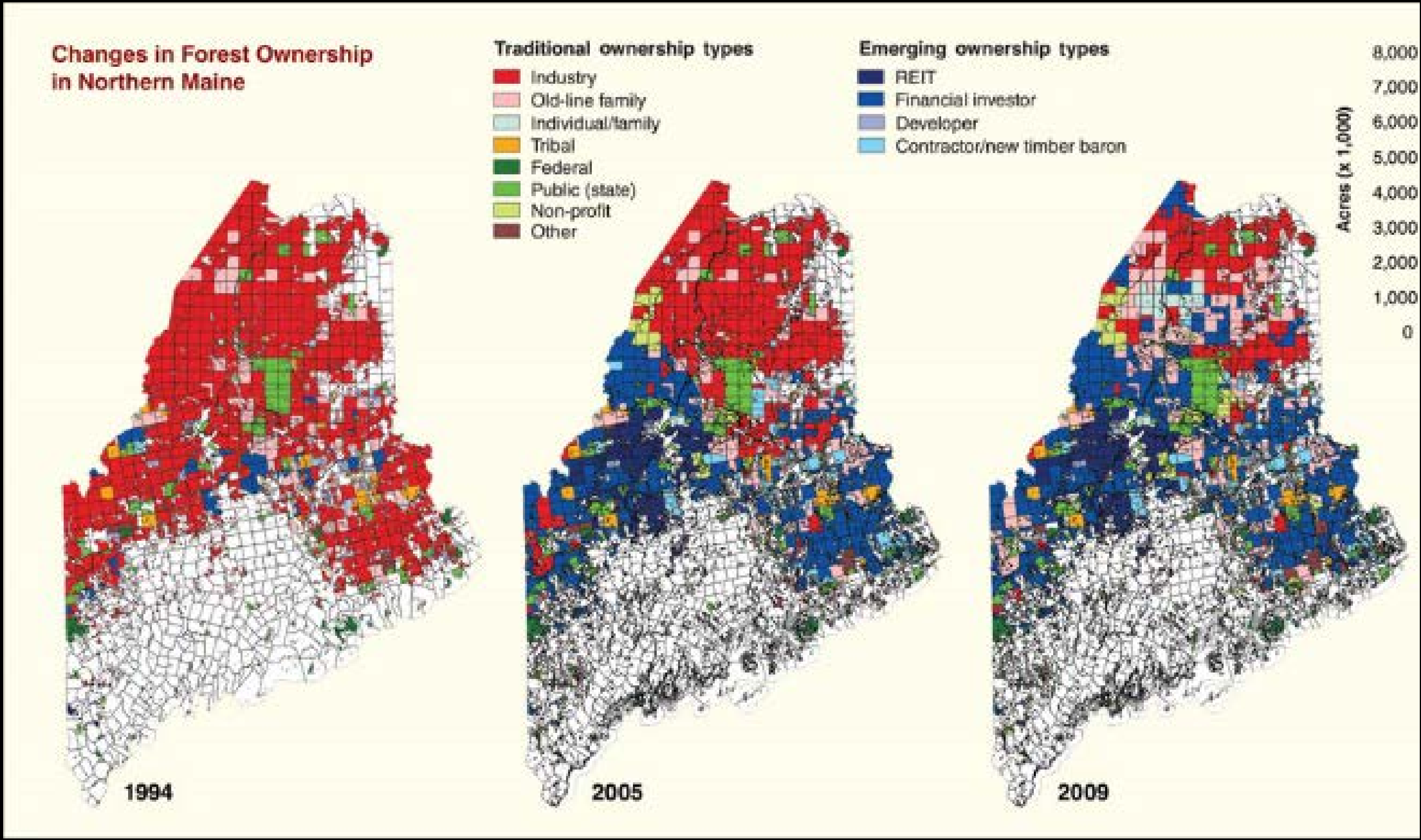


Hennigar et al. 2013

Percent change in forest area (2010-2110)



Ownership change

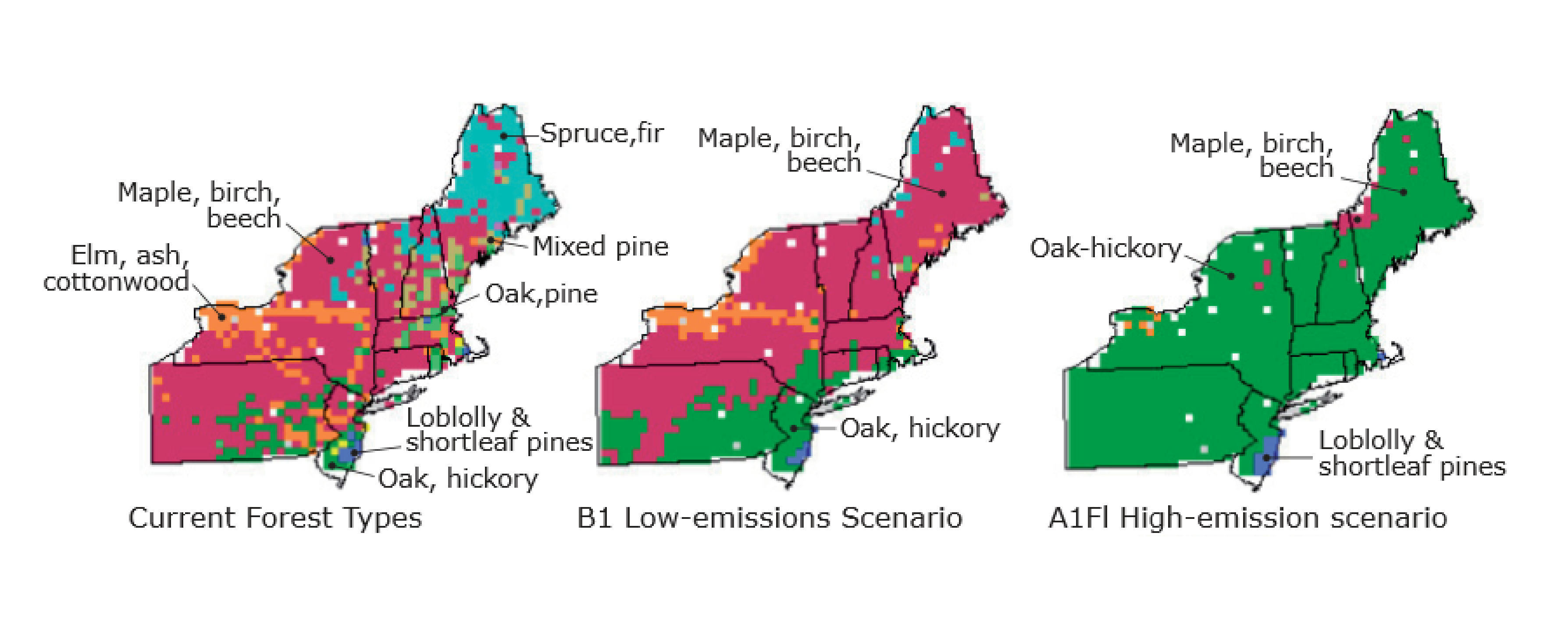


Lilliholm et al. 2010

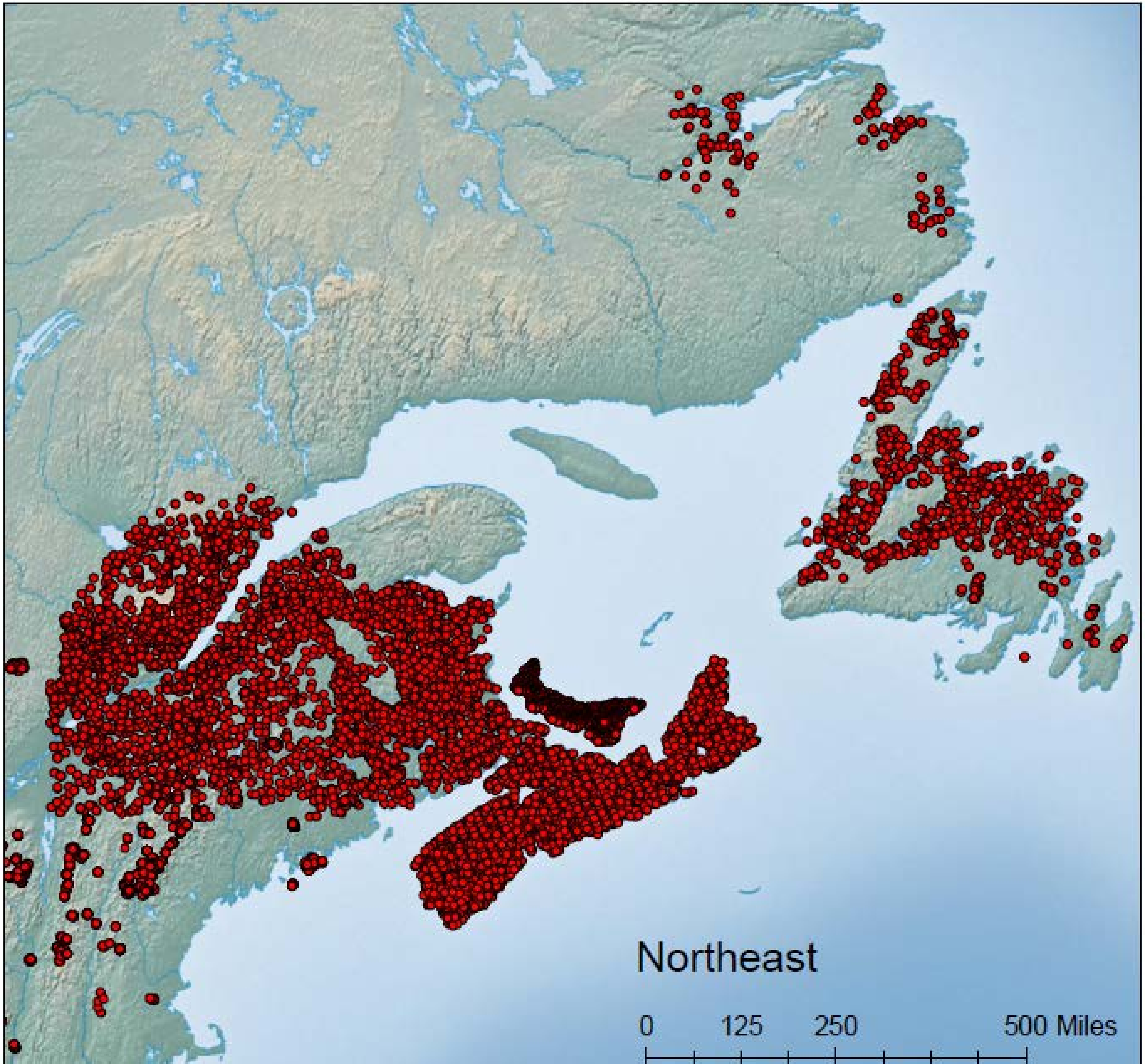
Freed from state clear-cut restrictions, Maine's largest landowner says it's doing better forestry

Gabor Degre | BDN

Recently harvested hardwood logs are piled up before being trucked from a J.D. Irving Ltd. logging



Adapted from Iverson et al 2007

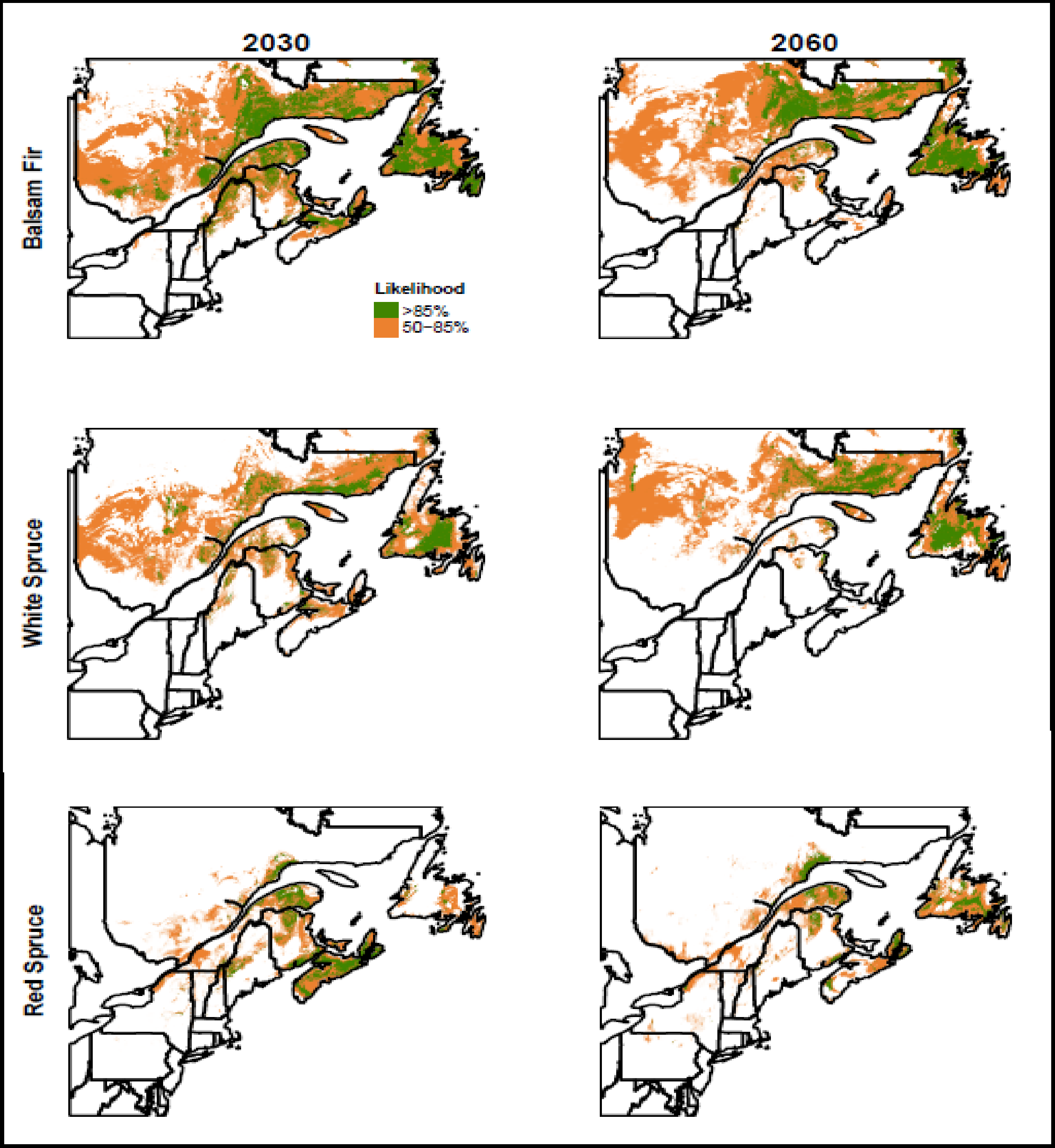

Northeast
0
125
250
500 Miles

Suitable habitat for S-F forest

- Number of days $>5^{o}C$
- Mean temp in the coldest month

- Mean annual precipitation
- Growing season precipitation

- Associated with areas that are colder and snowier



2030
2060
Balsam Fir
White Spruce
Red Spruce
Likelihood
>85%
50–85%

THE UNIVERSITY OF MAINE
1865
Celebrating 150 years

MAINE'S CLIMATE FUTURE

2015 UPDATE

Maine's Average Annual Temperature

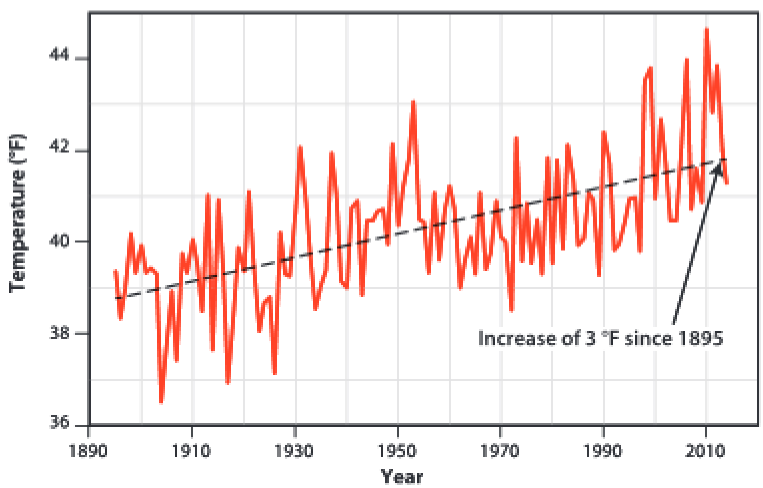


Figure 1. Mean annual temperature, 1895–2014, averaged across Maine from gridded monthly station records from the U.S. Climate Divisional Dataset (*ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php*). A simplified linear trend (black line) indicates that temperature increased 3 °F over the record period.

Maine's Changing Seasons

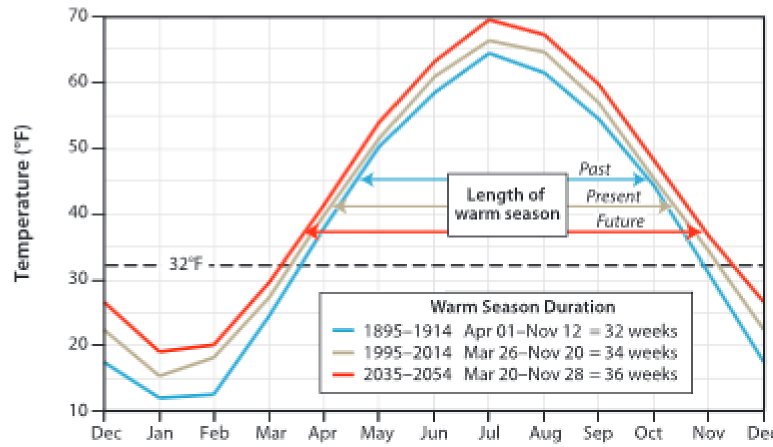


Figure 3. Mean monthly temperature averaged across Maine for historical (1895–1914), recent (1995–2014), and future (2035–2054) time periods. Historical and recent data from the U.S. Climate Divisional Dataset (*ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php*), and future prediction from an ensemble simulation of the IPCC emissions scenario A2.

Present and Future Temperature

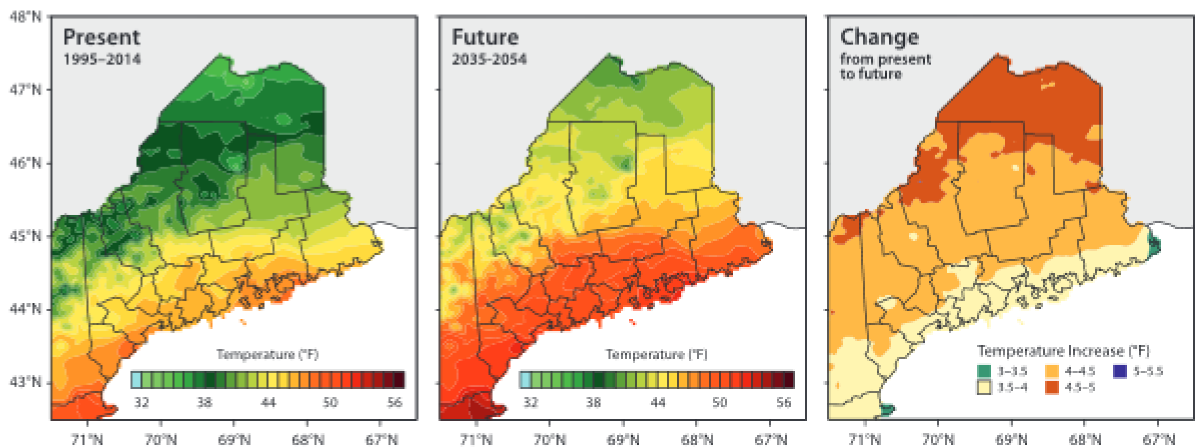


Figure 2. Maps showing mean annual temperature for 1995–2014 (left), 2035–2054 (center), and the predicted change or difference between the two time periods (right). The predicted rise in temperature by 2050 ranges 3.0–5.0 °F from the coast inland to the Canadian border. Maps derived from an ensemble simulation of the IPCC A2 emissions scenario.[1]

Maine's Total Annual Precipitation

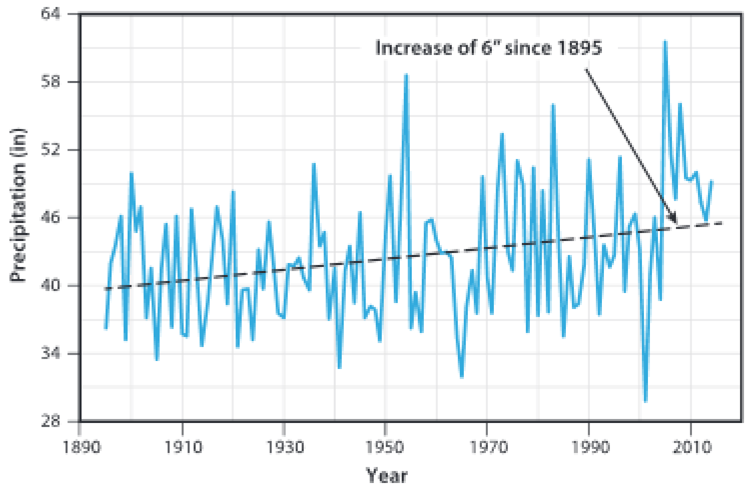
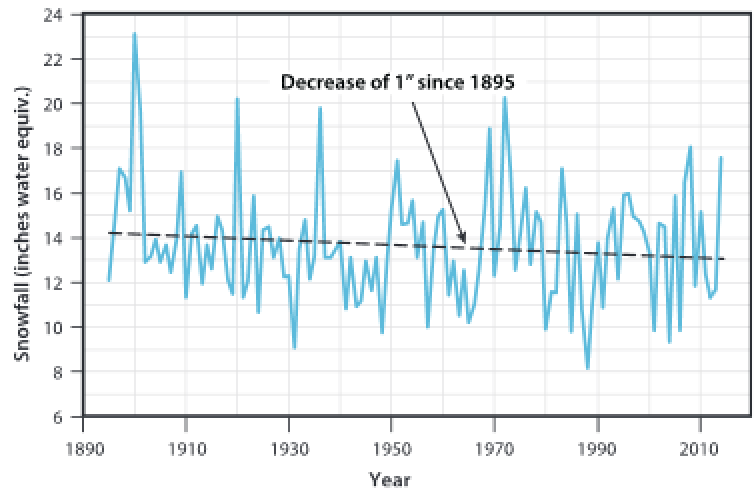


Figure 6. Total annual precipitation, 1895–2014, averaged across Maine from gridde
U.S. Climate Divisional Dataset (*ncdc.noaa.gov/monitoring-references/maps/us-climate-div*
(black line) indicates that precipitation increased six inches, or about 13%, during the reco

Maine's Total Annual Snowfall



2014, averaged across Maine, derived from gridded monthly temperature and
. Climate Divisional Dataset (*ncdc.noaa.gov/monitoring-references/maps/us-*
end (black line) indicates that snowfall decreased approximately 1.0 inches (6.6%)

Projected Snowfall Decline

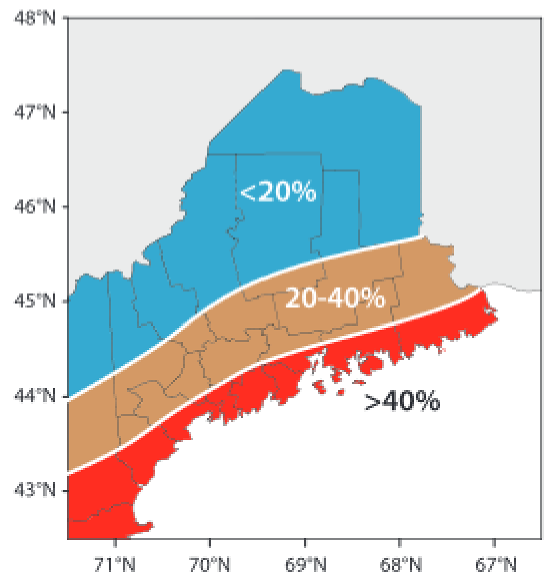


Figure 10. Map showing the predicted change or difference in total accumulated winter snow by climate zone from 1995–2014 to 2035–2054. The greatest changes are predicted to be along the coast, where many winters of the future will bring rain instead of snow. Map derived from an ensemble simulation of the IPCC A2 emissions scenario.

Forest Management & Lynx Habitat Trends

Erin Simons-Legaard

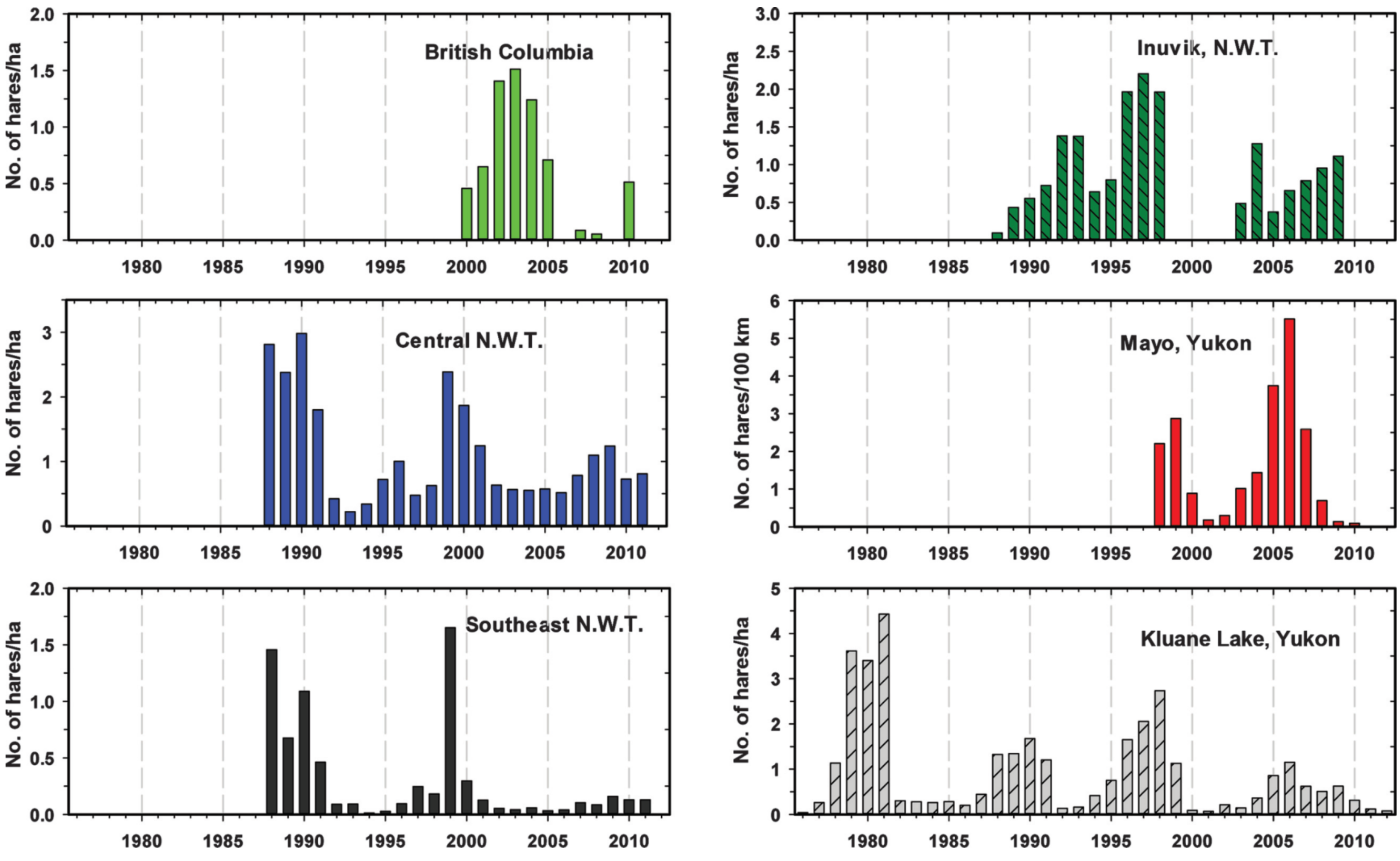
Collaborators: Kasey Legaard, Dan Harrison, Mark McCollough, Aaron Weiskittel, Caitlin Andrews

Southern snowshoe hares: updates, questions, forecasts

Karen Hodges
University of British Columbia Okanagan

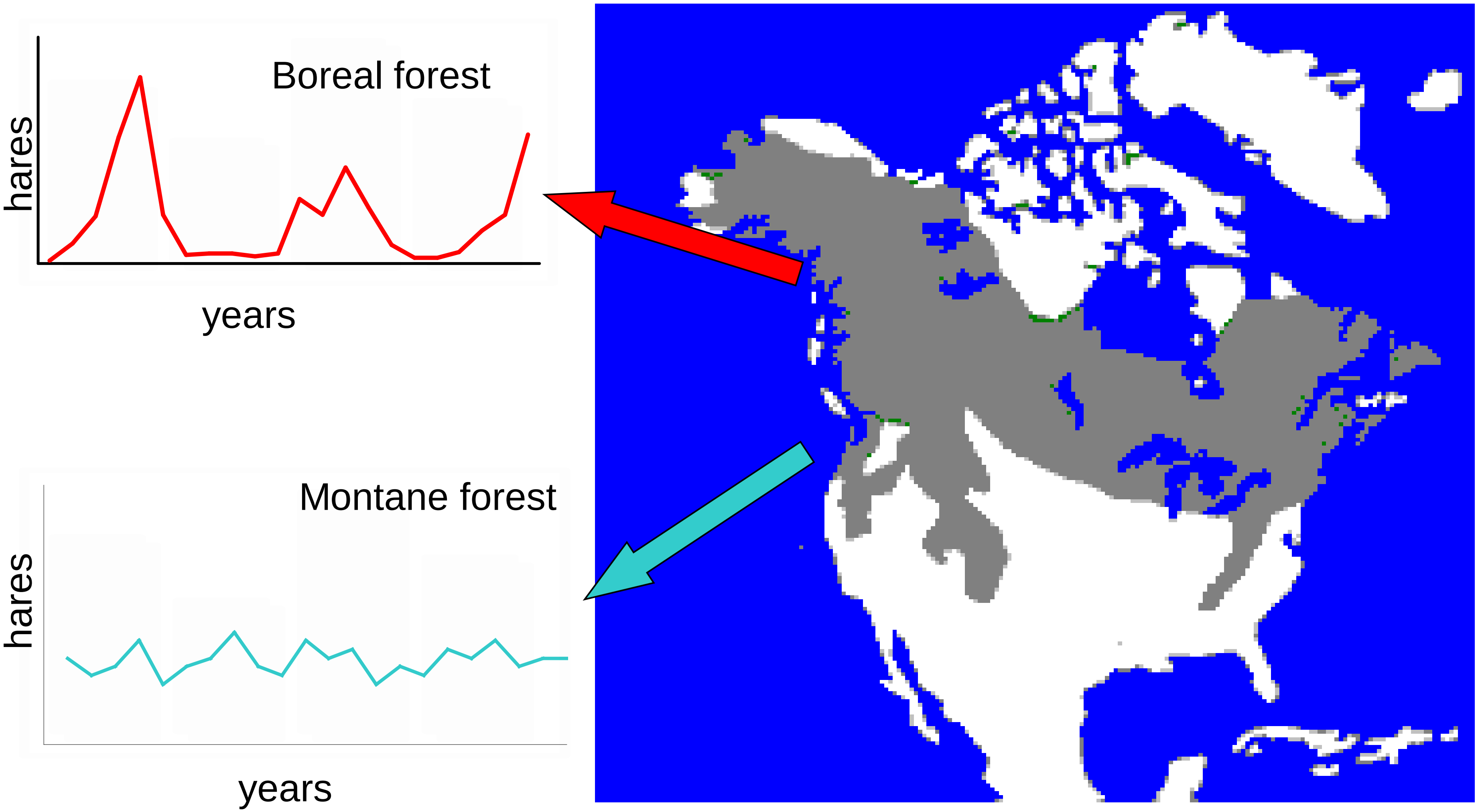
MAJOR POINT #1. Northern hare cycles are highly variable.

(iffy synchrony, variable peak heights and amplitudes)



Krebs et al. 2013. Canadian Journal of Zoology 91:562-572

Is the cycle gradient, as told by textbooks, true?



Major stand types in NW Montana

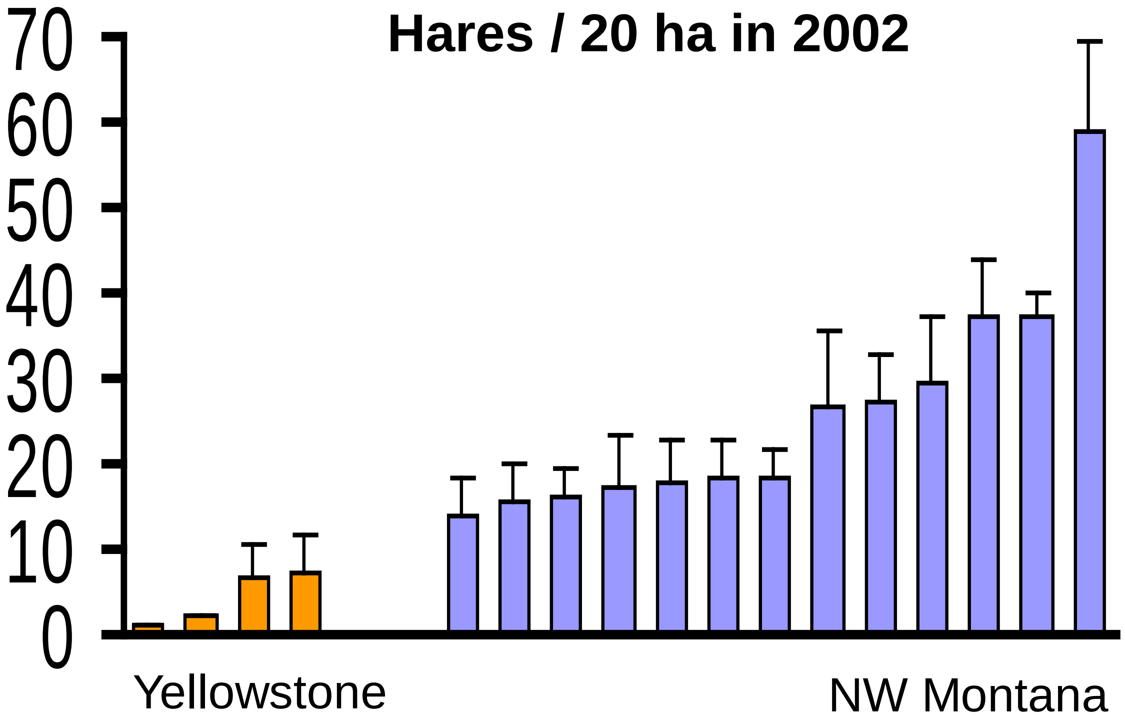
"thinned"

"unthinned"

"mature"

MAJOR POINT #3A.

Region matters enormously to hare abundances.



we trapped 13 sites:
only 4 sites had hares.

Western hare densities differ substantially across landscapes (mostly live-trapping data)

NW Montana (2001-12): 0.72 ± 0.12 hares/ha
Mills & Hodges unpublished

Oregon (2001-2): 0.25-0.42
Abele et al. 2013

Wyoming (YNP) (2002-7): 0.20
Hodges et al. 2009

Idaho (1998-2000): 0.09
Wirsing et al. 2002

Washington (2003-4) 0.82 ± 0.07
Lewis et al. 2009

Wyoming (2006-8): 0.48-1.69
Berg et al. 2012 (pellets)

Colorado (2002-3): 0.154
Zahratka & Shenk 2008

Hare densities vary with landscapes further east, too (mostly pellet data)

Maine 1.00-1.85
Homyack et al. 2007

Maine (summary of others): 0-1.8
Simons-Legaard et al. 2013

Voyageurs NP, Minnesota (2006-9): ~0.35 hares/ha
Moen et al. 2012

northeast Minnesota (2003-6): ~0.64 hares/ha
McCann and Moen 2011

Landscape attributes matter to stand quality for hares

In North Cascades, WA:

hare density increased with:
--stand saplings
--stand medium trees
--“moist forest” within 300 m

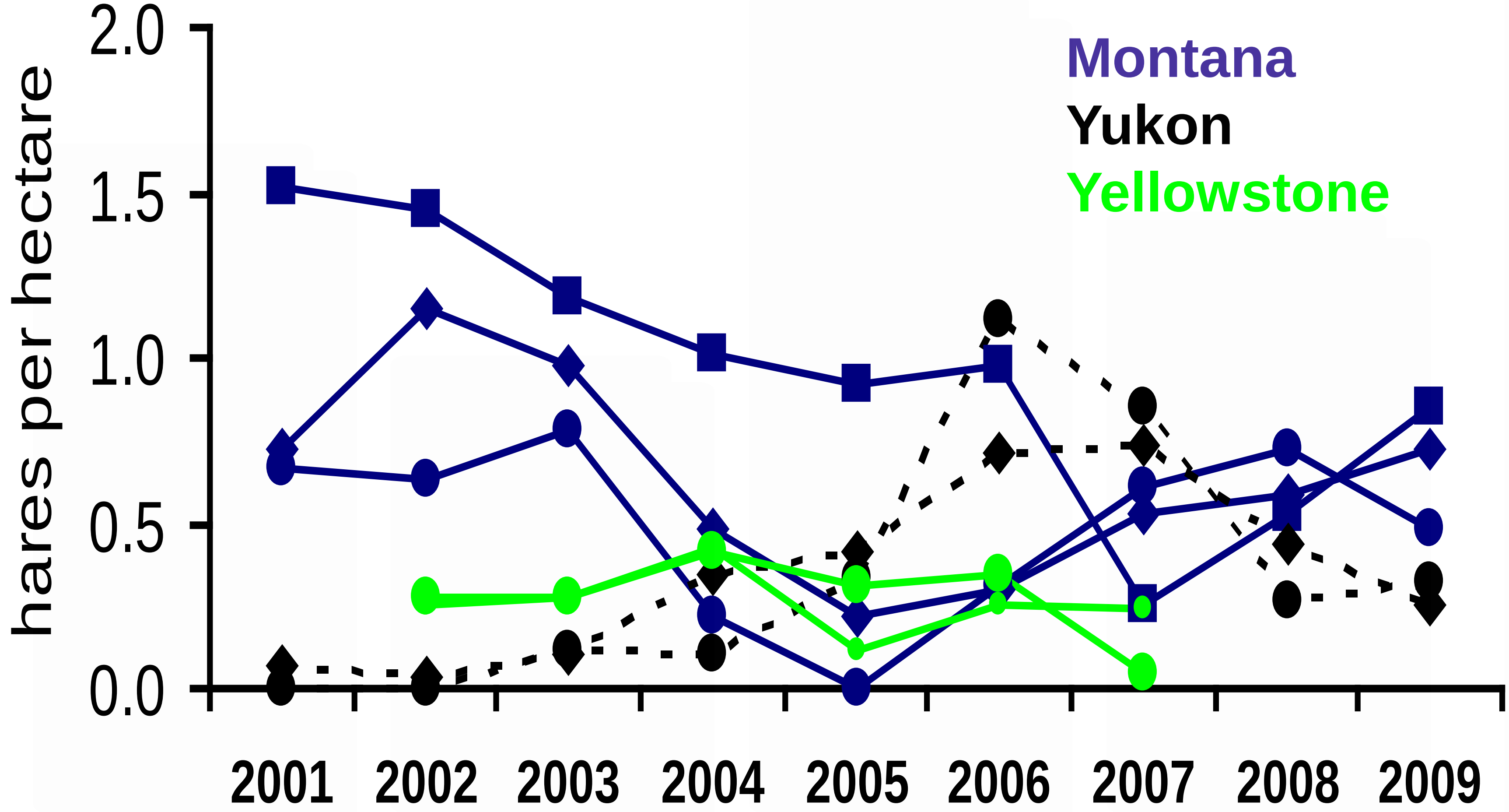
and decreased with
--“open” forest within 300 m.

Variables within 300 m more explanatory than variables within 600 m

Lewis et al. 2009. Journal of Mammalogy 92:561-567.

MAJOR POINT #3B.

Hare population dynamics also differ with region (cyclicity, synchrony, amplitude, and peak densities vary!)

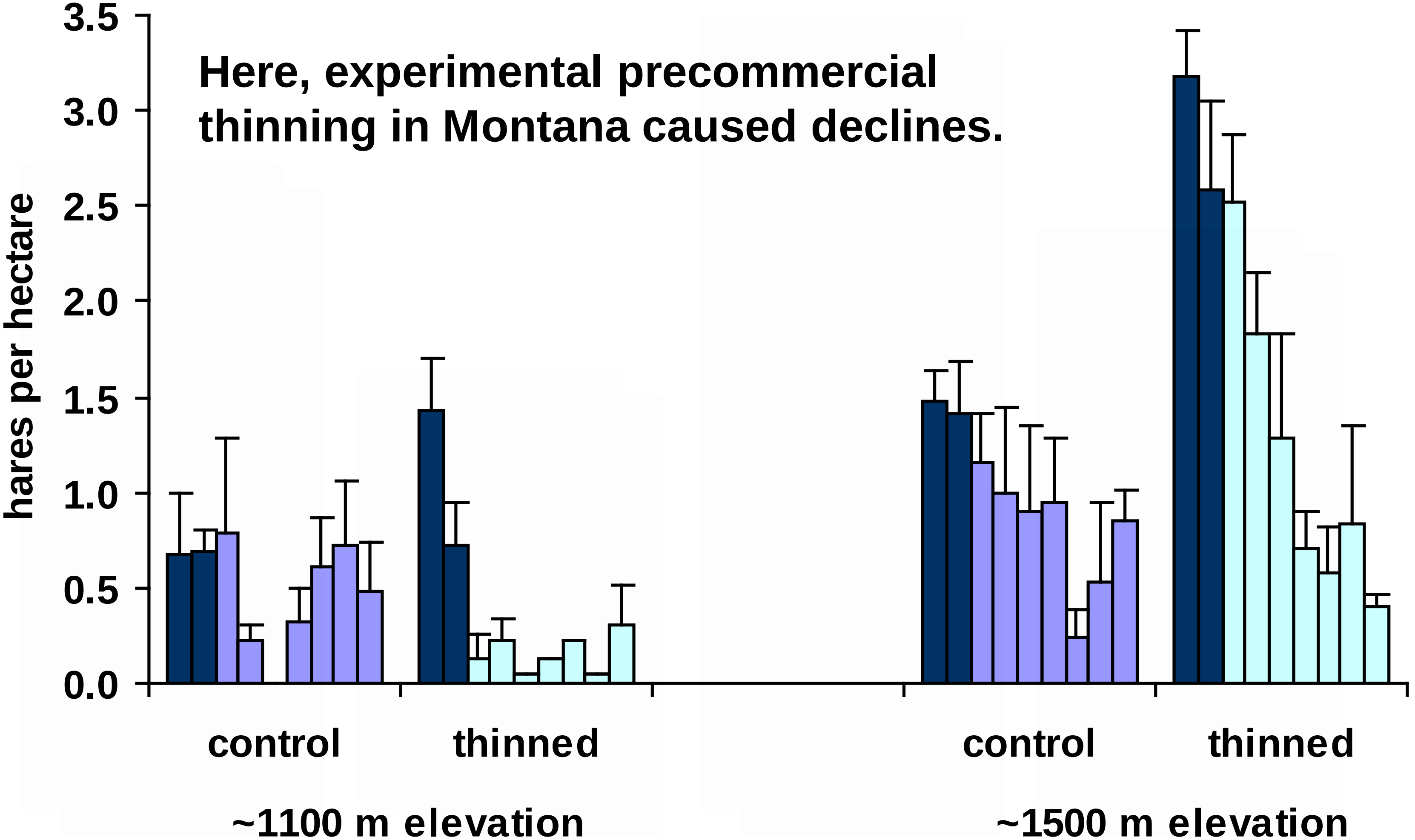


What happens to hares when habitats are disturbed?

MAJOR POINT #4A.

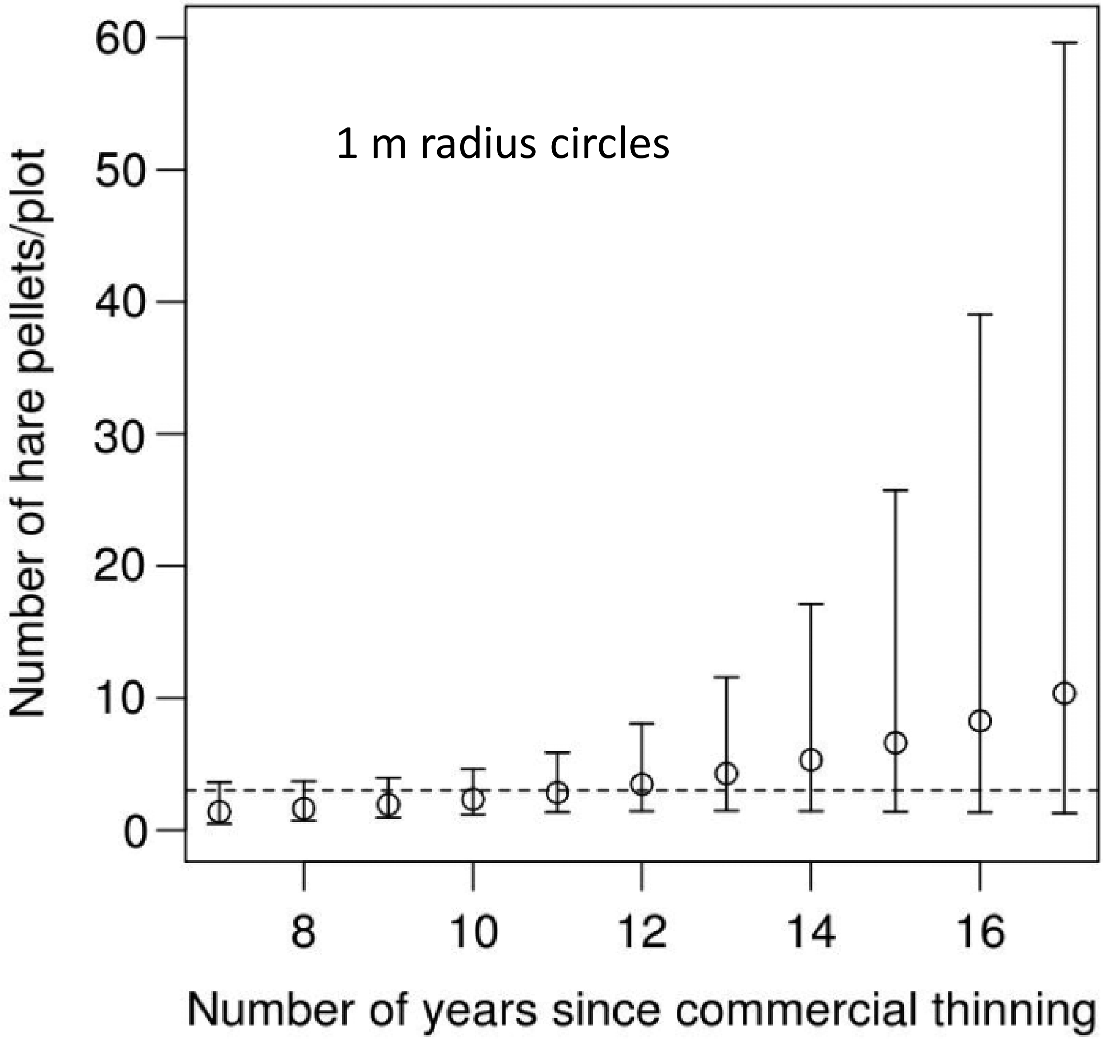
Forestry actions that reduce stand structure reduce hare abundances.

Here, experimental precommercial thinning in Montana caused declines.



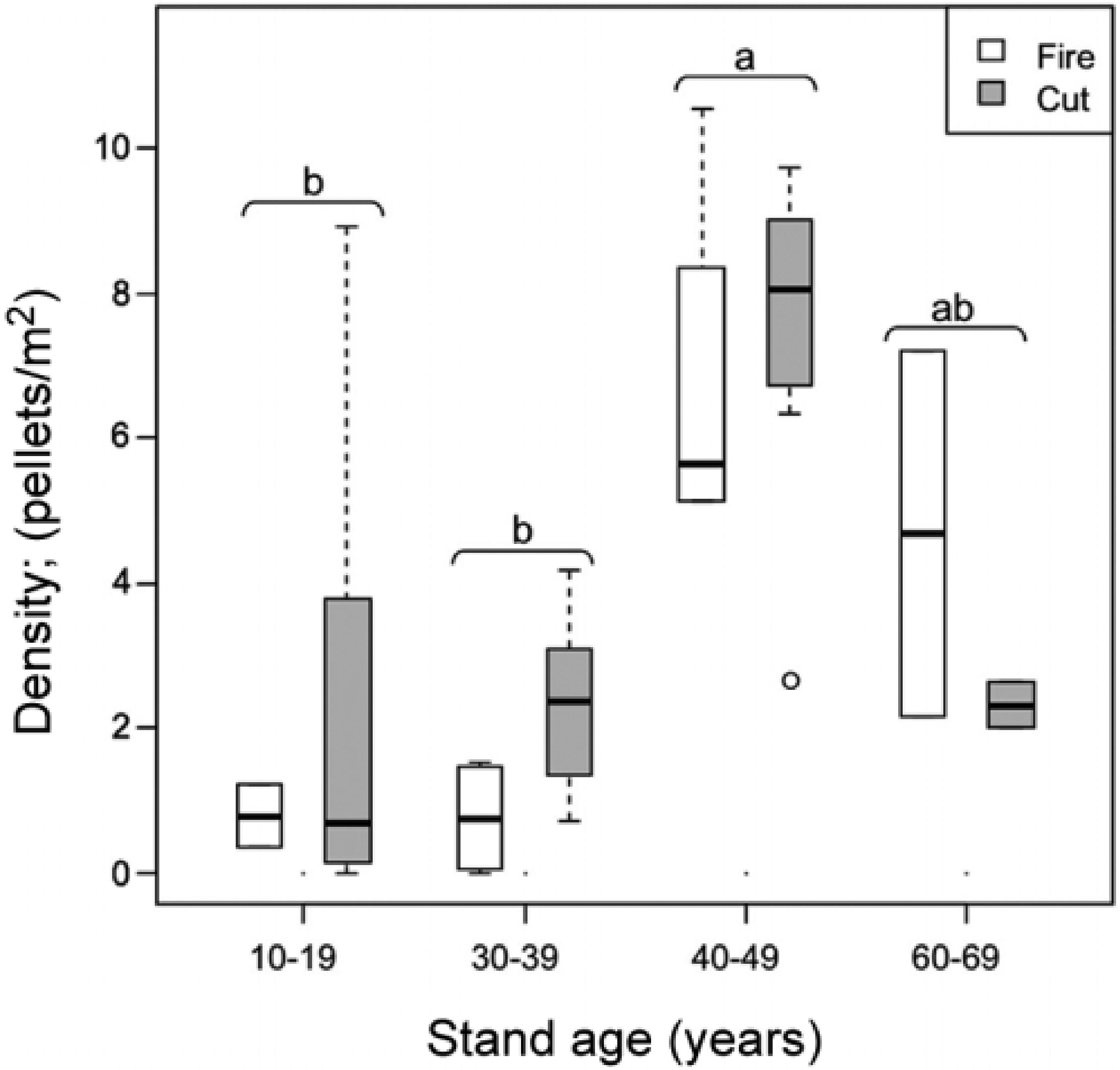
Hodges and Mills, unpublished

In Quebec, hare densities increase with years since commercial thinning



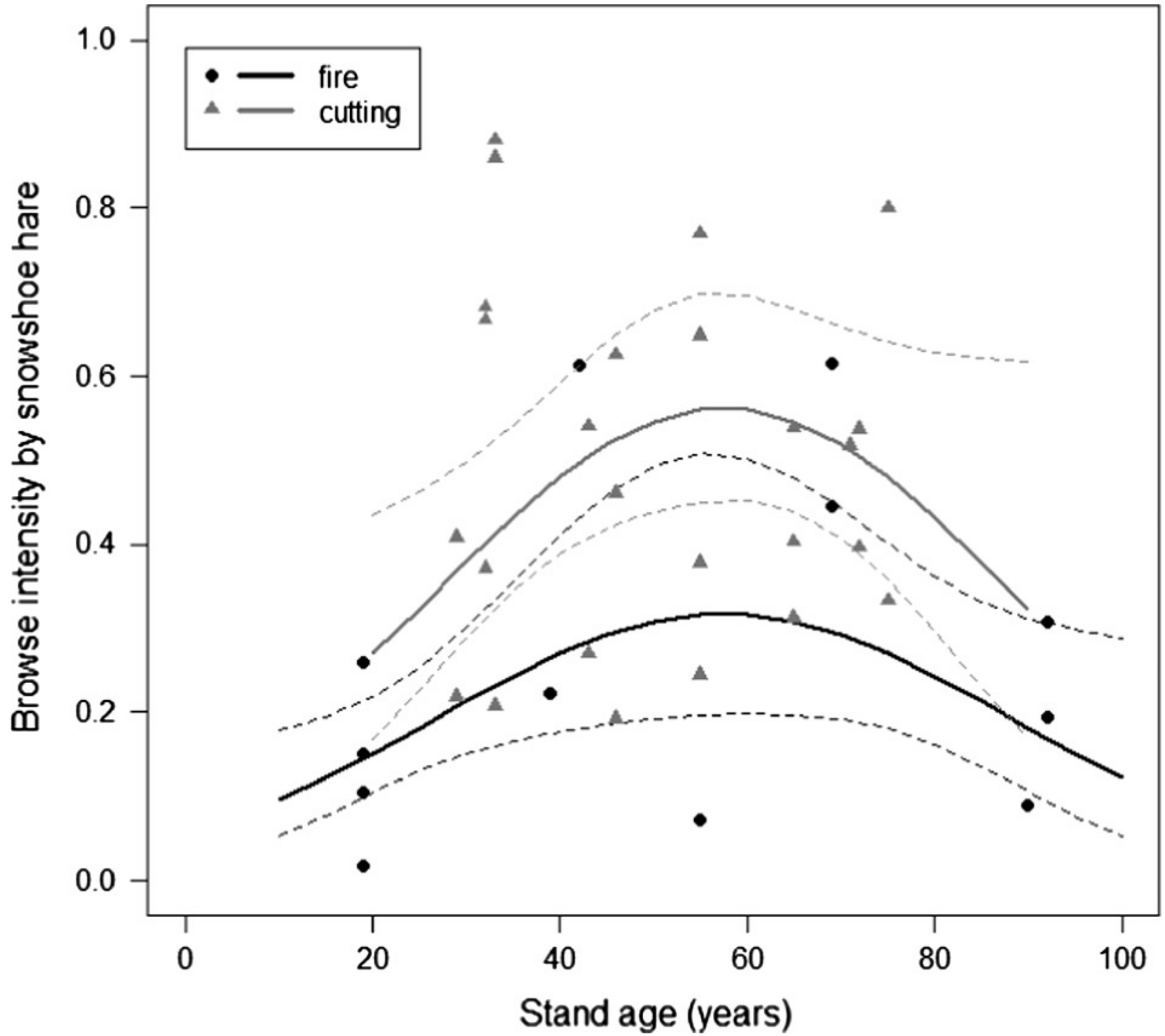
Bois et al. 2012 . Canadian Journal of Forest Research 42:123-133

And with years post-fire or post-harvest



Quebec, Hodson et al. 2011. Canadian Journal of Zoology 89: 908-920

In Quebec, forest age & history matter to snowshoe hares



Allard-Duchene et al 2014. Forest Ecology and Management 313:17-25

MAJOR POINT #4B. Fires destroy habitats short-term.

has hares
in 2002-2003

2003 'East' fire

has no hares
in 2004-2007

YELLOWSTONE

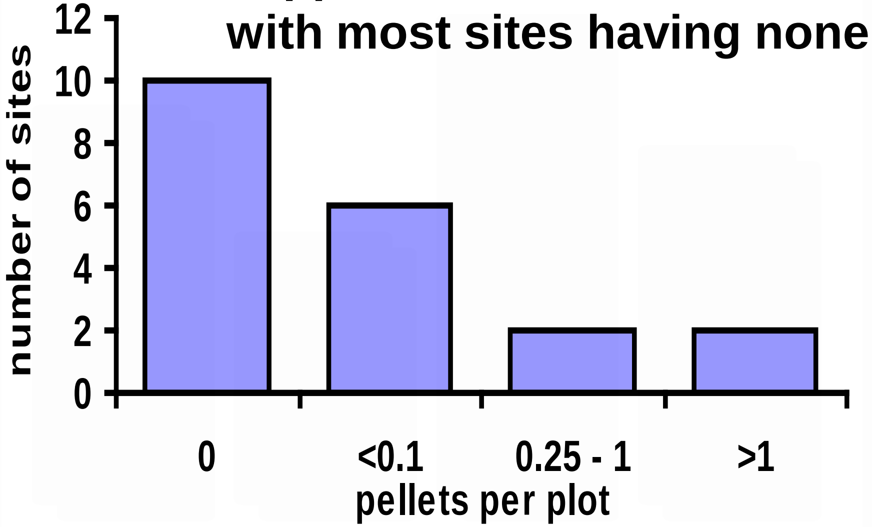
not good hare
habitat in 2011

MAJOR POINT #4C.
Hares re-use burned sites as soon as habitat enables them to do so.

We sampled 1988 burns in Yellowstone from 2002-2007

Yellowstone stands regenerating after the 1988 fires. . .

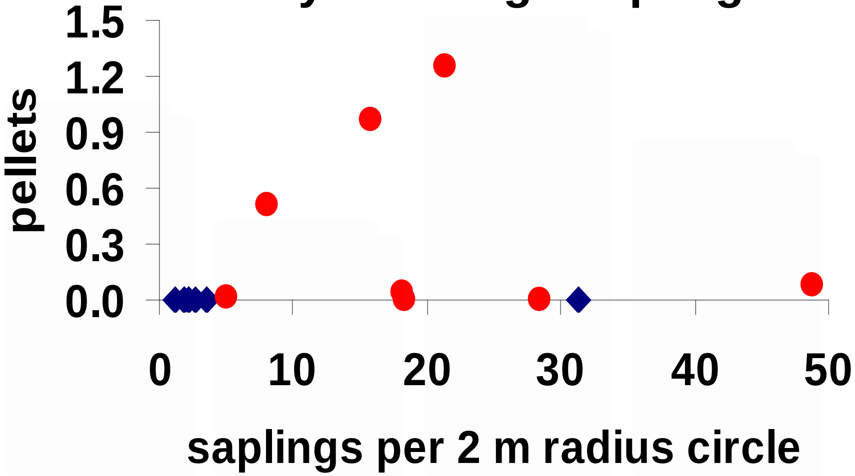
support few hares,
with most sites having none



has hares

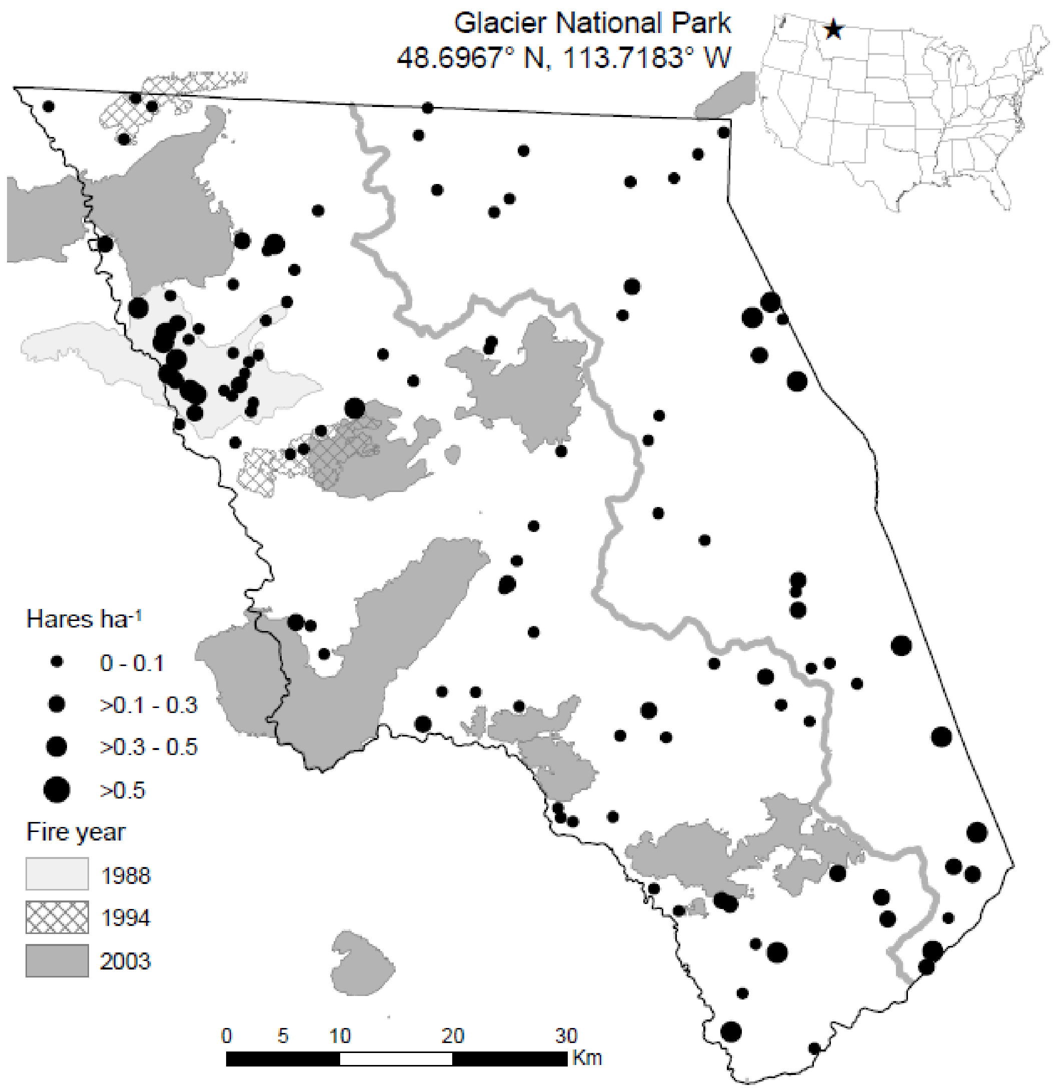
has no hares

are most likely to have hares
if they have high sapling densities



Hodges, Mills, and Murphy. 2009. J. Mammalogy 90:870-878

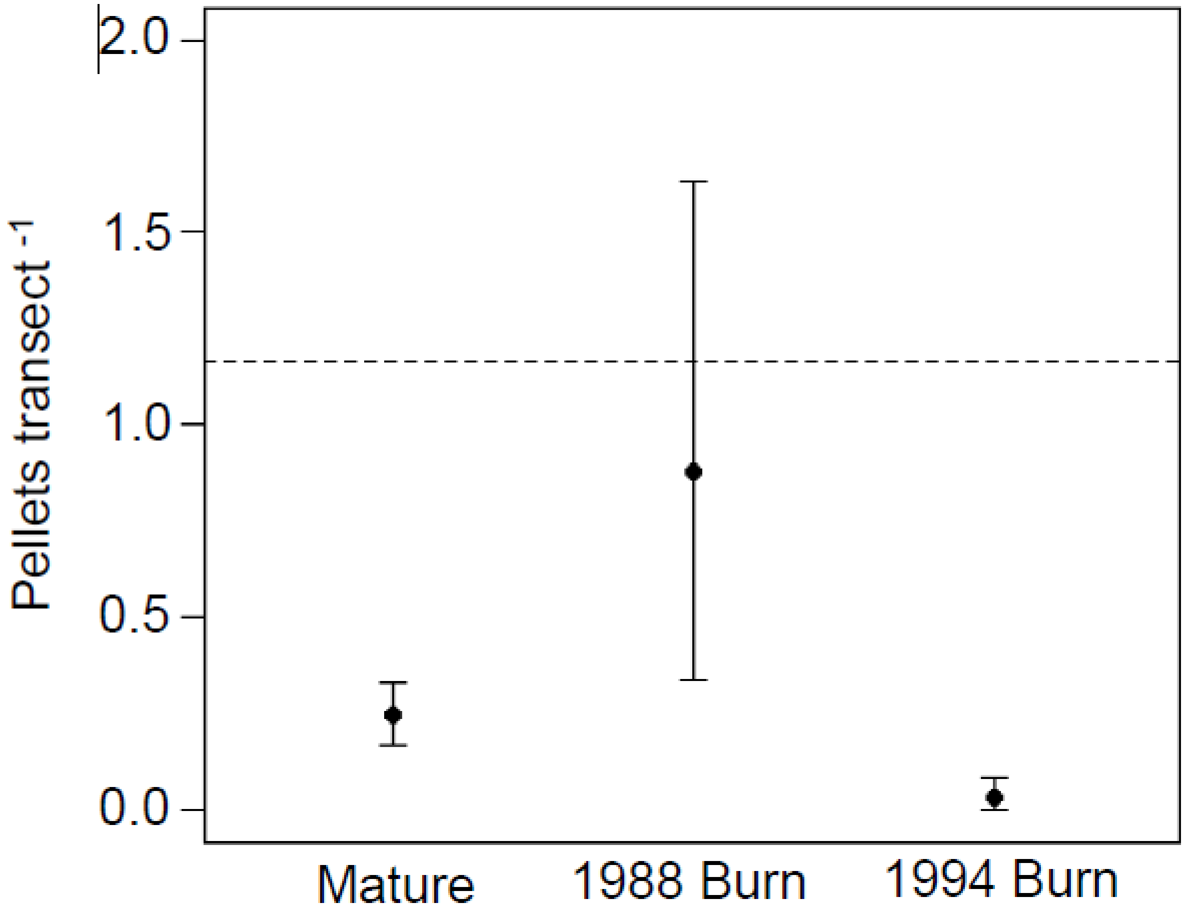
In Glacier National Park, we found similar patterns



data 2005-2007

Cheng, Hodges & Mills 2015. Fire Ecology 11:119-136.

High mean—and high variance—
in hare density in 1988 burns (17-19 yr post-fire)



n=87 n=23 n=4

Cheng, Hodges & Mills. 2015. Fire Ecology 11:119-136

Stands regenerating after 1988 fires: Glacier beats Yellowstone

	Yellowstone (2002-2007)	Glacier (2005-2007)
sites with hare pellets	47%	80%
maximum density (hares/ha)	1.3	2.4
average density	0.14	0.39
average density for sites with hares	0.27	0.49

Cheng, Hodges & Mills 2015, Hodges et al. 2009

Speculation #1:
How many hares do we need to keep lynx around?

Problem 1: Tally Lake sites in western MT: regionally high hares, but full of bobcats instead of lynx

Problem 2: Yellowstone has very low hare abundances, but has lynx

Problem 3: Spatial scales for "regional density" poorly articulated (lynx home range sizes vary, presumably partly in response to hare densities)

Problem 4: Lynx diets vary; we know less about red squirrel abundances than hare abundances

Speculation #2:
Future distribution and abundance of snowshoe hares

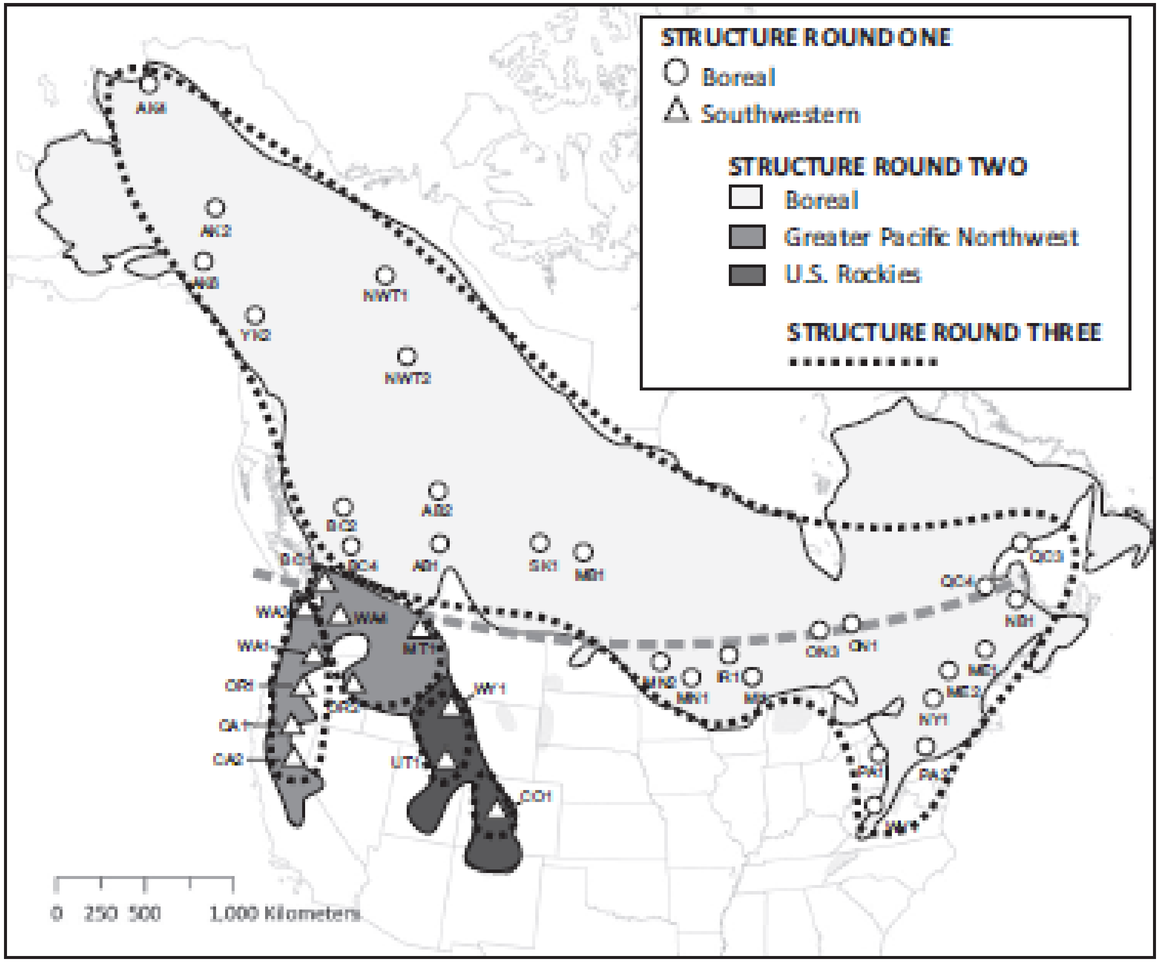
With very high confidence:
if we completely lose southern boreal / montane forest, hare numbers will decline in those areas.

1. **Forest loss (harvest, thinning, fire), will mean fewer hares at least for a few years.**
   Unknown impacts of salvage logging post-fire.

2. **We know more about hares and trees than about hares and shrubs. But understory cover and browse are very important to hares.**

3. **We don't know much about hares and winter snows (a few regional models, not much local or specific)**

Speculation #3:
Some hare lineages may be at risk themselves
(or may respond differently to upcoming challenges)



High gene flow across boreal range

High genetic structure in southern range

Cheng et al. 2014. Molecular Ecology 23:2929-2942.

Speculation #4:
Impacts of climate change on snowshoe hares?

1. Fires, insect outbreaks, changed forest regeneration
   --habitat structure matters to hares, so changed habitats means changed distribution / abundance

2. Coat colour issues?
   --mismatch coat / forest floor may increase mortality
   --molt cue is daylength

2. Changing forest community?
   --Unclear impacts on hares of different predator communities
   --impacts of predation by bobcats, fisher, etc. are poorly known compared to raptors, lynx, coyote

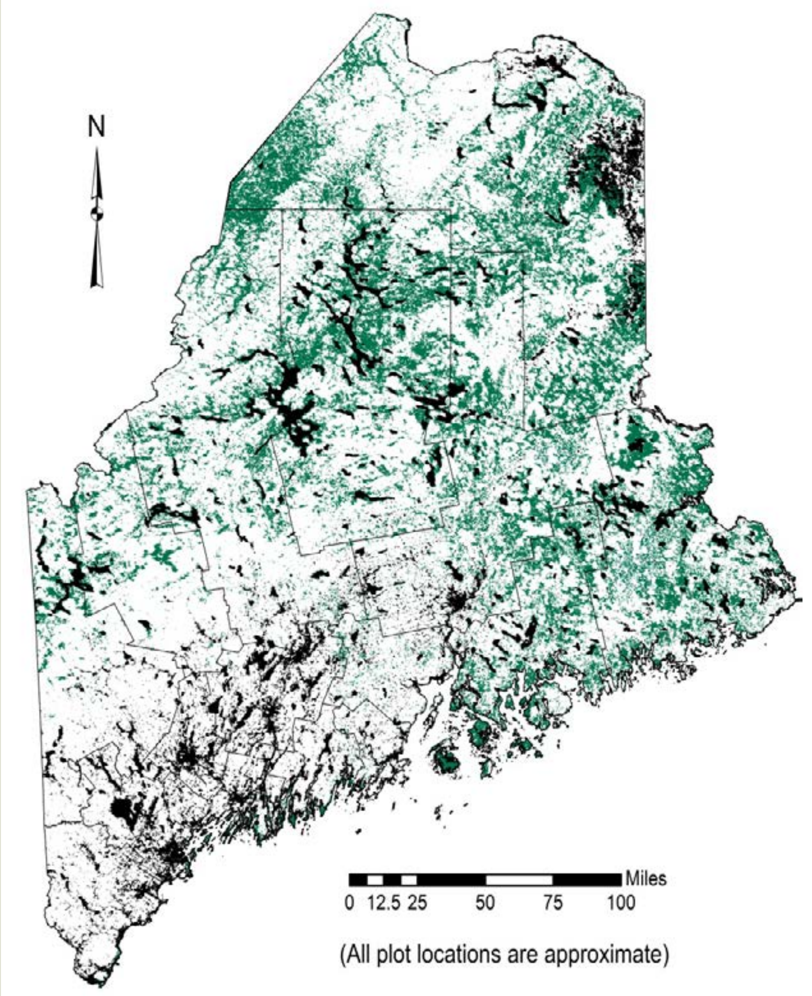
Frontiers in snowshoe hare research

1. Explaining regional variation in dynamics, peak abundance
2. Predicting post-fire re-colonization and density
3. Predicting responses to climate change (fires, winter snow pack, forest conditions: molt timing, physiology, demography)
4. Physiology – demography links (predation stress and reproduction)

Status of Lynx In Maine

Maine's Forest – contiguous forestland

- ~18 million acres of forest
  - 6 mill acres spruce/fir
- Privately owned–forest mgmt.
- Limited development pressures
- Easements on 2.5 million acres
  - Protected from development
  - Active forest management

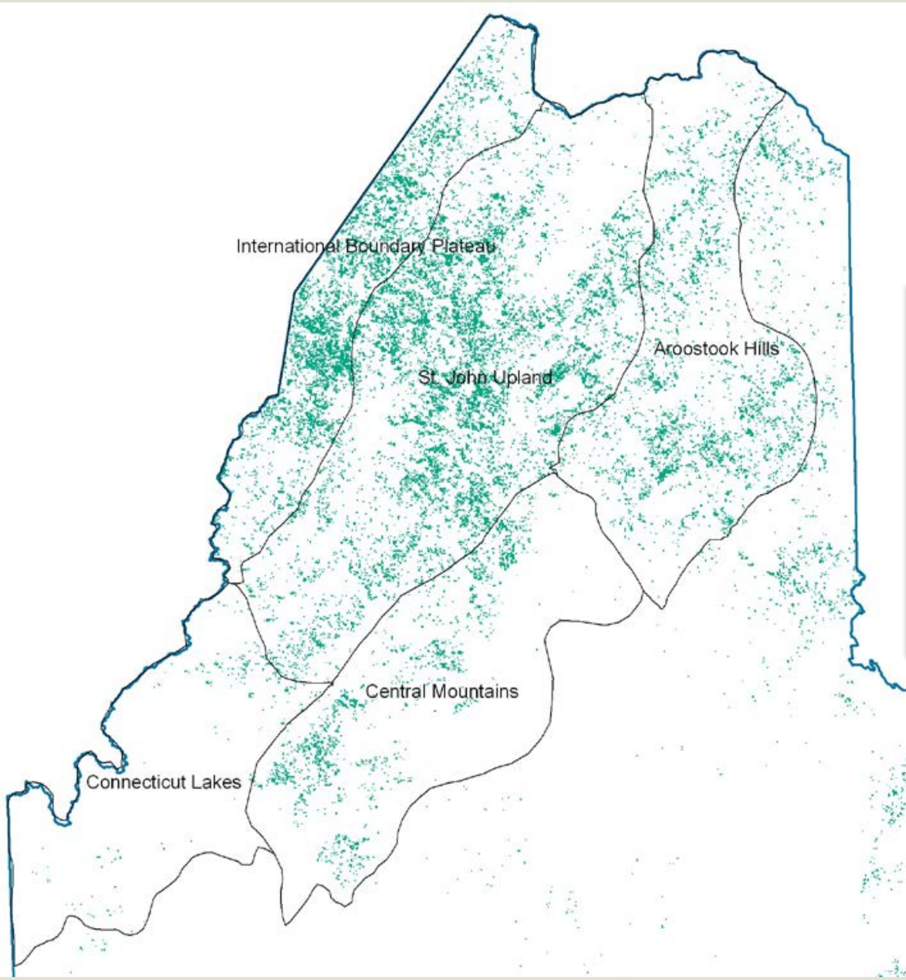


Distribution of spruce/fir forest type group, Maine 2012 (Homer et al. 2012)

1970-85 Budworm Outbreak

1990s – Today
Extensive Areas of Regenerating Forest

Forest Conditions–Forest Inventory Data

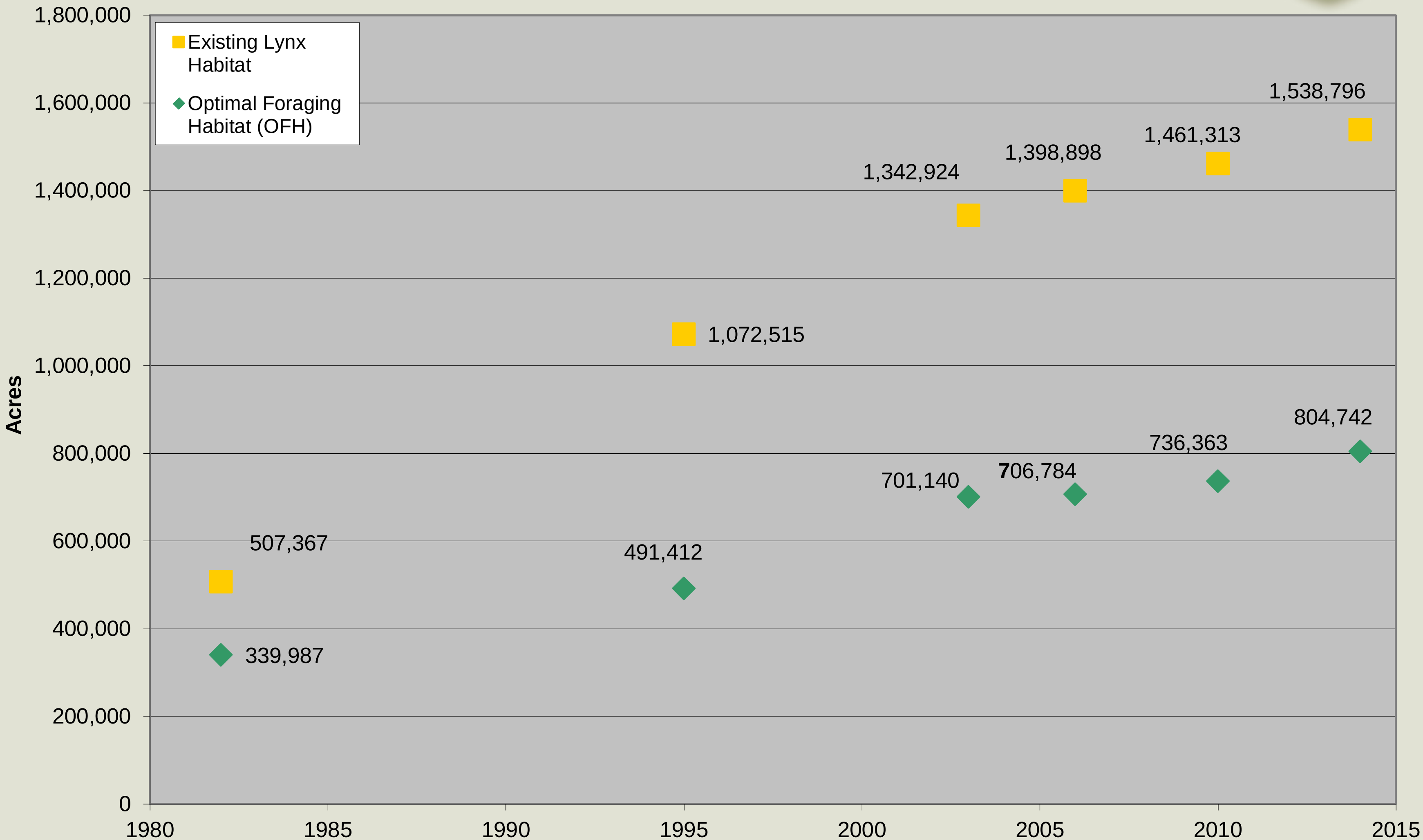


3 million of acres of S/F forest

	Sapling	Dense
1982	½ million	340,000
1995	1 million	½ million
2006	1.4 million	700,000

Source: Maine Forest Service – Ken Laustsen

Forest Inventory UPDATE 2014



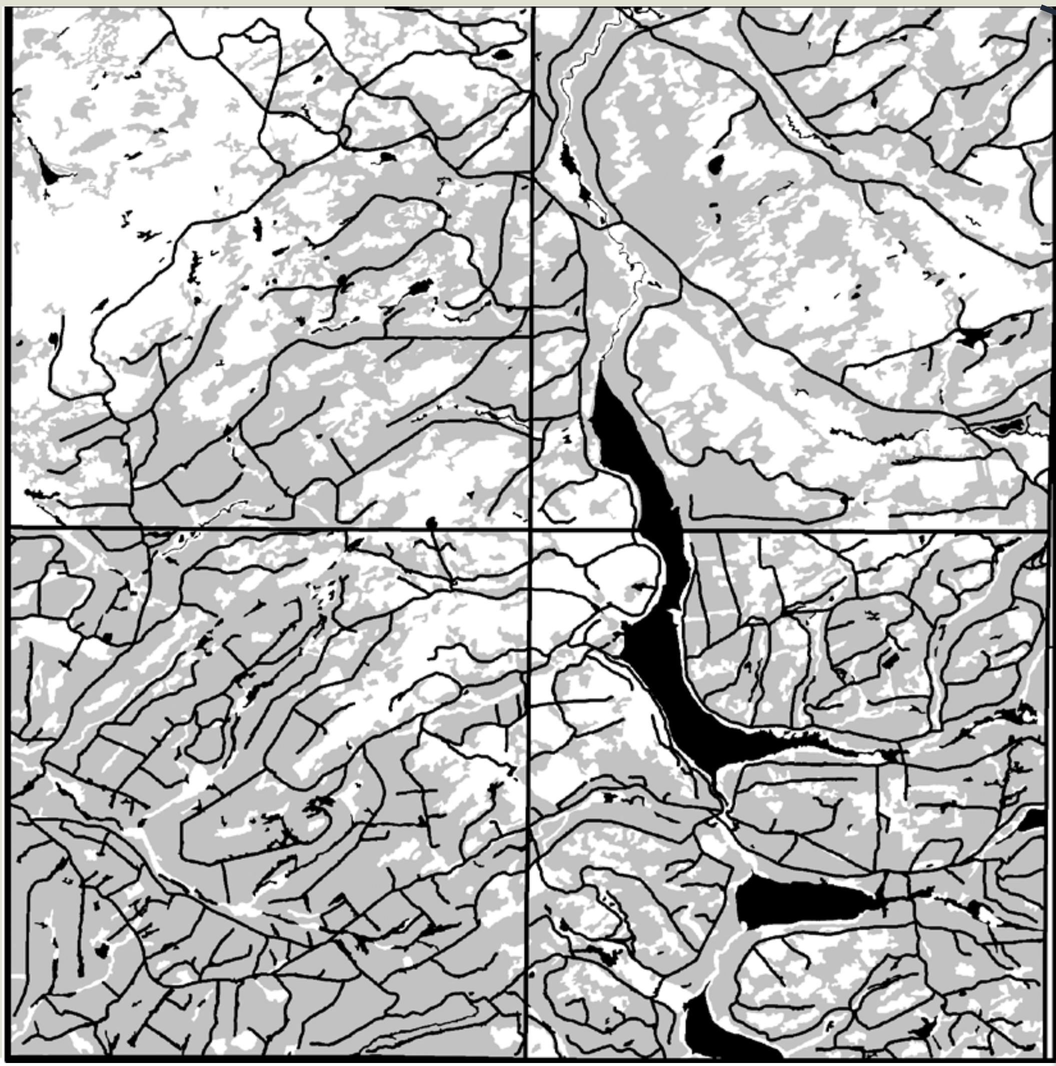
Monitoring Lynx in Maine

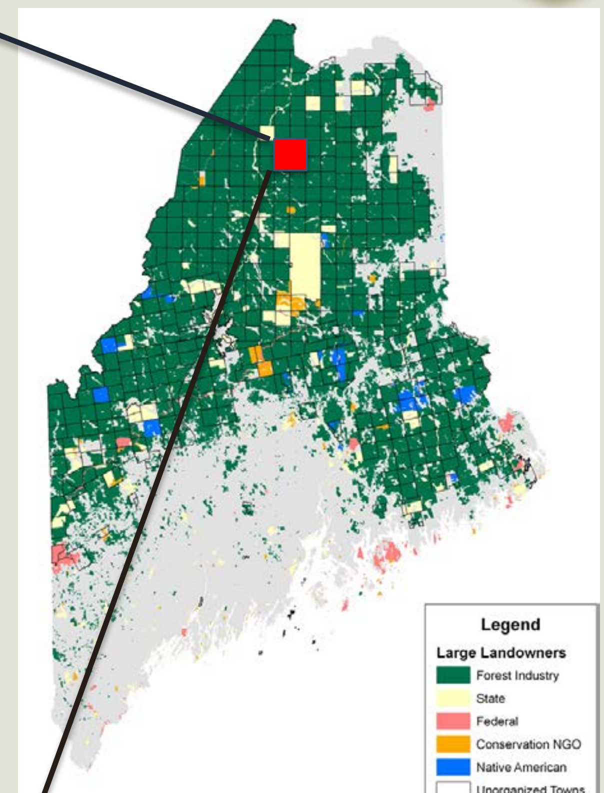
1. Radio Telemetry Study: 1999–2011
2. Periodic Winter Snow Track Surveys
   - 1995–98, 2003–2008, 2015–2017
3. Credible Sightings – MDIFW Staff
4. Incidental Take

Radio Telemetry Study: 1999–2011

- Captured 191 lynx
  - 113 kittens in 43 litters
  - 85 radioed
- Occupy small home ranges
- Lynx select best habitats
- Good reproduction and survival

Radio Telemetry Study: 1999–2011

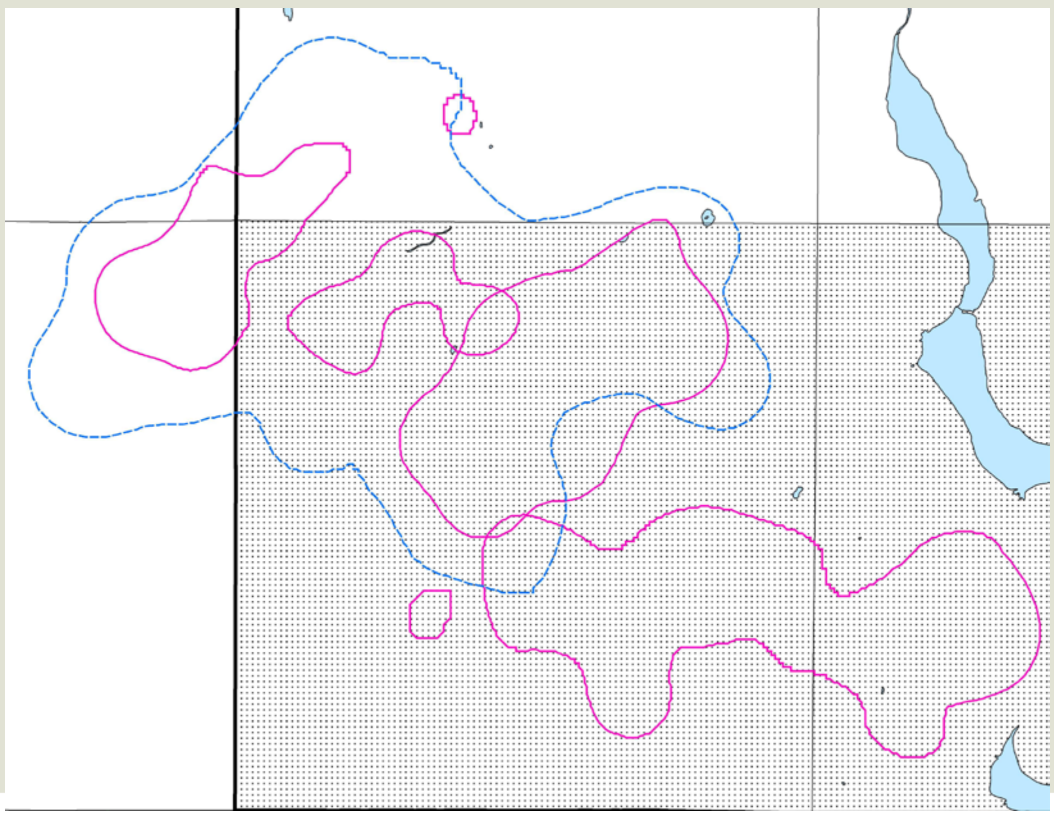




Budworm Impacted
46% s/f clear cuts

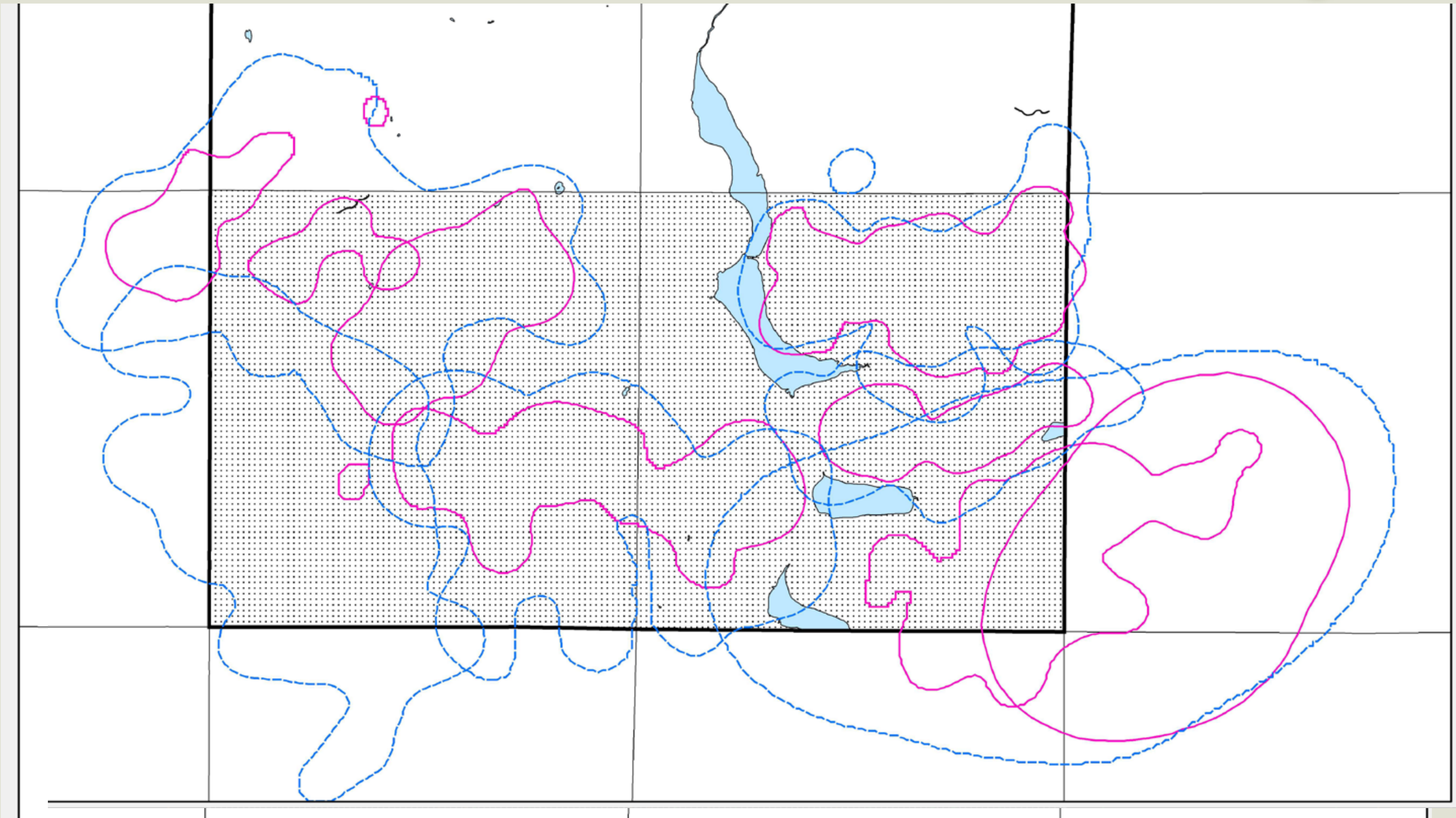
Radio Telemetry Study : 1999–2011

- Home range : 25 km^2 F, 50 km^2 M
- Male home range overlaps 3 females



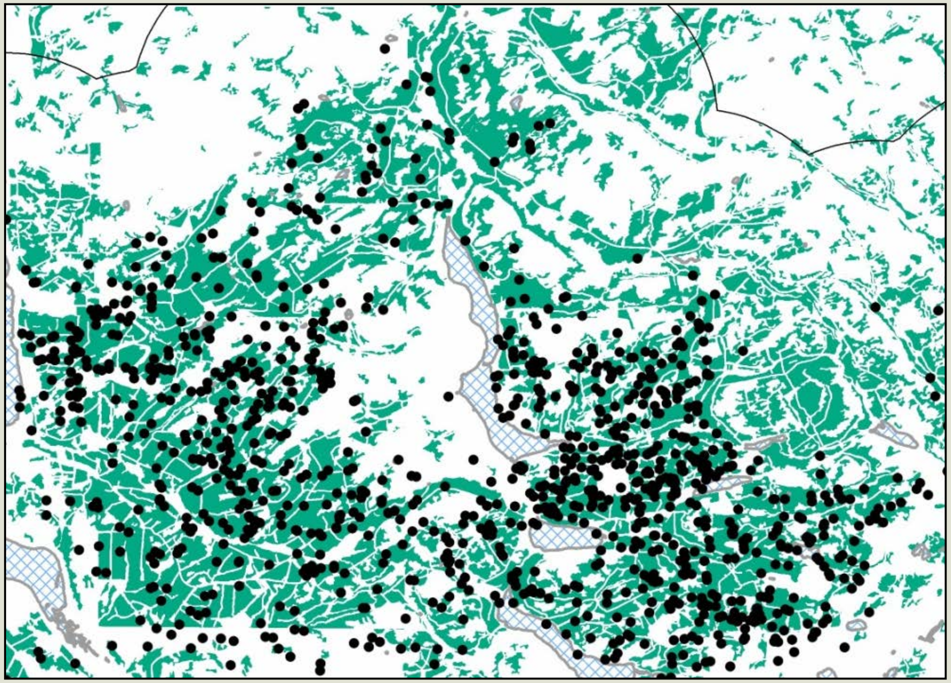
Radio Telemetry Study : 1999–2011

MAINE
DEPT. OF INLAND FISHERIES AND WILDLIFE



Radio Telemetry Study : 1999-2011

- Habitat Use – Selection for S/F sapling forest
    - 1,800-2,300 acres in Female HR
    - 3,000 -4,000 acres in Male HR



Radio Telemetry Study: 1999-2011

- Population demographics
  - 65% of adult females with kittens
  - Average litter size: 2.63 (range 1-5)
  - Kitten Survival: 78%
  - Annual Adult Survival: 76% (SE=3.37)
    - Predation
    - Starvation-lungworm

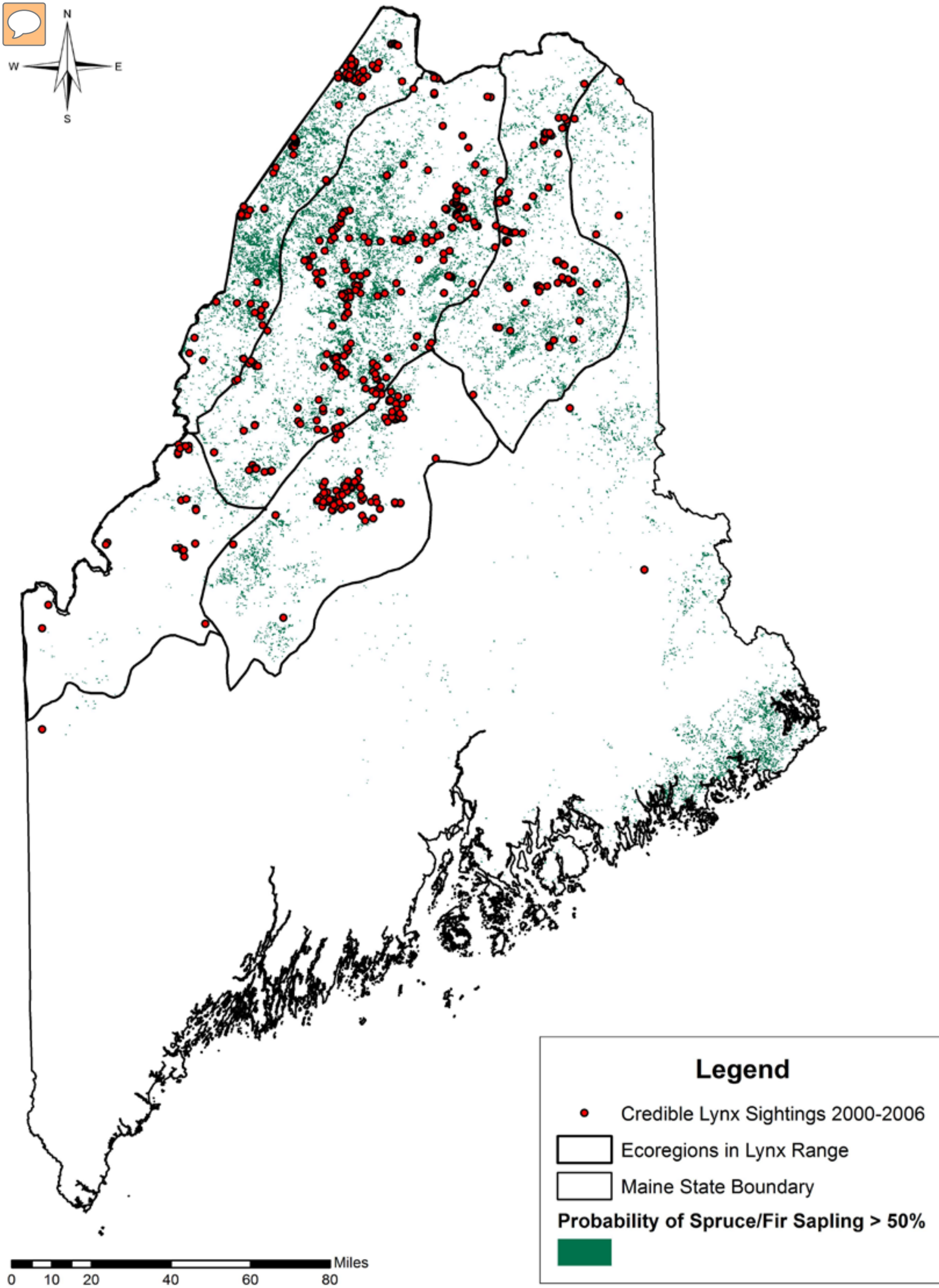
Reproduction: Lynx Study Area (400km^2)

				Hares/Ha	
Year	AF	# Litters	Productivity	in CC	in SHW
1999	1	1	100%		
2000	3	3	100%		
2001	4	4	100%	2.22	
2002	9	9	100%	1.8	
2003	7	6	86%	1.85	
2004	9	7	78%	1.79	
2005	5	4	80%	1.92	0.87
2006	7	1	14%	1.19	0.97
2007	7	2	29%	0.99	0.65
2008	4	0	0%	0.8	0.66
2009	4	0	0%	0.75	0.64
2010	5	5	100%	0.91	0.96
2011	1	1	100%	1	1.31

Population Estimate

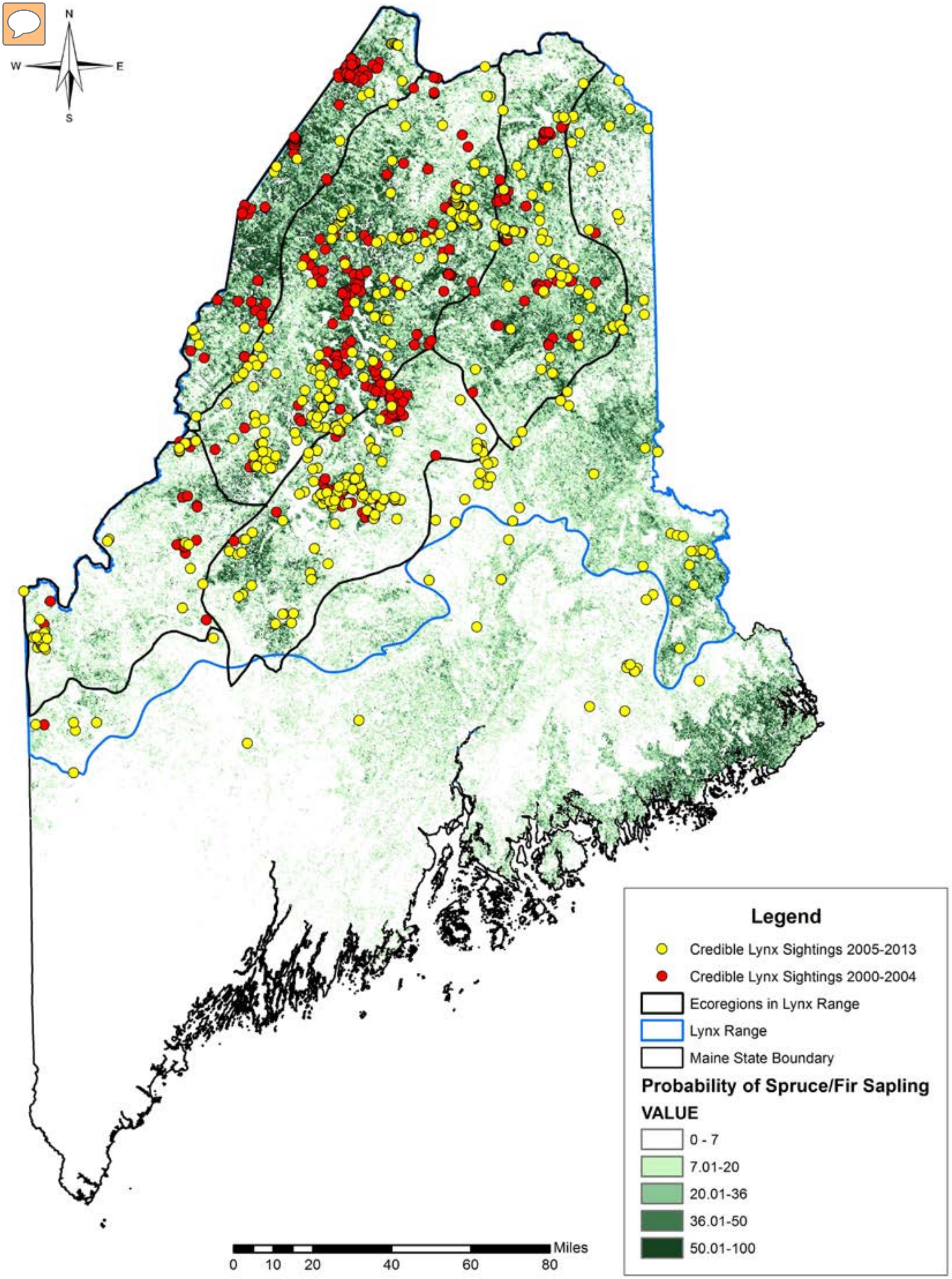
- Available lynx habitat in northern Maine – FIA
- Proportion of habitat occupied – track surveys
- Amount of lynx in occupied areas – habitat in h.r.

See Appendix IV – Maine's Lynx Assessment



2006 Population Estimate

750 – 1,000 Adult Lynx



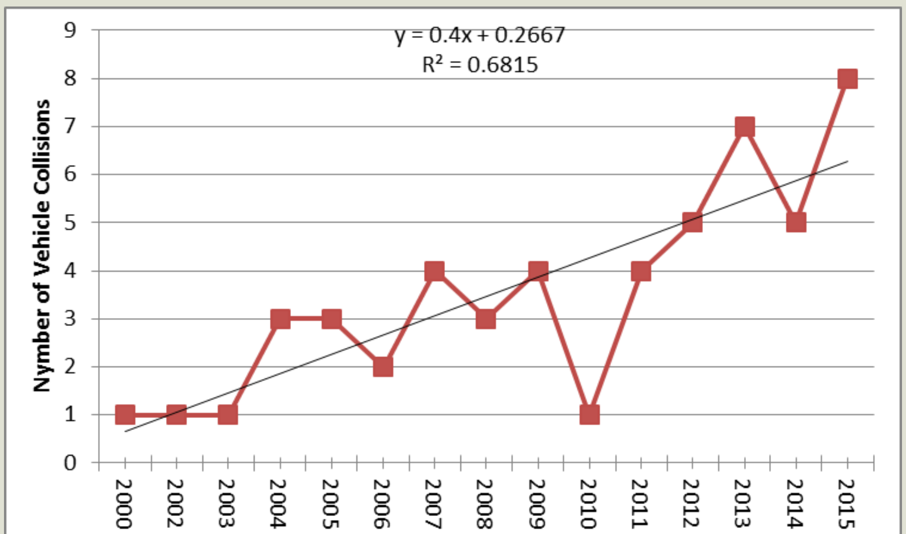
2015 Population Estimate

> 1,000 Adult Lynx

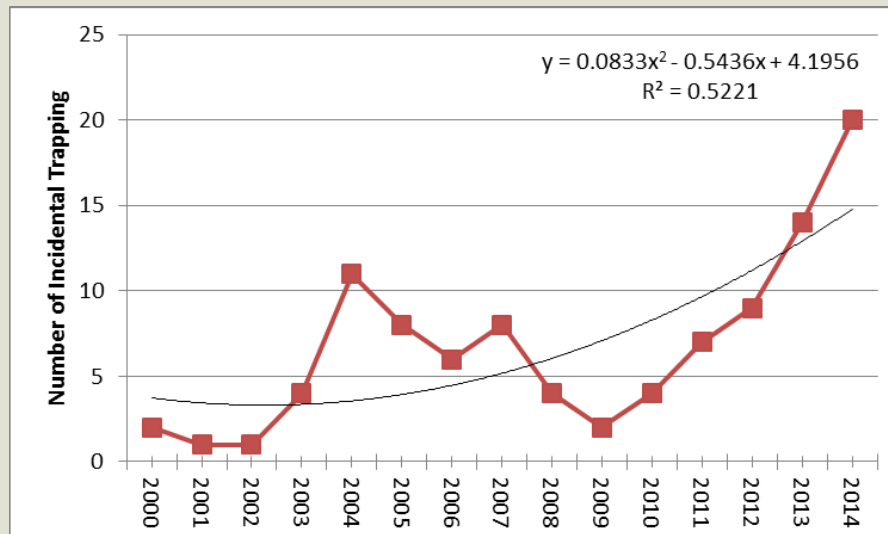
Credible Sightings

Indices suggest Maine's lynx pop still increasing

Road Mortalities

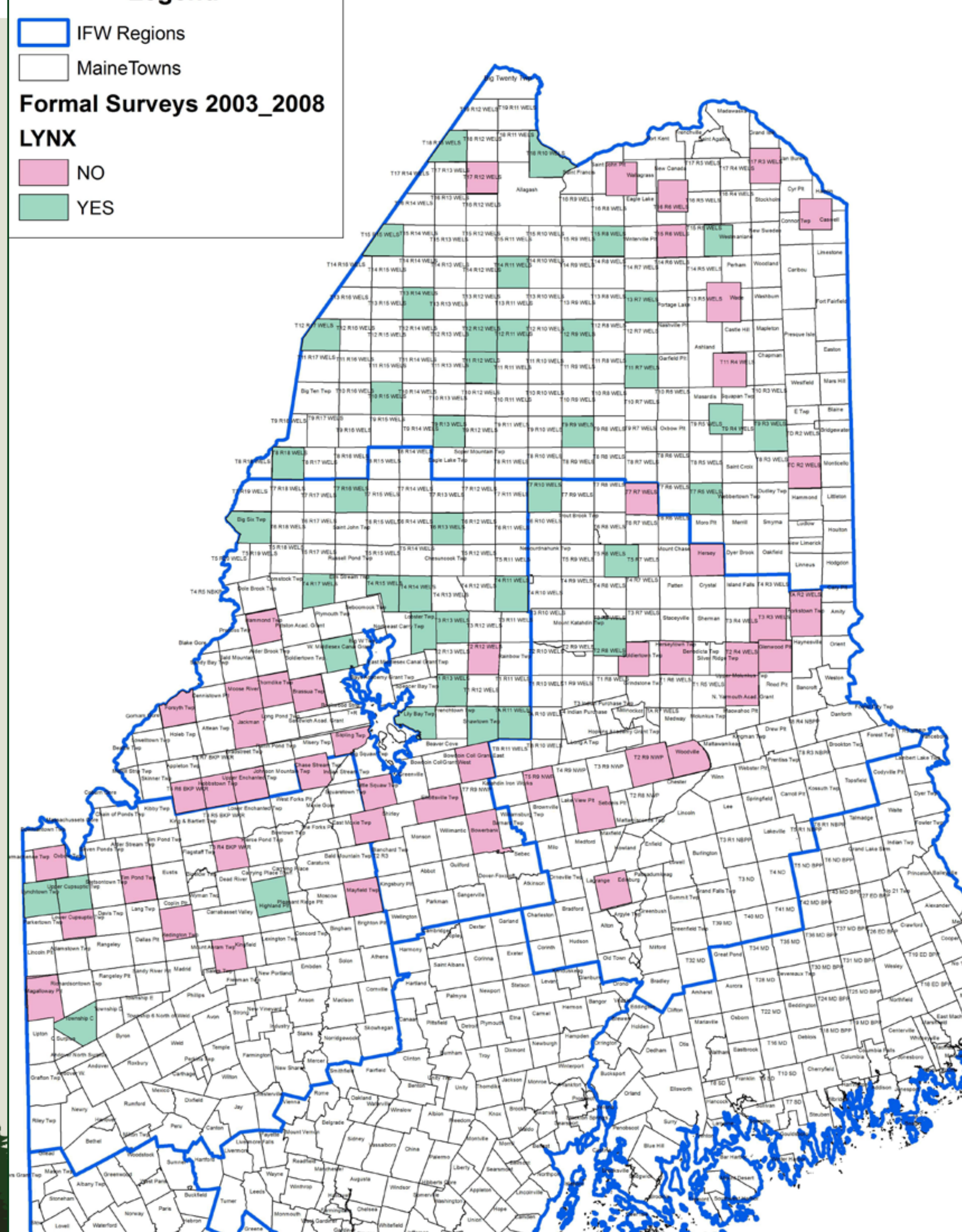


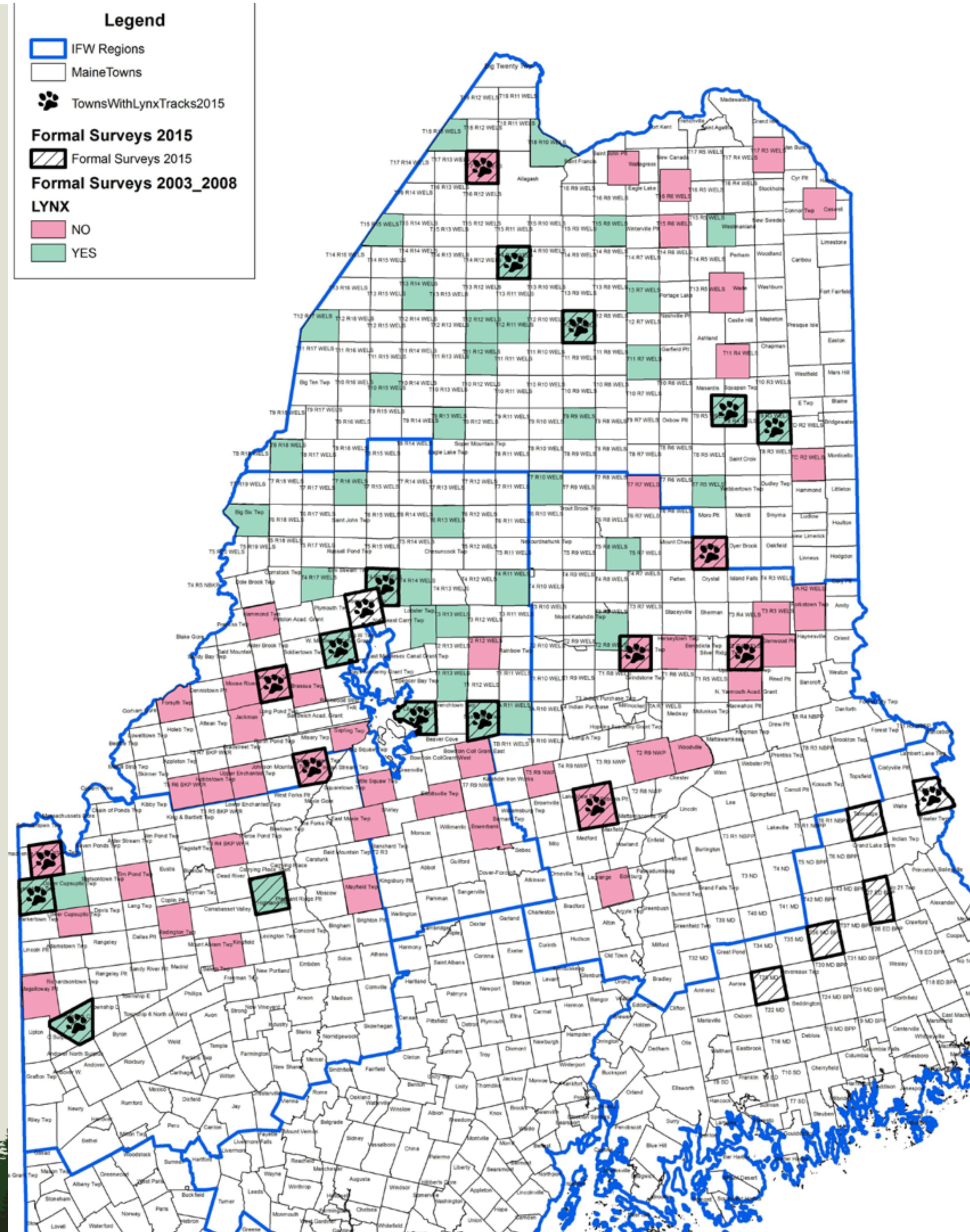
Incidental Captures in Traps



Periodic Winter Track Surveys

- Snowmobile 55–80 km Unplowed Roads / 100km2
- 24–72 hrs. after snow/wind event
- GPS survey route and track intercepts
- Collect additional data at track
  - Photograph
  - Measurements
  - Assign STQ
  - Number of Individuals
  - Direction of Travel


IFW Regions
MaineTowns
Formal Surveys 2003_2008
LYNX
NO
YES


Legend
IFW Regions
MaineTowns
TownsWithLynxTracks2015
Formal Surveys 2015
Formal Surveys 2015
Formal Surveys 2003_2008
LYNX
NO
YES

Monitoring Lynx – Track Surveys

Time period	Number of towns surveyed	Number of towns with lynx	% occupied
1995–1998	116	10	9%
2003–2008	91	43	47%
2015	24	19	79%

19 towns surveyed in 2003–08 and 2015

Time period	Number of towns surveyed	Number of towns with lynx	% occupied
2003–2008	19	11	58%
2015	19	18	95%

Preliminary Occupancy Models

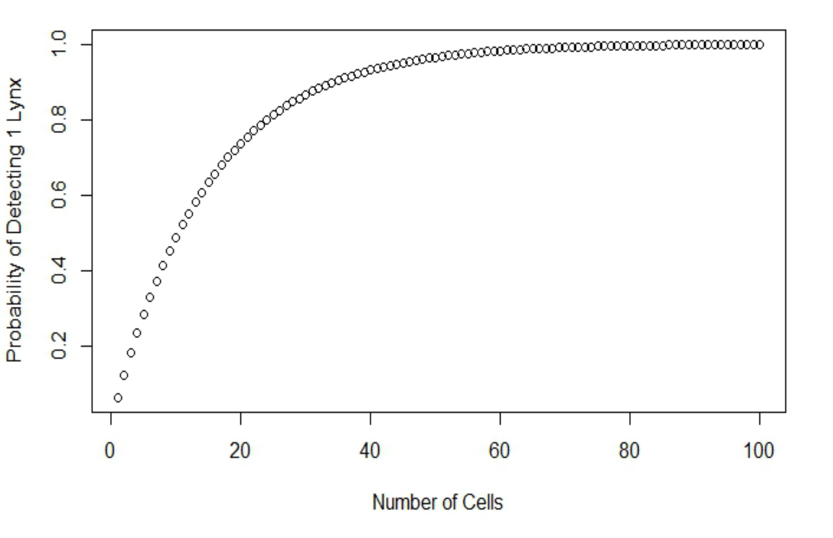
2003

Naïve estimate: 17/19 towns

Ψ = 0.897 +/- 0.07 SE

Mean Detection rates:

p = 0.065 +/- 0.007 SE



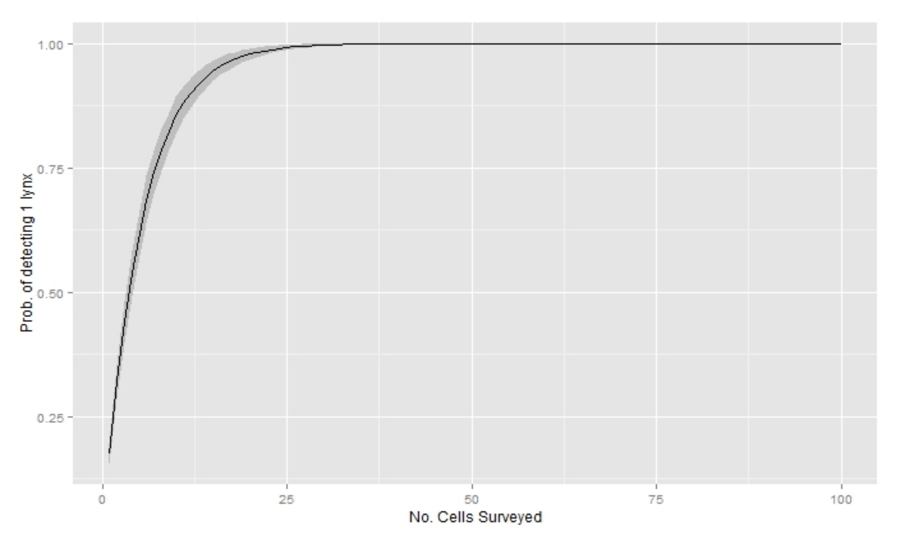
2015

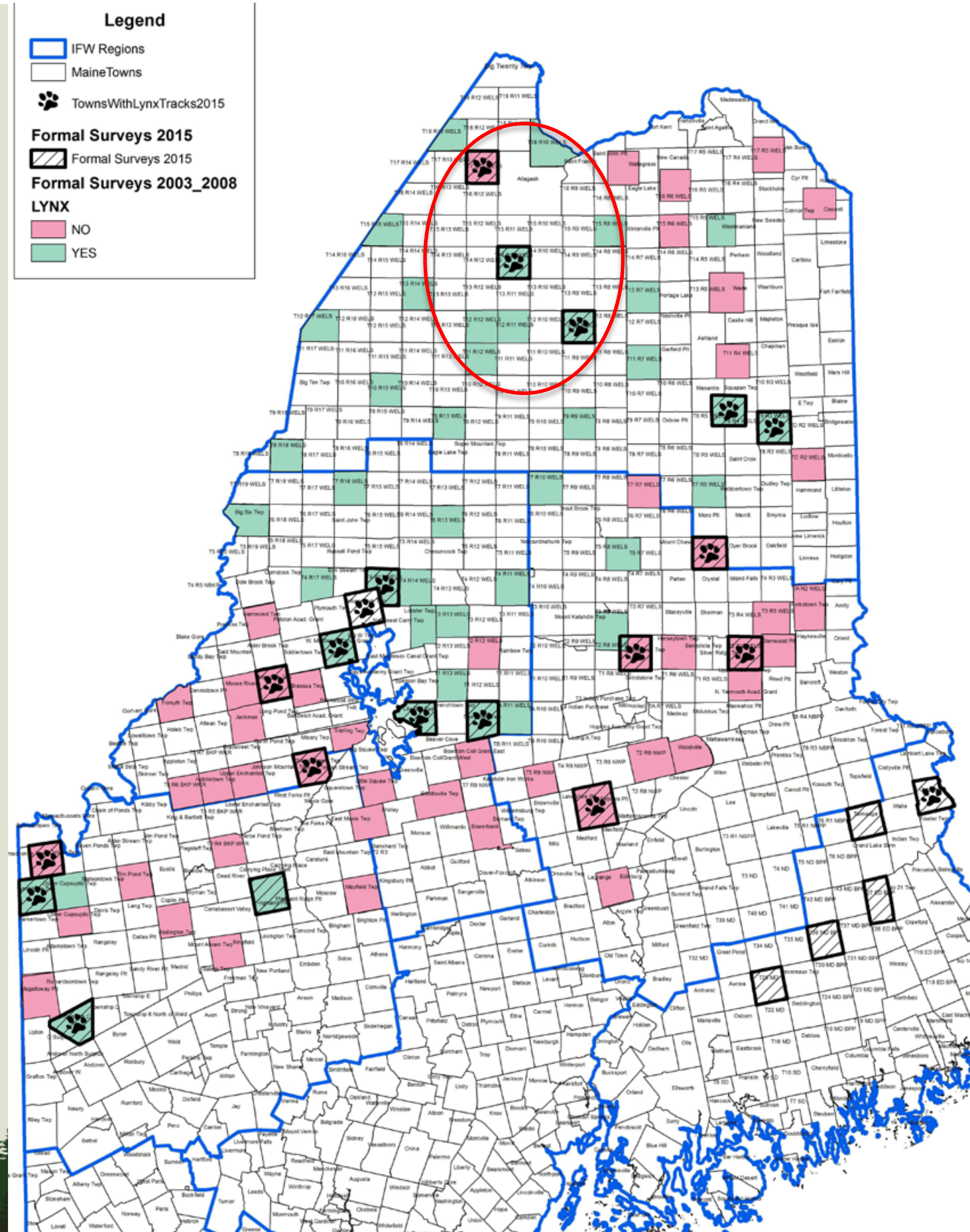
Naïve estimate: 18/19 towns

Ψ = 0.951 +/- 0.05 SE

Mean Detection rates:

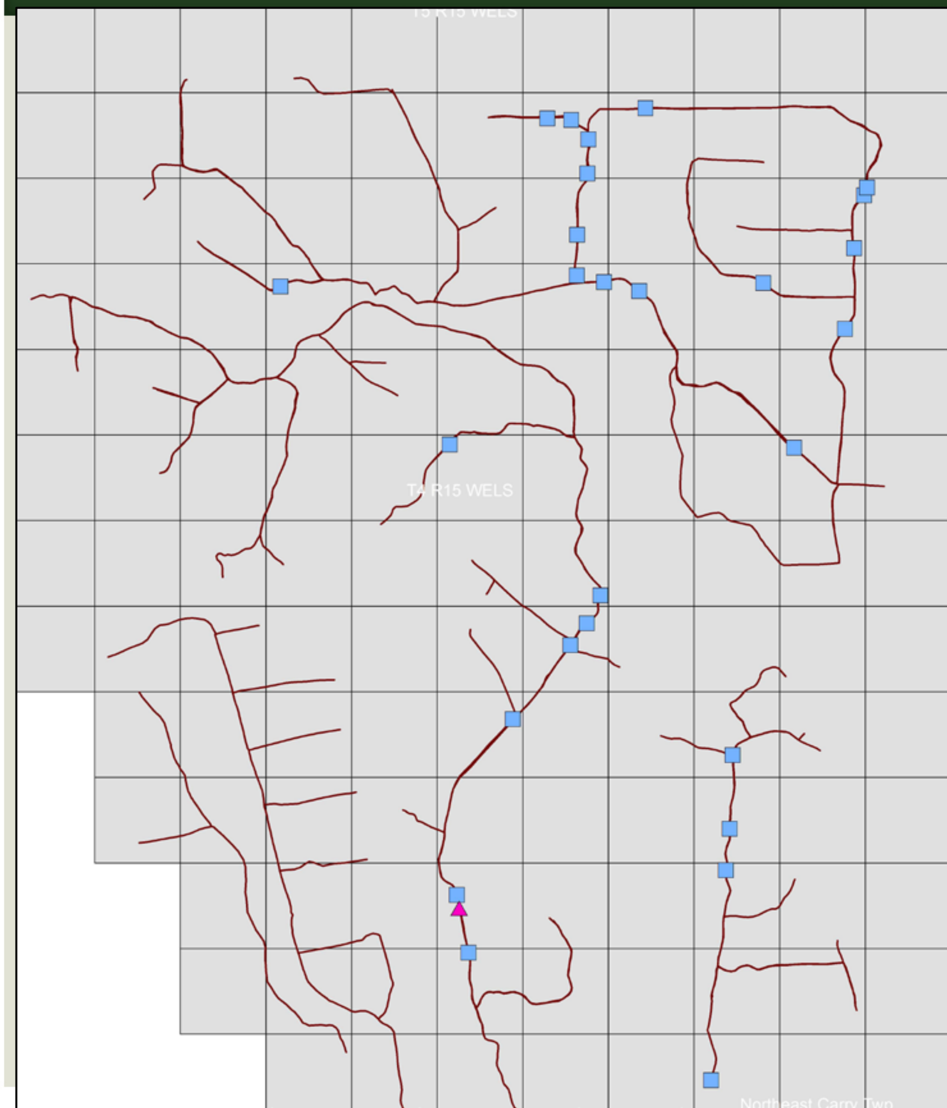
p = 0.176 +/- 0.010 SE

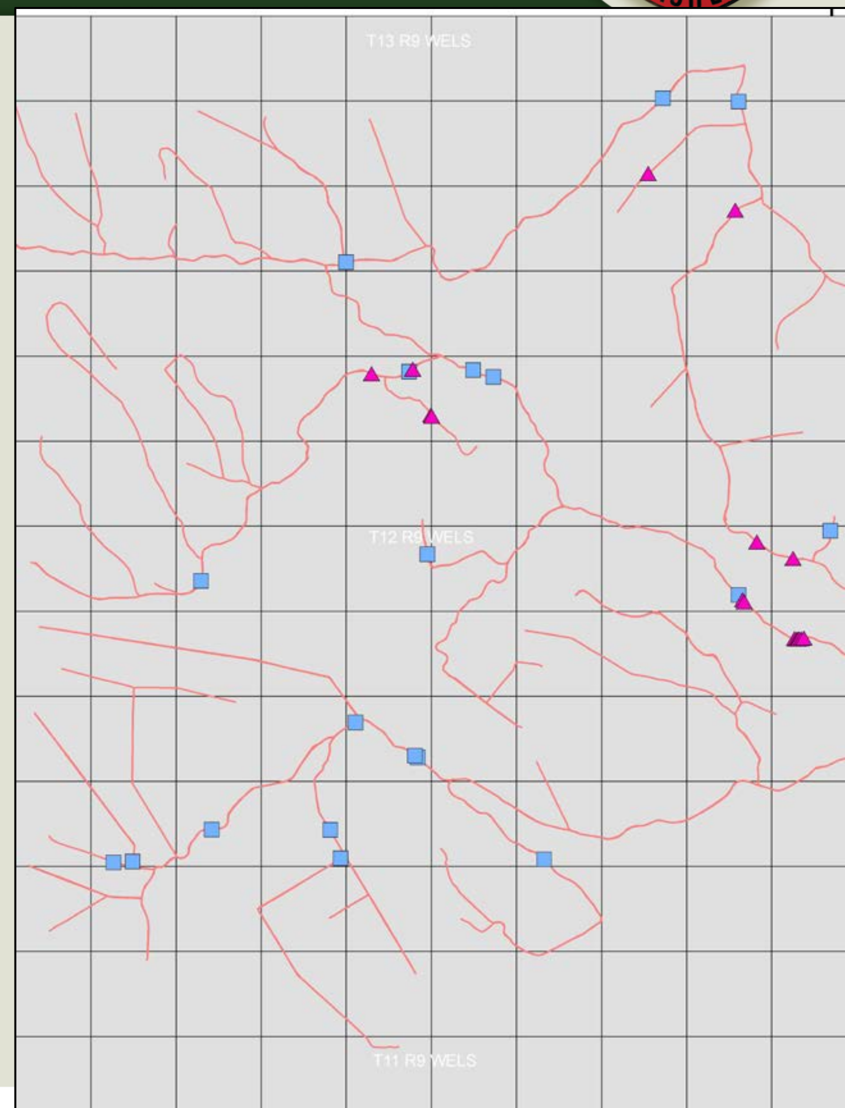



Legend
IFW Regions
MaineTowns
TownsWithLynxTracks2015
Formal Surveys 2015
Formal Surveys 2015
Formal Surveys 2003_2008
LYNX
NO
YES

Detection Higher 2015

▲ =2003 tracks ■ =2015 tracks

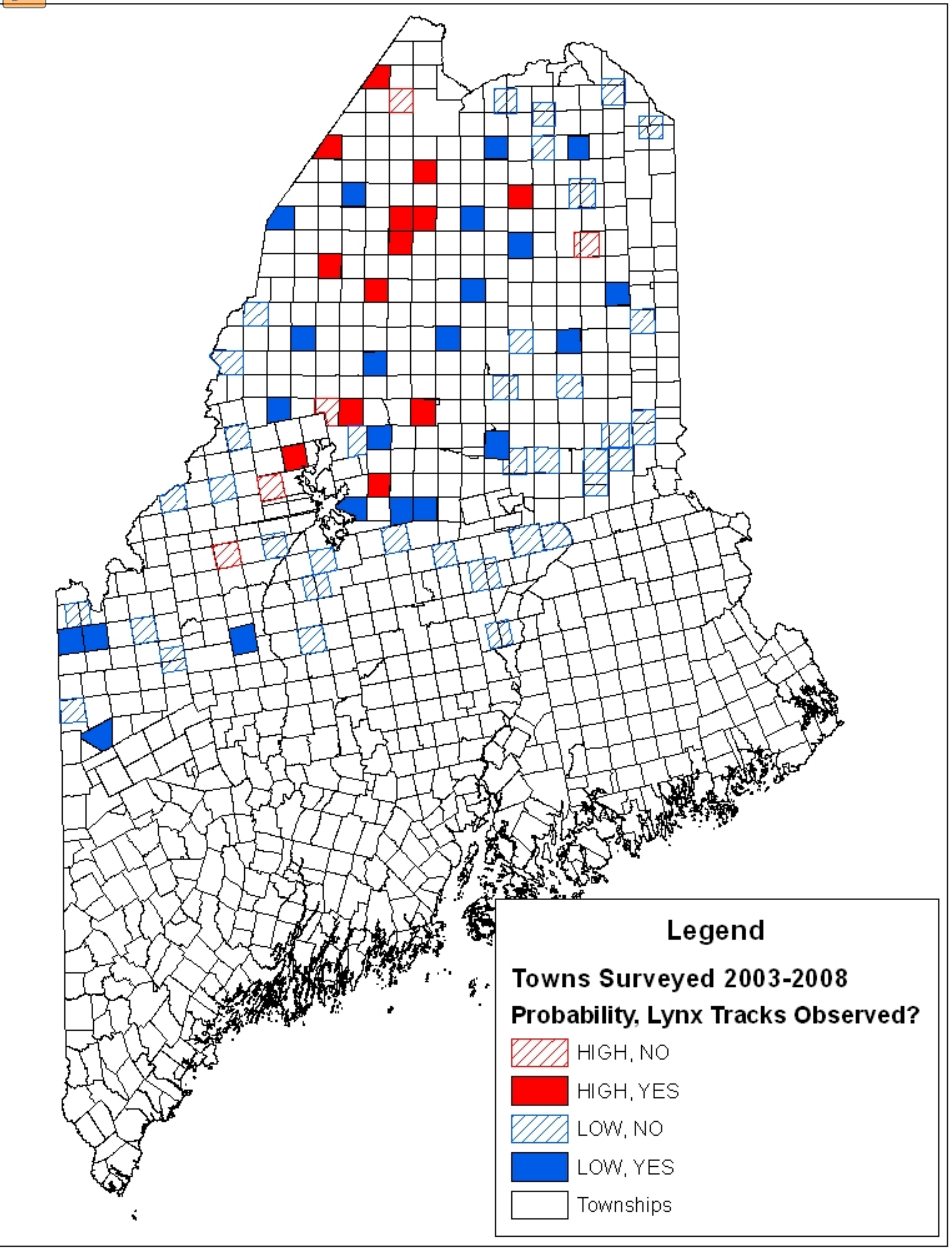




Future Surveys

- Surveys to continue 2016 and 2017
  - Resurvey areas previously surveyed
  - 25 towns each year for 3-4 years.
  - Same survey design

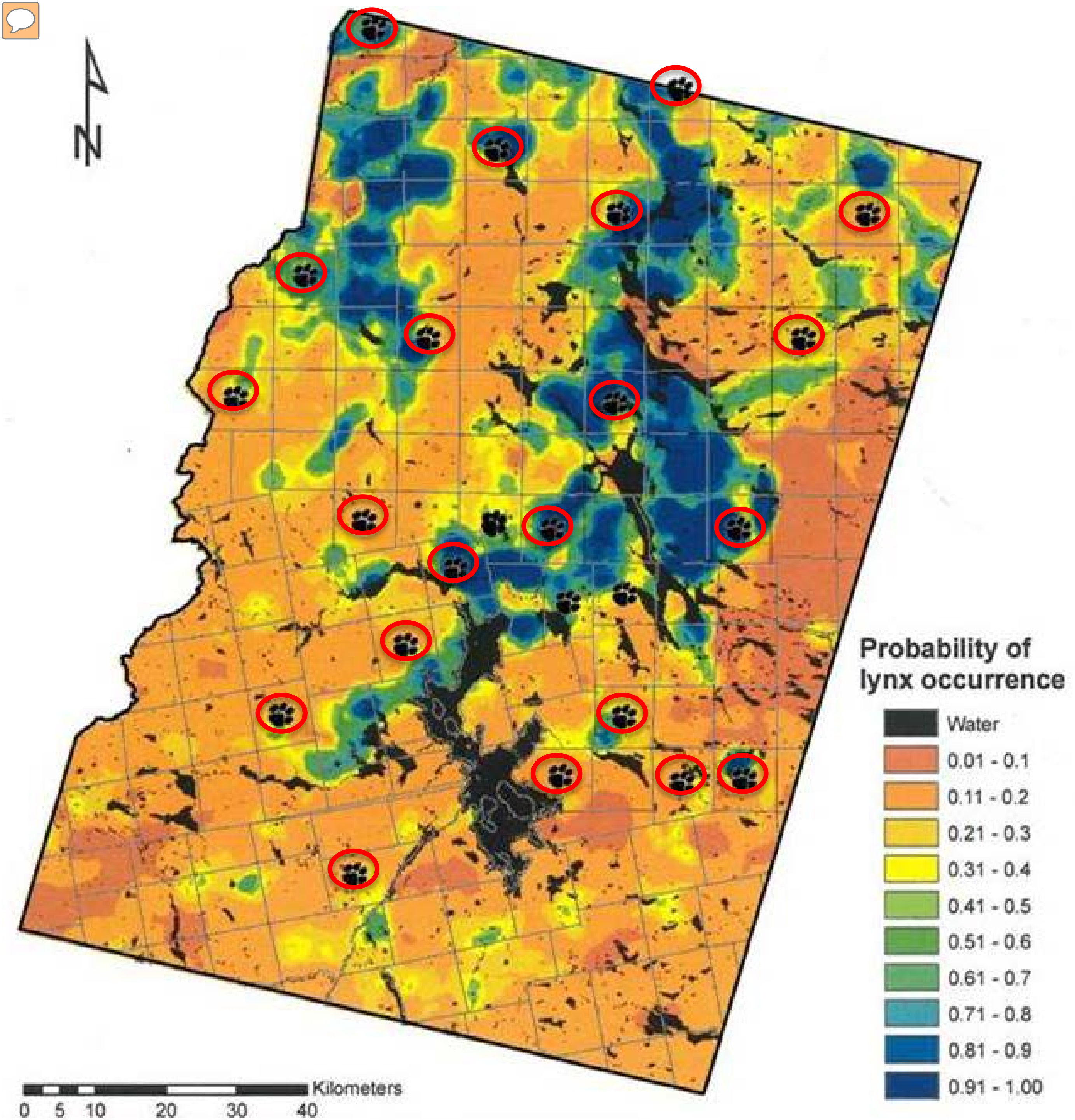
- Occupancy modeling –
  - Has Occupancy Increased (i.e., expanding)?
  - Has Prob. Of Detecting Lynx Increased?
  - Has density/pop increased?



2003-08 Track surveys

Found lynx in

- 22 of 55 Low Probability
- 13 of 18 High Probability


N
Probability of lynx occurrence
Water
0.01 - 0.1
0.11 - 0.2
0.21 - 0.3
0.31 - 0.4
0.41 - 0.5
0.51 - 0.6
0.61 - 0.7
0.71 - 0.8
0.81 - 0.9
0.91 - 1.00
Kilometers
0 5 10 20 30 40

Current Models:

Data

- From colonizing population of lynx that occupied best habitat first

- Limited data on value of Partial Harvest
  - Most of s/f forest cut in 1980s
  - PH in remaining smaller patches of s/f or mixed forest

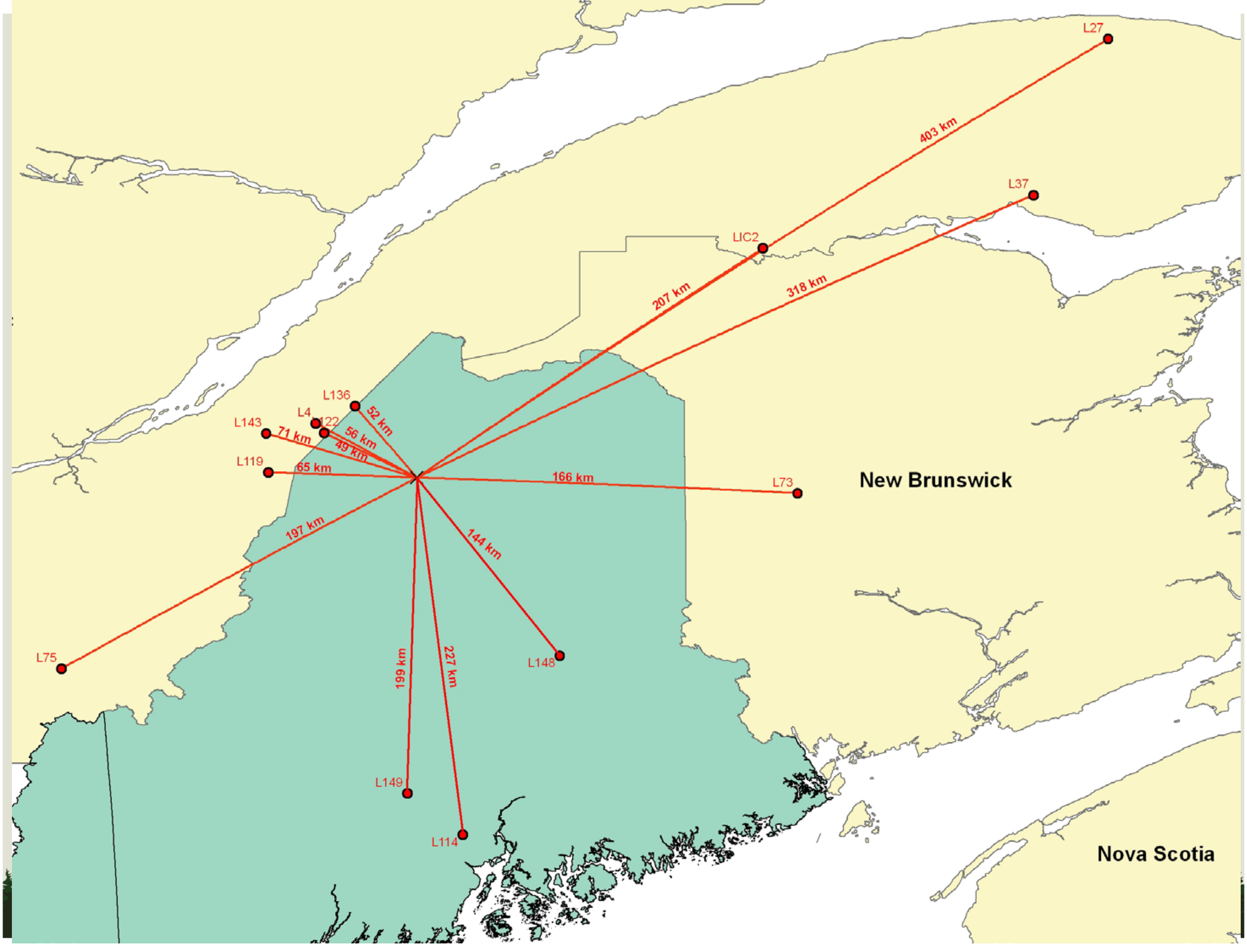
Future

- Another Budworm Outbreak on Horizon
- FPA – allowances for larger clearcuts
  - Wildlife Value
  - Response to disease
- Will PH in maturing s/f forest provide adequate habitat for hares and lynx?

Shelterwoods –emulate clear cuts

Summary

- Maine's lynx population is robust
- Populations are still increasing
- Forest disturbance benefit lynx
- Land Use Regulations did not lead to current conditions
- Provide private land managers forest stand characteristics that support hares and lynx



L27
403 km
L37
LIC2
207 km
318 km
L136
52 km
L4
L122
L143
71 km
56 km
49 km
L119
65 km
166 km
L73
New Brunswick
197 km
144 km
L75
L148
199 km
227 km
L149
L114
Nova Scotia

Canada lynx in Minnesota

Exploitation

Pre-1965 Bounty
1965 Unprotected

Management

1976 Furbearer

Protection

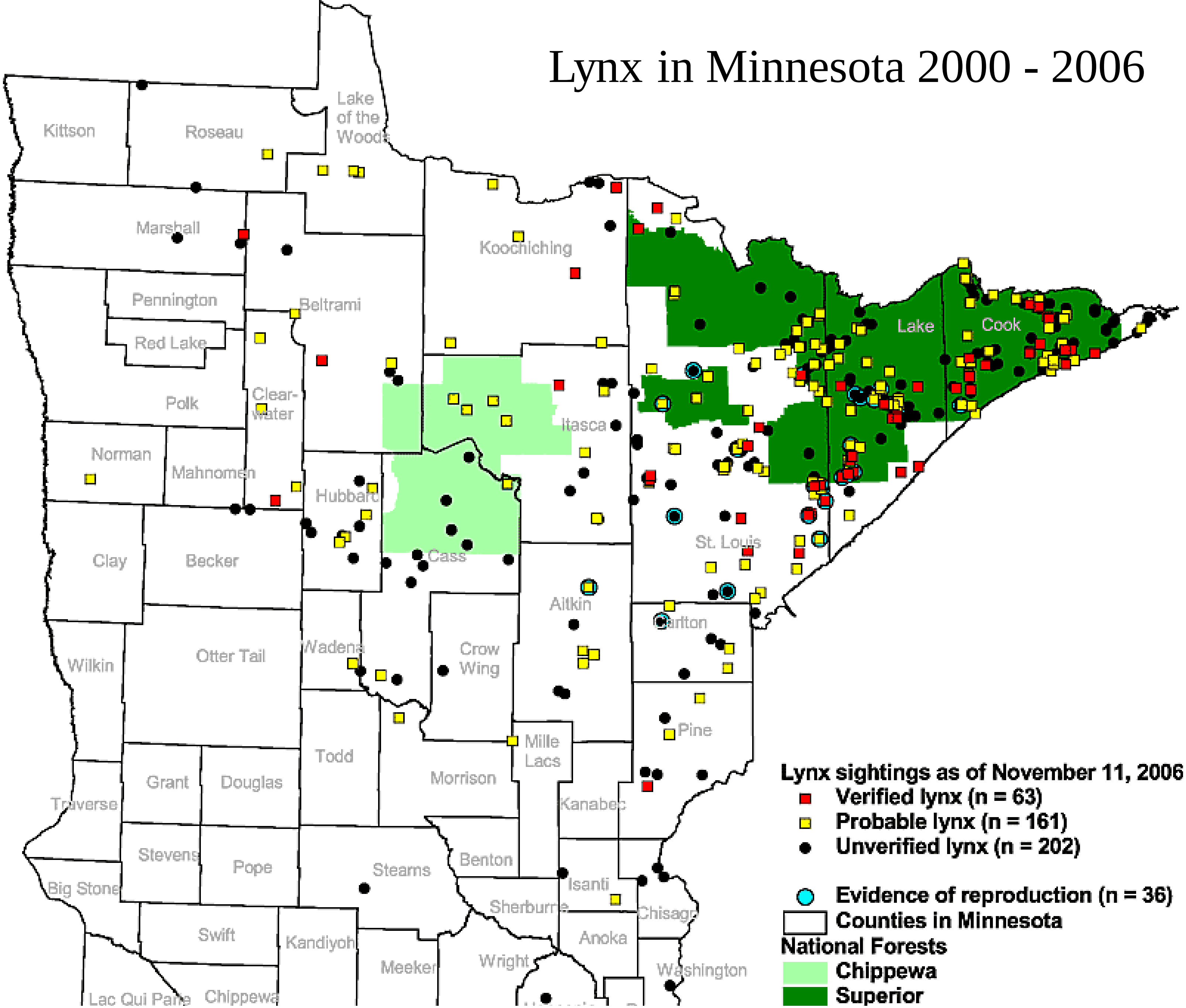
1984 Season closure
2000 ESA Threatened status

Current

~2000 Hair snare, Snow-tracking and DNA analysis
2003 Telemetry project

2015 “There are ~4,000 moose, 2,200 wolves, and 50 to 300 Canada lynx in Minnesota.”

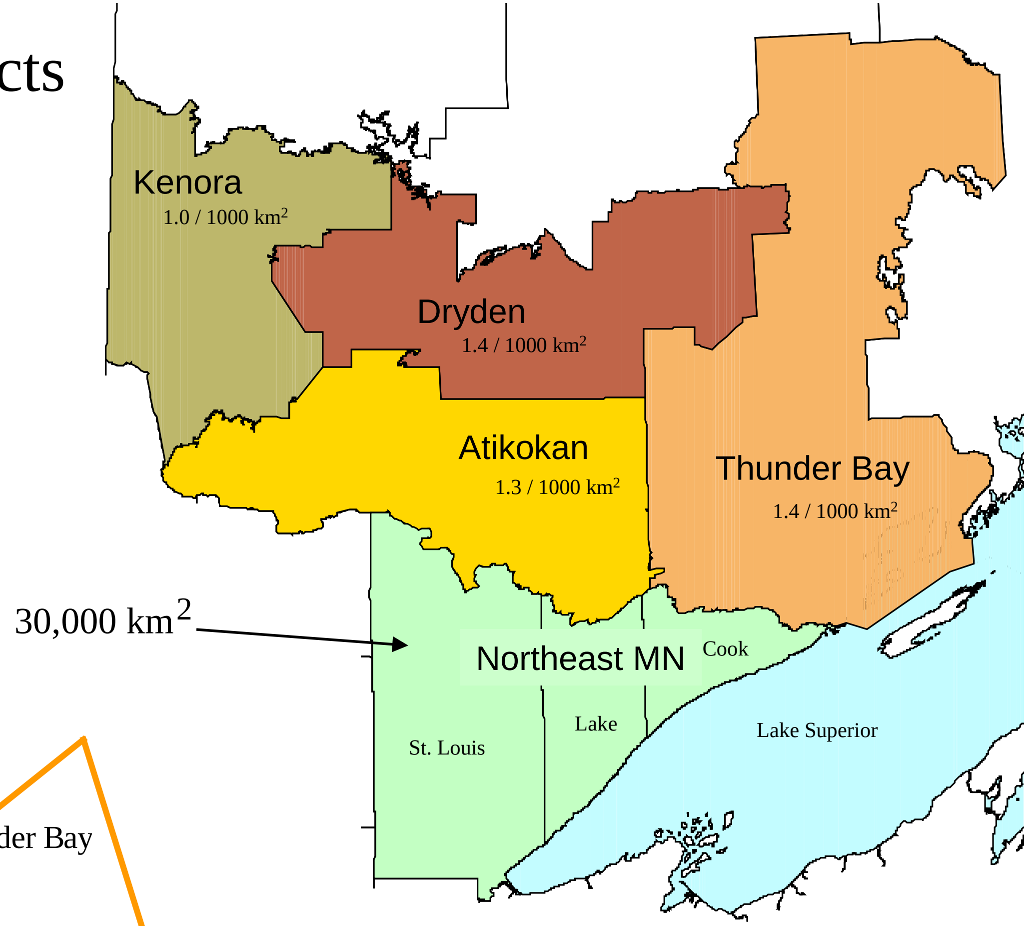
Lynx in Minnesota 2000 - 2006

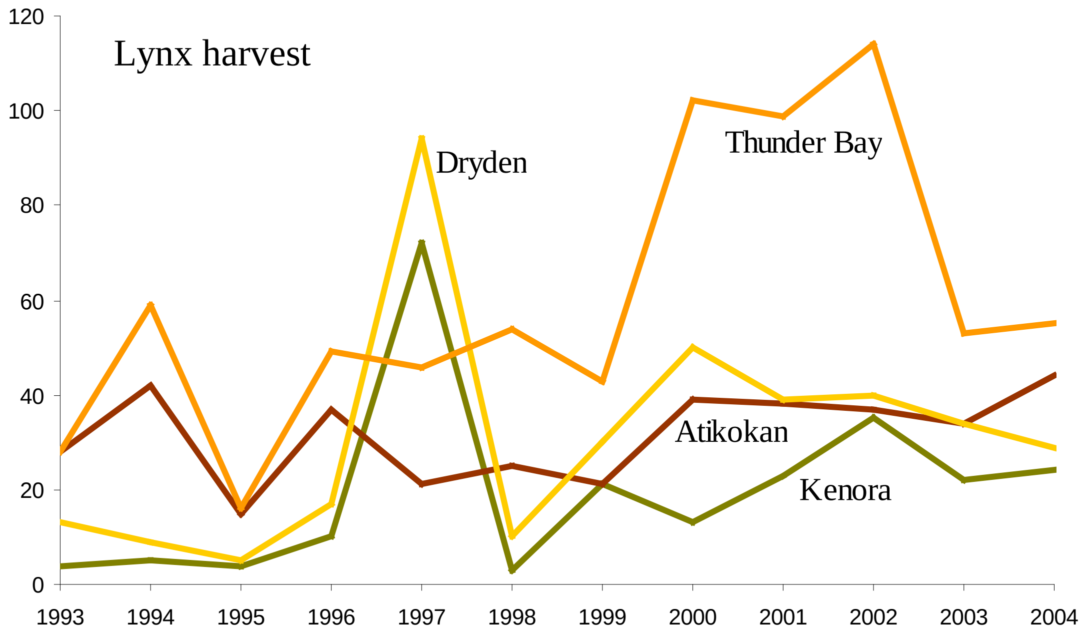


http://www.dnr.state.mn.us/eco/nhnrp/research/lynx_sightings.html

Historical harvest in ON Districts

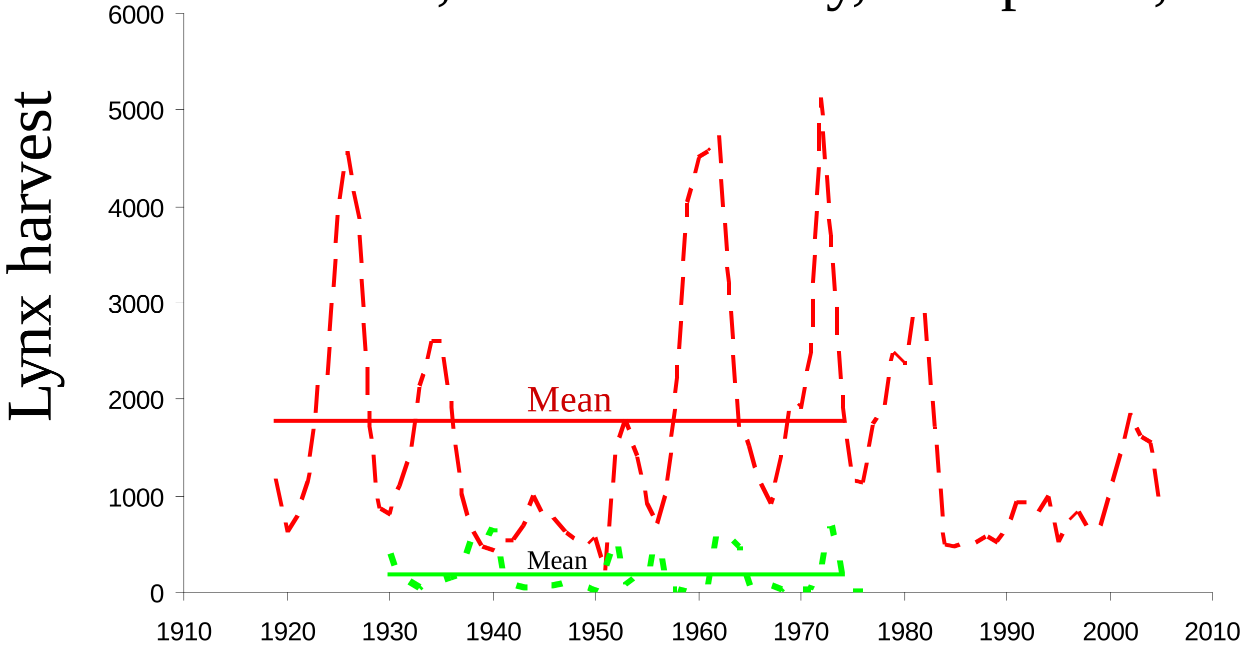
NE MN as an ON "district"
~ 30 lynx / year

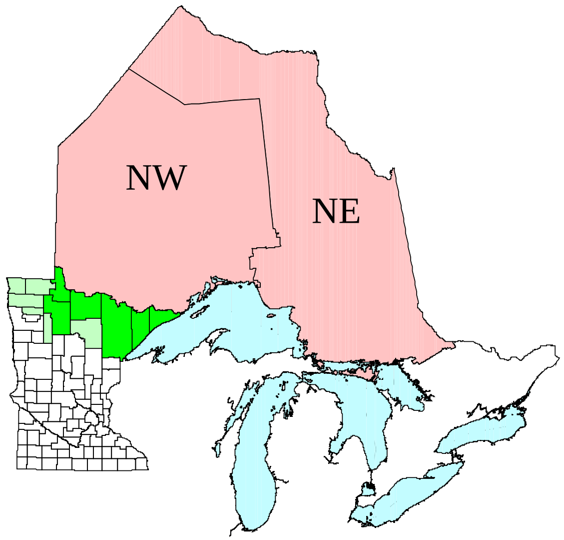




Ends 2004, need to update

Historical harvest comparison – with caveats
Effort, Human density, Pelt prices, …



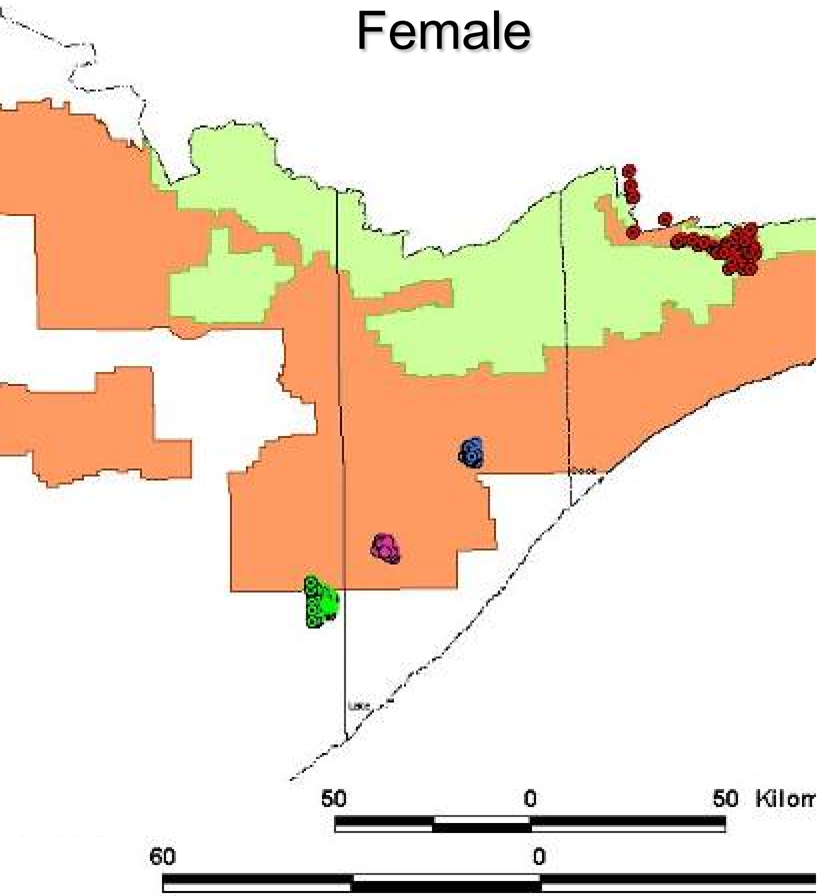


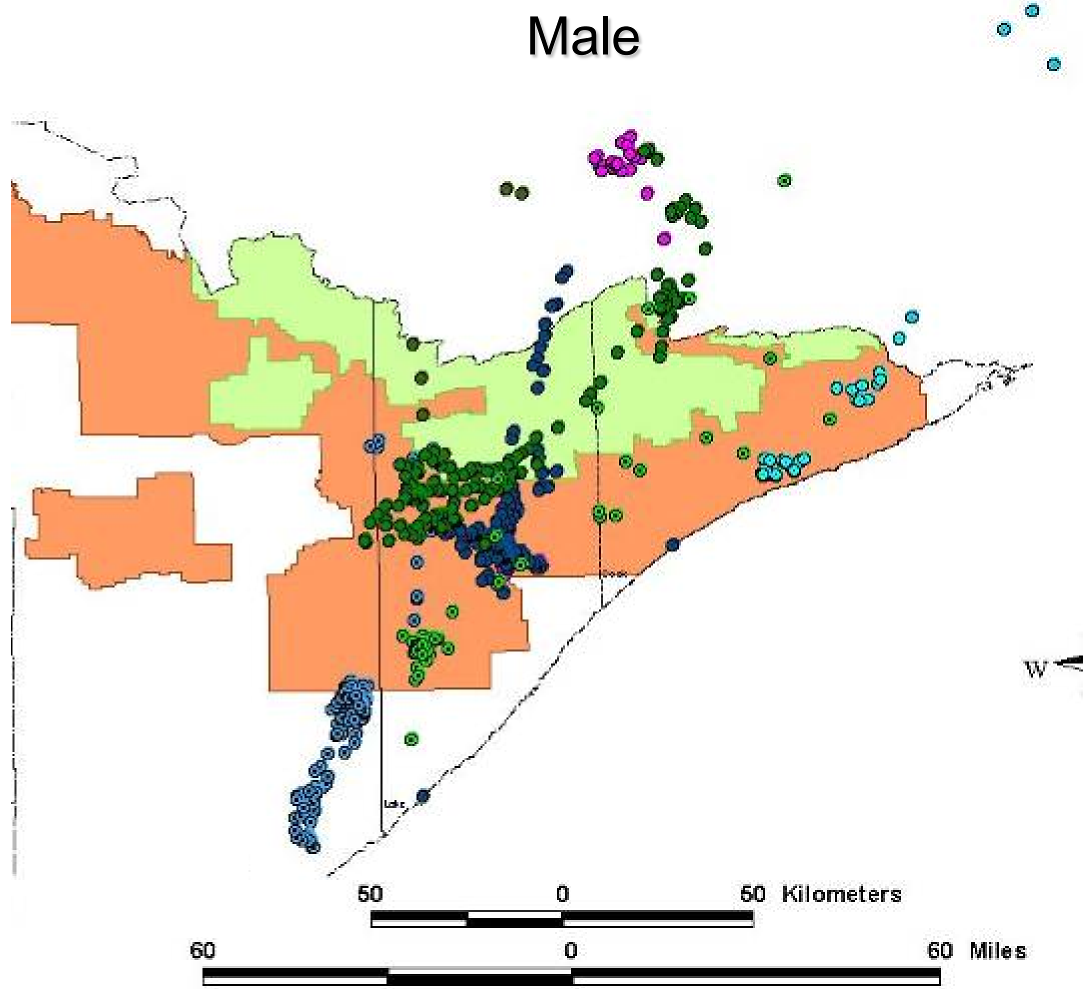
MN harvest 1930 to 1977 (McKelvey et al.)
Twice harvest in Montana
40x harvest in other states

Harvest data from MN DNR and ON MNR

			Harvest / 1000 km^2 1929 – 1983	
Region	**Harvest %**	**km^2**	**Mean**	**Maximum**
Ontario - NE and NW regions	---	909,192	1.88	5.72
All northern MN Counties	67%	71,977	1.65	3.73
Counties 1977 range includes	50%	48,224	1.84	4.15

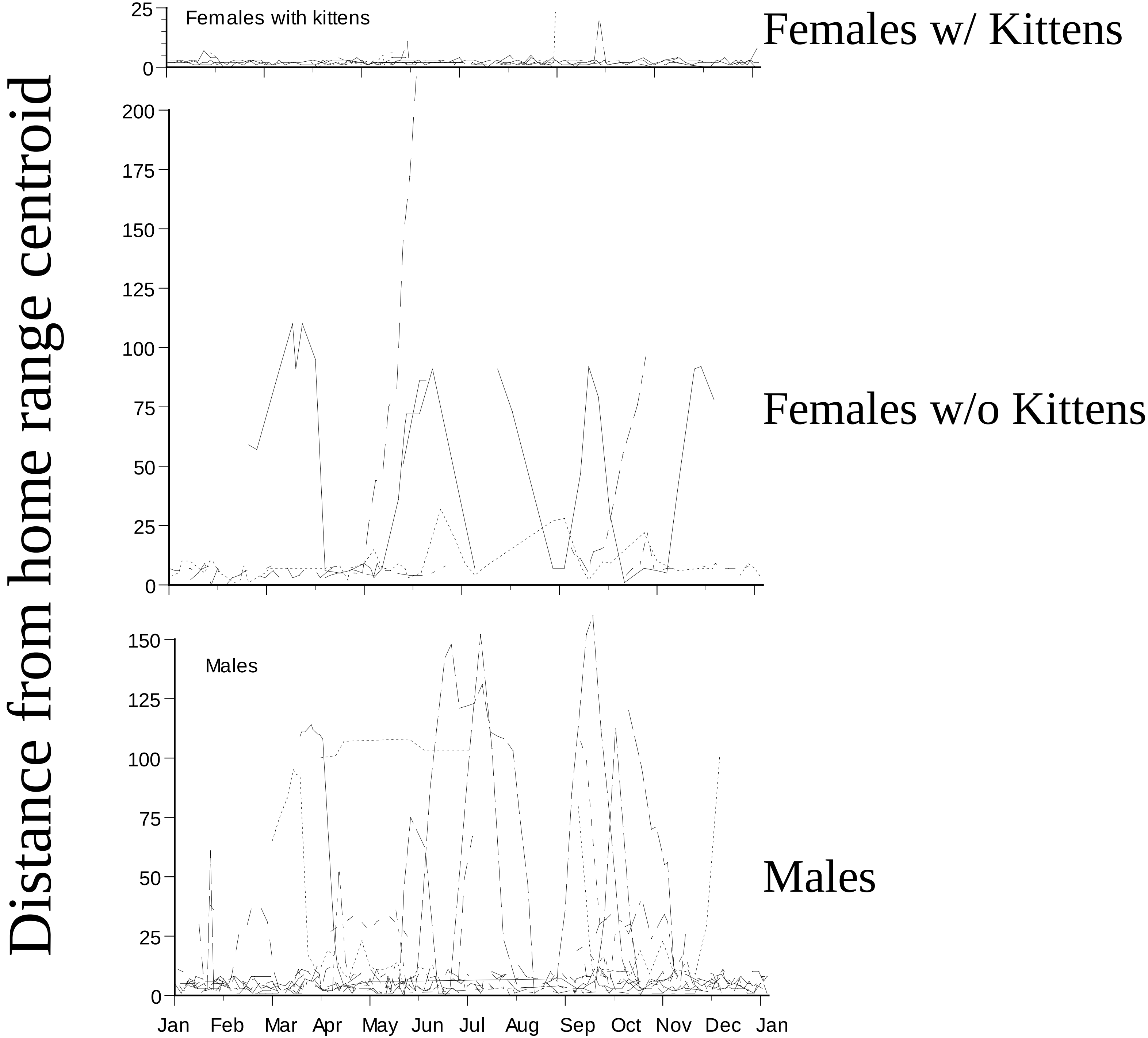
1990's: Residents or Refugees?
Now: Residents and "Refugees"

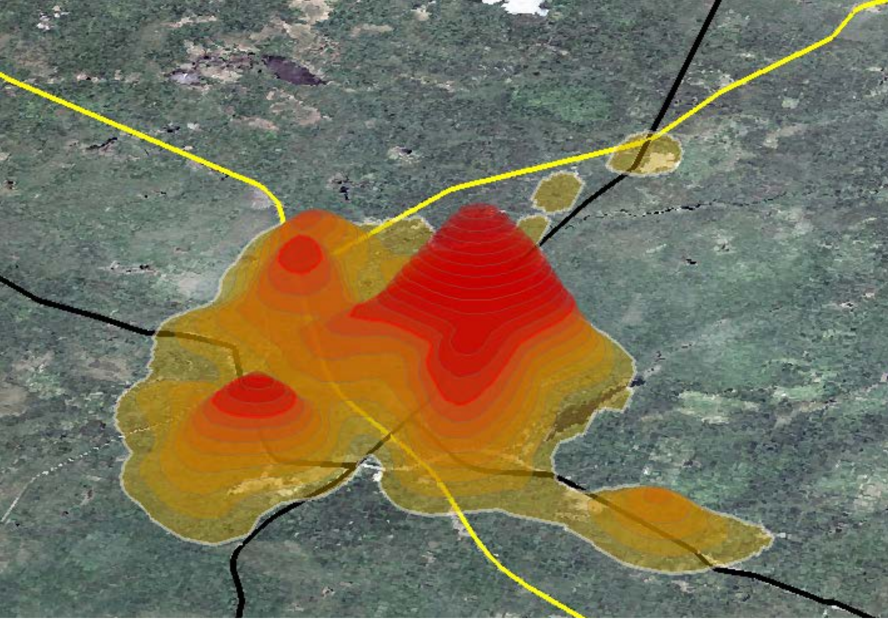




	MCP home range (km^2)	
Location	Female	Male
North of 50°	67	74
South of 50°	71	175
Minnesota	21	267

Burdett et al. 2007


Distance from home range centroid
Females with kittens
Females w/ Kittens
Females w/o Kittens
Males
Males
0
25
50
75
100
125
150
175
200
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan

	Home Range				Core Area		
LULC Cover Type	Mean	SEM	n		Mean	SEM	n
Mixed-wood forest	40	3	6		39	5	6
Wetland bog	10	2	6		8	2	6
Conifer	21	2	6		19	2	6
Non-Forested	7	2	6		4	1	6
Regeneration (conifer)	**21**	**4**	**6**		**30**	**6**	**6**

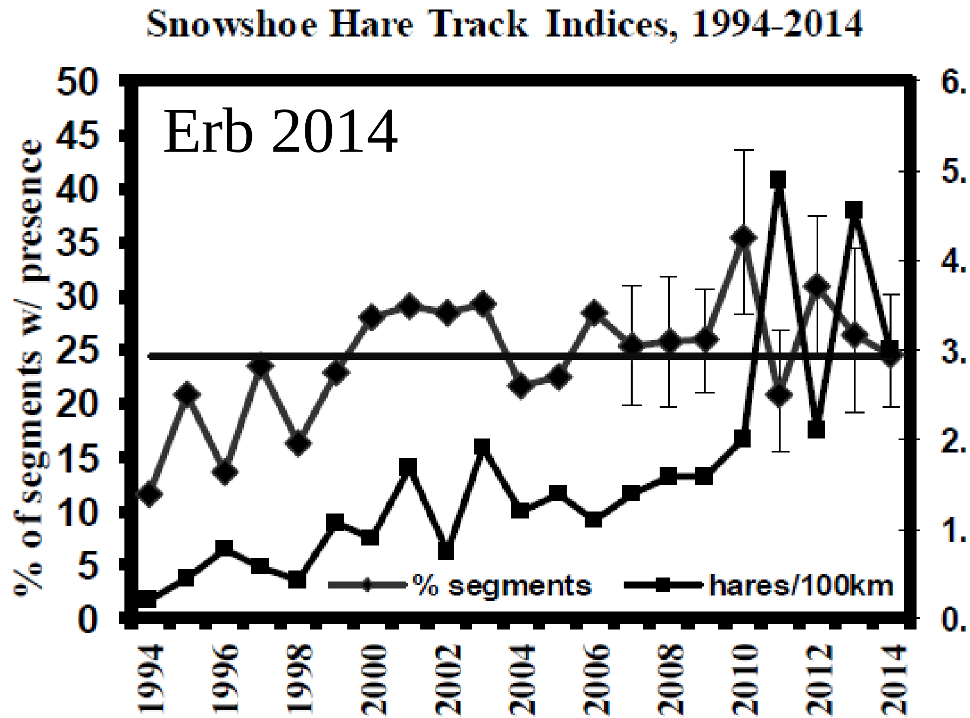
Reproduction

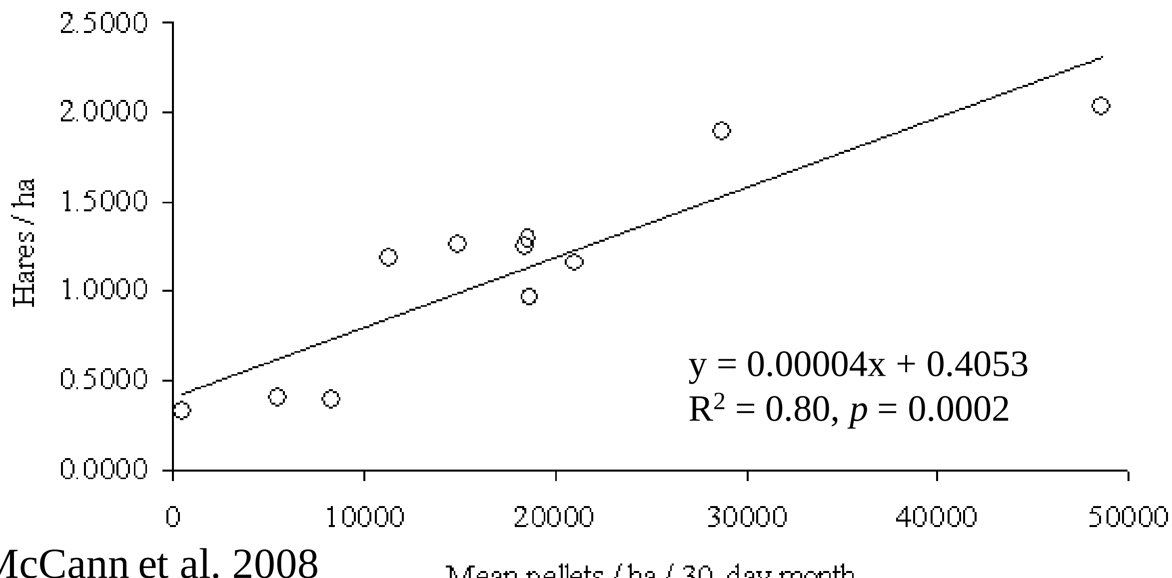
Moen et al. 2008

10 dens & 33 kittens

14 studies:

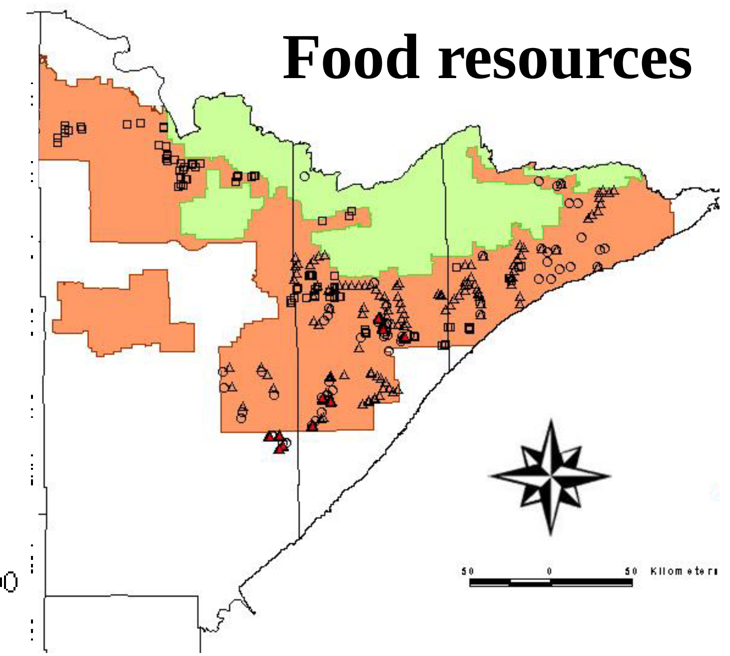
- 82% in Blowdown
  - 3% in logging debris
  - 5% in dense shrubs
  - 5% in rocks
  - 4% in open



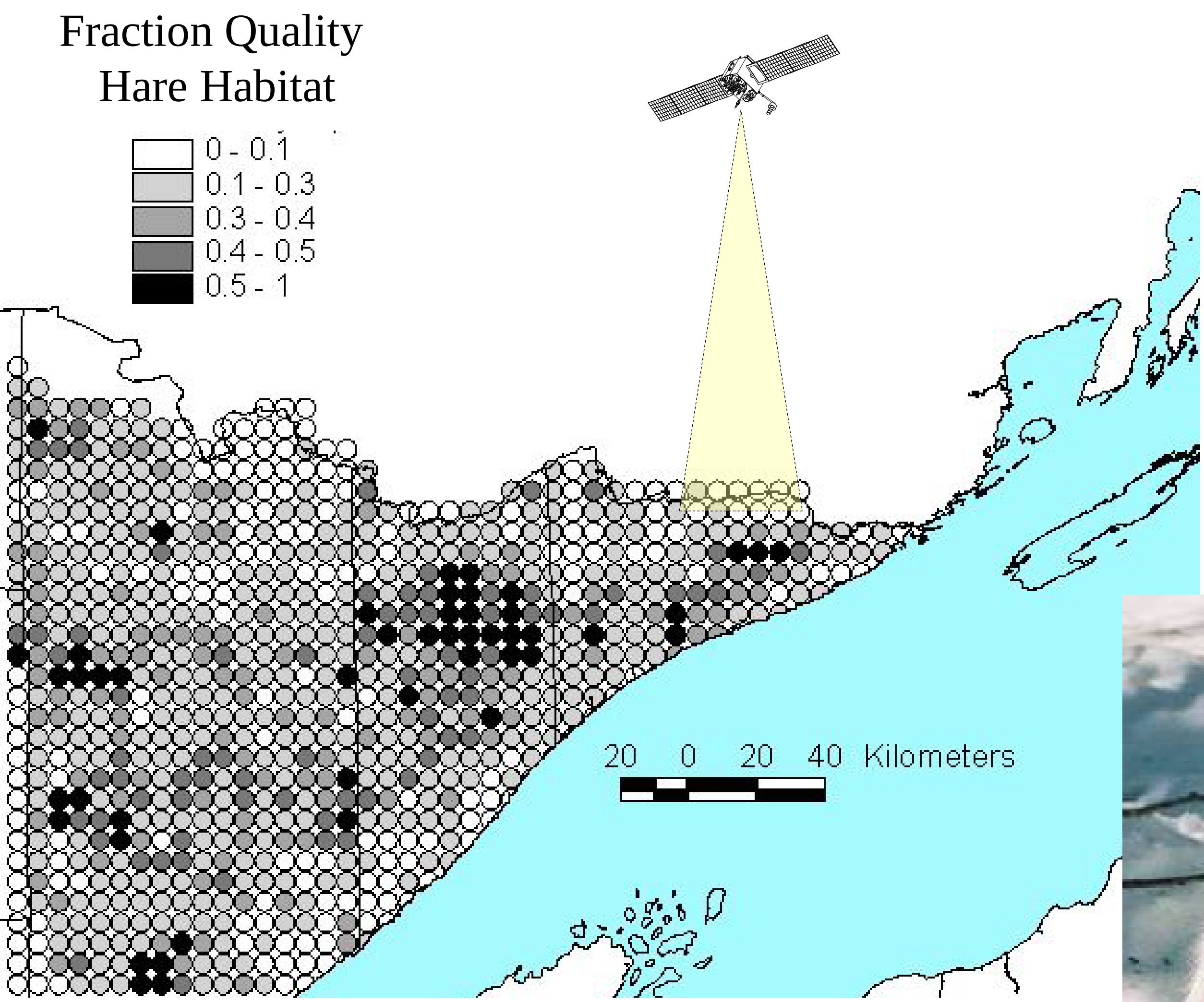


McCann et al. 2008

Food resources

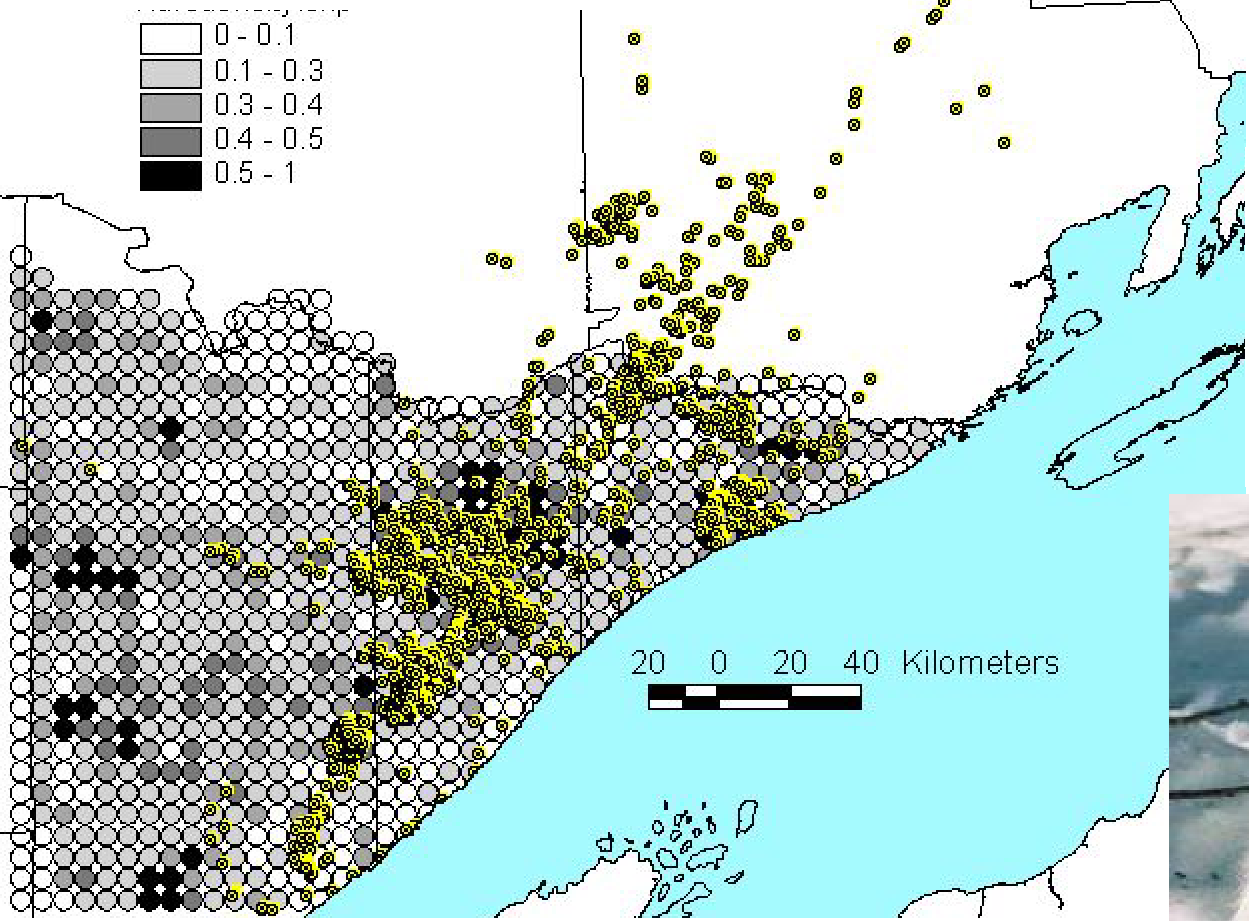


Food resources



McCann 2006
McCann et al. 2008

Fraction Quality
Hare Habitat



Food resources

Predicted hare use

vs.

Lynx locations

McCann 2006
McCann et al. 2008
McCann and Moen 2011

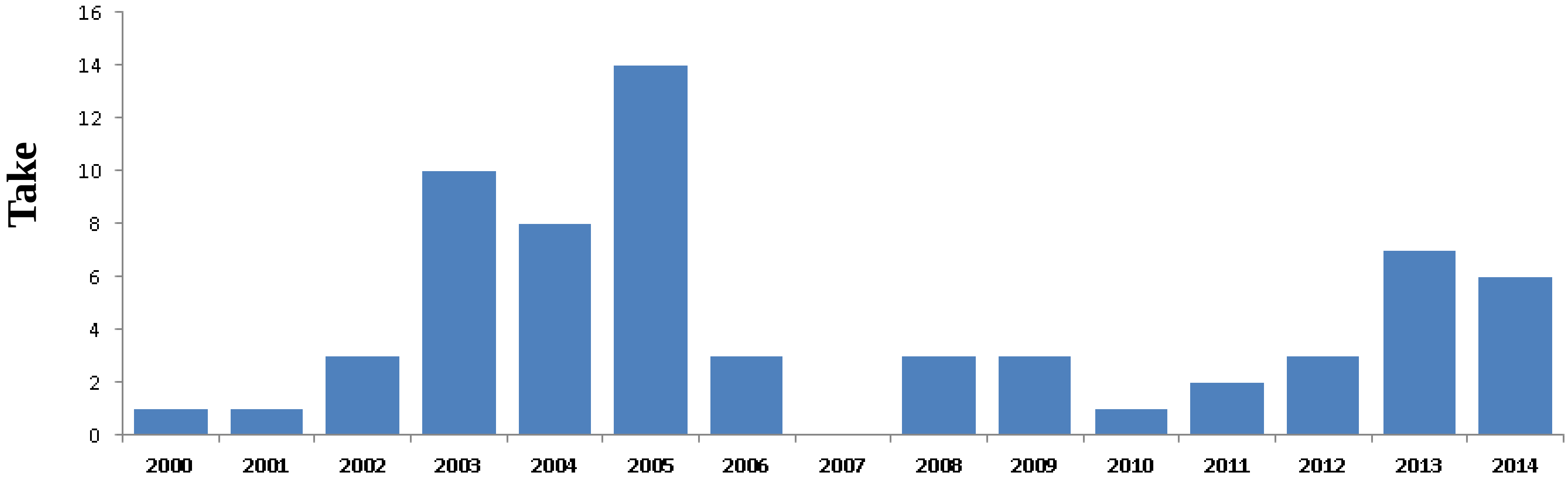
Cumulative Mortality

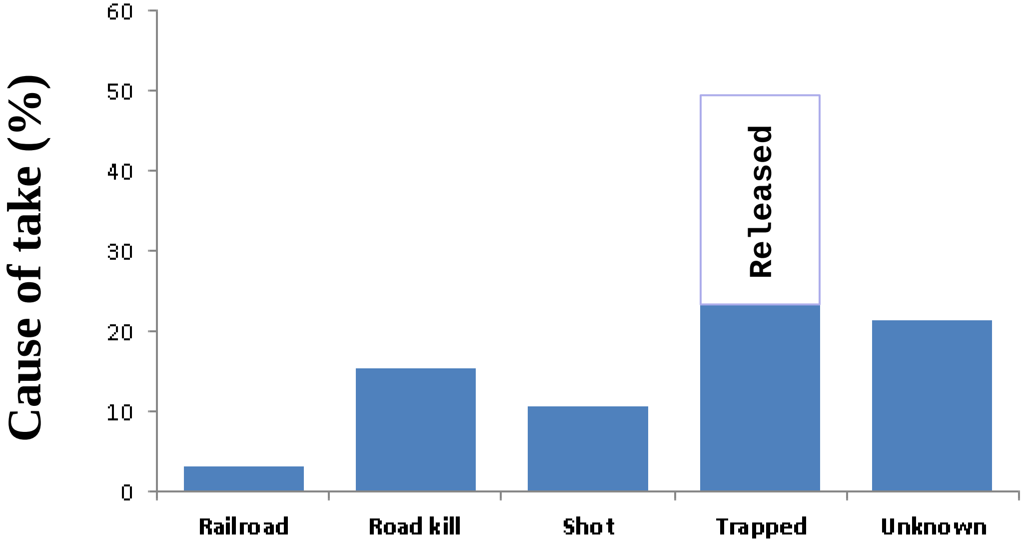
	2003	2004	2005	2006	2007	2008
Collared	5	17	32	33	33	33
Dead	2	3	14	17	17	17
Mortality (%)	40	14	34	52	52	52

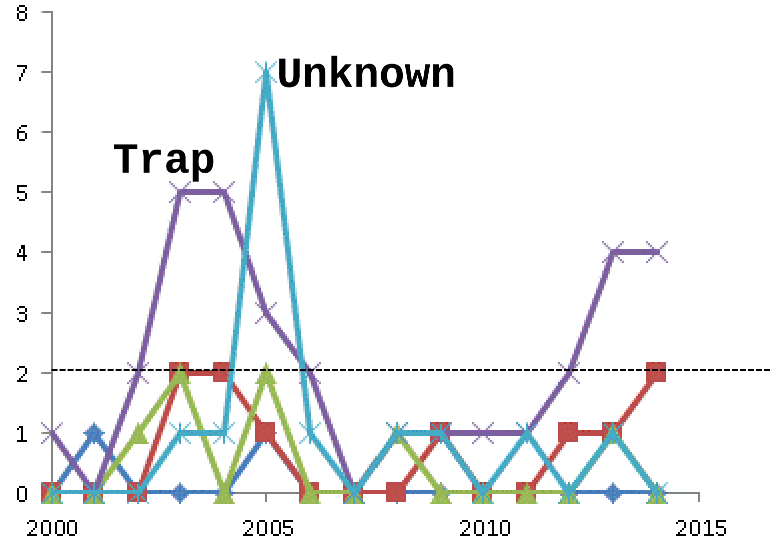
Cause of death:	Telemetry		Report
Vehicle	2	1*	7
Incidental catch	2	2	6
Illegal kill	1	1	3
Legal harvest (ON)	5		
Suspicious	4	1	
Nonhuman mortality	4		
Unknown	1		3
Total	19		19

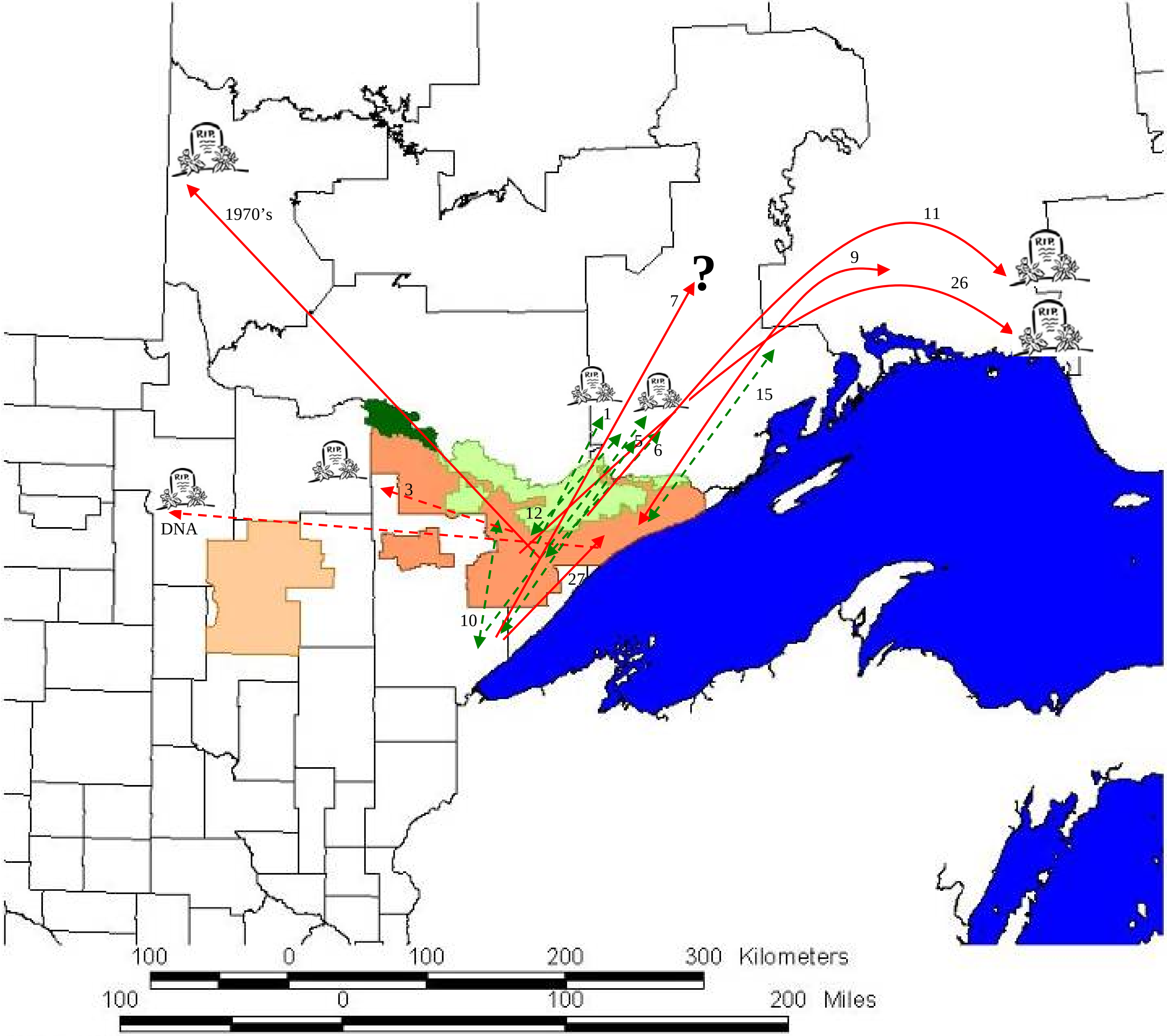
* Born in MN (1 alive)

Take database for adult lynx as of 2014-2015









Female

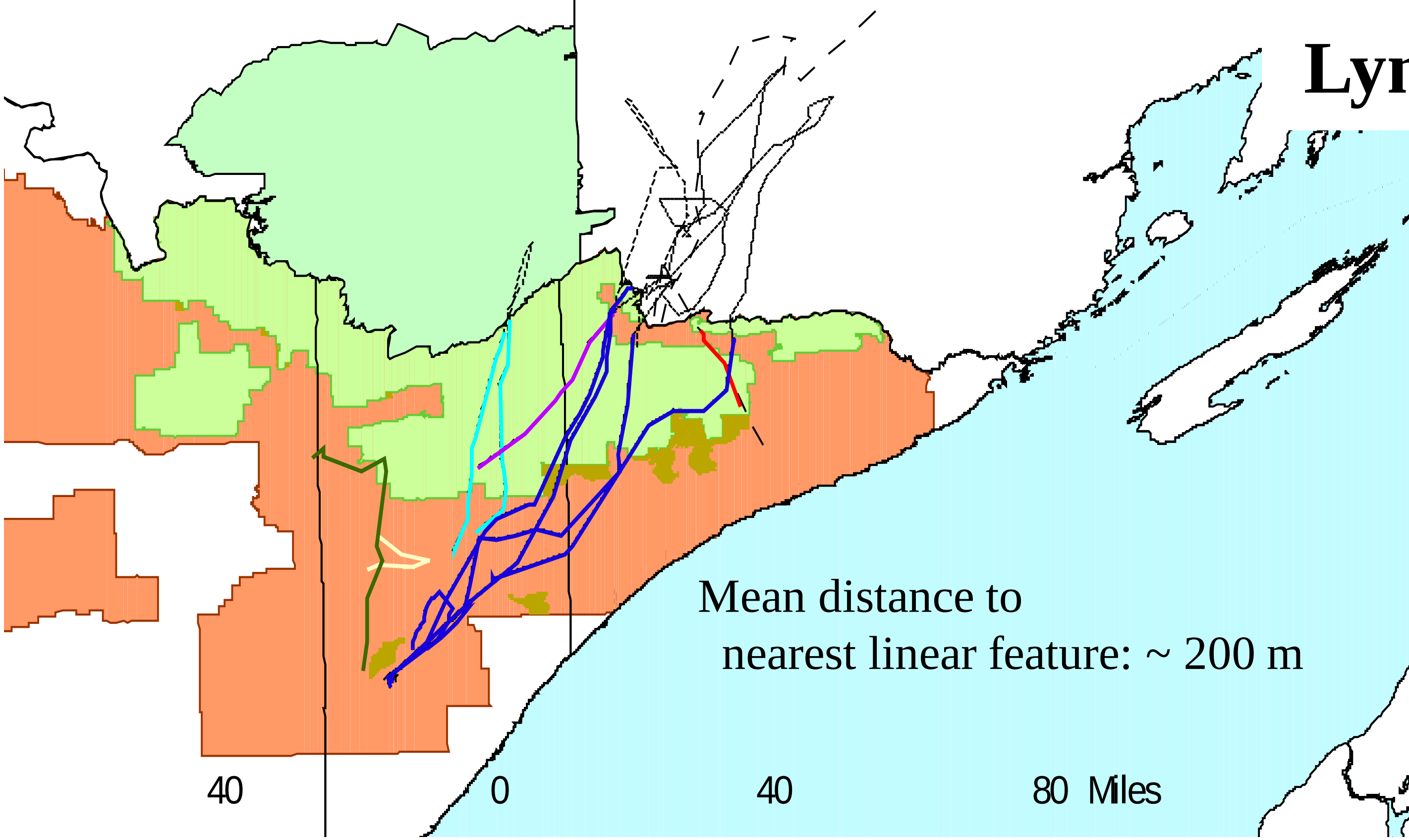
7, 26, 9, 11

Male

1, 34, 15?

Moen et al. *in review*

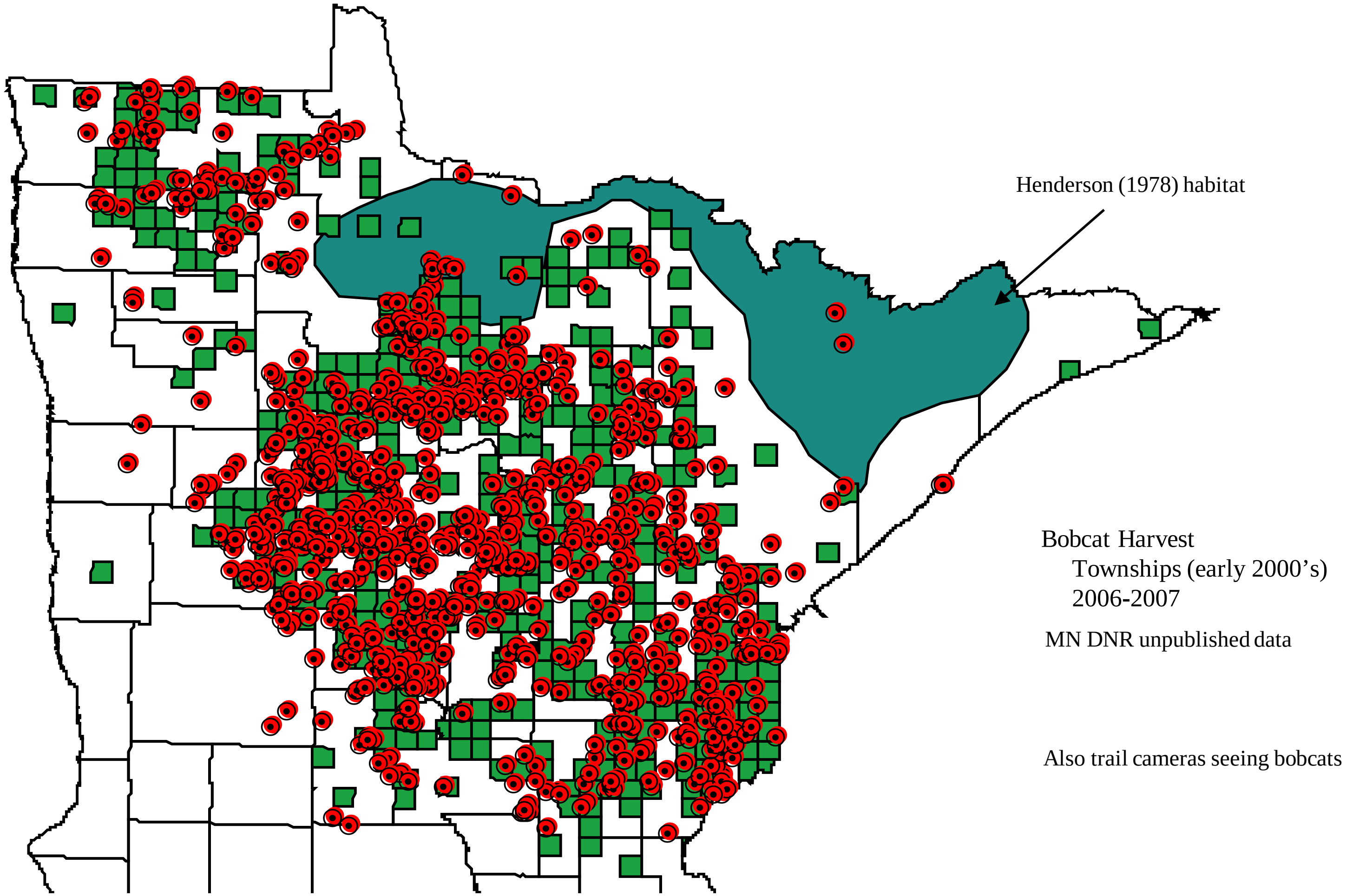
Lynx and Roads



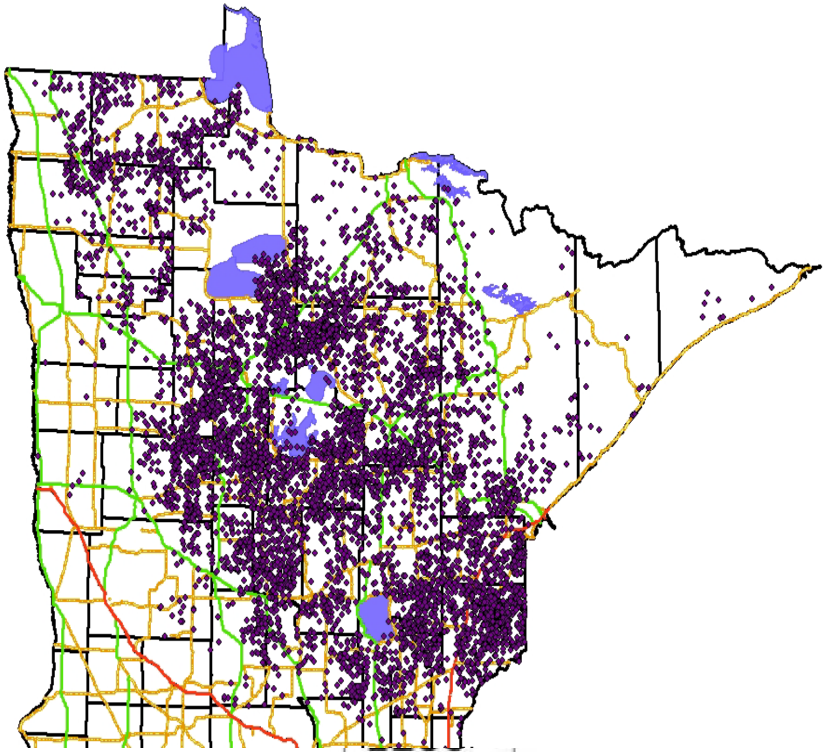
Category	Road and trail density
All LAU's	**1.19 ± 0.10**
Trip LAU's	**1.23 ± 0.07**
Trip points buffered to 500 m	**1.25 ± 0.23**
Home Range 50% Kernel	**1.47 ± 0.26**
Home Range 95% Kernel	**1.12 ± 0.14**

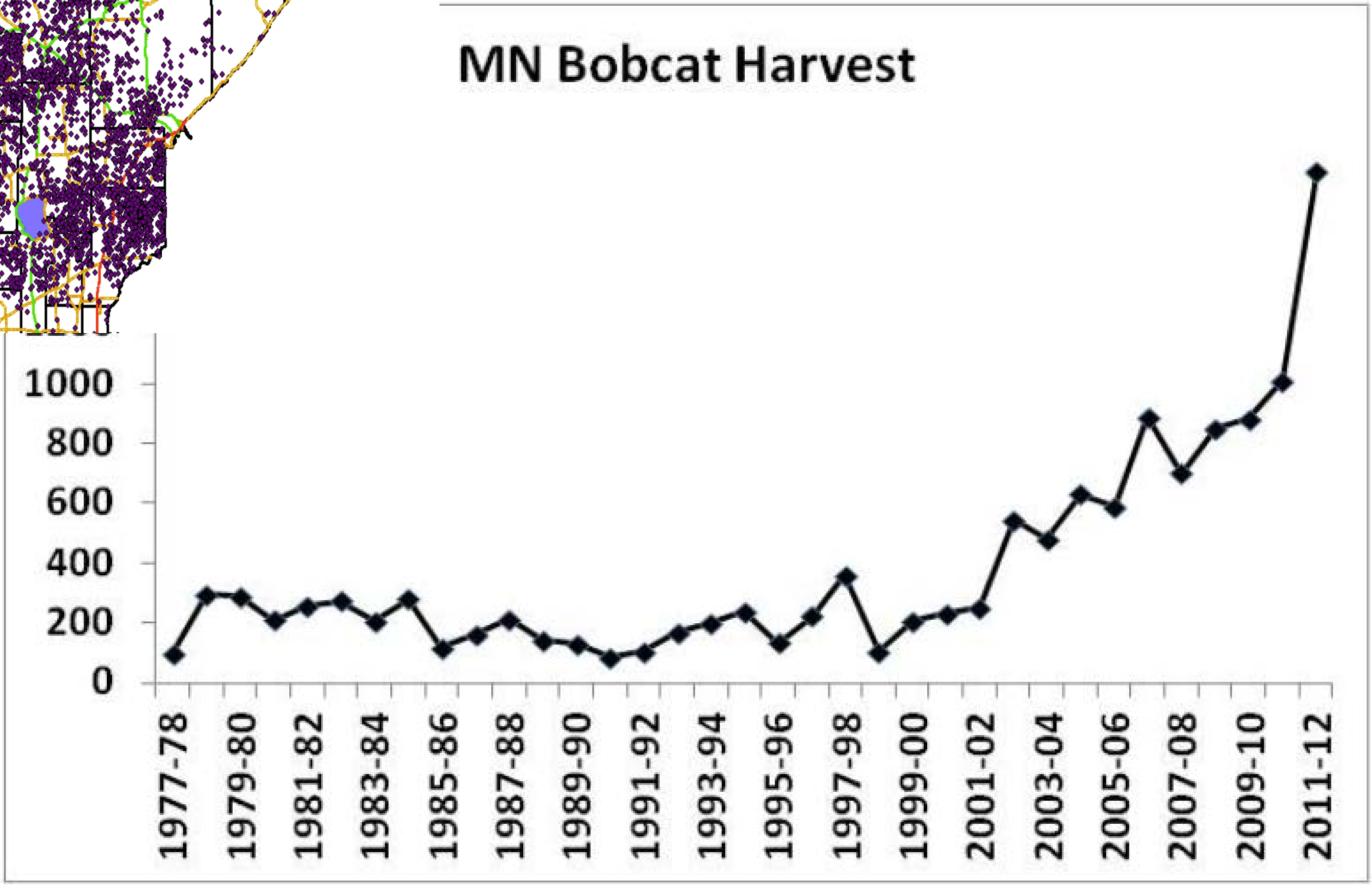
Lauren Terwilleger
Home range analysis

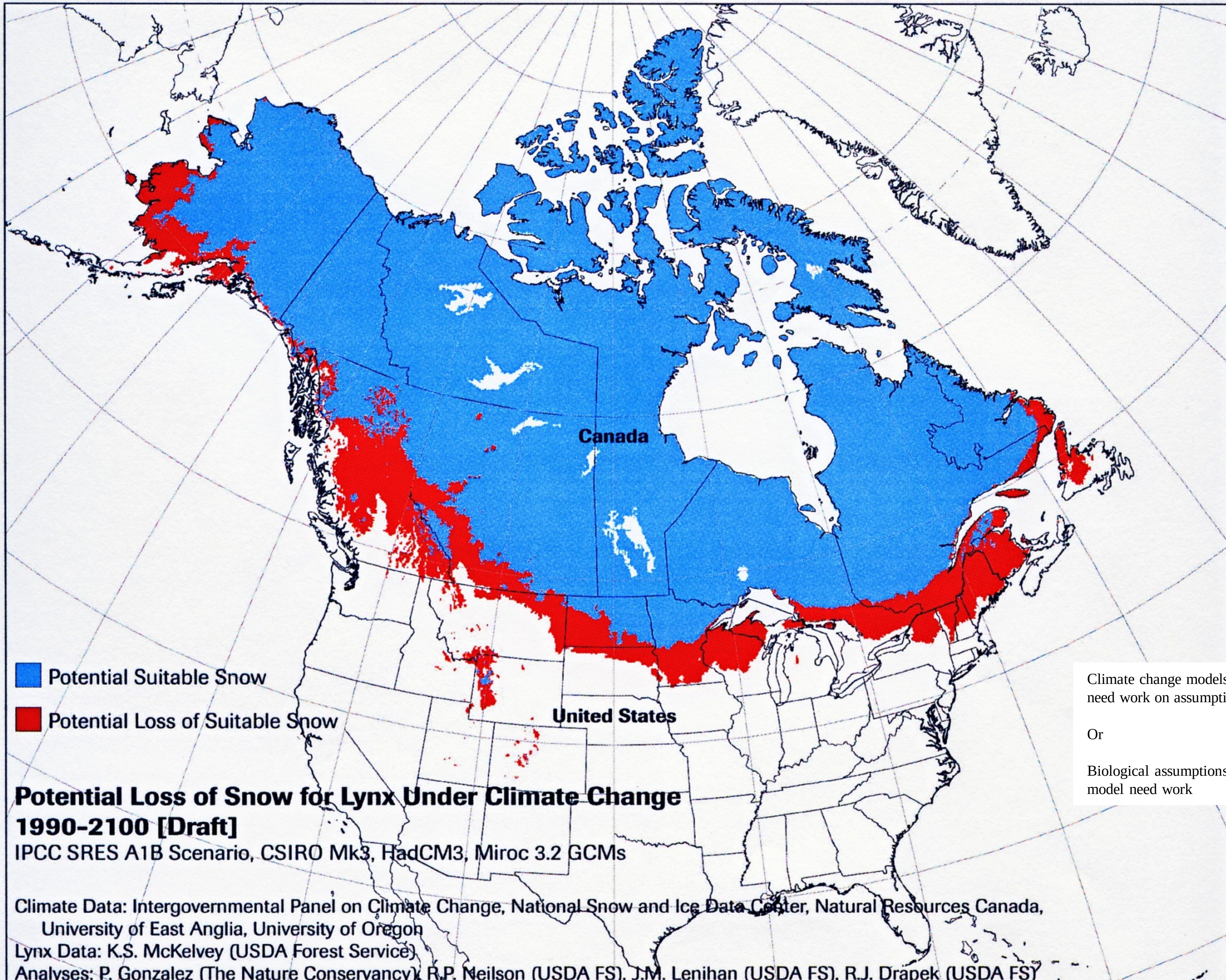
Long-term (decades): Bobcat and Lynx



Bobcat harvest (Erb 2012)



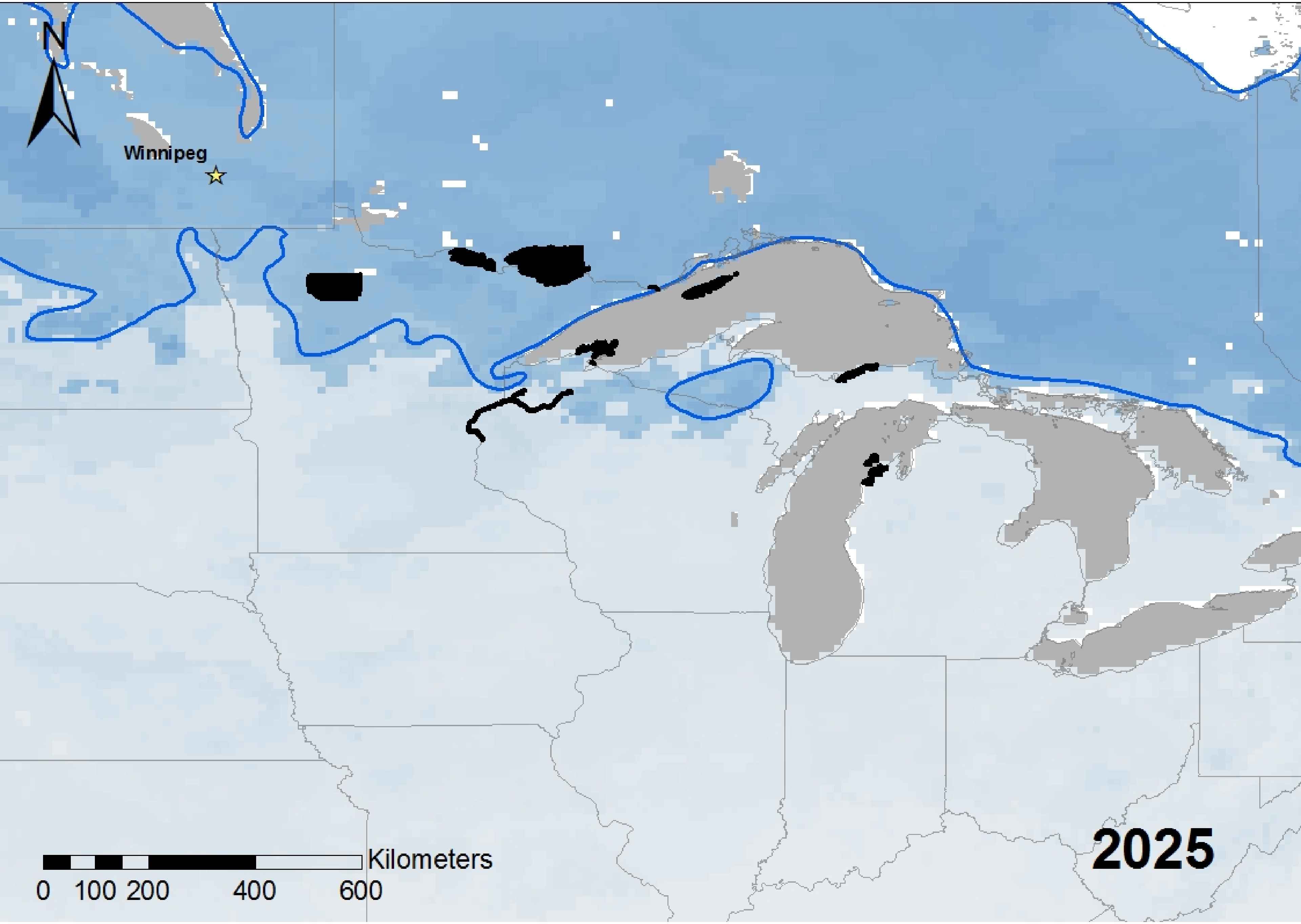


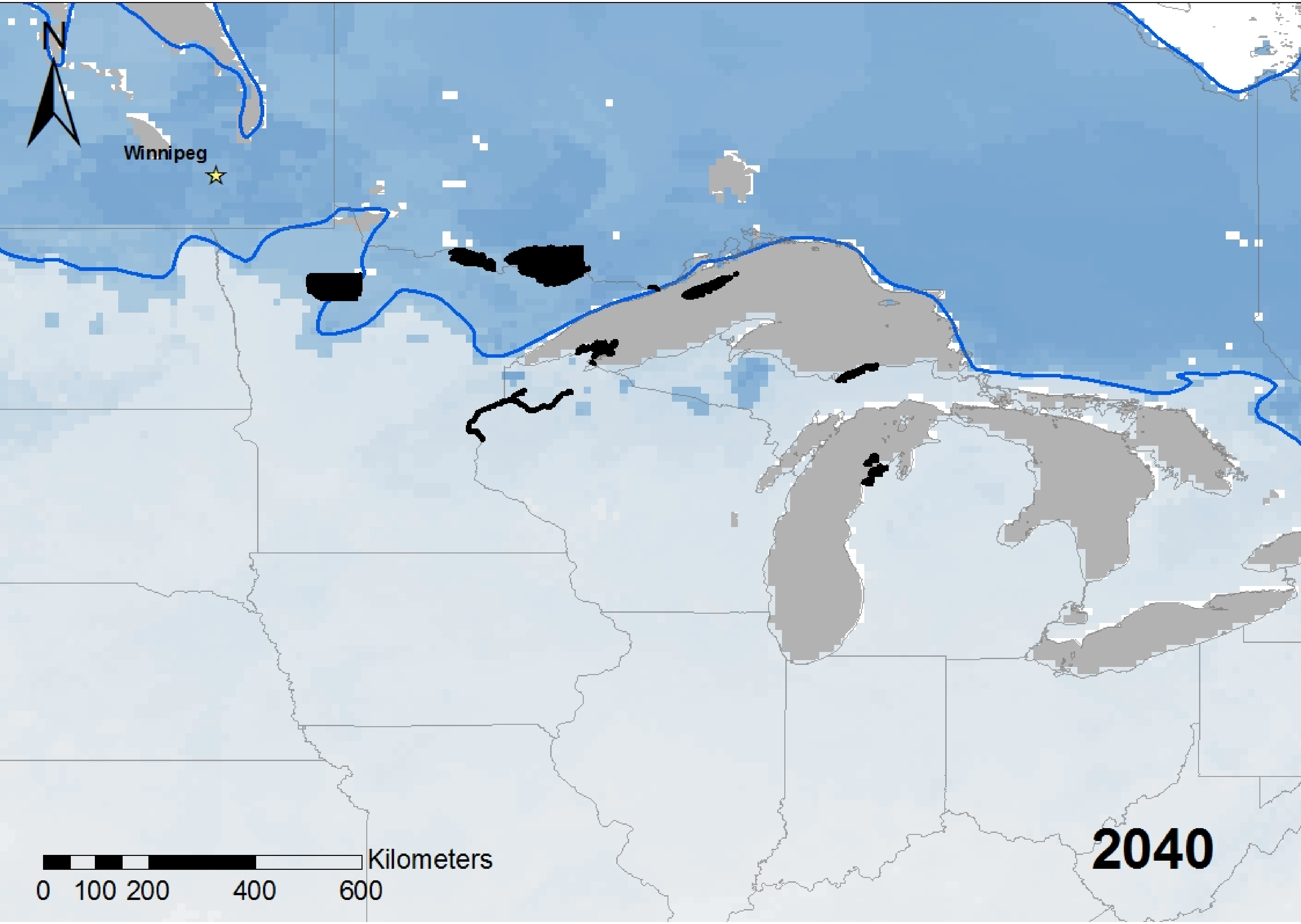


Climate change models need work on assumptions

Or

Biological assumptions in model need work


N
Winnipeg
Kilometers
0 100 200 400 600
2025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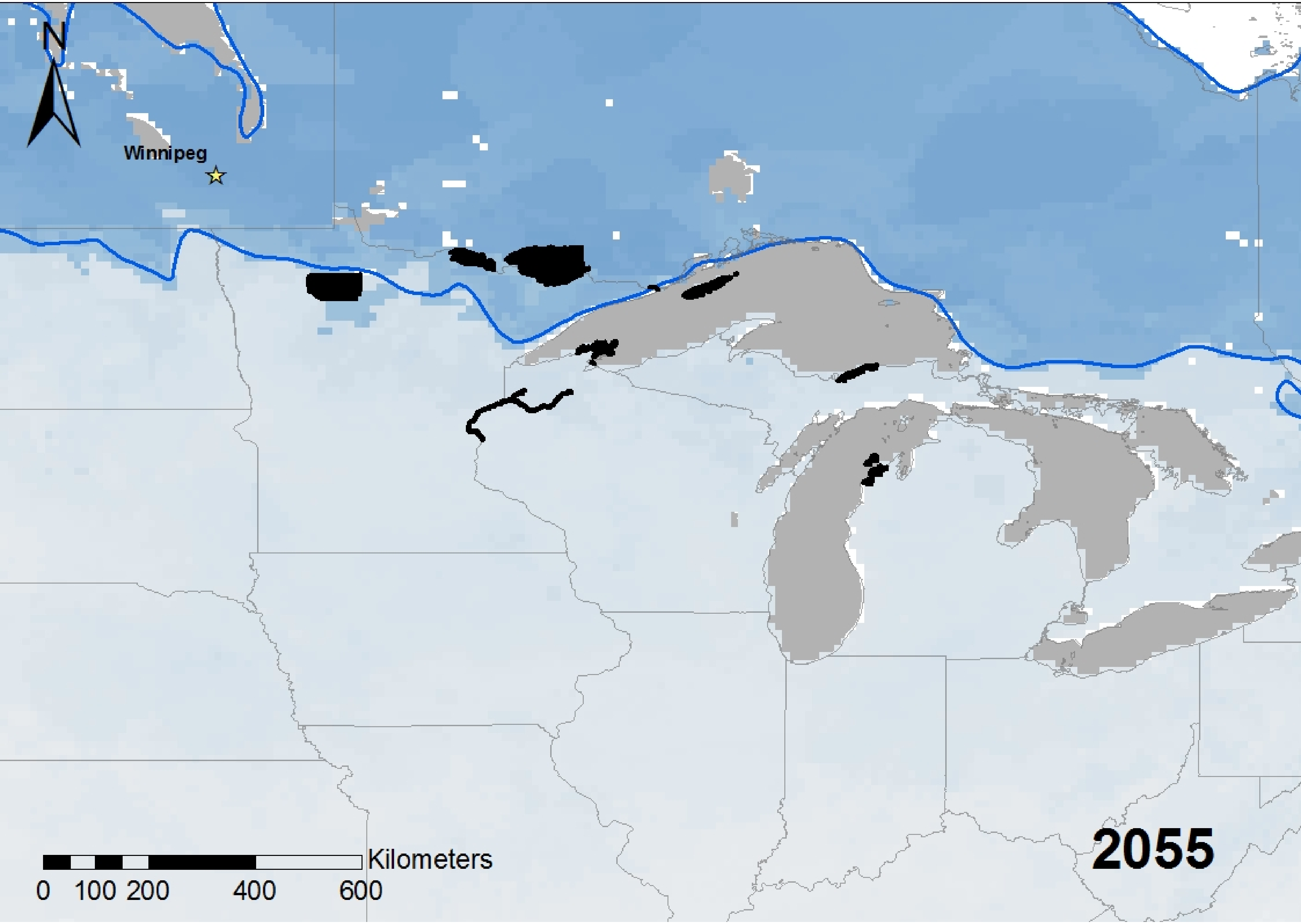
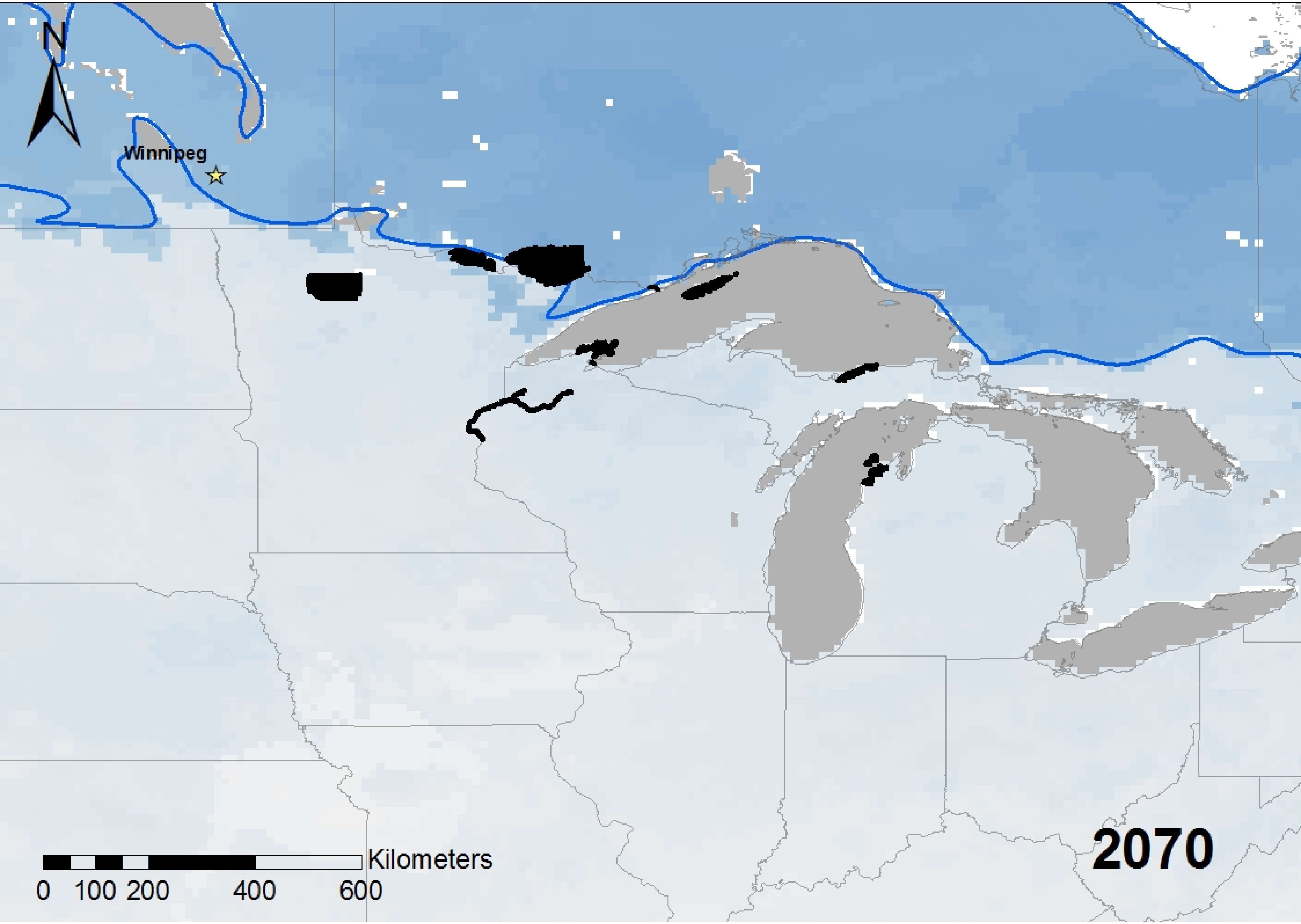
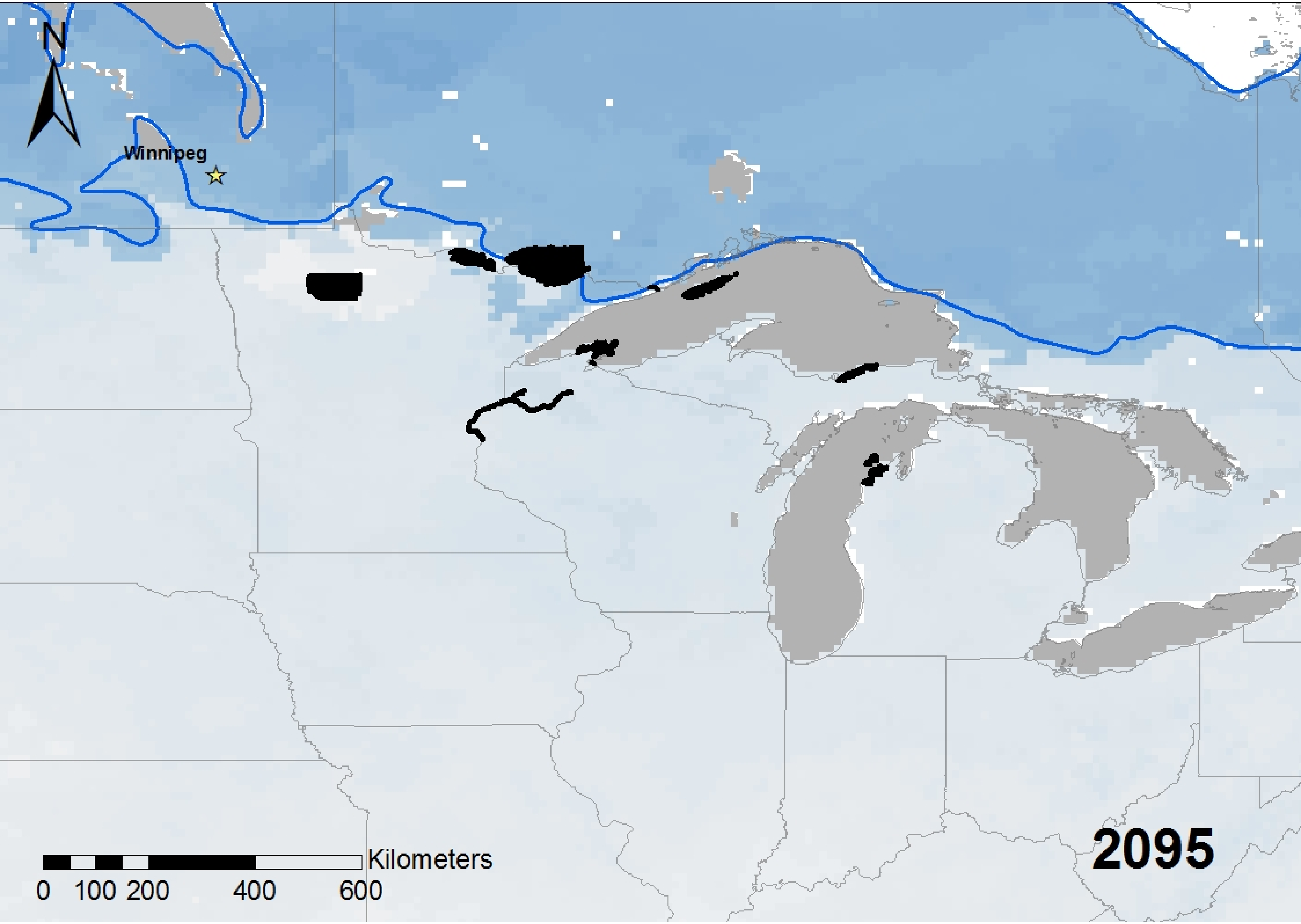
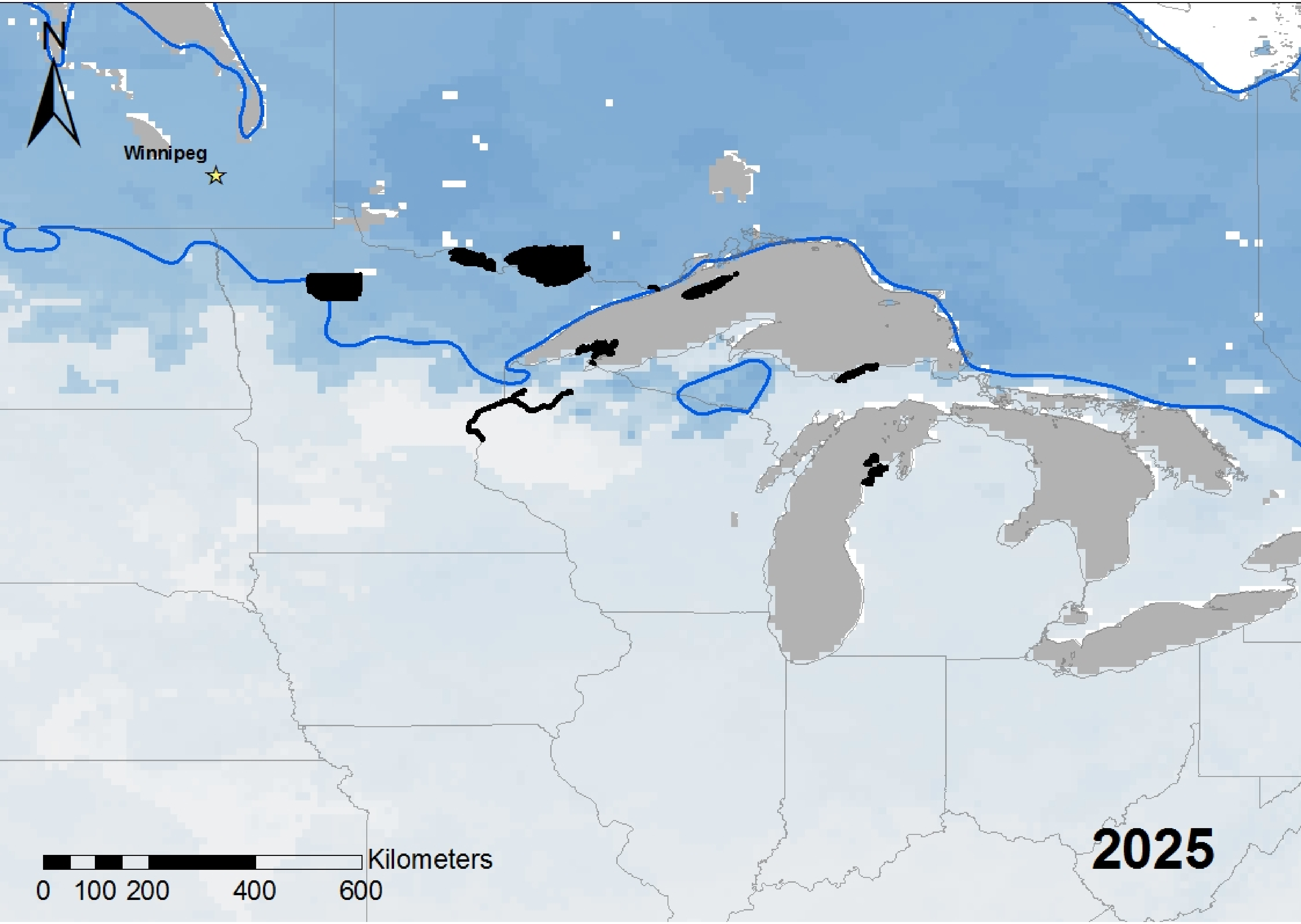
Winnipeg
Kilometers
0 100 200 400 600
2040

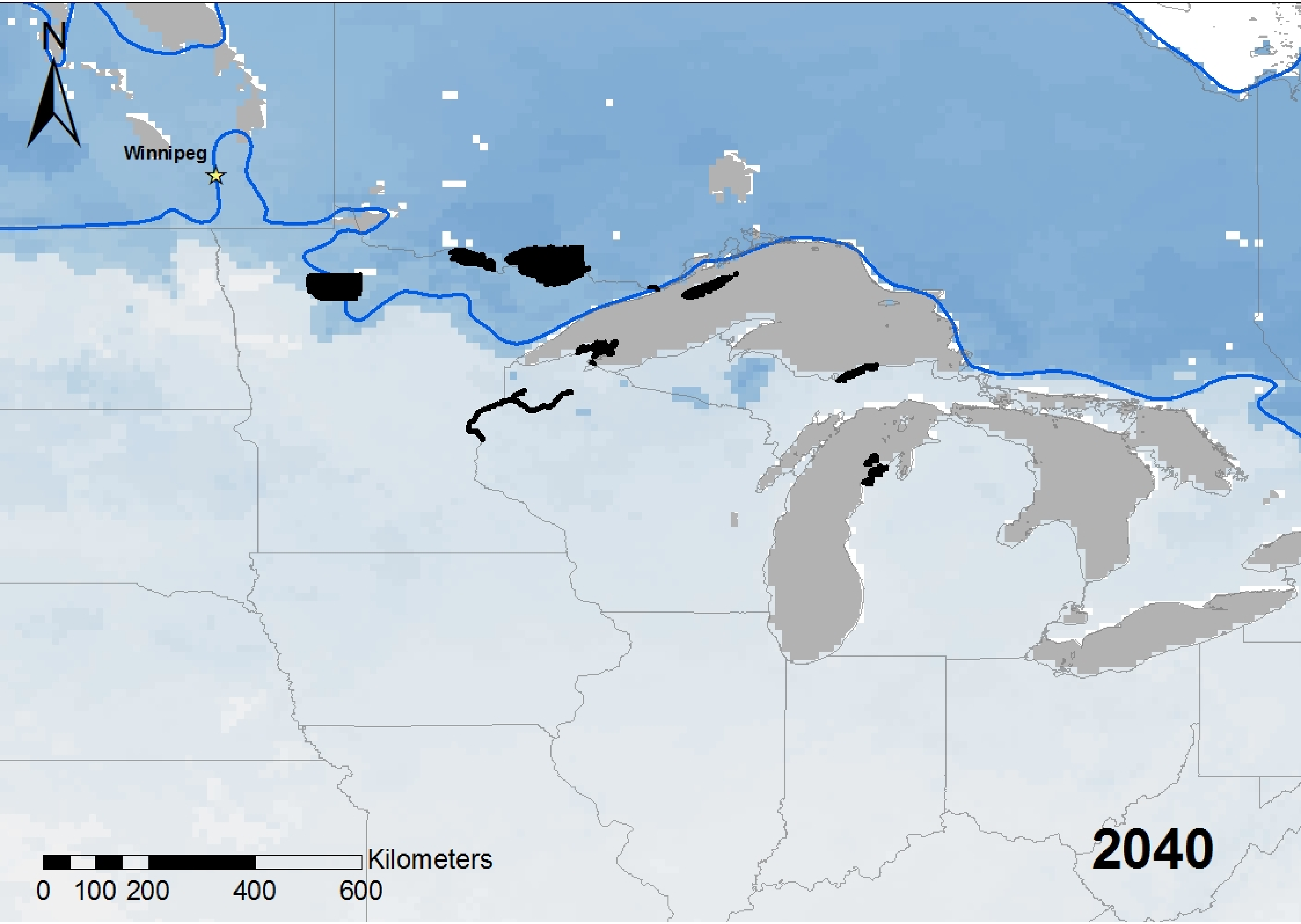


N
Winnipeg
Kilometers
0 100 200 400 600
2055


N
Winnipeg
0 100 200 400 600
Kilometers
2070


N
Winnipeg
Kilometers
0 100 200 400 600
2095


N
Winnipeg
Kilometers
0 100 200 400 600
2025


N
Winnipeg
Kilometers
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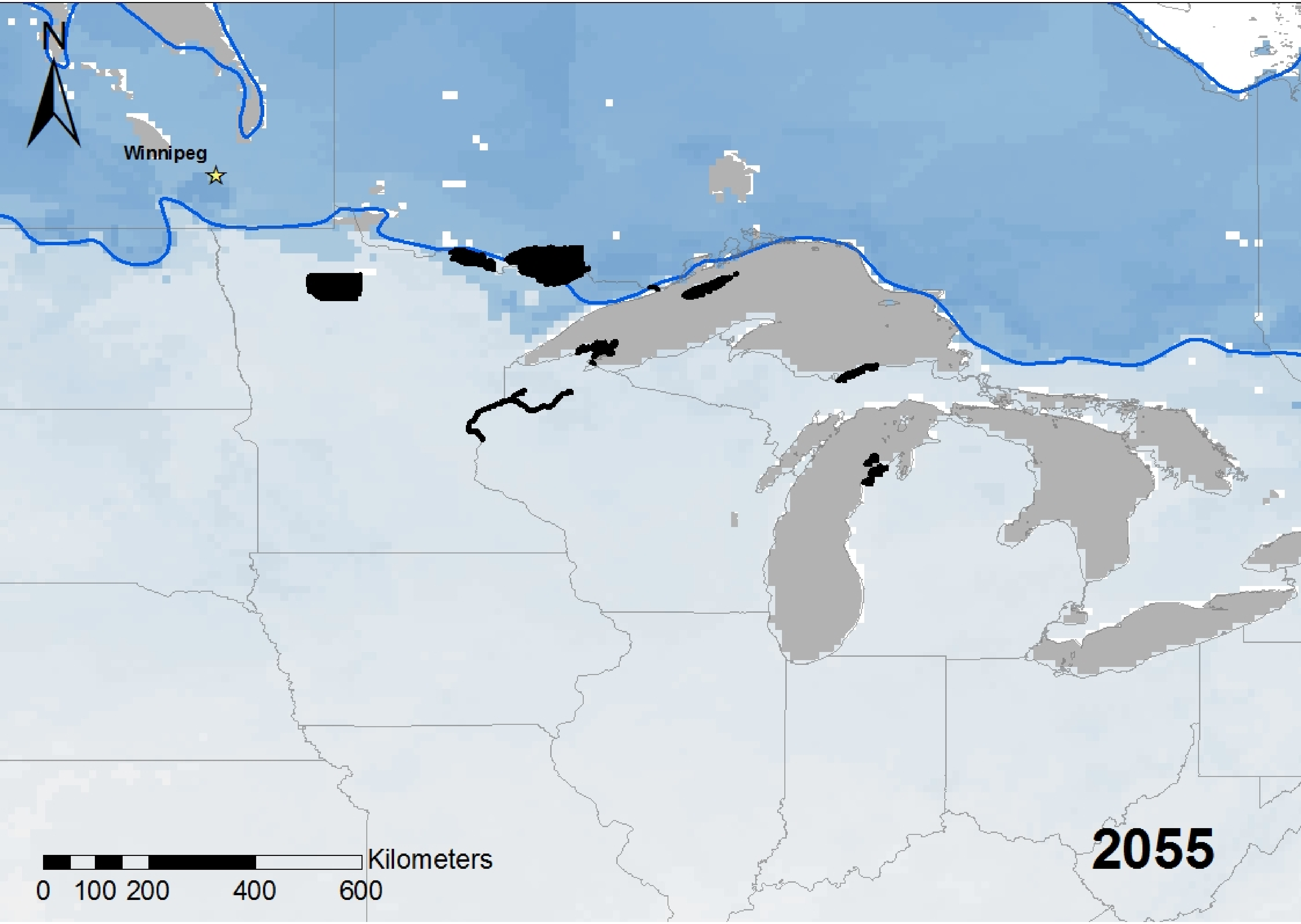
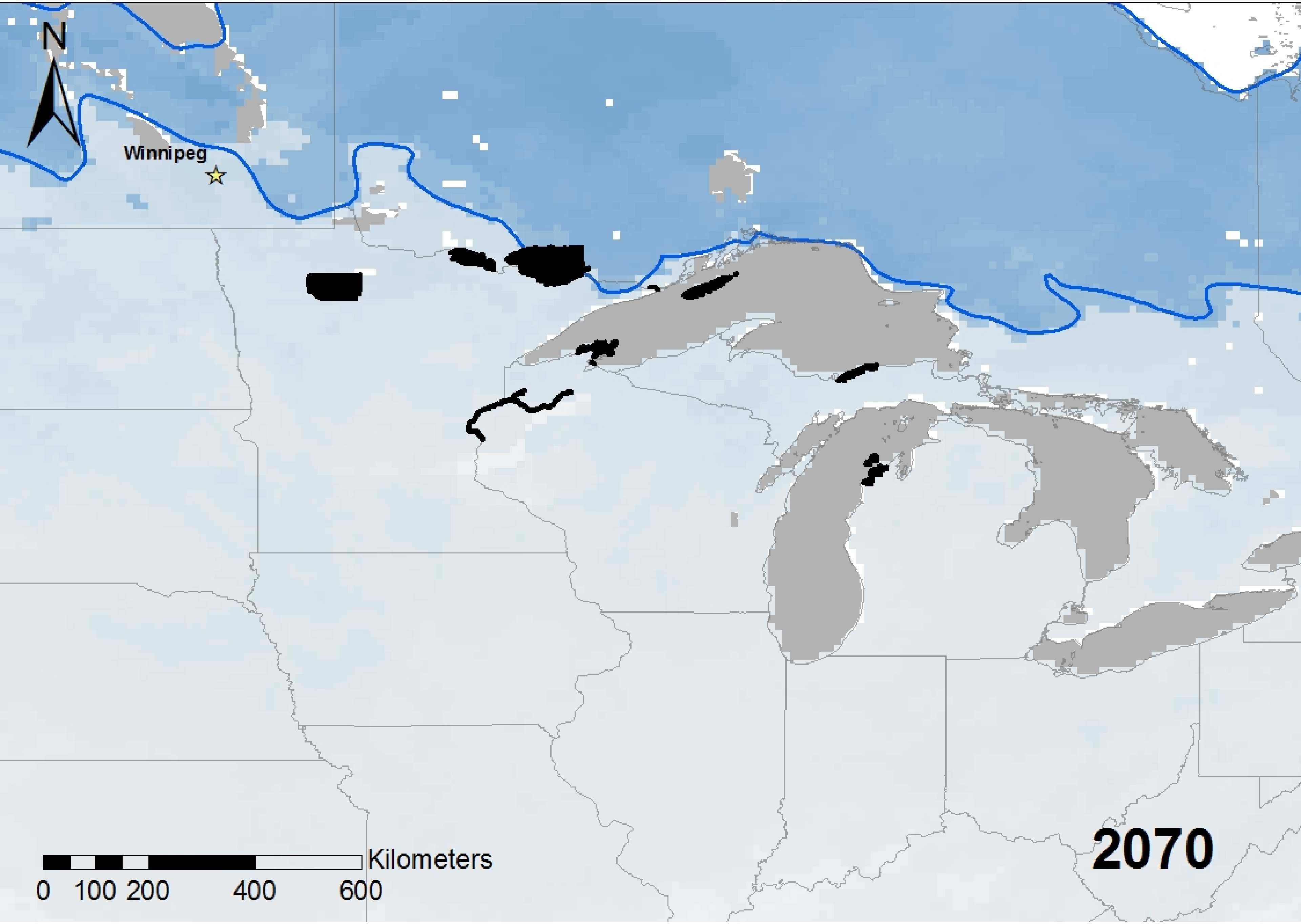
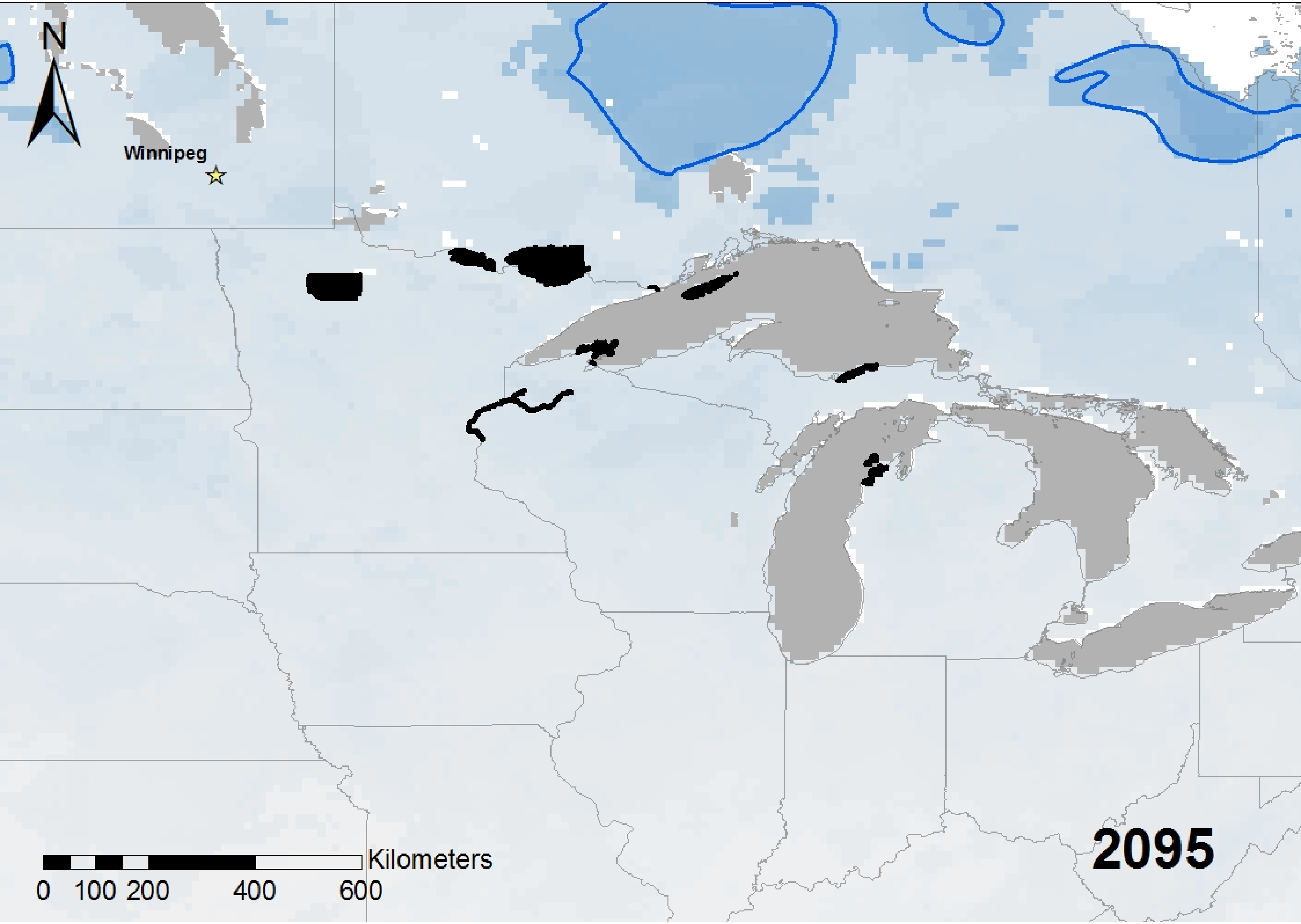
2040



N
Winnipeg
Kilometers
0 100 200 400 600
2055


N
Winnipeg
Kilometers
0 100 200 400 600
2070


N
Winnipeg
Kilometers
0 100 200 400 600
2095

Canada Lynx of the Great Lakes Region - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.nrri.umn.edu/lynx/

Canada Lynx of the Great Lakes Regi...

CANADA LYNX IN THE GREAT LAKES REGION

Home | Research | Methods | Animals and Images | Information | Publications

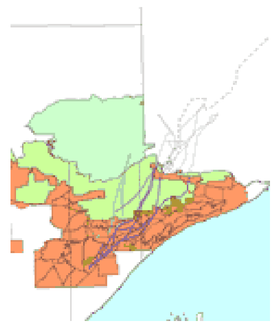
2008 Annual Report

Minnesota historically supported the largest lynx population in the Great Lakes region.

We are studying distribution, abundance, persistence, and habitat use of Canada lynx in northeastern Minnesota. Since 2003 we have placed radiocollars on 33 lynx, obtained over 15,000 lynx locations, located dens, and documented movements and habitat use.

The lynx project is in transition from biological research to using research results for management. Annual reports, publications, and theses will be added periodically.

Sights and sounds of Lynx. We've been lucky enough to catch some lynx on tape. Watch the videos or Listen to the recordings.



Read about how **Canada lynx make long-stance movements** from Minnesota to Ontario here (946 KB pdf)

A LCCMR proposal was recently recommended for funding to work on lynx issues with agencies and stakeholder groups. If approved, this project would begin in 2011. See the LCCMR recommendations here.

Click here to find out how to report a lynx sighting.

USGS Biological Resources

Minnesota DNR Department of Natural Resources

U.S. Fish & Wildlife Service

Forest Service U.S. Department of Agriculture

Minnesota Zoo

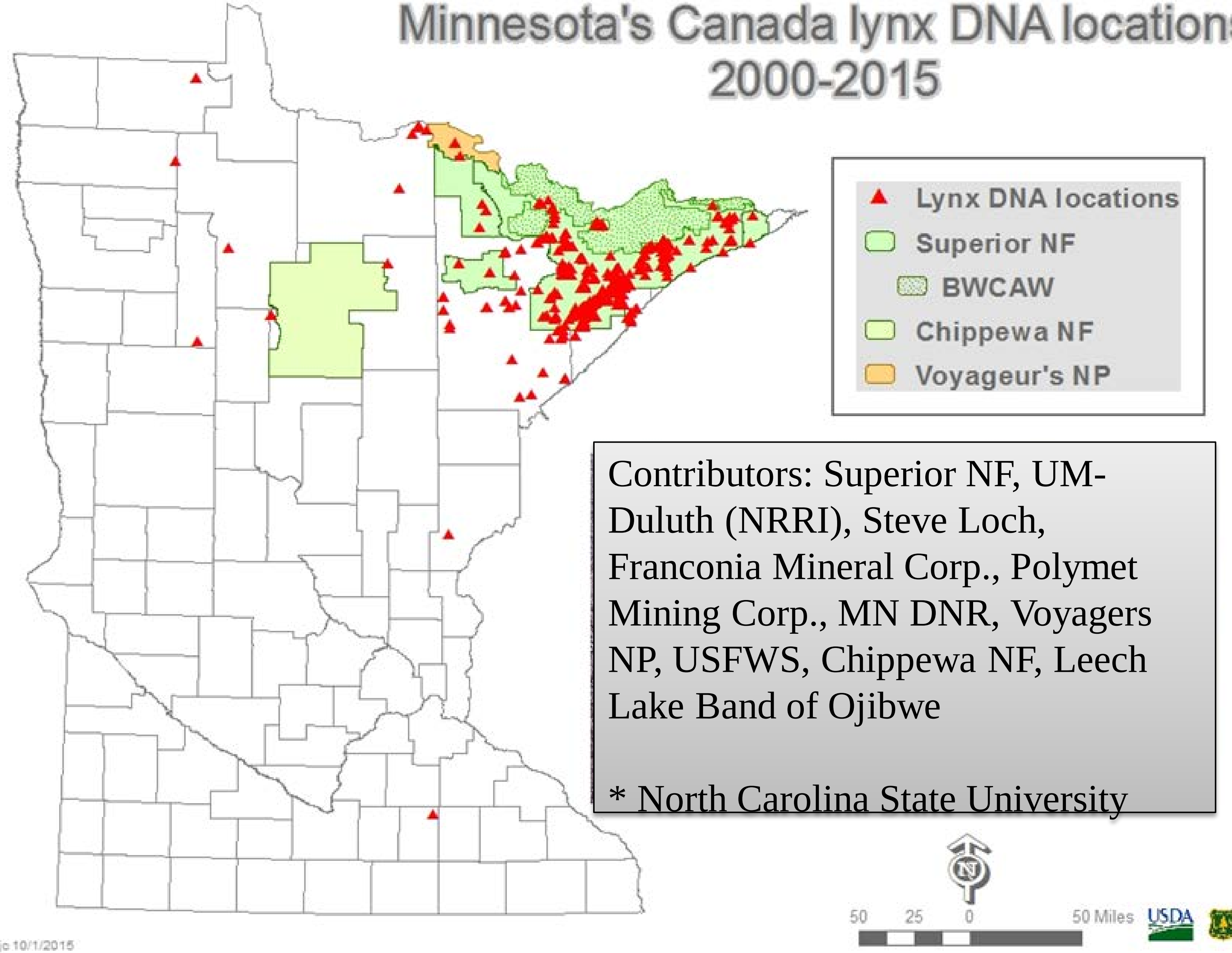
ncasi

Potlatch

UMD Duluth NRRI

www.nrri.umn.edu/lynx

Minnesota's Canada lynx DNA locations 2000-2015

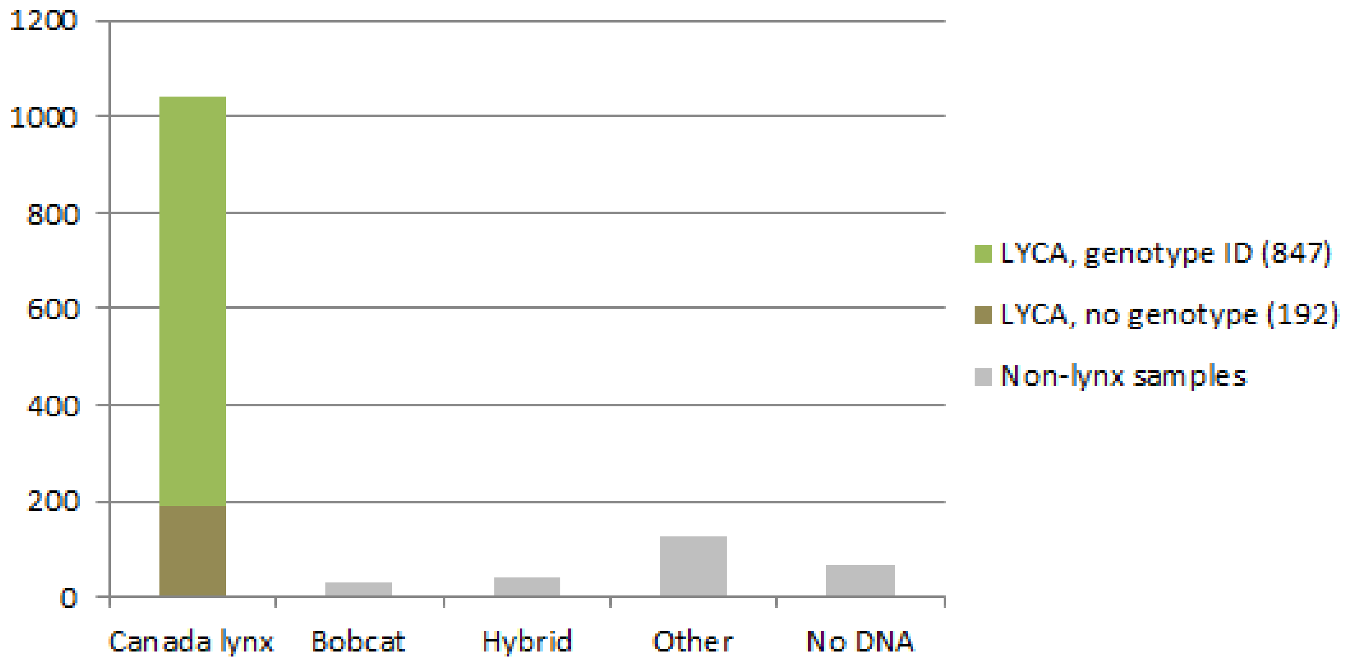


Contributors: Superior NF, UM-Duluth (NRRI), Steve Loch, Franconia Mineral Corp., Polymet Mining Corp., MN DNR, Voyagers NP, USFWS, Chippewa NF, Leech Lake Band of Ojibwe

* North Carolina State University

Species ID and Individuals

- 1,306 samples
- 1,039 (80%) lynx
- 268 individual lynx (47%F, 53%M)

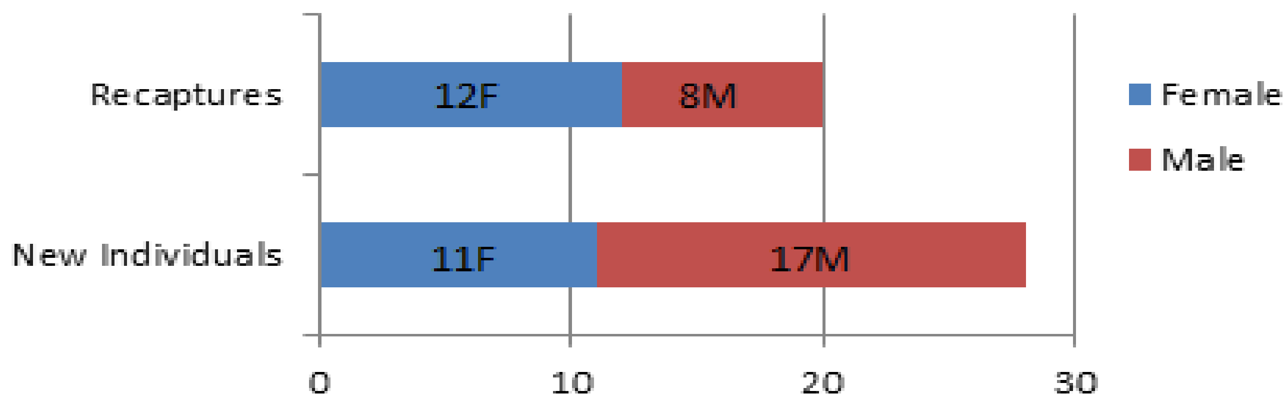


Species Identification Results (*n* = 1,240)

Hybrids

- 42 samples F1 lynx- bobcat hybrid
- 13 unique individuals (5F, 8M)

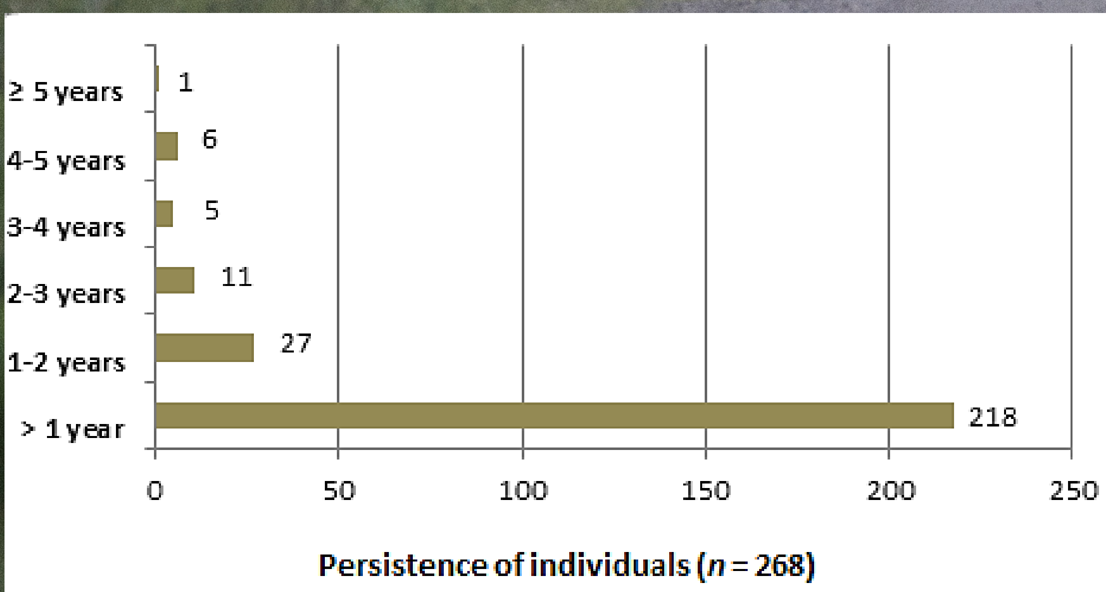
2014-2015 results



2015 Canada lynx individuals detected (*n* = 48)

- 133 samples
- 84% lynx
- 48 unique individuals (23F, 25M)
- 20 recaptures
- 28 new captures
- 2 F1 Canada lynx-bobcat hybrid recaptures (both male)

Persistence



Recruitment

Current Distribution, Status, and Threats of Canada Lynx in Montana and Wyoming

John Squires, Rocky Mountain Research Station, Missoula, MT

Basis of Assessment - Montana:

a) Lynx Research Program at RMRS initiated in 1998

b) Captured and collared 175 individuals

c) Recorded 169,782 GPS and 3043 VHF locations that document lynx movements and resource-use

d) Investigated the following topics regarding lynx in Montana:

Basis of Assessment:

- Resource selection

  Squires, J. R, N. J. DeCesare, J. A. Kolbe, and L. F. Ruggiero. 2008. Hierarchical den selection of Canada lynx in western Montana. Journal of Wildlife Management 72:1497-1506.

  Squires, J. R., N. J. DeCesare, J. A. Kolbe, and L. F. Ruggiero. 2010. Seasonal Resource Selection of Canada Lynx in Managed Forests of the Northern Rocky Mountains. Journal of Wildlife Management 74:1648-1660.

- Prey Selection

  Squires, J. R. and L. F. Ruggiero. 2007. Winter prey selection of Canada lynx in northwestern Montana. Journal of Wildlife Management 71:310-315.

- Competition

  Kolbe, J. A., J. R. Squires, D. H. Pletscher, and R. F. Ruggiero. 2007. The effect of snowmobile trails on coyote movements within lynx home ranges. Journal of Wildlife Management 71:1409-1418.

Basis of Assessment:

- Activity Patterns

Kolbe, J. A. and J. R. Squires. 2007. Circadian activity patterns of Canada lynx in western Montana. Journal of Wildlife Management 71:1607-1611.

Olson, L. E., J. R. Squires, N. J. DeCesare, J. A. Kolbe. 2011. Den use and activity patterns in female Canada lynx (Lynx canadensis) in the Northern Rocky Mountains. Northwest Science 85(3):455-462.

- Detection/Monitoring

Squires, J. R., K. S. McKelvey, L. F. Ruggiero. 2004. A snow-tracking protocol used to delineate local lynx, Lynx canadensis, distributions. Canadian Field-Naturalist 118:583-589.

McKelvey, K. S., J. Von Kienast, K. B. Aubry, G. M. Koehler, B. T. Maletzke, J. R. Squires, E. L. Lindquist, S. Loch, M. K. Schwartz. 2006. DNA analysis of hair and scat collected along snow tracks to document the presence of Canada lynx (Lynx canadensis). Wildlife Society Bulletin 34:451-455.

Squires, J. R., L. E. Olson, D. L. Turner, N. J. DeCesare, and J. A. Kolbe. 2012. Estimating detection probability for Canada lynx using snow-track surveys in the Northern Rocky Mountains. Wildlife Biology 18:215-224.

Basis of Assessment:

- Connectivity

Squires, J. R., Nicholas J. DeCesare, Lucretia E. Olson, Jay A. Kolbe, Mark Hebblewhite, and Sean A. Parks. 2013. Combining resource selection and movement behavior to predict corridors of Canada lynx at their southern range periphery. Biological Conservation 157:187–195.

Basis of Assessment - Wyoming:

a) Wyoming Game and Fish Department (WGF), in cooperation with the Shoshone National Forest (SNF), initiated lynx surveys during winter 1995/96

- no lynx detected on SNF
- Impetus for WGF to fund additional surveys, trapping, and telemetry in the Wyoming Range

b) During 1997-98, WGF searched approximately 2055 km of maintained snowmobile routes and 2400 km of non-maintained trails for lynx tracks in 12 areas (Laurion and Oakleaf 1998) – 6 lynx tracks detected

Basis of Assessment - Wyoming:

c) During winter 1998-99, three general areas were searched (Laurion and Oakleaf 1999) - 6 tracks located in Wyoming Range.

d) RMRS, in cooperation with WGD, conducted lynx surveys in 2000, 2001, and 2002

- 2000 – Wyoming Range: 5 lynx tracks - kitten and female
- 2001 – Wyoming Range: 5 lynx tracks
- 2002 – no detections

Basis of Assessment - Wyoming:

e) Yellowstone Park Lynx survey from 2001 – 2004 (1,143 km ski-based snow tracks, 749 km snowmobile-based survey, 693 km aircraft survey, and 35 hair snare transects - 105-175 stations; Murphy et al. 2006. Distribution of Canada Lynx in Yellowstone National Park. Northwest Science 80:199-206)

f) DNA confirmed detections of 3 lynx – 1 female, 1 female with male kitten, and 1 male. All detections on east side of Yellowstone Park – east shore Yellowstone Lake.

Basis of Assessment - Wyoming:

g) Endeavor Wildlife Research Foundation conducted track/DNA surveys between 2004-2005 in southern GYA (Bridger-Teton Nat. Forest including Gros Ventre and Teton Wilderness areas) – searched 4,320 miles and detected (DNA confirmed) 18 lynx tracks. Confirmed presence in Wyoming Range.

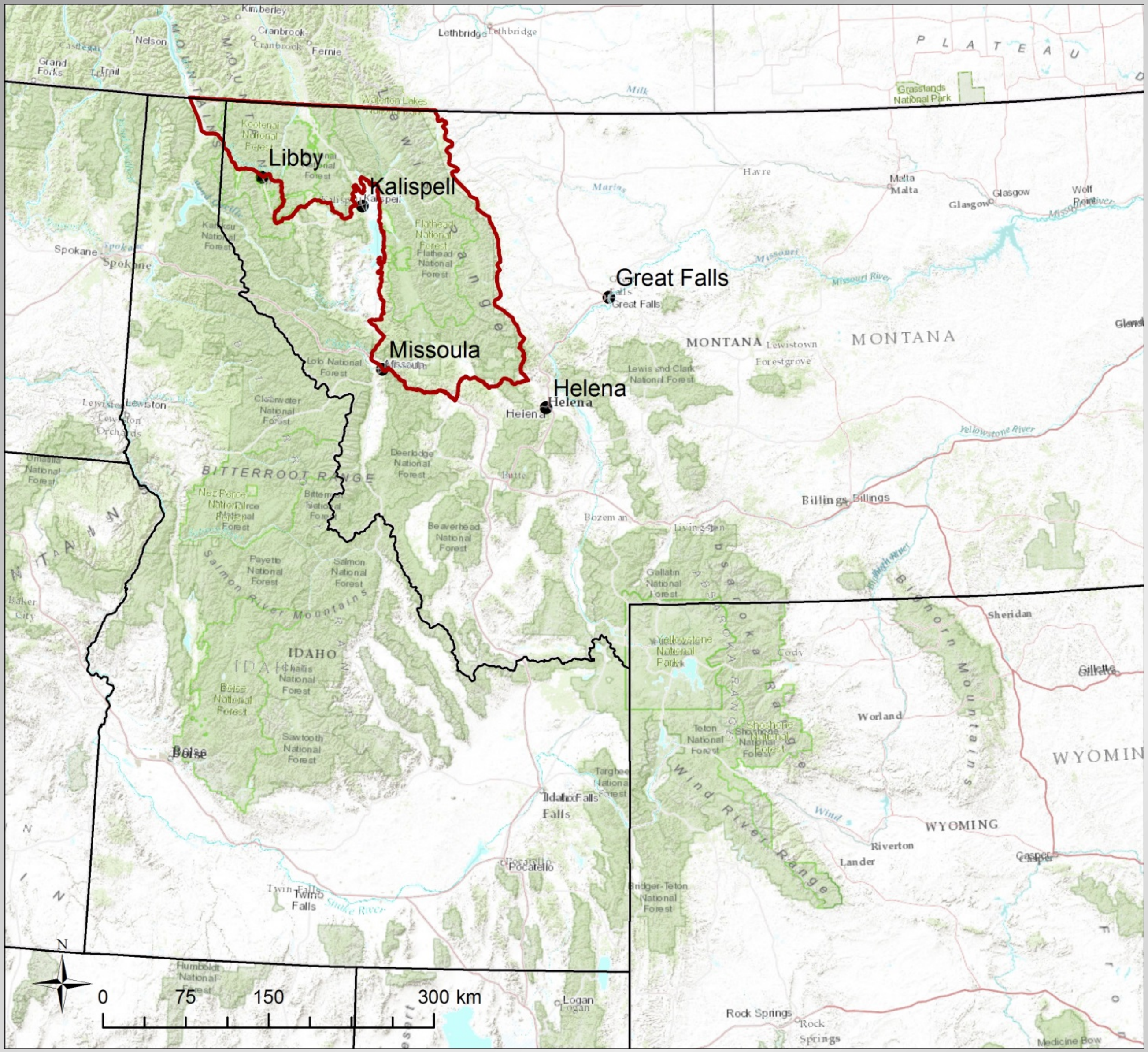
h) In 2008-2009, Endeavor Wildlife Research searched 2,854 miles for winter tracks throughout the GYA – documented 6 detections on Togwotee Pass, 2 possible detections in Yellowstone National Park, and 1 possible detection on the Beartooth Plateau.

Basis of Assessment – Wyoming (telemetry):

e) From 2006-2007, WGF collared 2 lynx (one male, 1 female) in Wyoming Range – monitored throughout the year with conventional ground and aerial telemetry (1996 – 2001) – (N=219 locations – male, N = 212 - female)

f) In 2000, female died. WGF asked RMRS to replace the collar on male with ARGOS (N = 258). Documented summer exploratory movements of male (1999 –2001) based on conventional and Argos telemetry (Squires and Oakleaf. 2005. Movements of a male Canada lynx crossing the Greater Yellowstone Area, including highways. Northwest Science 79:196-201).

Status - Montana



Status - Montana

Litter size of lynx in western Montana, 1999 – 2007

	Seeley Lake			Purcell Mountains			Combined		
Year	**Litters**	**Kittens**	**Kittens / litter**	**Litters**	**Kittens**	**Kittens / litter**	**Litters**	**Kittens**	**Kittens / litter**
1999	2	4	2.00				2	4	2.00
2000	4	6	1.50				4	6	1.50
2001	3	8	2.67				3	8	2.67
2002	3	4	1.33				3	4	1.33
2003	5	14	2.80				5	14	2.80
2004	5	15	3.00	5	16	3.20	10	31	3.10
2005	5	12	2.40	6	19	3.17	11	31	2.82
2006	3	5	1.67	3	8	2.67	6	13	2.17
2007	3	7	2.33	8	22	2.75	11	29	2.64
MLE Mean [1]	**33**	**75**	**2.24**	**22**	**65**	**2.95**	**55**	**140**	**2.53**
MLE Var [1]			**0.002**			**0.084**			**0.008**
95% CI			**2.21-2.27**			**2.67-3.23**			**2.51-2.55**

Status - Montana

Proportion of successful adult Canada lynx

	Seeley Lake (N=52 breeding-age females)			Purcell Mountains (N=28)			Combined (N = 80)		
Year	**Females**	**Females w kittens**	**Prop**	**Females**	**Females w kittens**	**Prop**	**Females**	**Females w kittens**	**Prop**
1999	4	2	0.50				4	2	0.50
2000	6	4	0.67				6	4	0.67
2001	9	3	0.33				9	3	0.33
2002	6	2	0.33				6	2	0.33
2003	5	3	0.60				5	3	0.60
2004	6	4	0.68	5	5	1.00	11	9	0.82
2005	6	5	0.83	7	7	1.00	13	12	0.92
2006	3	3	1.00	6	4	0.67	9	7	0.78
2007	3	3	1.00	10	7	0.70	13	10	0.77
MLE [1] Mean			**0.61**			**0.83**			**0.67**
MLE Var [1]			**0.01**			**0.01**			**0.02**
95% CI			**0.42-0.81**			**0.43-0.98**			**0.45-0.82**

Model-selection results for 8 *a priori* models of monthly survival rate based on three categorical covariates (age, sex, site), each having two levels.

Model	AICc	Delta	AIC Weight	Model Likelihood	Number of Parameters
{S(age + site)}	510.261	0	0.4374	1	3
{S (age + sex + site)}	511.204	0.9425	0.2731	0.6242	4
{S (age)}	512.838	2.5766	0.1206	0.2757	2
{S (age+ sex)}	513.74	3.4792	0.0768	0.1756	3
{S (site)}	515.287	5.0255	0.0355	0.081	2
{S (sex+ site)}	515.414	5.1528	0.0333	0.0761	3
{S (.)}	517.458	7.1965	0.0120	0.0274	1
{S (sex)}	517.556	7.2954	0.0114	0.0261	2

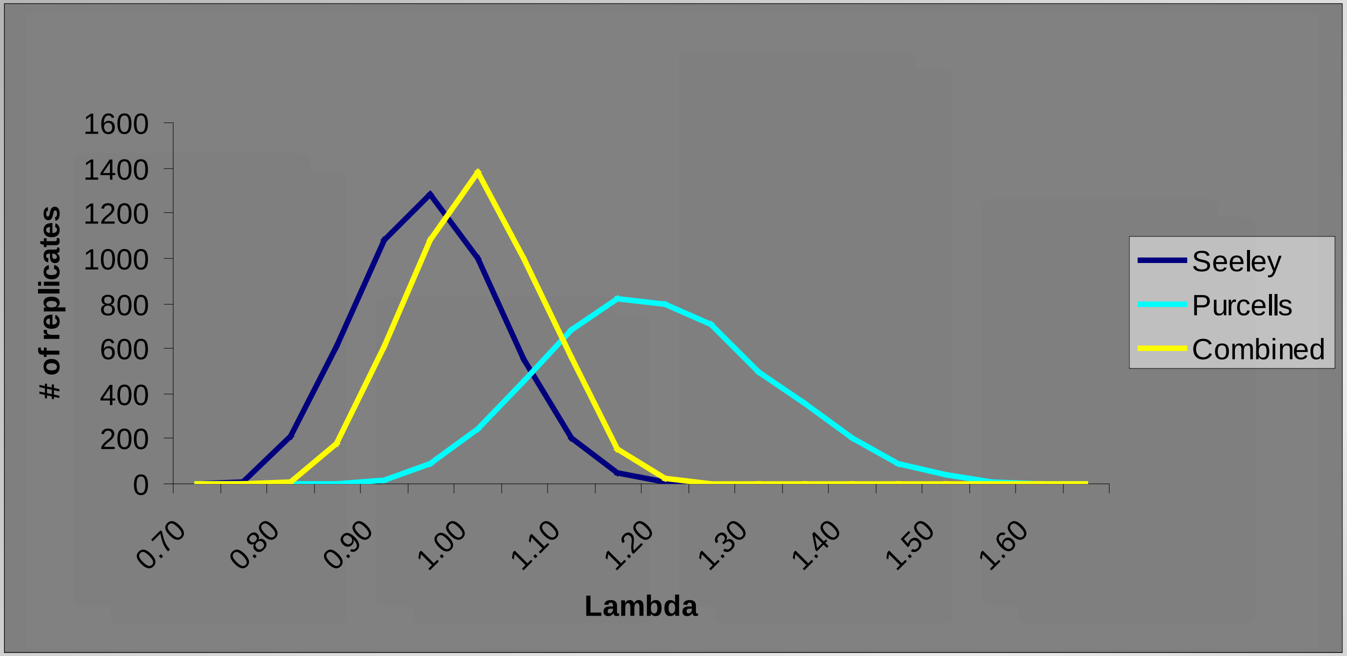
We estimated survival based on 125 lynx monitored monthly from 1999-2007 using a staggered entry design; we documented 2376 lynx-use months during this period.

Annual Survival Rate of female lynx on the Seeley Lake(1999-2007) and Purcell (2003-2007) Study Areas including a combined estimate.

		Female Subadult Survival [1]	Female Adult Survival [1]
Seeley	Mean	**0.515**	**0.747**
	Variance	0.014	0.003
	95% CI	0.283 - 0.746	0.648 - 0.846
Purcells	Mean	**0.683**	**0.846**
	Variance	0.017	0.004
	95% CI	0.428 - 0.937	0.721 - 0.970
Combined	Mean	**0.520**	**0.753**
	Variance	0.010	0.002
	95% CI	0.322 - 0.718	0.659 - 0.847

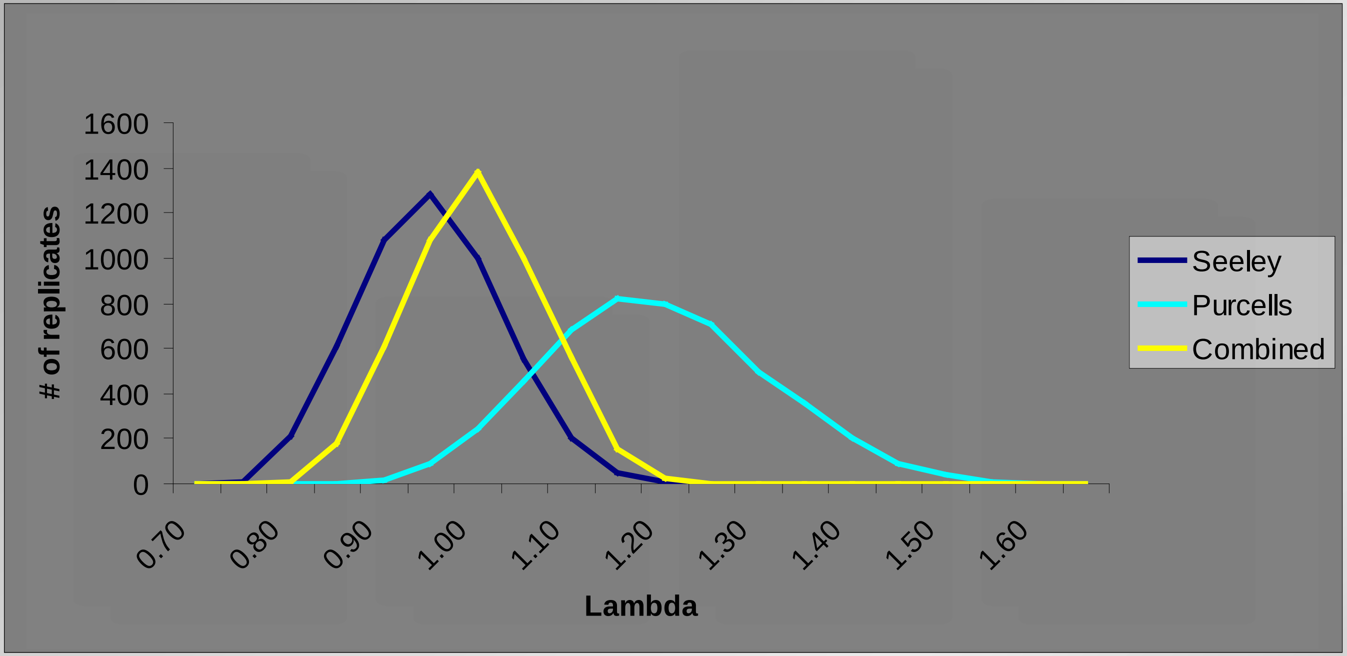
Status - Montana

Frequency distribution of λ values from 5000 replicates in which lynx vital rates were chosen from a uniform distribution bounded by their 95% confidence intervals



Status - Montana

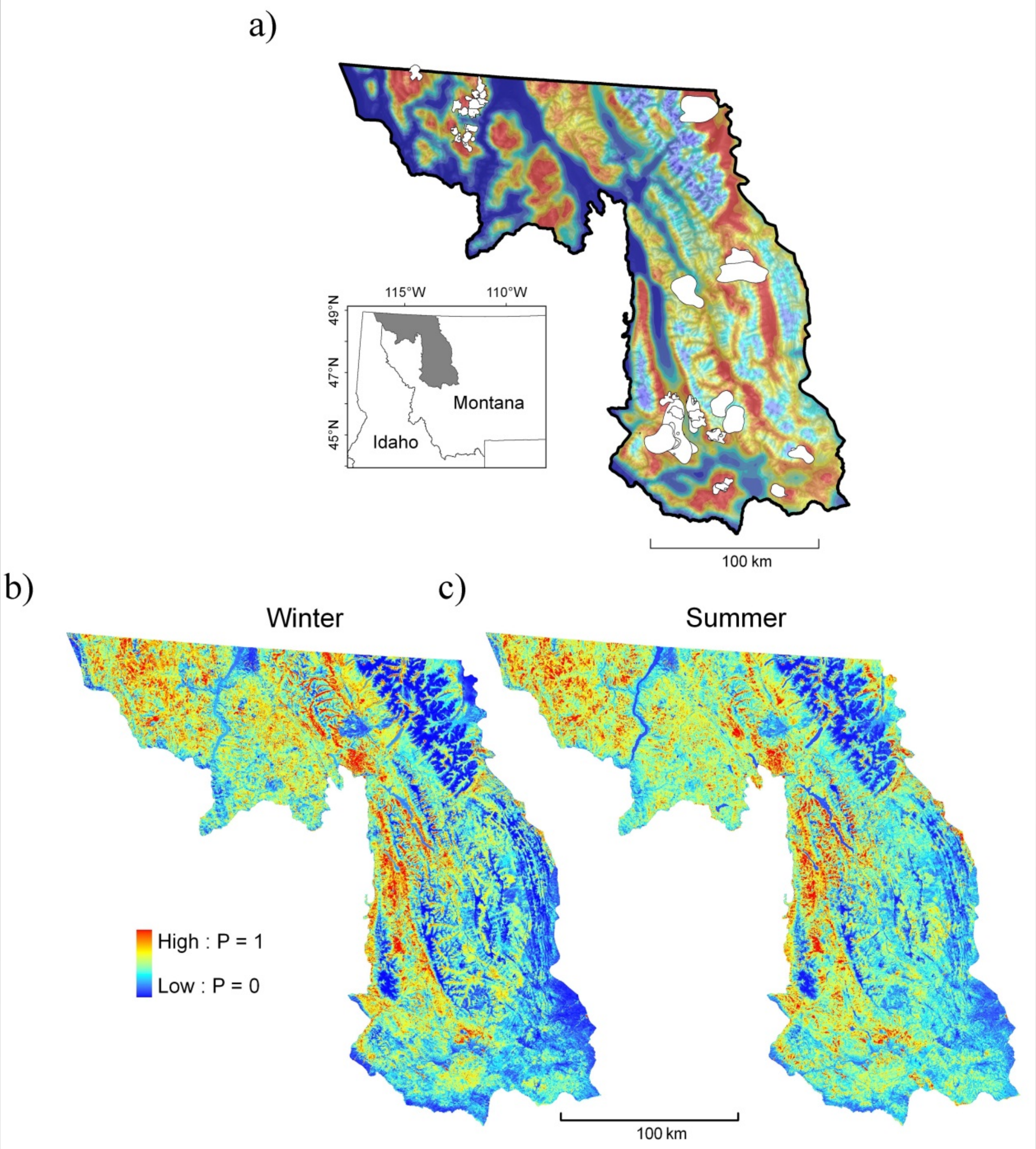
- Mean λ for Seeley Lake was 0.925 (95 % CI = 0.923 - 0.927) compared to 1.168 (95% CI = 1.165-1.171) in the Purcell Mountains
- Combined λ from both study areas was 0.973 (95% CI = 0.971-0.975)



Status - Montana

- Distribution in Montana remained generally unchanged since the 2000 listing
- Understanding of distribution has been refined with surveys conducted in Salish, Purcell, Seeley-Swan, Garnet and Bitterroot Mountains and northern GYA.

Status - Montana



Status - Montana

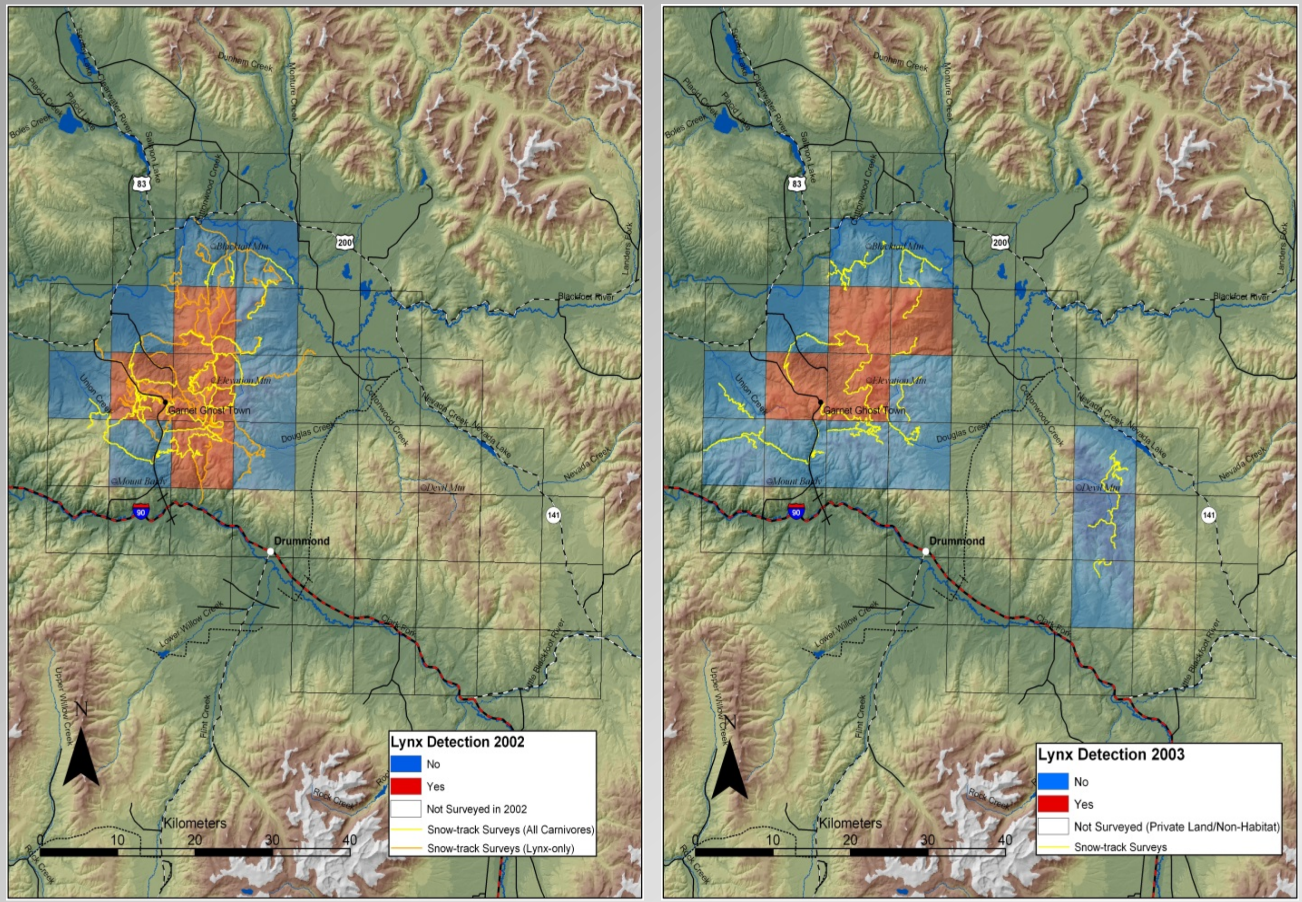
- Garnet Range has supported lynx populations since the 1980s (research documented)
- It appears that lynx recently contracted from the Garnet Range, Montana

Status - Montana

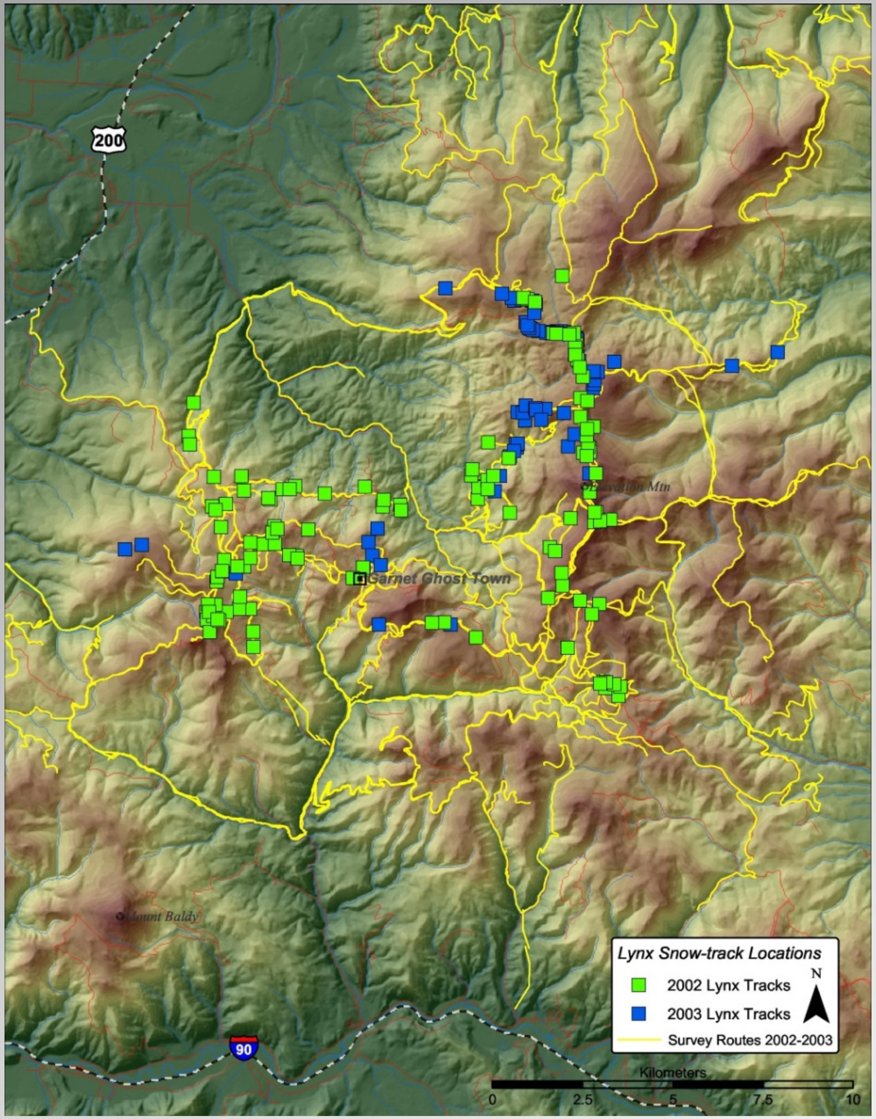
- RMRS surveyed 242 km of roads and trails for all carnivores and an additional 220 km of lynx-only surveys in Garnets in 2002-03.
- Documented lynx (n = 37 detections) in 4 of 12 pixels searched . We detected 115 additional lynx tracks during lynx-only surveys that extended the spatial extent and intensity of our search.

Status - Montana

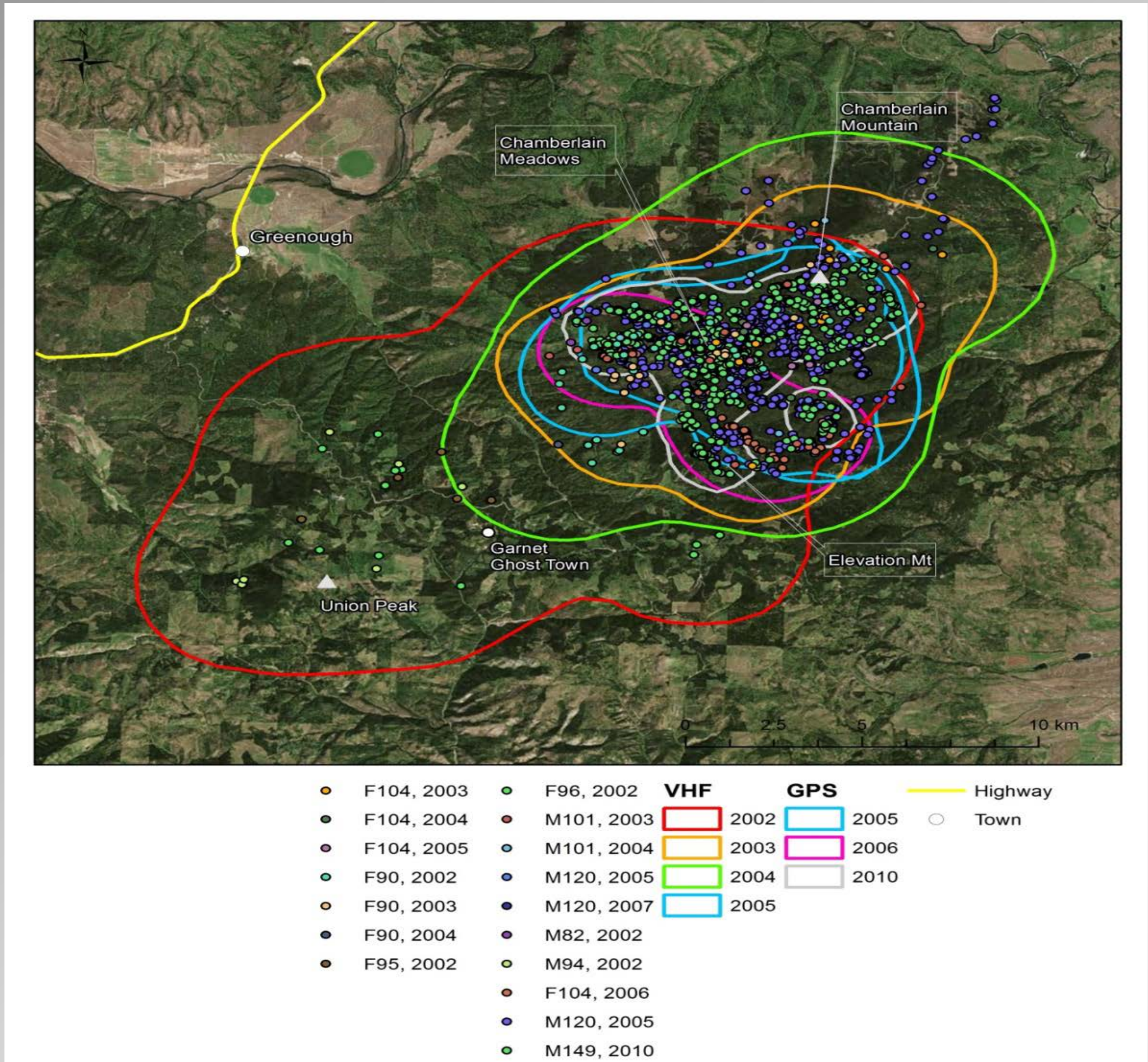
- In 2003, we expanded our effort and detected lynx (n = 37) in Garnets in similar areas to those of 2002 in 4 of 16 pixels surveyed .



Survey pixels and snow-track survey routes were lynx were detected in the Garnet Range, Montana, 2002 and 2003.



All lynx tracks documented during snow-track surveys in the Garnet Range, Montana, winters 2002 and 2003.



Chamberlain Mountain
Chamberlain Meadows
Greenough
Garnet Ghost Town
Elevation Mt
Union Peak
0
2.5
5
10 km
F104, 2003
F104, 2004
F104, 2005
F90, 2002
F90, 2003
F90, 2004
F95, 2002
F96, 2002
M101, 2003
M101, 2004
M120, 2005
M120, 2007
M82, 2002
M94, 2002
F104, 2006
M120, 2005
M149, 2010
VHF
2002
2003
2004
2005
GPS
2005
2006
2010
Highway
Town

Status - Montana

- In 2010, RMRS conducted follow-up surveys and trapping in the Garnet Range.
- Captured only 2 males in the Garnets despite an extensive trap effort - 1 individual was a recapture from 2007 and 1 new capture.
- In 2010, lynx restricted spatially in Garnet Range

Status - Montana

- Recent surveys (winter 2014-2015) that incorporated track surveys and cameras failed to detect lynx in Garnet

Status - Montana

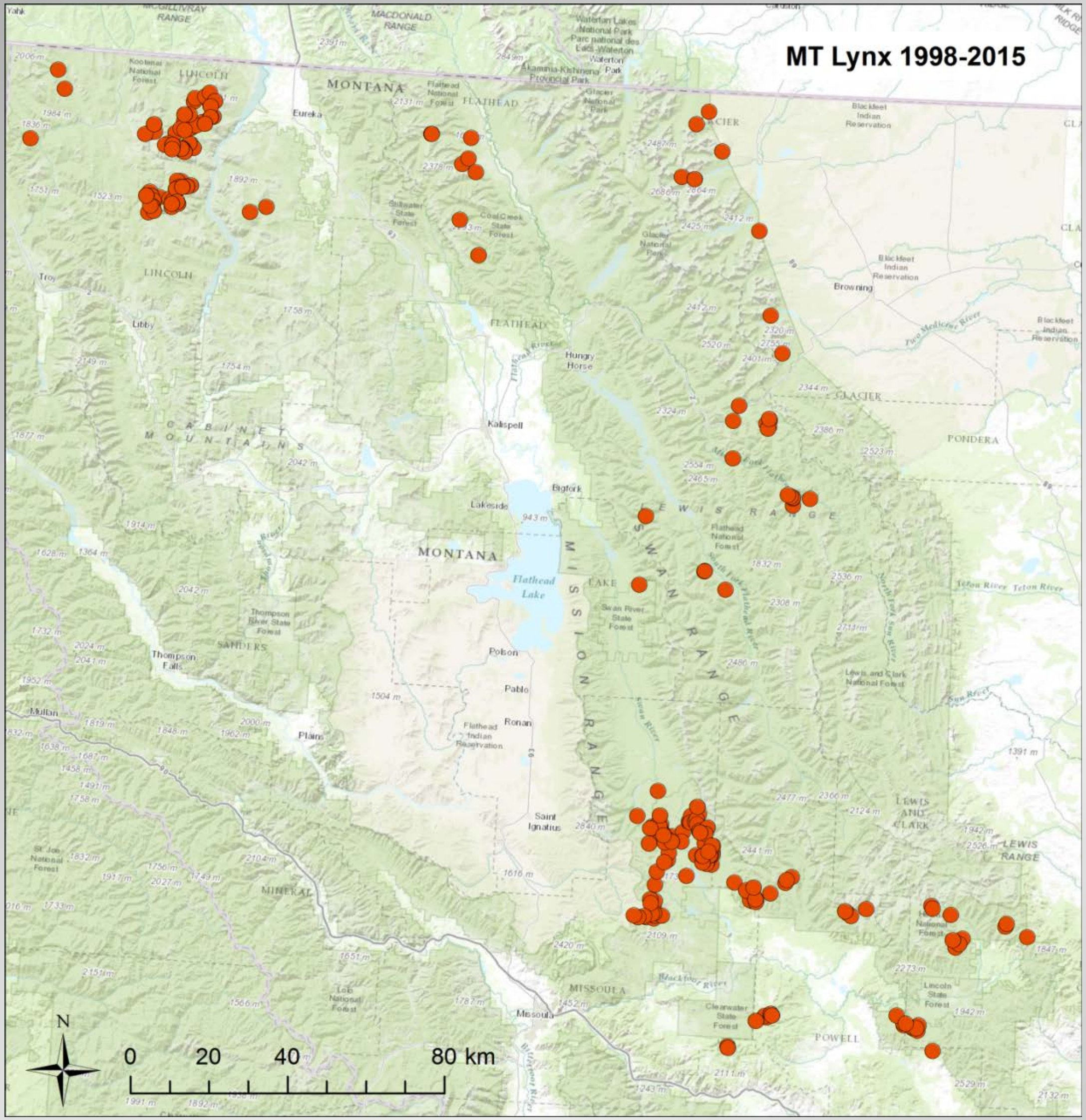
Purcell Mountains =

111 lynx

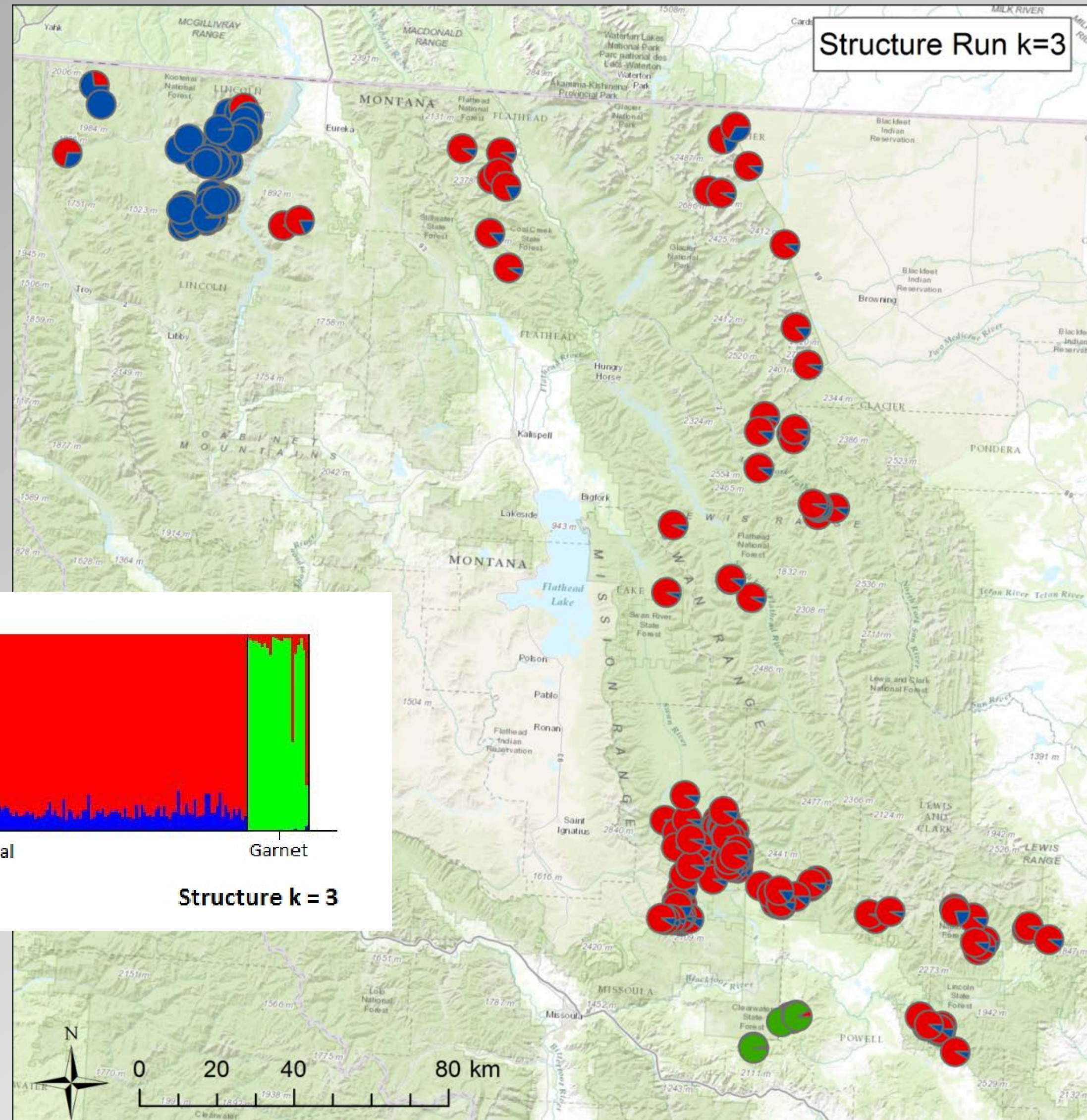
Central = 187

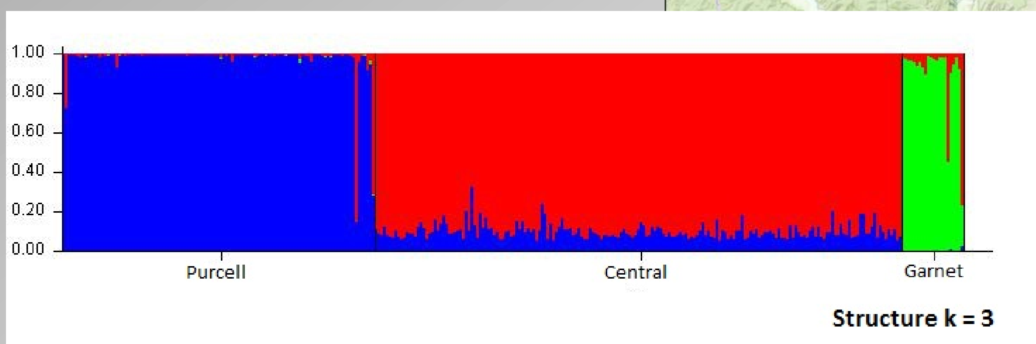
Garnett = 22

Total = 320



Status - Montana





Status - Montana

- However, in lynx core-habitat near Seeley Lake, MT, conservation land purchases increased protection across >100,000 acres of land.

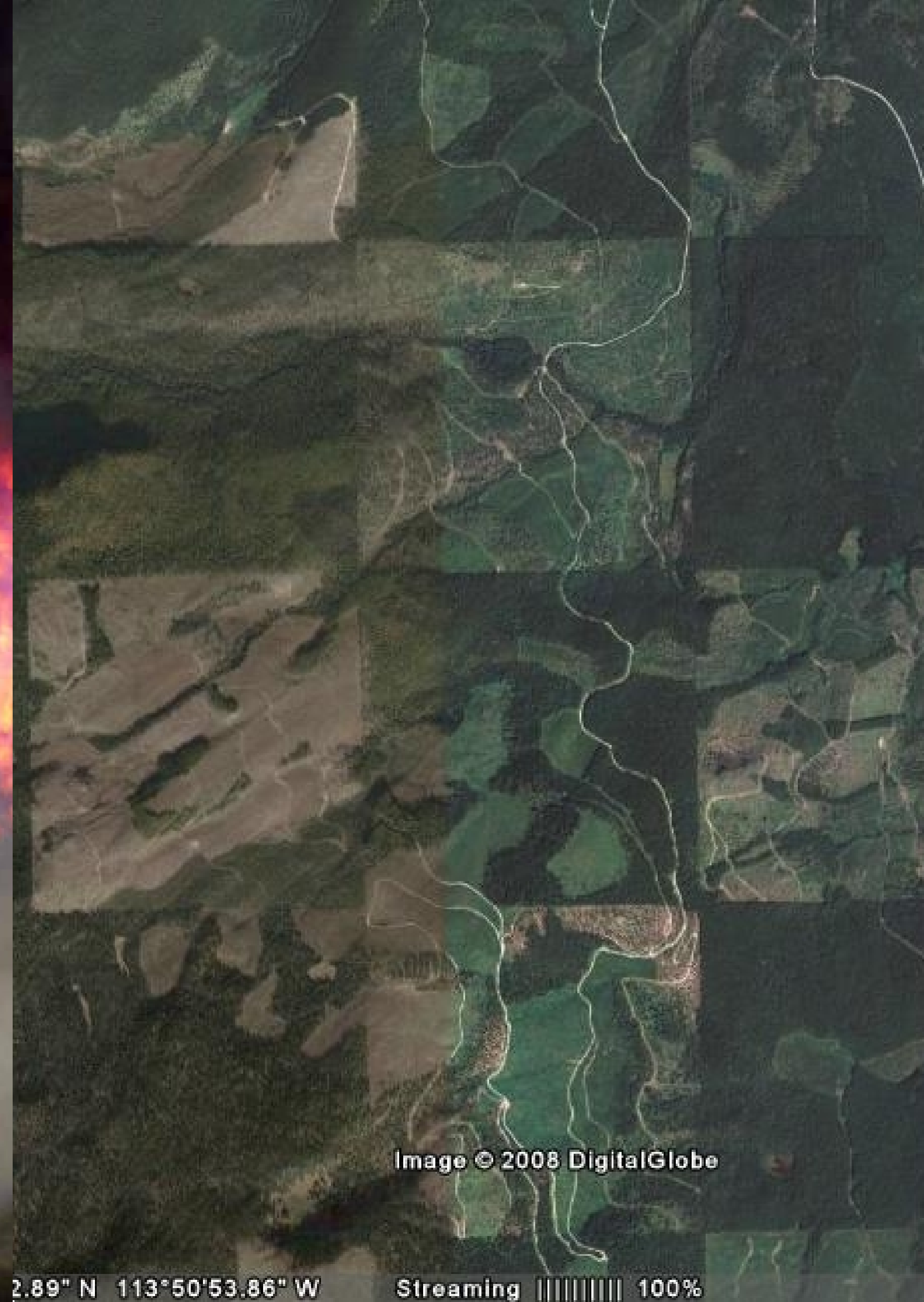
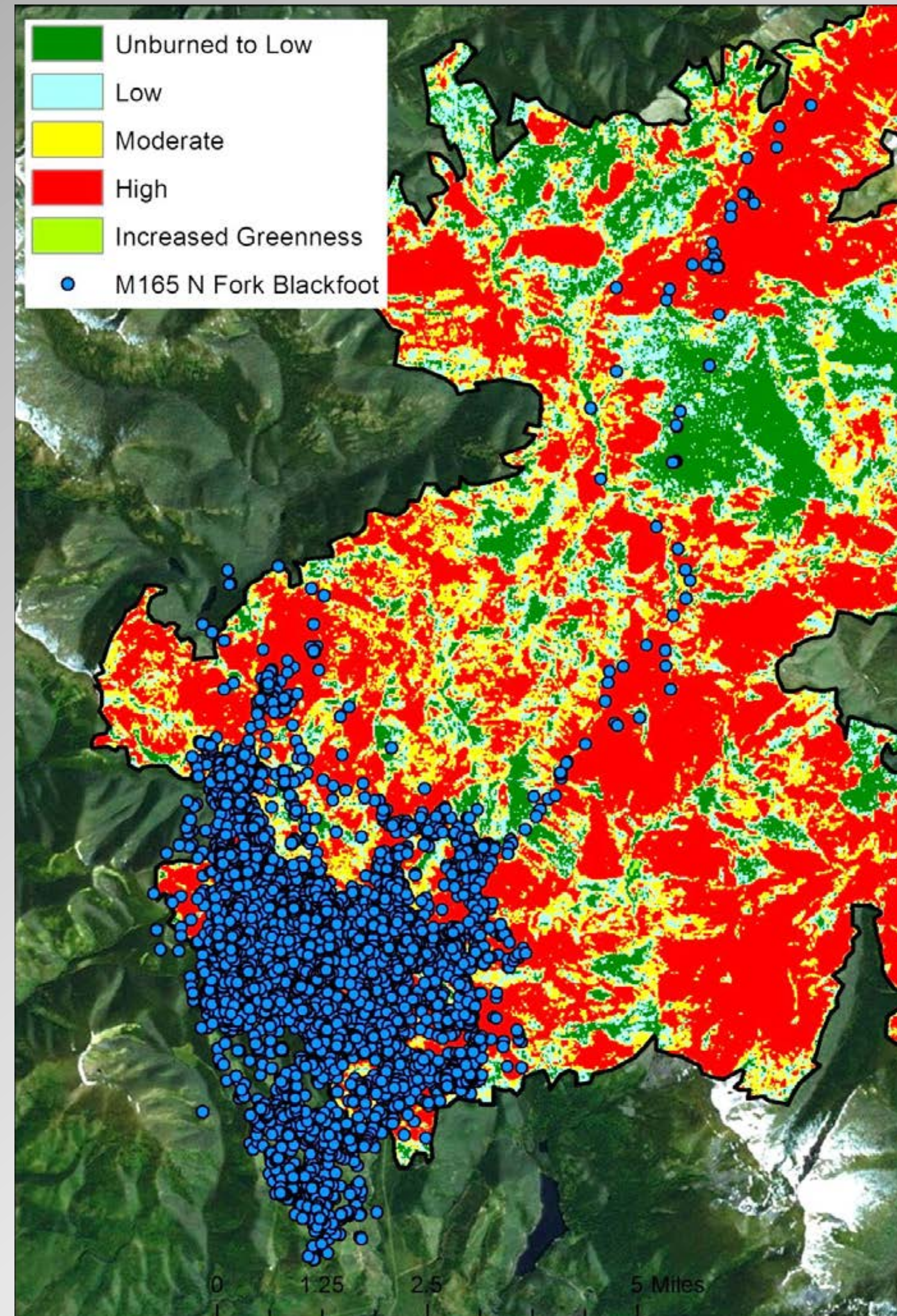


Image © 2008 DigitalGlobe
2.89" N 113°50'53.86" W
Streaming 100%

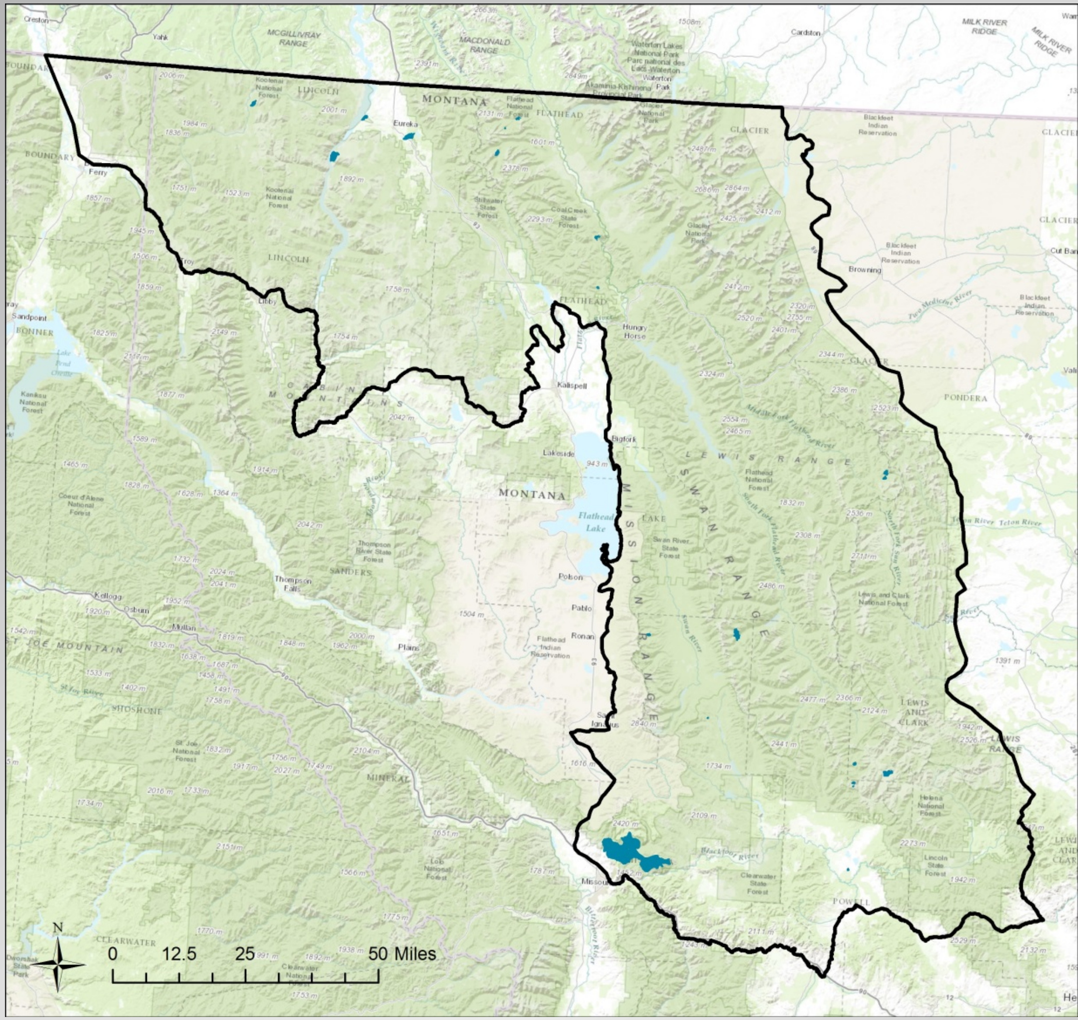
Risk factors - Montana

Lynx use of burns by severity



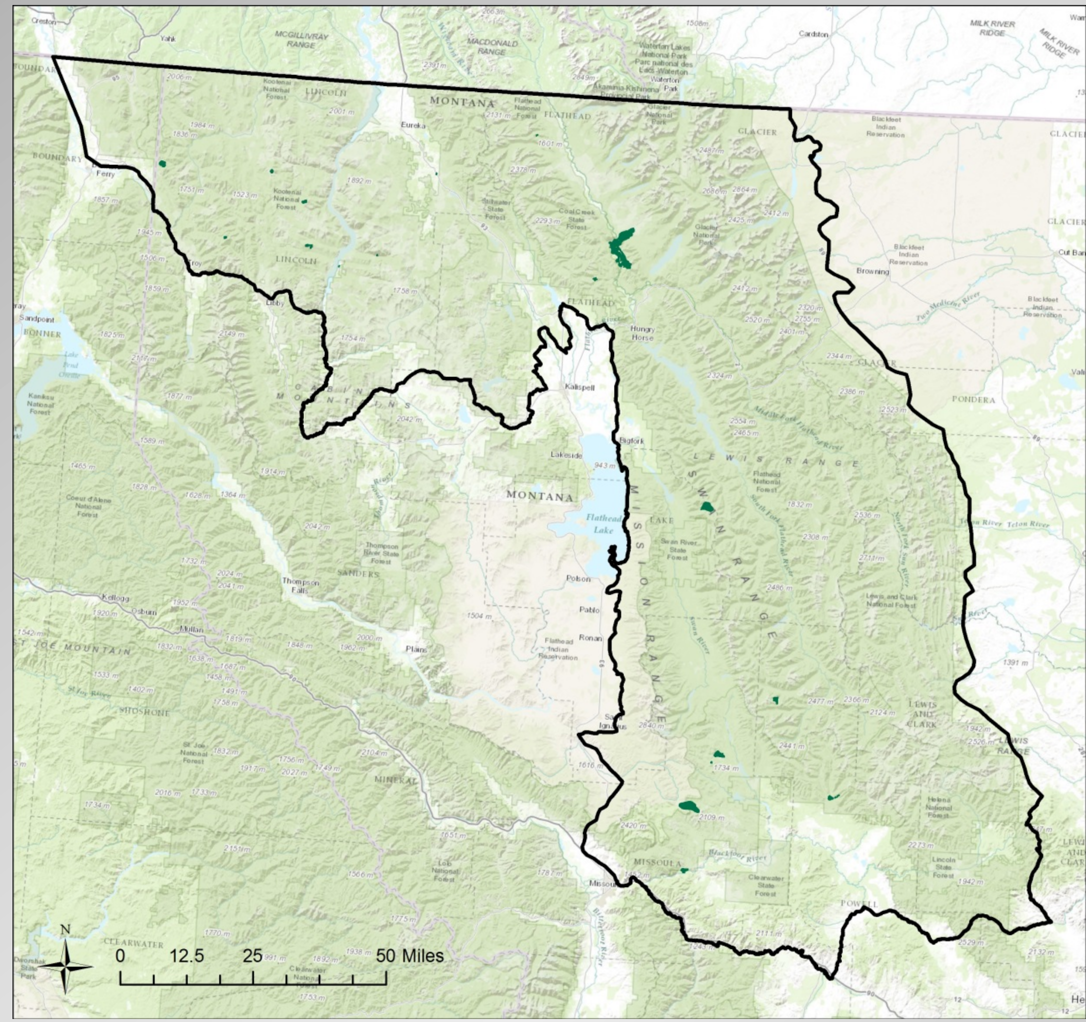
1950

29, 777 acres



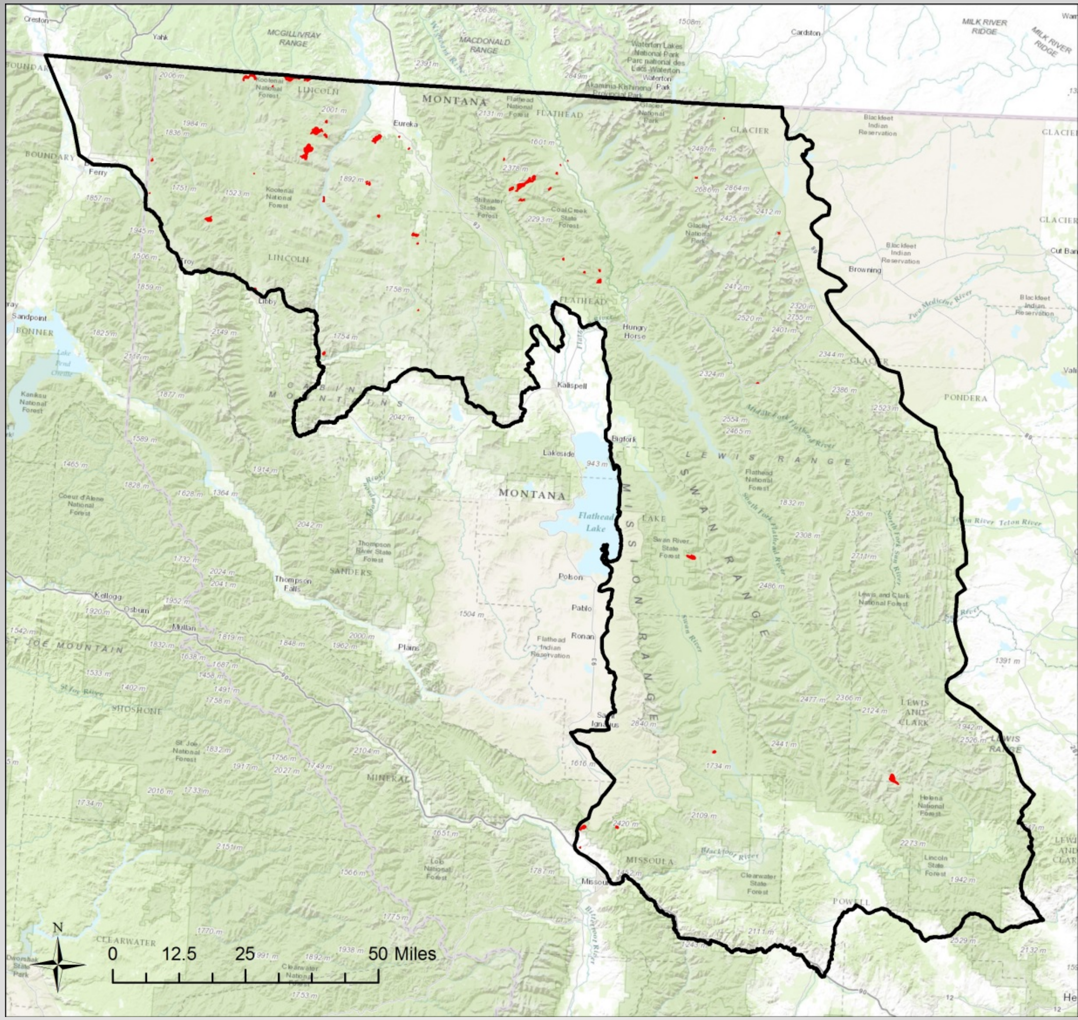
1960

17, 230 acres



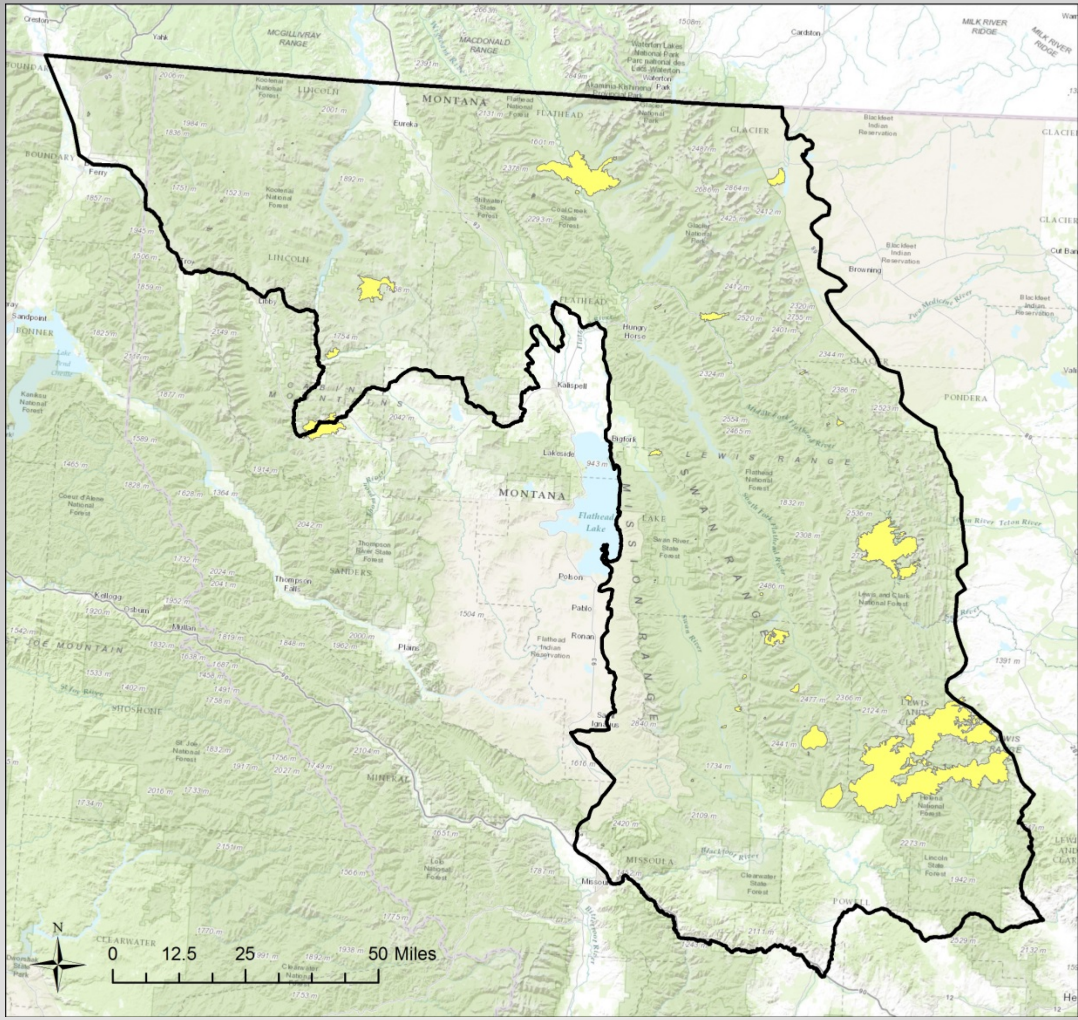
1970

14, 112 acres



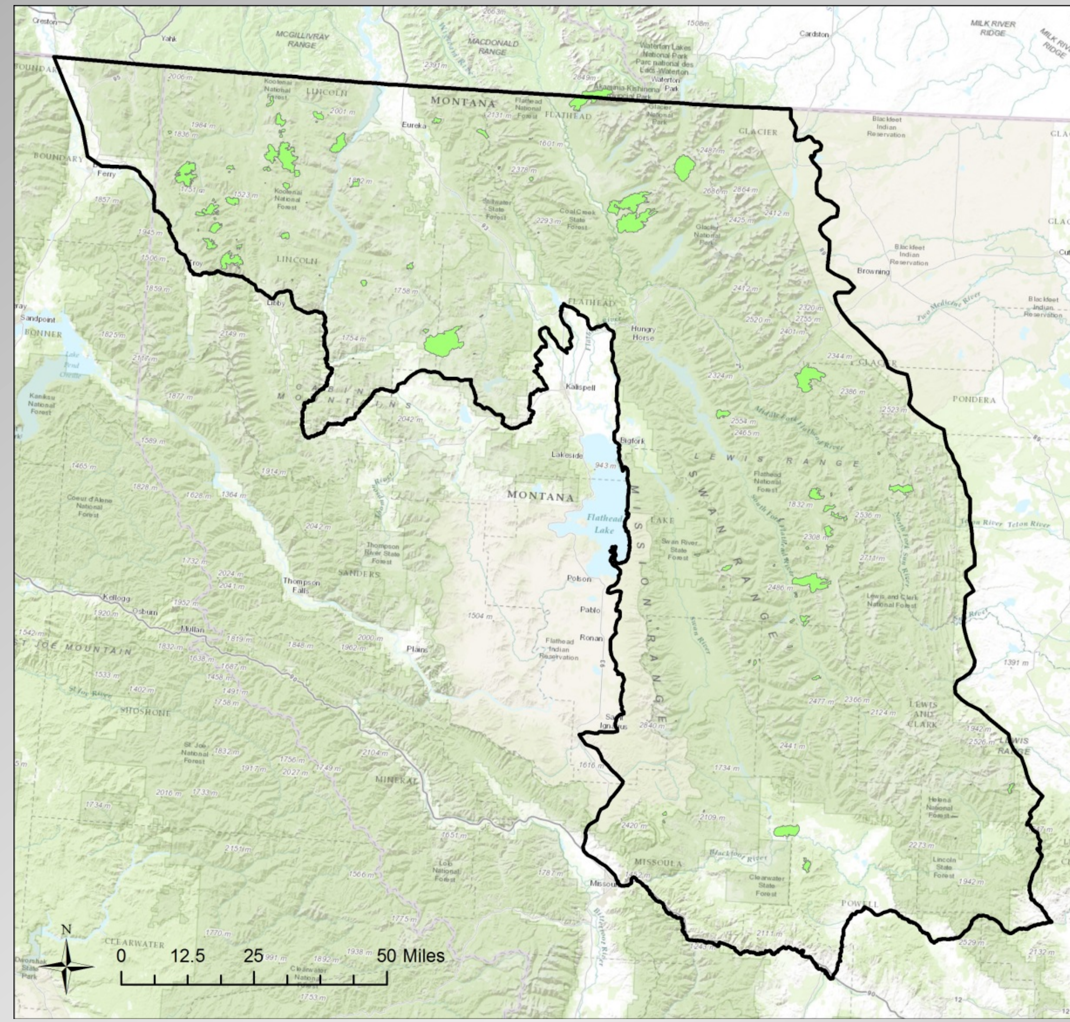
1980

307,310 acres



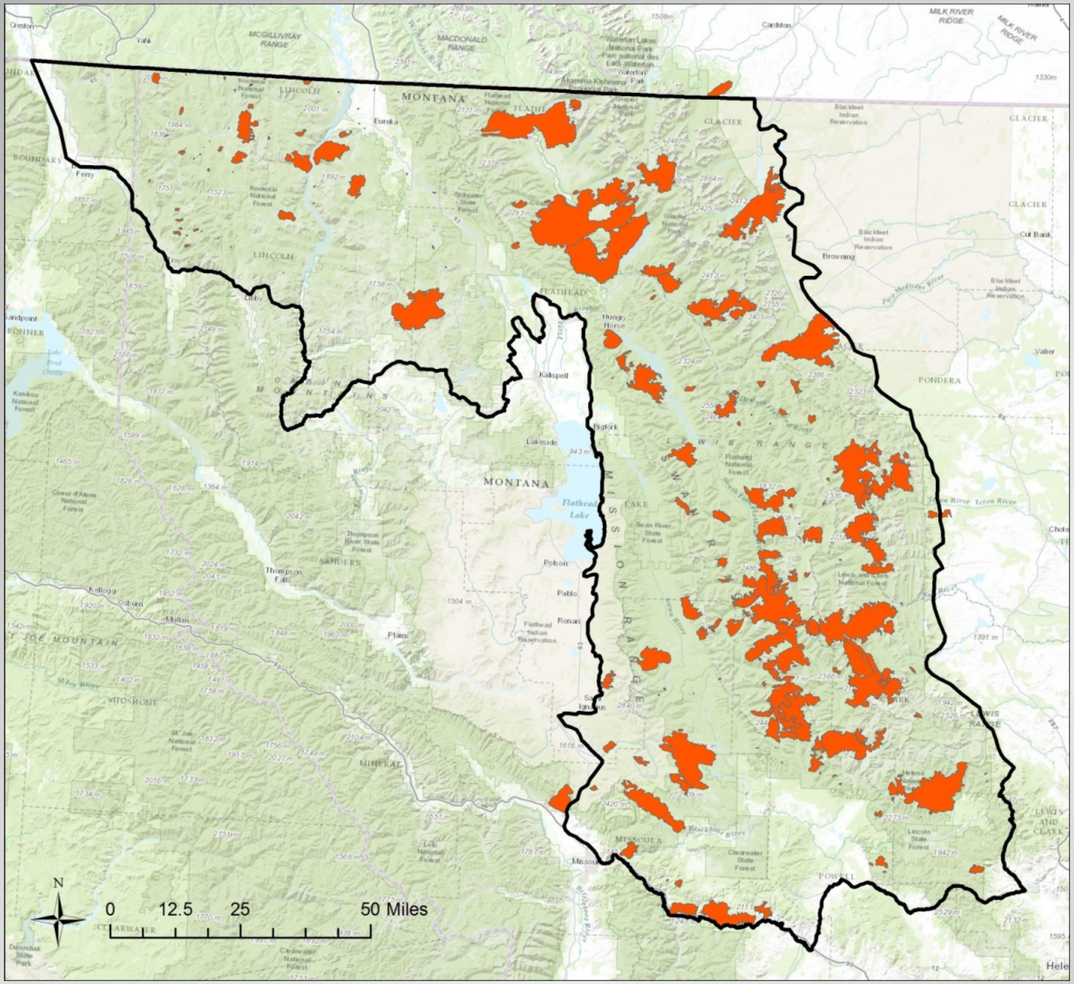
1990

143,123 acres



2000-2013

1,030,892 acres

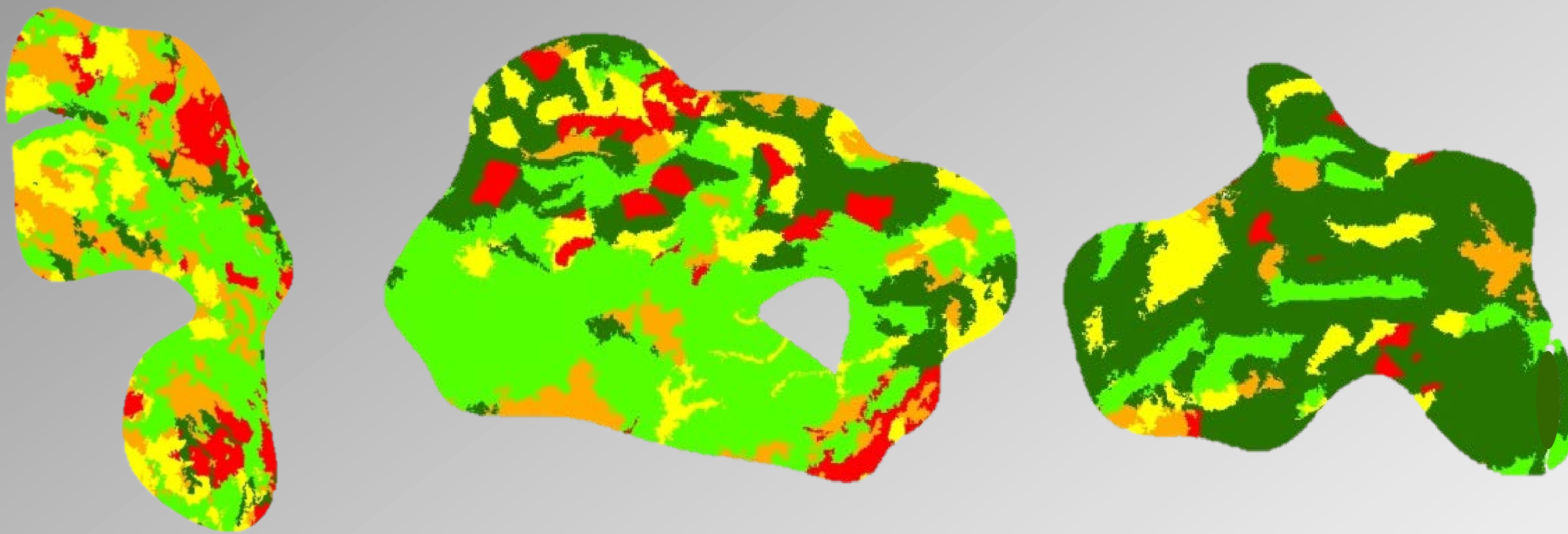


Risk factors - Montana

- Lynx exhibit both positive and negative effects from forest silviculture

- Habitat relationships vary dramatically across contiguous US populations

Index of Connectivity (IC) of **Mature Forest**



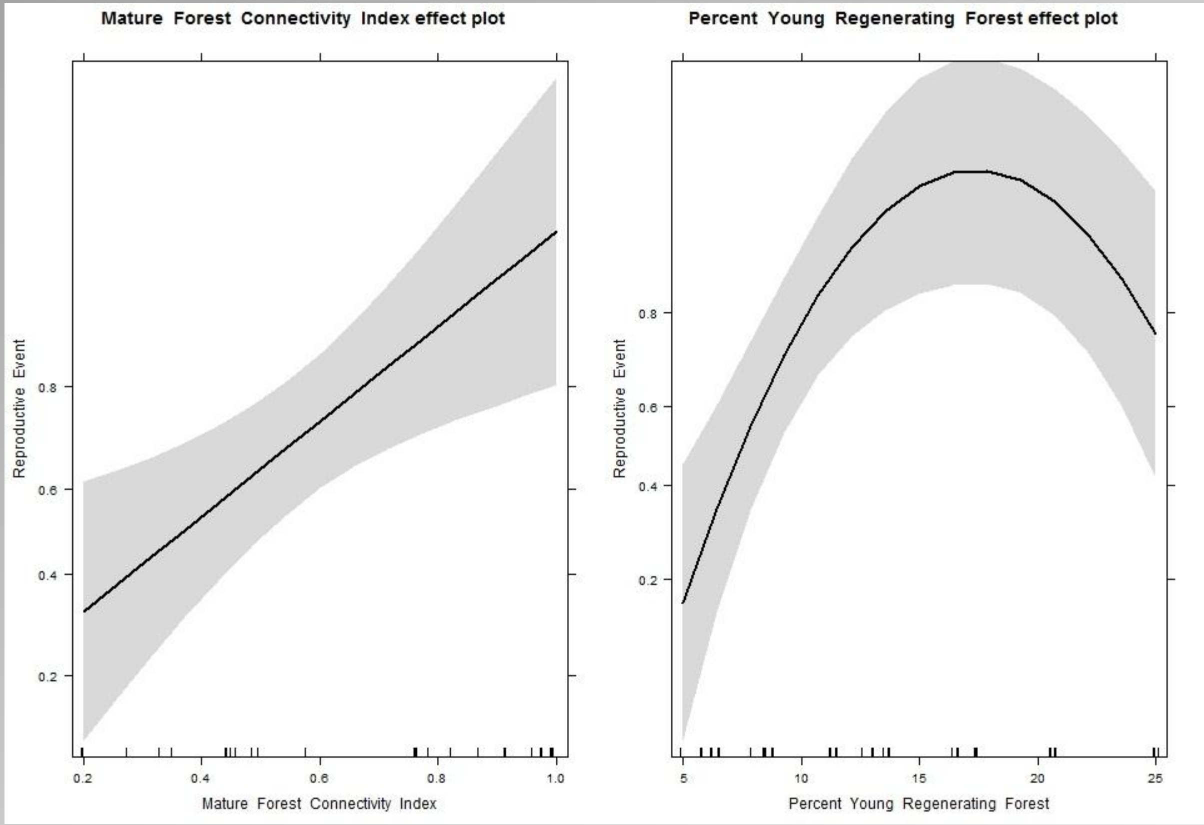
IC = 0.09 | **IC = 0.48** | **IC = 0.81**

0 ⟷ **1**

Legend

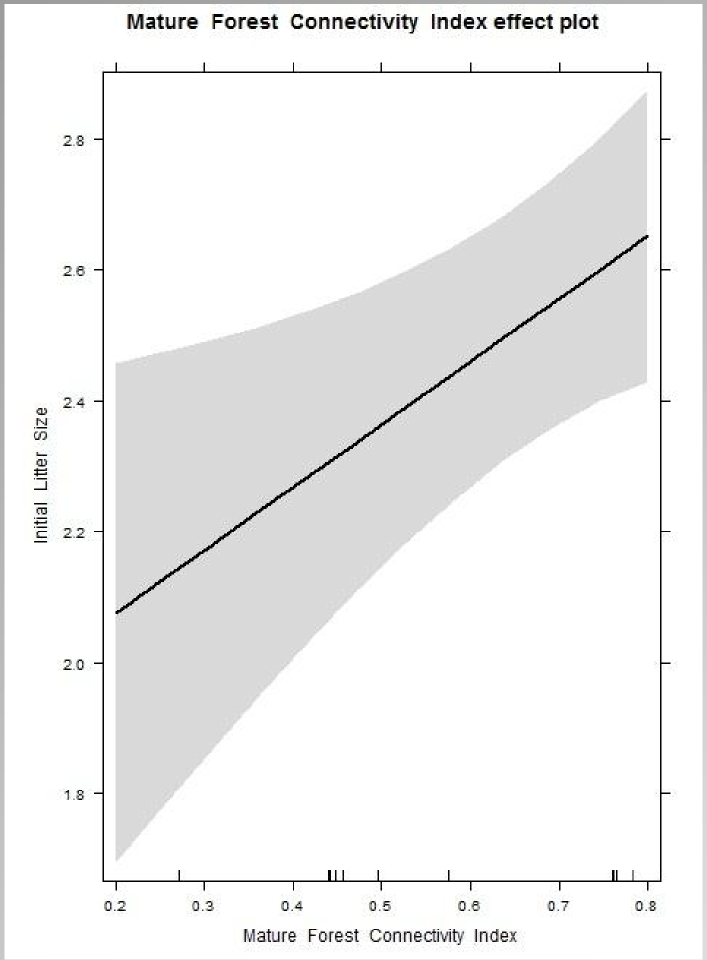
- = Open
- = Thin
- = Young Regenerating
- = Old Regenerating
- = Mature Forest

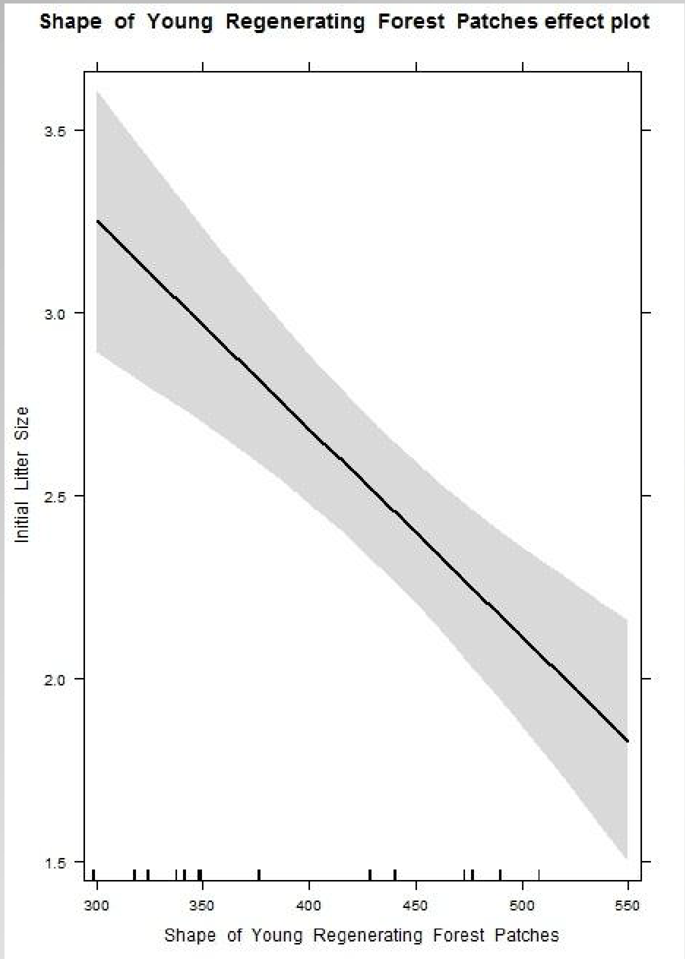
Produce a Litter (Kosterman 2014) ?



Top Multivariate Model	β	SE	95% CI	p-value
Connectivity mature forest	4.560	1.5345	1.552, 7.568	0.003
Percent young forest	1.019	0.2614	0.507, 1.532	≤0.001
Percent young forest^2	-0.029	0.0081	−0.045, −0.014	≤0.001

Initial Litter Size

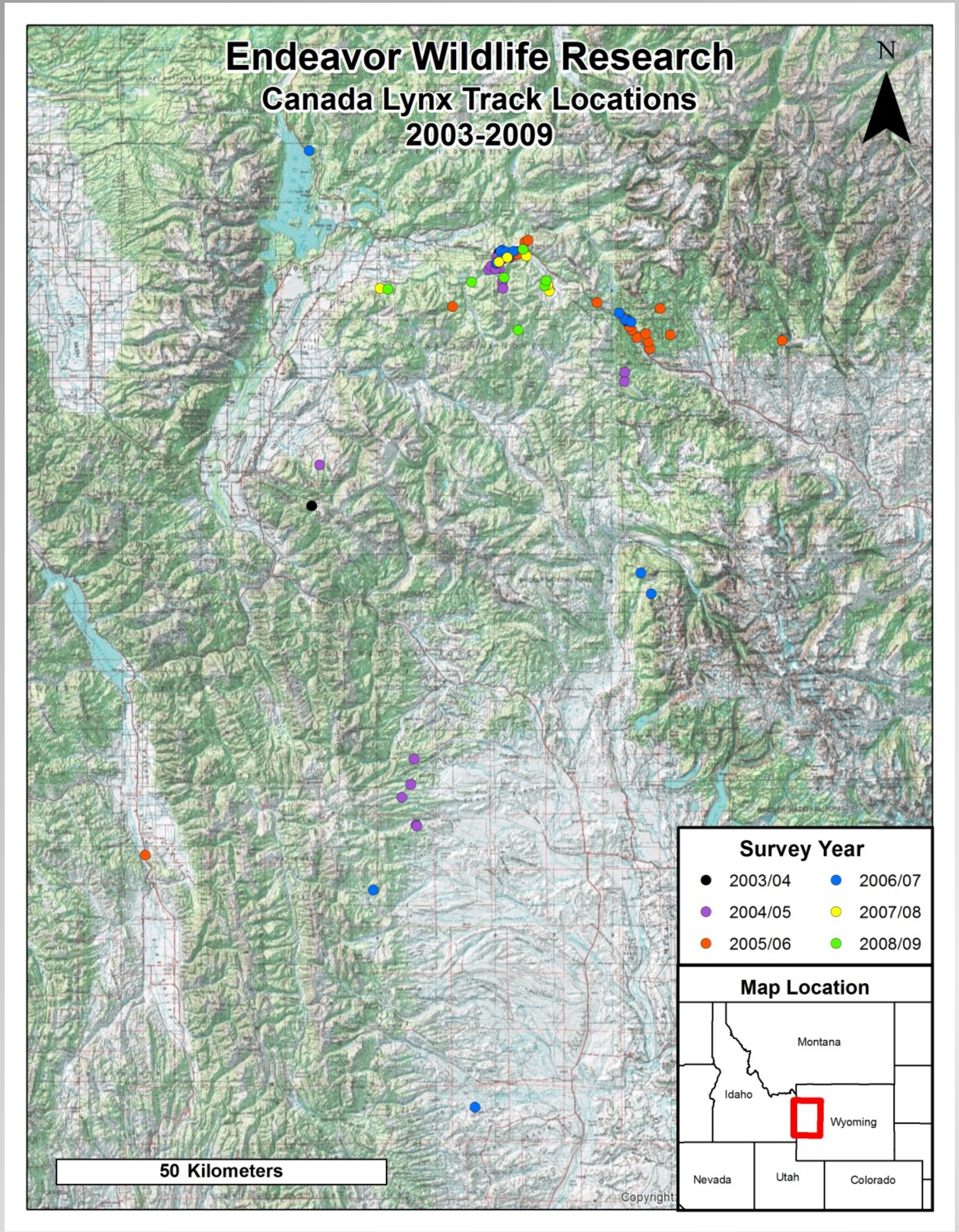




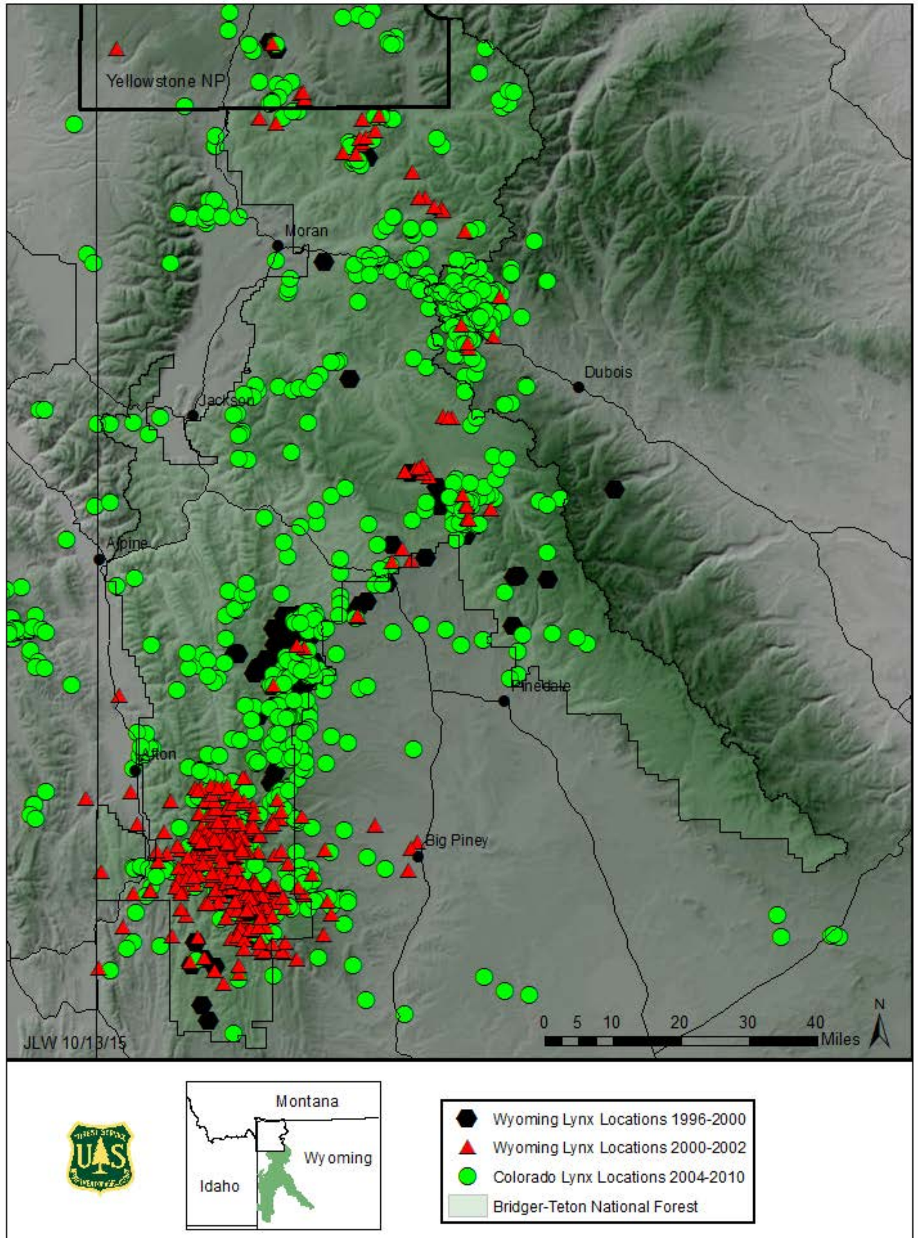
Top Multivariate Model:	β	SE	95% CI	p-value
Connectivity mature forest	0.959	0.3739	0.214, 1.705	0.013
Shape young forest	−0.006	0.0011	−0.008, −0.003	≤0.001

Status – Wyoming

- Documentation of lynx in GYA since early 1900’s
- Wyoming Range extending north to Togwotee Pass and east side of Yellowstone Lake former range


Endeavor Wildlife Research
Canada Lynx Track Locations
2003-2009
N
Survey Year
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
Map Location
Montana
Idaho
Wyoming
Nevada
Utah
Colorado
50 Kilometers

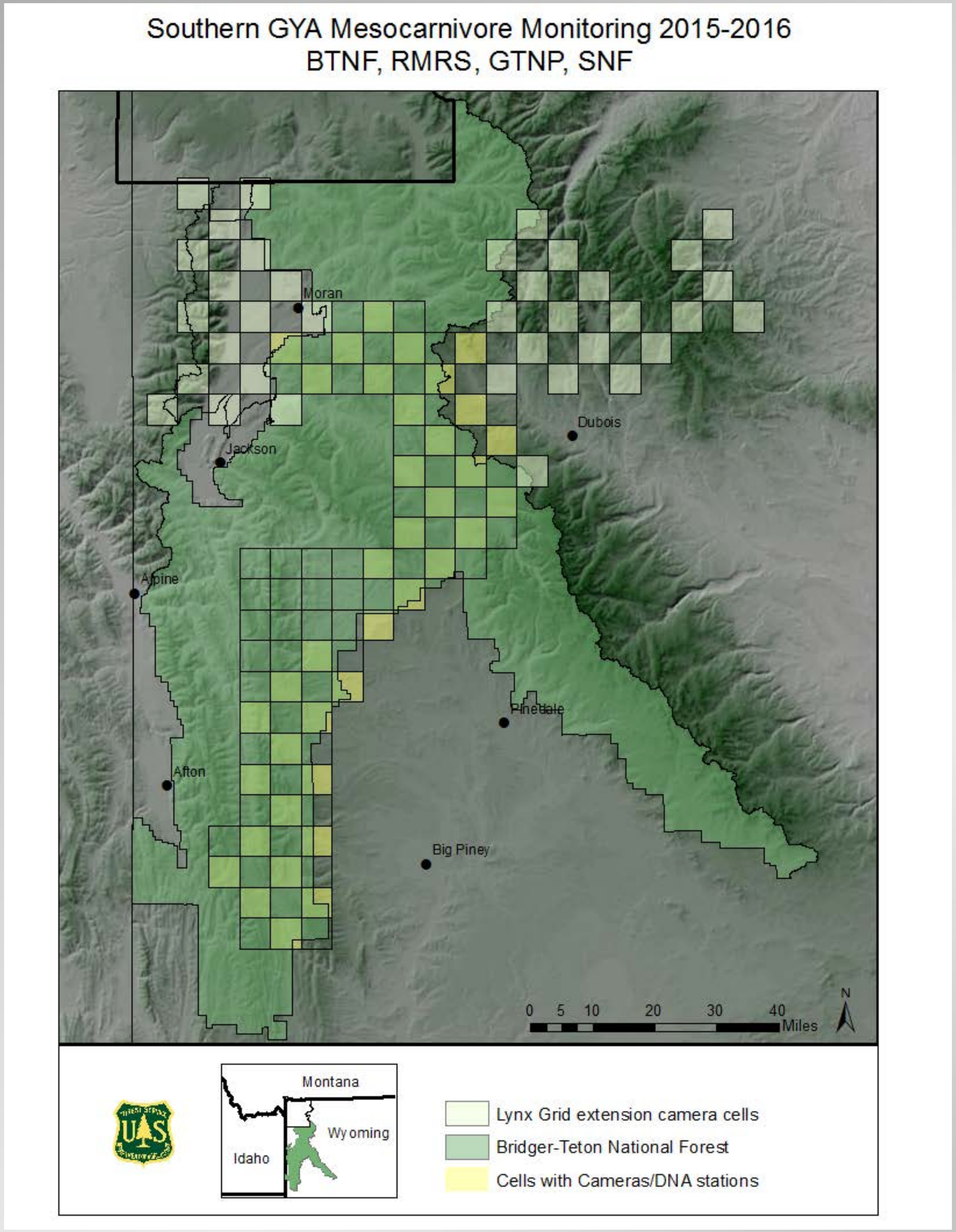
Southern GYA Mesocarnivore Monitoring 2015-2016
BTNF, RMRS, GTNP, SNF



Status – Wyoming

- 2010 surveys suggest the distribution of lynx in Wyoming contracted since 1997-2005
- RMRS, in cooperation with WGF, attempted to capture lynx but couldn't locate "natives" only 2 individuals from Colorado

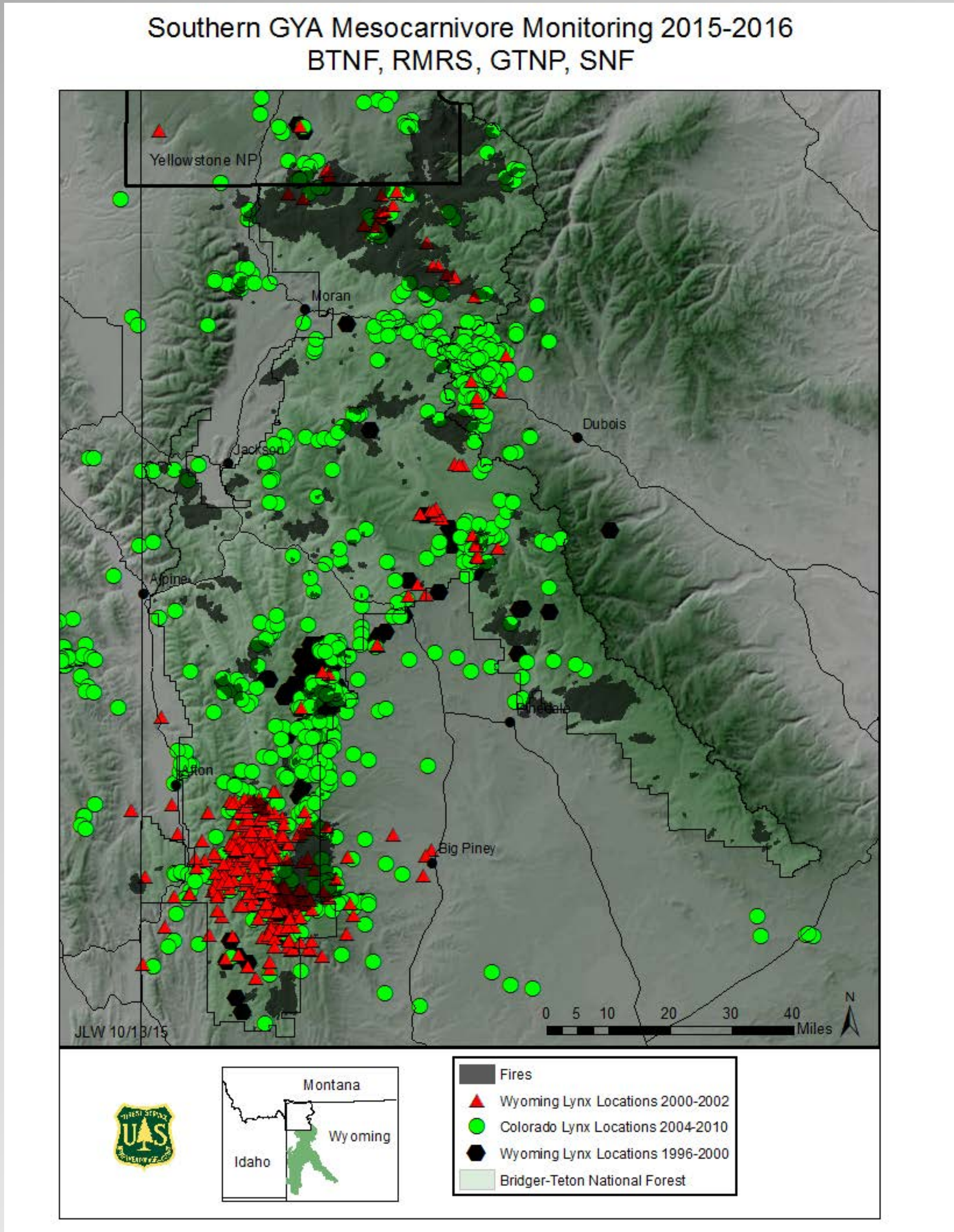
Status – Wyoming



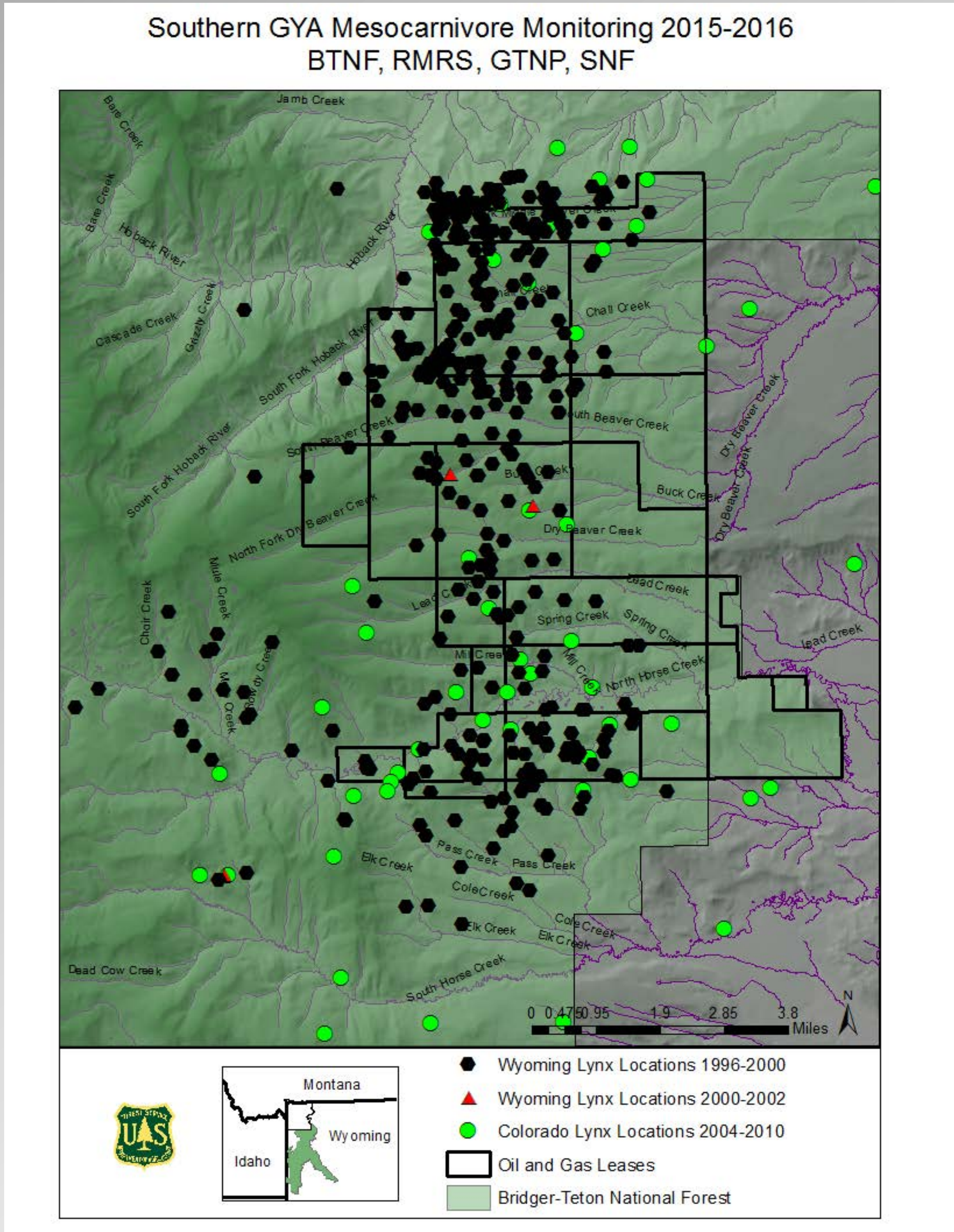
Risk factors – Wyoming

- Fire impacts to Wyoming Range
- Habitat fragmentation of Wyoming Range
- Oil / gas development of lynx habitat in Wyoming Range

Status – Wyoming



Status – Wyoming



Issues and Conclusions

- Lynx in Montana and Wyoming (may be throughout the continental US) persist as small populations consisting of relatively few individuals
- As such, have heightened risk to environmental and demographic factors

Issues and Conclusions

- Lynx distribution in Montana is similar to 2000, but with probably range contraction out of Garnet Range – cause of contraction unknown
- Small, relatively isolated populations may have persisted for long periods (duration unknown) based on records and genetic sub-structuring – long-lived individuals (average = 8.6 years, many females > 10ys)

Issues and Conclusions

- In Wyoming, lynx had a record of occupancy and distribution from 1997-2008 (??); documented since the turn of the century. Was the GYA a large enough “pool” for persistence?
- Limited data suggest that distribution in Wyoming contracted or the population failed in approximately 2010

Issues and Conclusions

- Vital rates do not suggest cyclicity

  How to rectify “waves,” observed vital rates, and fine-scale genetic substructuring?

Issues and Conclusions

- Increased fire intensity, frequency, and spatial extent in northern montane forests is a “the” primary risk factor to lynx habitat in Montana and Wyoming
- Humility is warranted when discounting “small” populations when challenged by environmental change

Current Research

- Remap of lynx habitat in Montana based on a revised RSF based on new forest composition surface from remote sensing and other environmental covariates.
- Determining the trajectory of lynx habitat in Montana relative to fire and forest management – MSU collaboration
- Formally evaluating how lynx respond to silvicultural treatment by a retrospective analysis - management of patch-level mosaics

Current Research

- Evaluating how lynx and hares respond to fire across a continuum of fire age and post-fire silvicultural treatment
- RMRS, in cooperation with the Bridger-Teton National Forest and the National Carnivore program, is conducting a formalized survey of lynx in the GYA incorporating sight-mark recapture via cameras and winter backtracking. Genetics collected using 3 methods – on backtracks, snags on baited trees (at camera stations), and snow-level rub pads.

Thank you

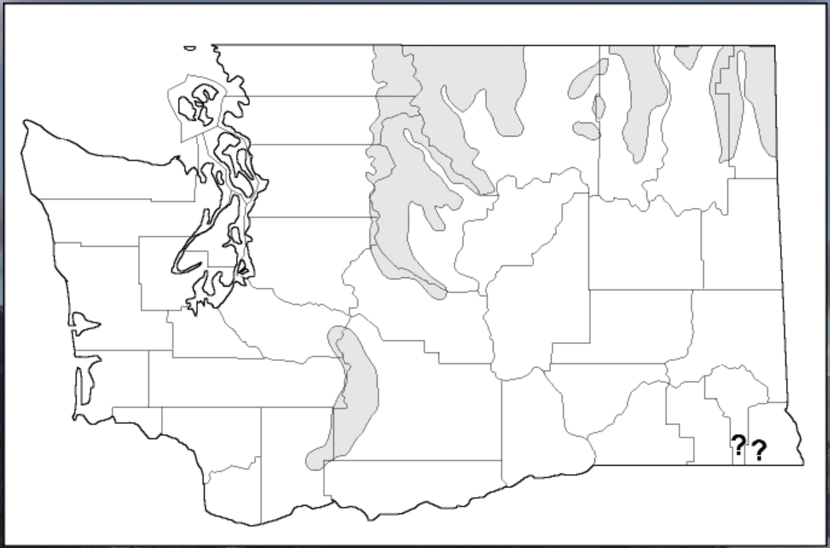
Lynx in Washington

Current Status and Potential Threats

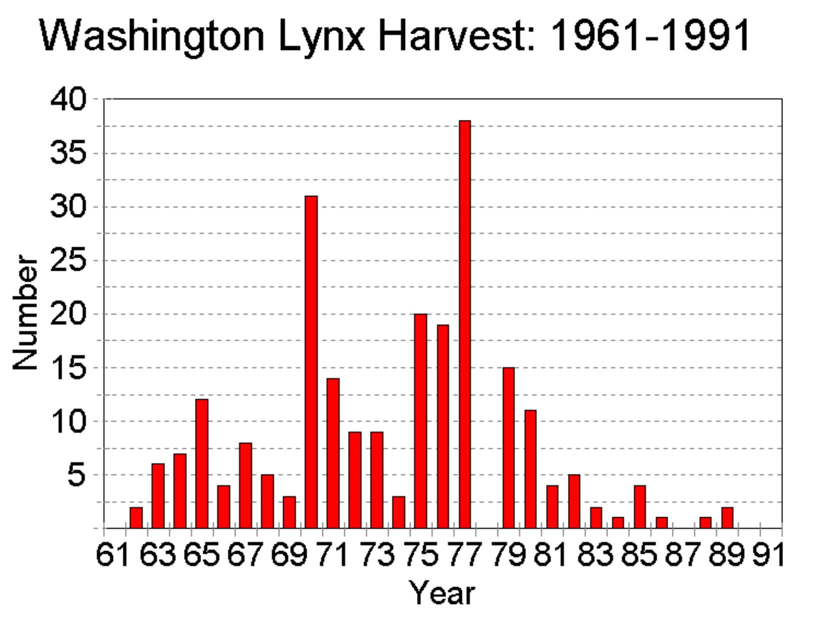
Benjamin Maletzke | Carnivore Biologist

Washington Department of FISH and WILDLIFE

Historical Records of Lynx in Washington

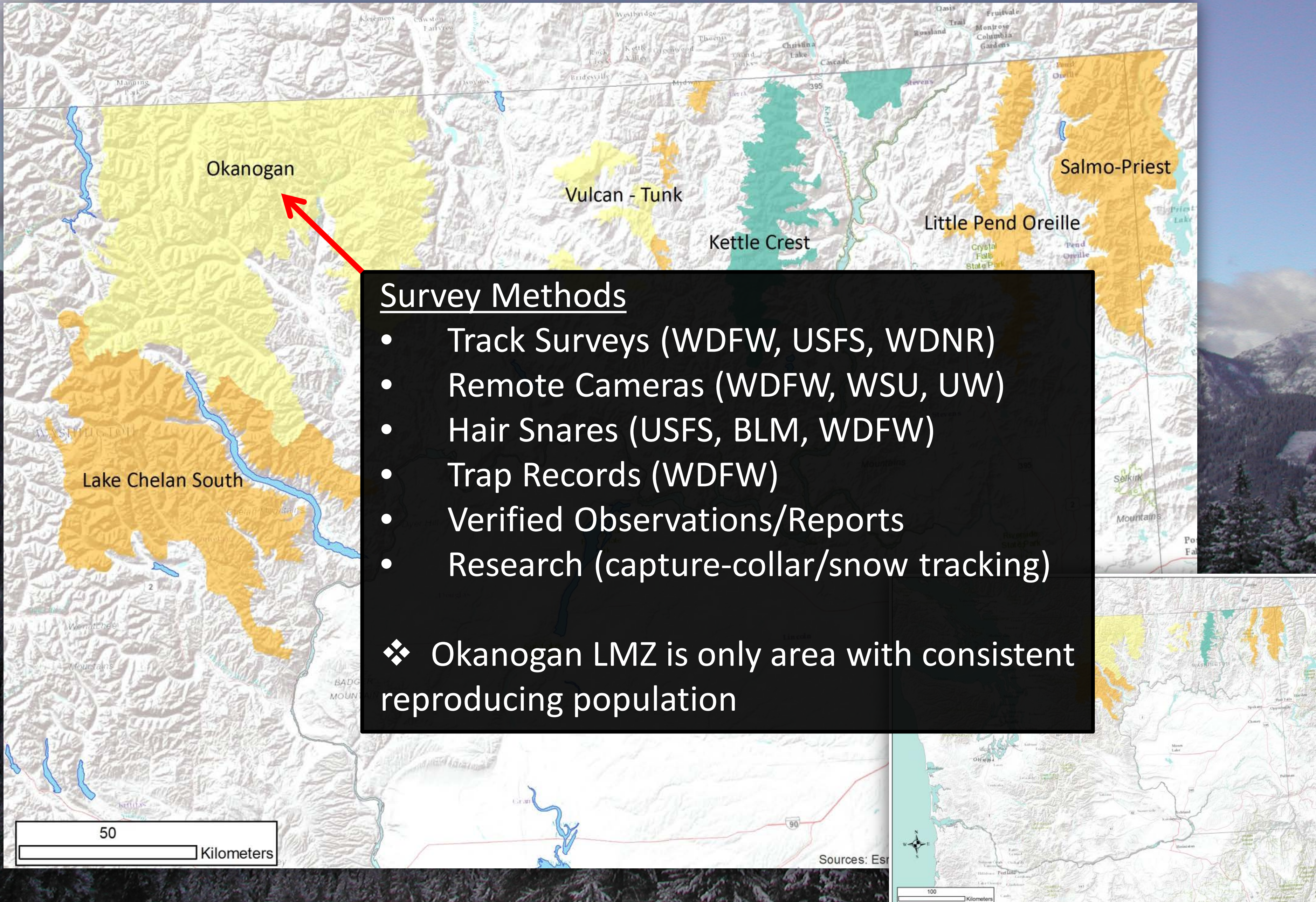


- State Listed as Threatened in 1993
- Recovery Plan 2001
- No take or harassment
- Management Plan



Stinson, D. W. 2001. Washington state recovery plan for the lynx. Washington Department of Fish and Wildlife, Olympia, Washington.

Lynx Surveys and Detections

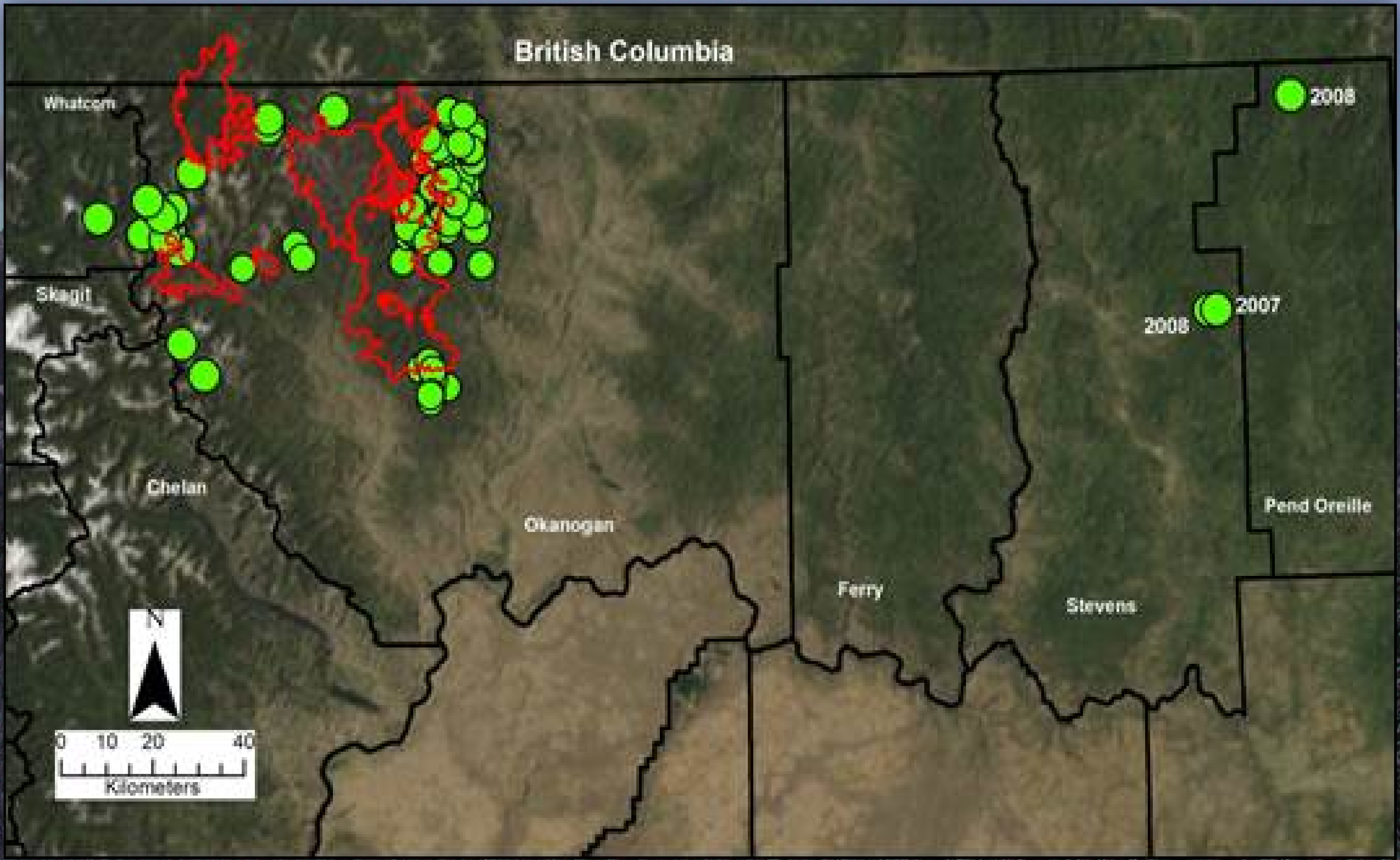


Survey Methods

- Track Surveys (WDFW, USFS, WDNR)
- Remote Cameras (WDFW, WSU, UW)
- Hair Snares (USFS, BLM, WDFW)
- Trap Records (WDFW)
- Verified Observations/Reports
- Research (capture-collar/snow tracking)

❖ Okanogan LMZ is only area with consistent reproducing population

Lynx Detections from 2005 – 2015



Research

Lynx:

- Habitat, Home range, Density (Koehler and Brittell 1990)
- Fine Scale Habitat Selection (Von Kienast 2003)
- Statewide Habitat Model (Maletzke 2004)
- Track surveys: 1987-present (USFS, WDFW, WDNR)
- Habitat Connectivity (Vanbianchi and Hodges 2015)
- Range and Density (Scully and Thornton ongoing)

Snowshoe hares:

- Habitat and Density (Koehler 1990)
- Habitat Matrix and Density (Lewis et al 2005, 2011)

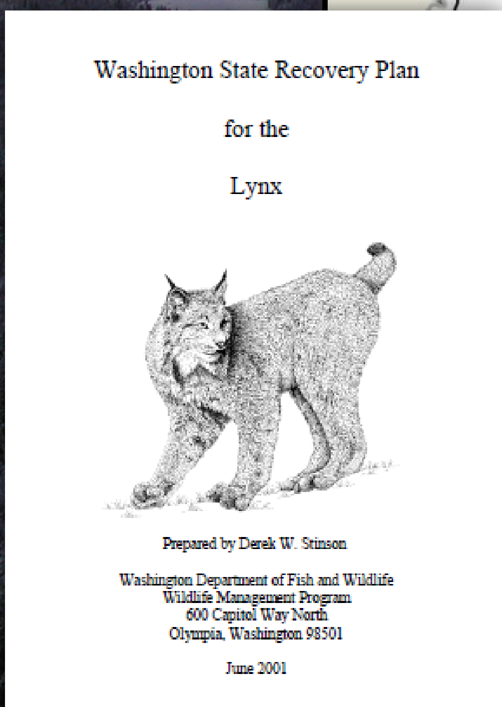
The USFWS's 5-factors for determining the need to list:

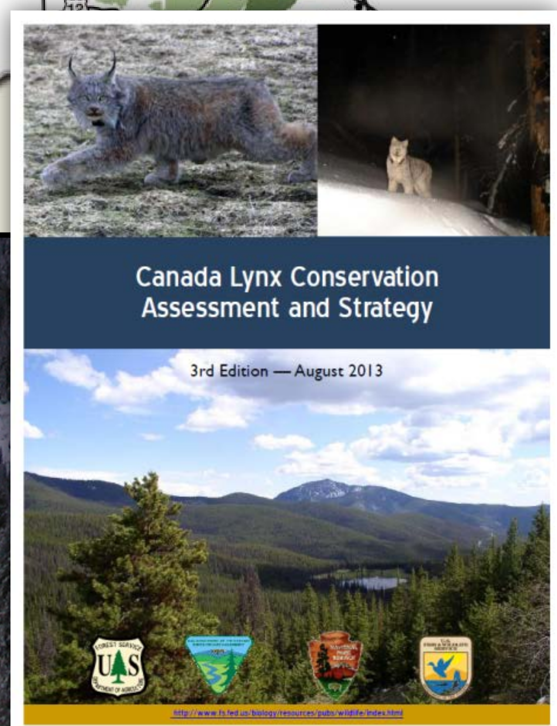
Listing a Species Requirement for USFWS

a. Present or threatened destruction of habitat or range
b. Over-utilization
c. Disease or predation
d. Inadequacy of existing regulations
e. Other natural or manmade factors affecting continued existence

Inadequacy of existing regulations?

Designated as Critical Habitat by USFWS





Disease or Predation?

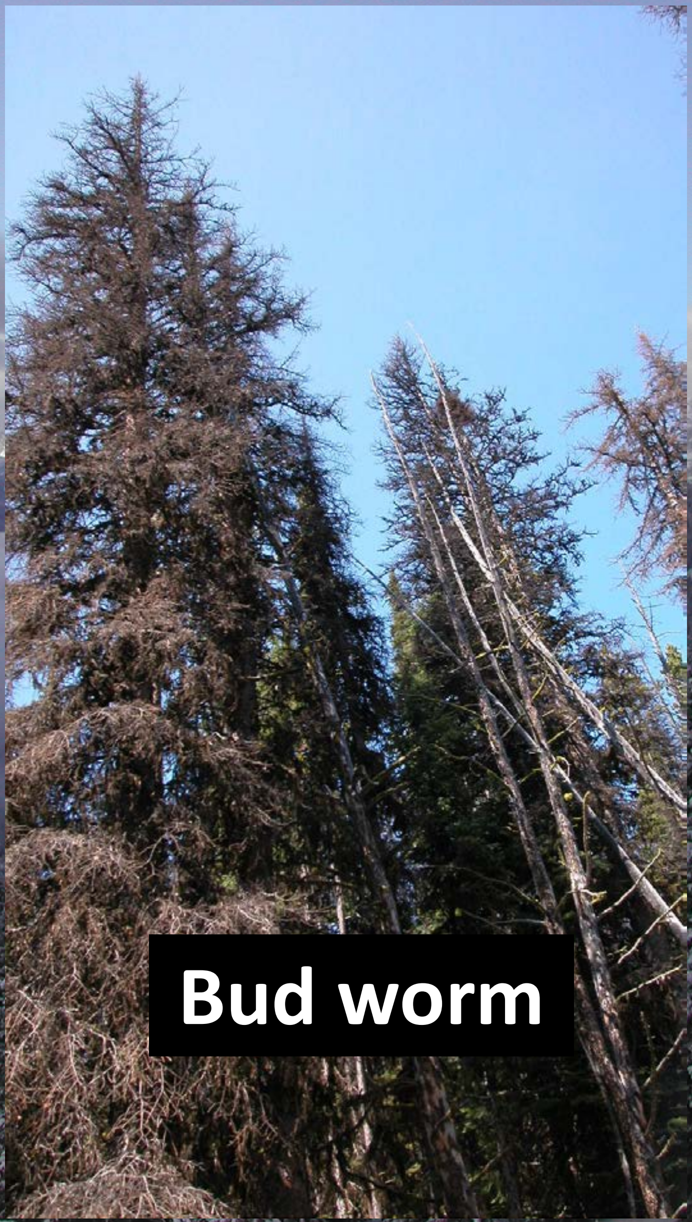
Disease?

- No documented cases in WA

Predation?

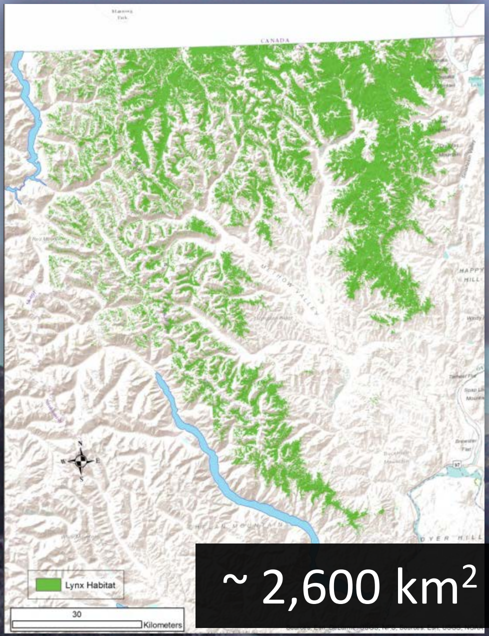
- 1 collared female killed by a cougar
- Warmer drier winters (Climate Change)
    - Decreased snow pack and persistence
    - Snow conditions (freeze/thaw events = crust)

Present or threatened destruction of habitat or range

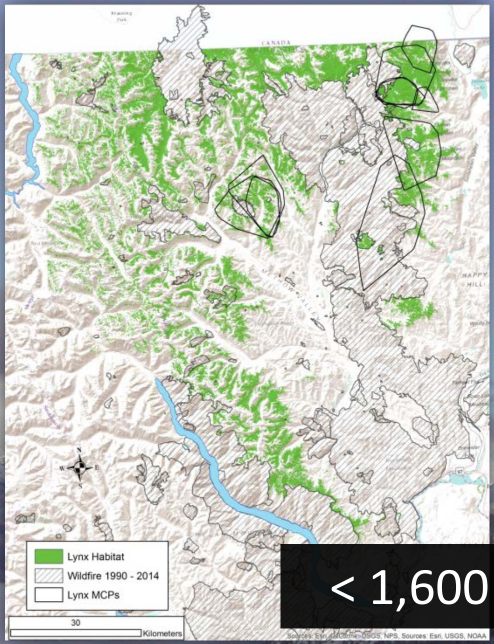



>1,000 km^2 burned
1994-present

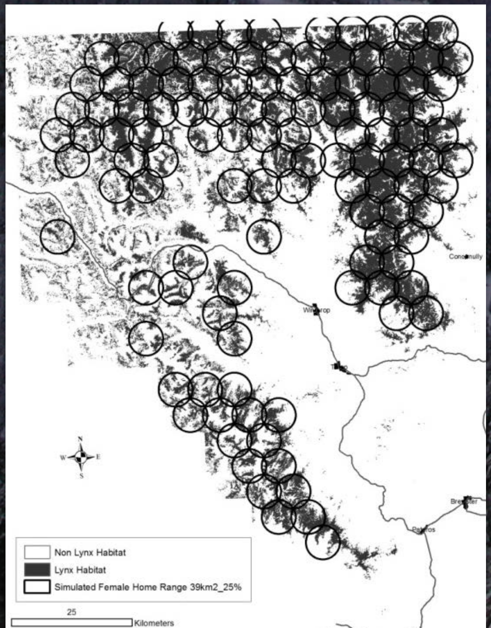
Present or threatened destruction of habitat or range

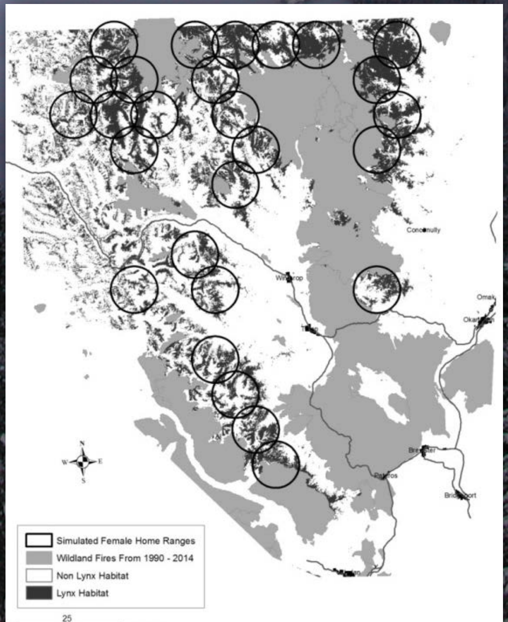


~ 2,600 km^2 in 1990 – 2002



< 1,600 km^2 in 2014



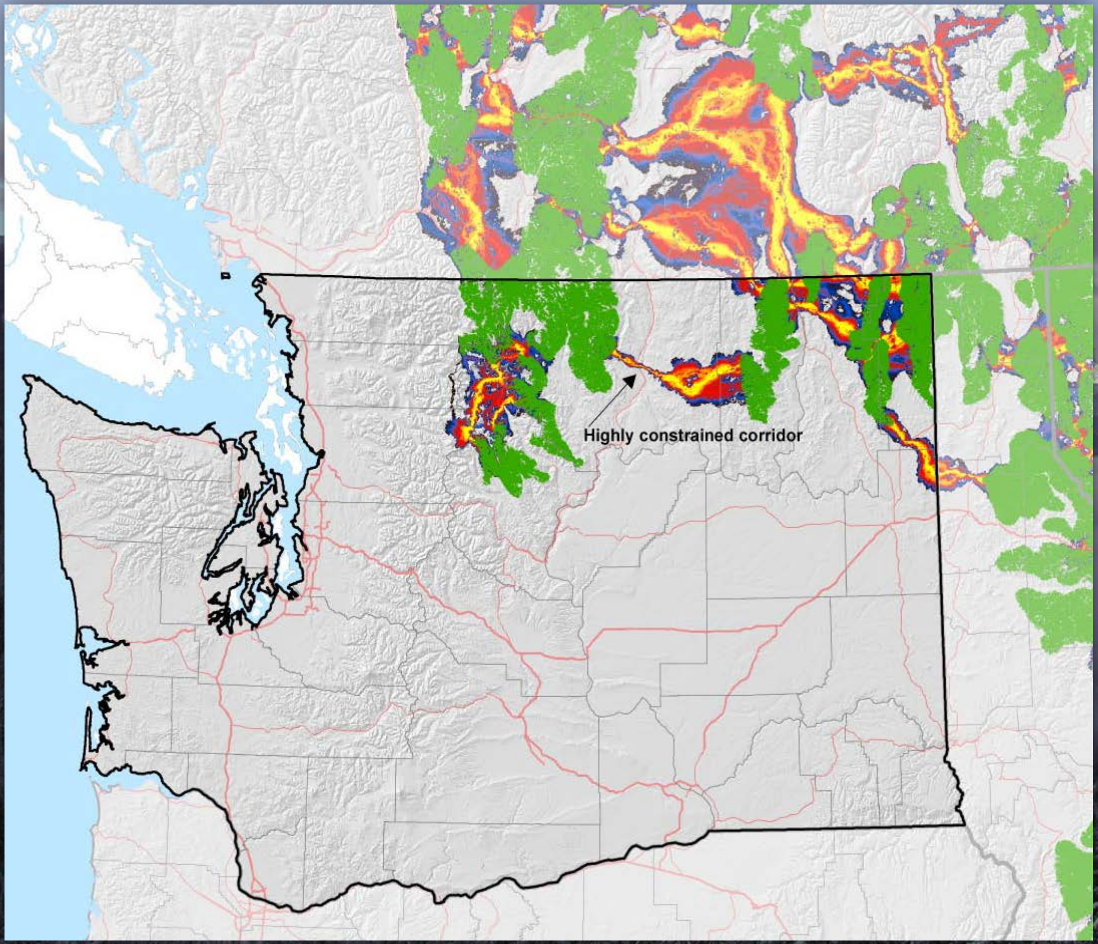


Natural or manmade factors affecting continued existence

Climate Change

- Snow persistence (Spatial and Temporal)
- Snow depth and condition
- Interspecific Competition
- Changes in Vegetation Cover
  - Temperature and precipitation driven
  - Fire Frequency, Intensity, and Size
- Prey Density
- Reduction and Isolation of suitable habitat

Natural or manmade factors affecting continued existence



Habitat Connectivity

Okanogan ~ currently okay

- Fire?
- Timber harvest?
- Trapping in BC?

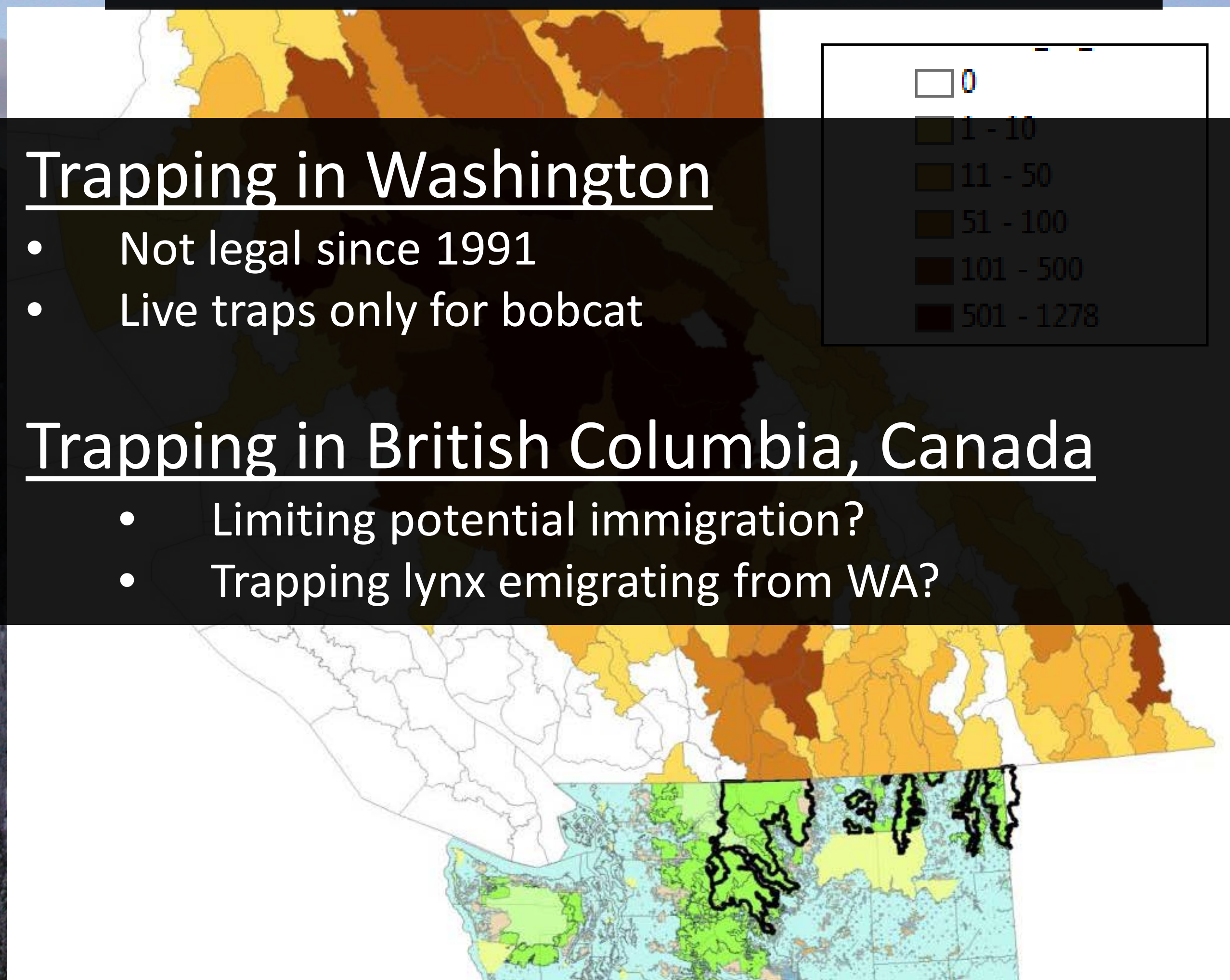
Kettle Crest

- Shrub-steppe?
- Highway/Fence?
- Kettle River?
- Habitat in BC

Washington Wildlife Habitat Connectivity Working Group (WHCWG). 2010. Washington Connected Landscapes Project: Statewide Analysis. Washington Departments of Fish and Wildlife, and Transportation, Olympia, WA

Natural or manmade factors affecting continued existence

BC lynx harvest by management unit, 1985-2011



Trapping in Washington

- Not legal since 1991
- Live traps only for bobcat

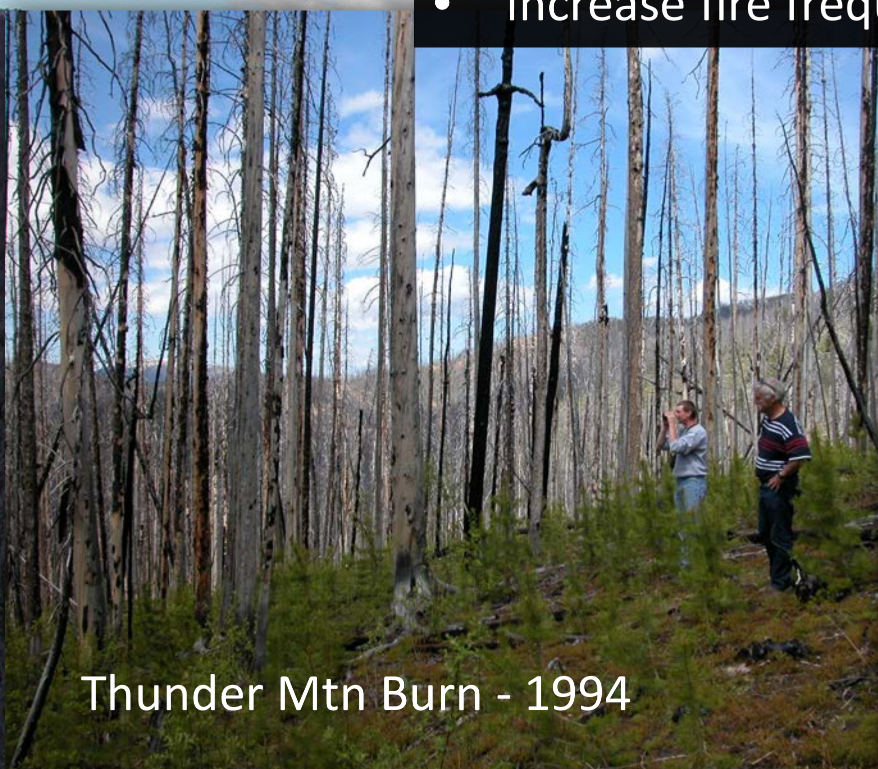
Trapping in British Columbia, Canada

- Limiting potential immigration?
- Trapping lynx emigrating from WA?

Present or threatened destruction of habitat or range

Regeneration after Wildfire

- 30% after 20 years
- > 35 – 40 years for lynx
- Vegetation shift (Climate change)?
- Increase fire frequency and severity?



Thunder Mtn Burn - 1994

Potential Management and Recovery Actions:

1. Resume periodic surveys and monitoring with partners/collaborators

2. Revisit/review current management practices (WDNR, USFS, USFWS, Colville Tribe, others) to see if we can make them more friendly toward lynx

3. Probability of population persistence (Population Viability Analysis over 10, 25, and 50 years…)

4. Cooperation and collaboration with BC ~ (adapt to be sensitive to the concerns in Washington)

5. Evaluate the need and feasibility of augmenting female lynx in Okanogan LMZ?

6. Evaluate the need and feasibility of reintroducing lynx to the Kettle Crest?

7. Up listing lynx in WA to indicate the current status and severity of threats

8. Seeking partner collaboration and additional funding to support the actions listed above


Questions?

Current Surveys and Distribution

Lynx Management Zone	Surveys Conducted	Detections
Salmo Priest	• Track Surveys	Occas. single tracks
Little Pend Oreille	• 20 remote cameras baited w/roadkill deer • Track Surveys	No Detections Occas. single tracks
Kettle Crest	• 60 remote cameras • Track Surveys • Hair Snag Grid • Trap Records	No Detections Occas. single tracks No Detections Last records ~ 1970's
Vulcan – Tunk	• 16 Remote cameras • Track Surveys	No Detections No Detections
Lake Chelan South	• Track Surveys	No Detections
Okanogan	• Capture/Collar Effort • Track Surveys • 300+ Remote Cameras • Trap Records • Pasaytan Wilderness Camera	Reproduction verified Reproduction verified Reproduction verified Records through 1991 15 – 25% detection rate

Status of Lynx in Colorado

Jake Ivan, Colorado Parks & Wildlife

Historical Occurrence

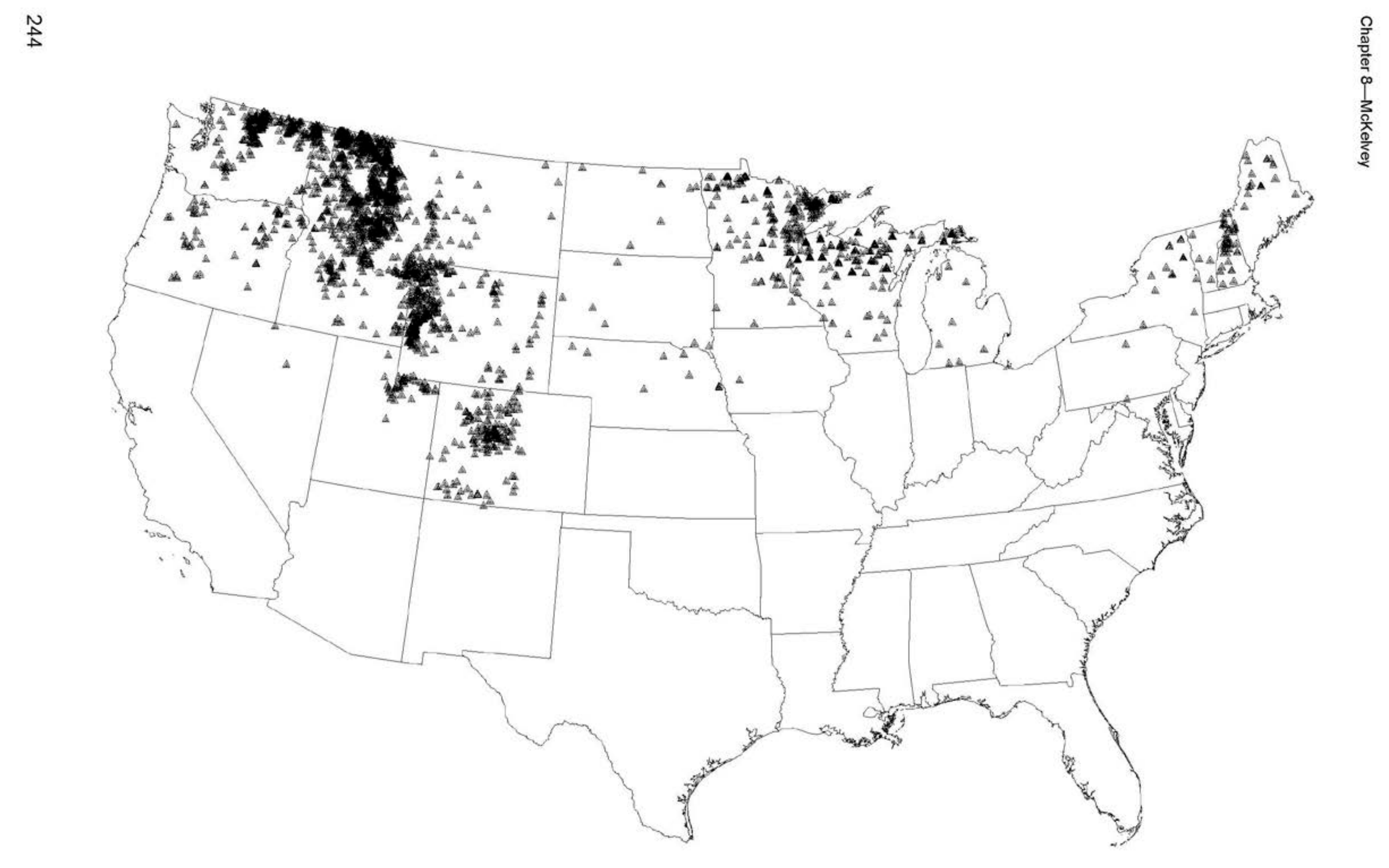


Figure 8.17—Spatial distribution of lynx occurrence data from 1842 to 1998 (Table 8.1).

McKelvey, K. S., K. B. Aubry, and Y. Ortega. 2000. History and distribution of lynx in the contiguous United States *in* Ecology and Conservation of Lynx. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Status in 1999

- 1973 - State Endangered (due largely to widespread predator control).
- 1974 - Last known lynx trapped in Colorado.
- 1978 – 1997 Statewide surveys (11) conducted to document presence in the state.
  - Some possible sign.
  - If present, only a handful of individuals – too few for a viable population.

Lynx Reintroduction (1999)

- Why?
  - Direction from Mission and Strategic Plan:

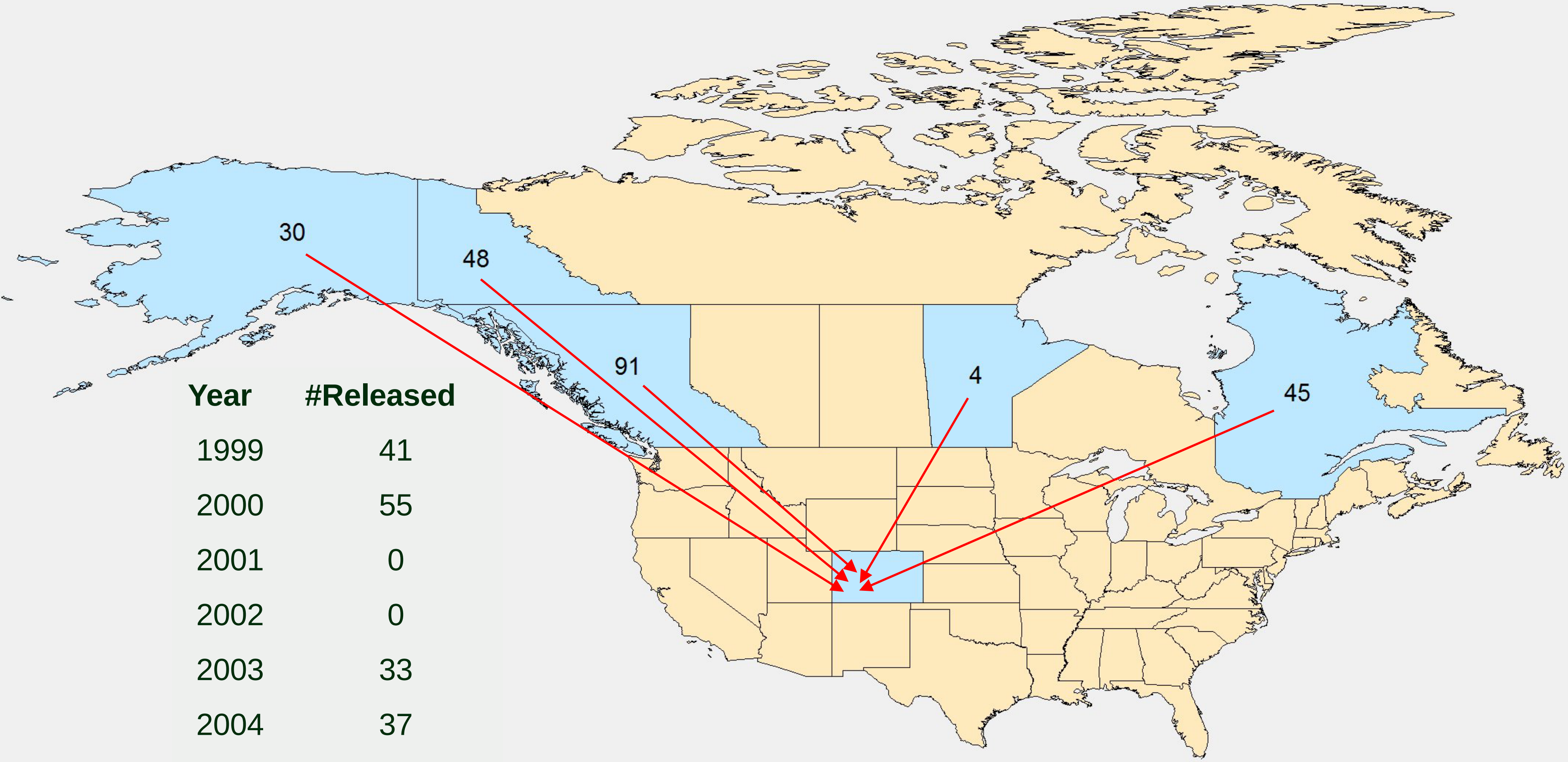
    "Ensure the long-term viability of native fish and wildlife and maintain the diversity of native wildlife across the state."
  - Threats that likely caused their demise (predator control) no longer an issue.
  - Natural re-colonization not likely due to geographic isolation.

Lynx Reintroduction

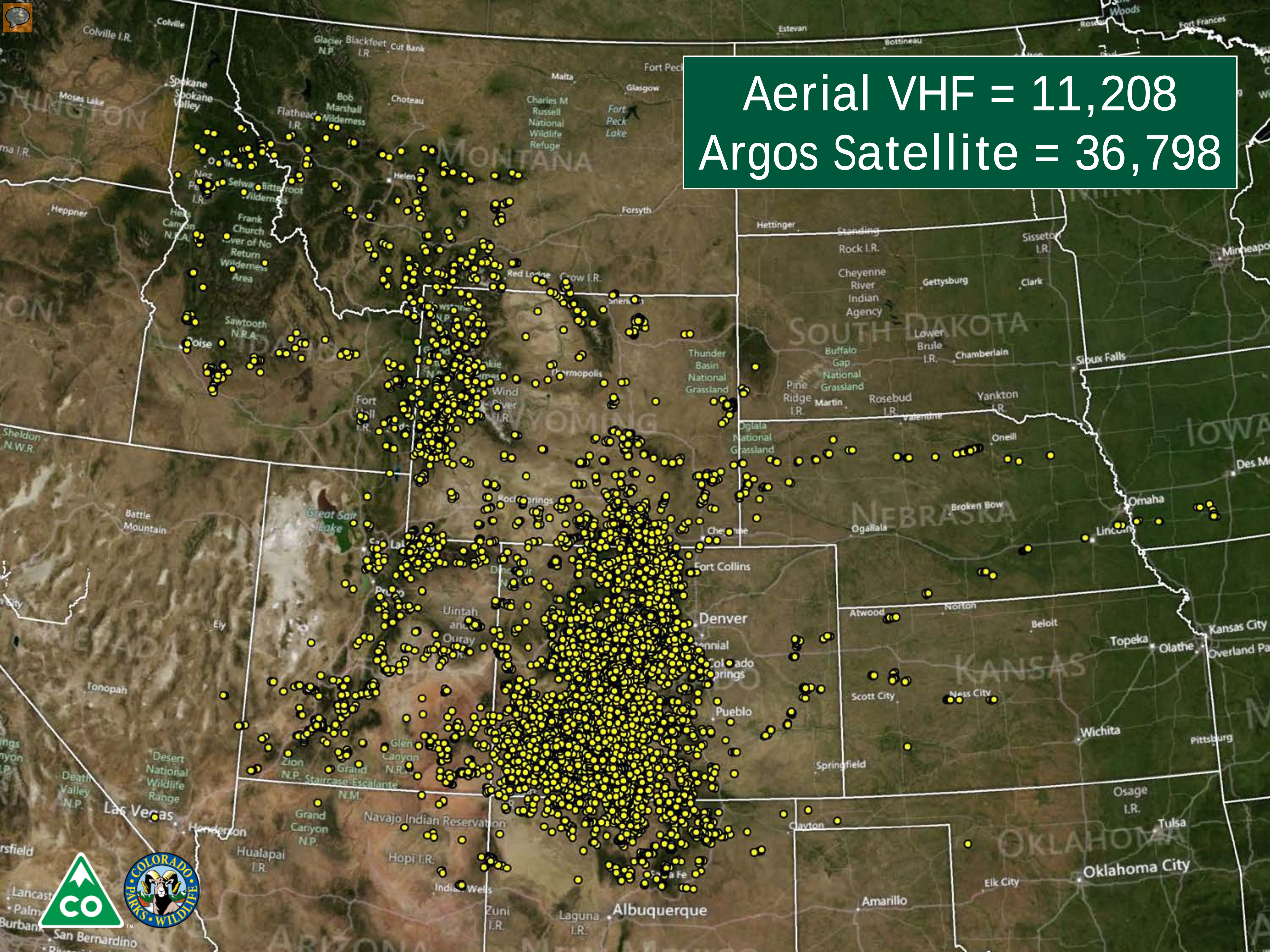
Primary Goal:

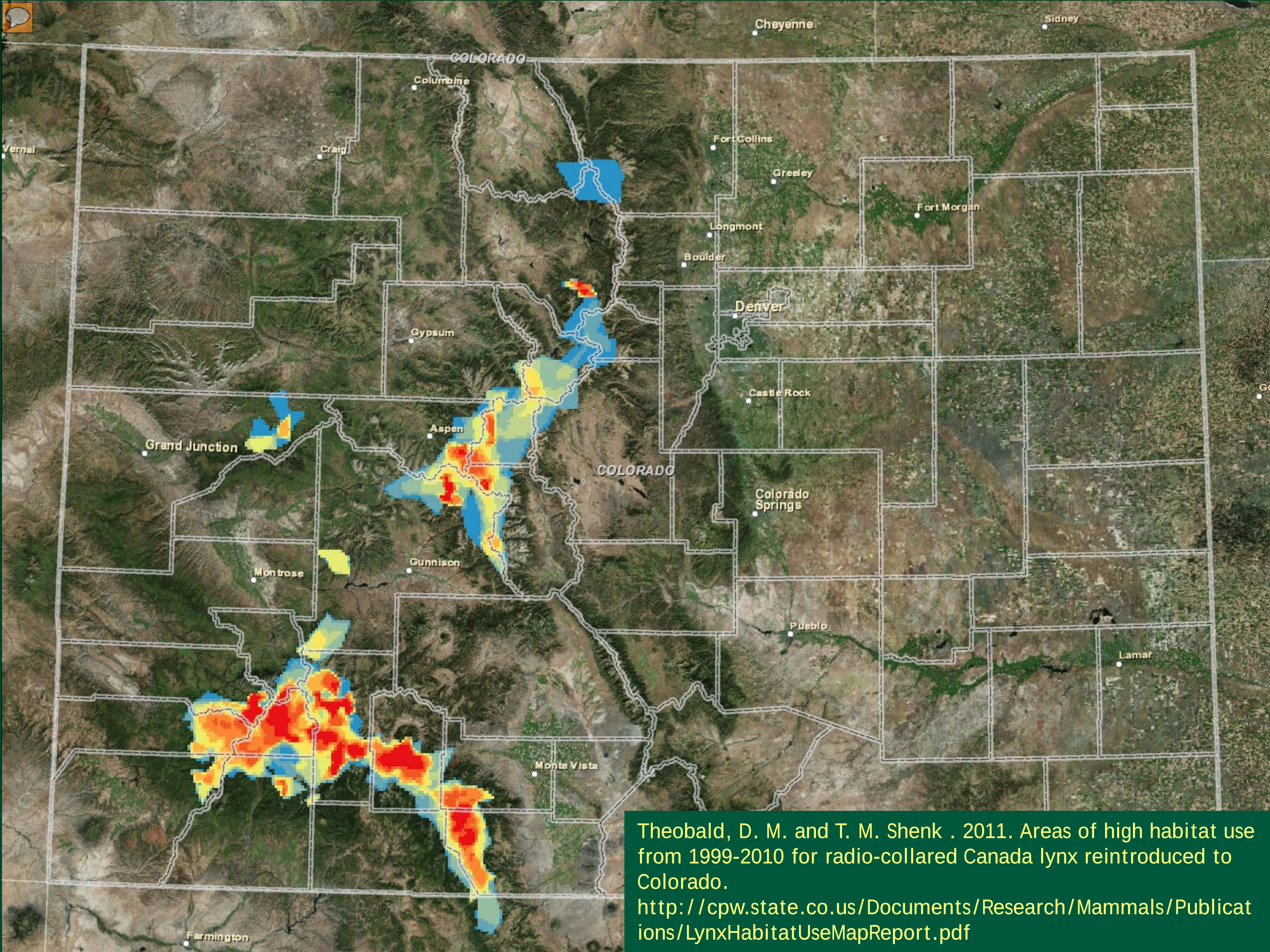
Establish a self-sustaining, viable population of lynx in the state.

Colorado Lynx Reintroduction



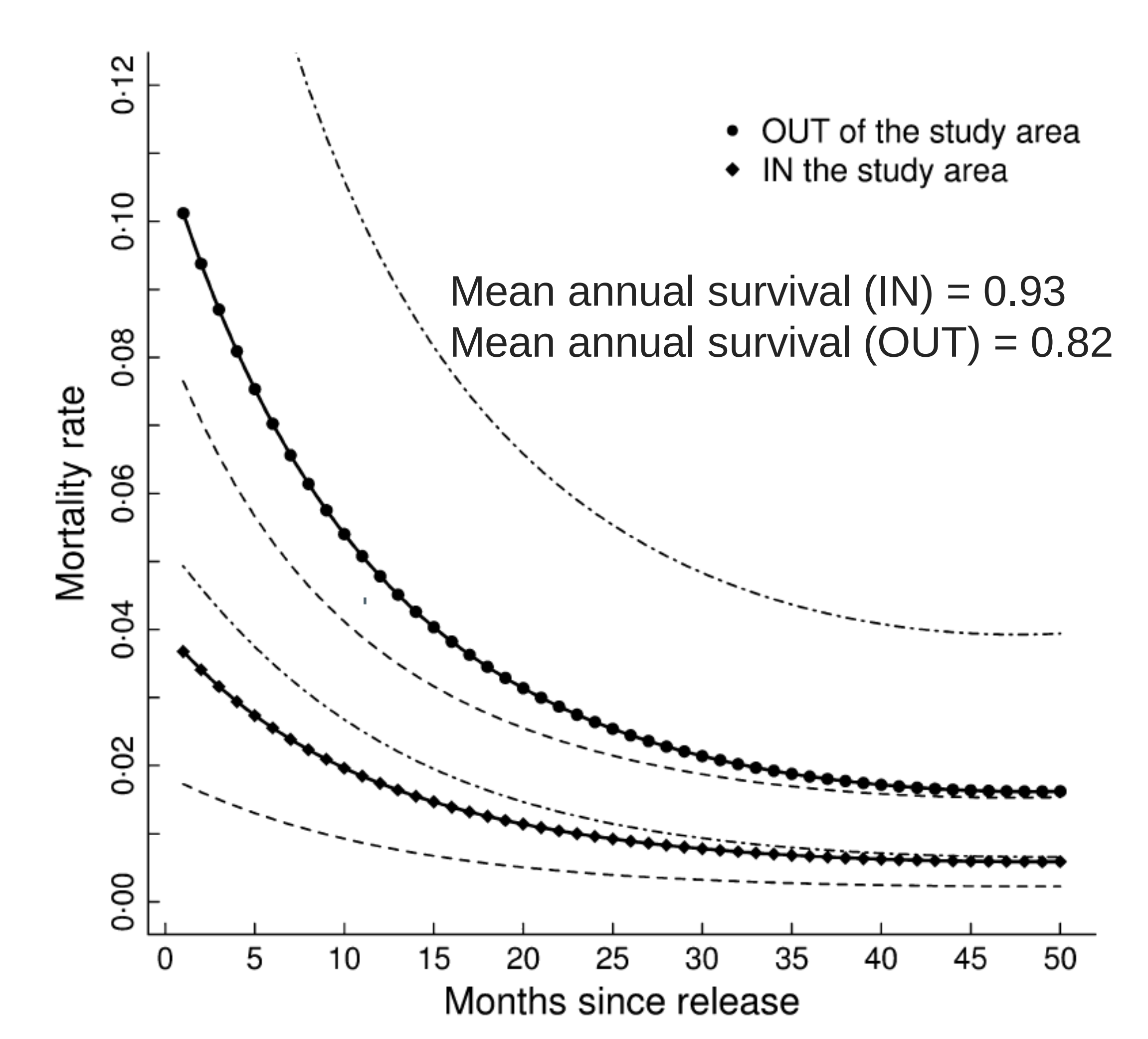
Year	#Released
1999	41
2000	55
2001	0
2002	0
2003	33
2004	37
2005	38
2006	14
Total	**218**


Aerial VHF = 11,208
Argos Satellite = 36,798
MONTANA
WYOMING
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
IOWA
Great Salt Lake
Spokane
Boise
Helena
Red Lodge
Thermopolis
Rock Springs
Cheyenne
Fort Collins
Denver
Colorado Springs
Pueblo
Santa Fe
Albuquerque
Las Vegas
Henderson
Omaha
Lincoln
Des Moines
Kansas City
Topeka
Olathe
Overland Park
Wichita
Tulsa
Oklahoma City
Amarillo
Ogallala
Broken Bow
Scott City
Ness City
Springfield
Clayton
Elk City
Sioux Falls
Yankton
Chamberlain
Gettysburg
Hettinger
Forsyth
Glasgow
Malta
Choteau
Cut Bank
Estevan
Bottineau
Fort Peck Lake
Moses Lake
Heppner
Battle Mountain
Tonopah
Ely
Uintah and Ouray I.R.
Zion N.P.
Glen Canyon N.R.A.
Grand Canyon N.P.
Navajo Indian Reservation
Hopi I.R.
Hualapai I.R.
Zuni I.R.
Laguna I.R.
Death Valley N.P.
Desert National Wildlife Range
Thunder Basin National Grassland
Oglala National Grassland
Buffalo Gap National Grassland
Pine Ridge I.R.
Rosebud I.R.
Cheyenne River Indian Agency
Standing Rock I.R.
Charles M Russell National Wildlife Refuge
Bob Marshall Wilderness
Frank Church River of No Return Wilderness Area
Sawtooth N.R.A.
Wind River I.R.
Crow I.R.
Fort Hall I.R.
Atwood
Norton
Beloit
Osage I.R.
San Bernardino
COLORADO PARKS & WILDLIFE
CO



Theobald, D. M. and T. M. Shenk . 2011. Areas of high habitat use from 1999-2010 for radio-collared Canada lynx reintroduced to Colorado.
http://cpw.state.co.us/Documents/Research/Mammals/Publications/LynxHabitatUseMapReport.pdf

Survival

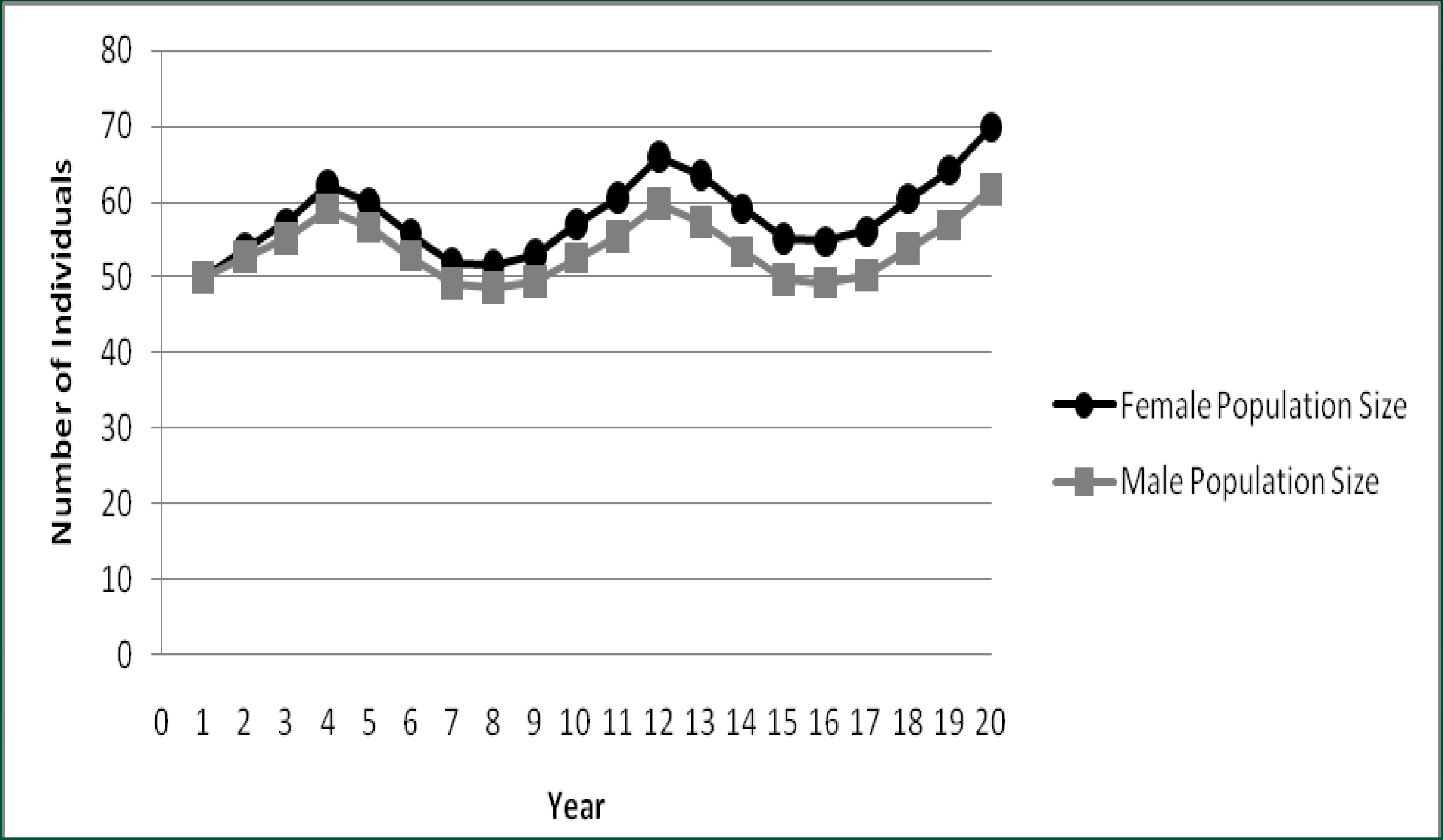


Devineau, O. T. M. Shenk, G. C. White, Doherty, P.F., Lucas, P. M., and R. H. Kahn. 2010. Journal of Applied Ecology 47:524-531.

Reproduction

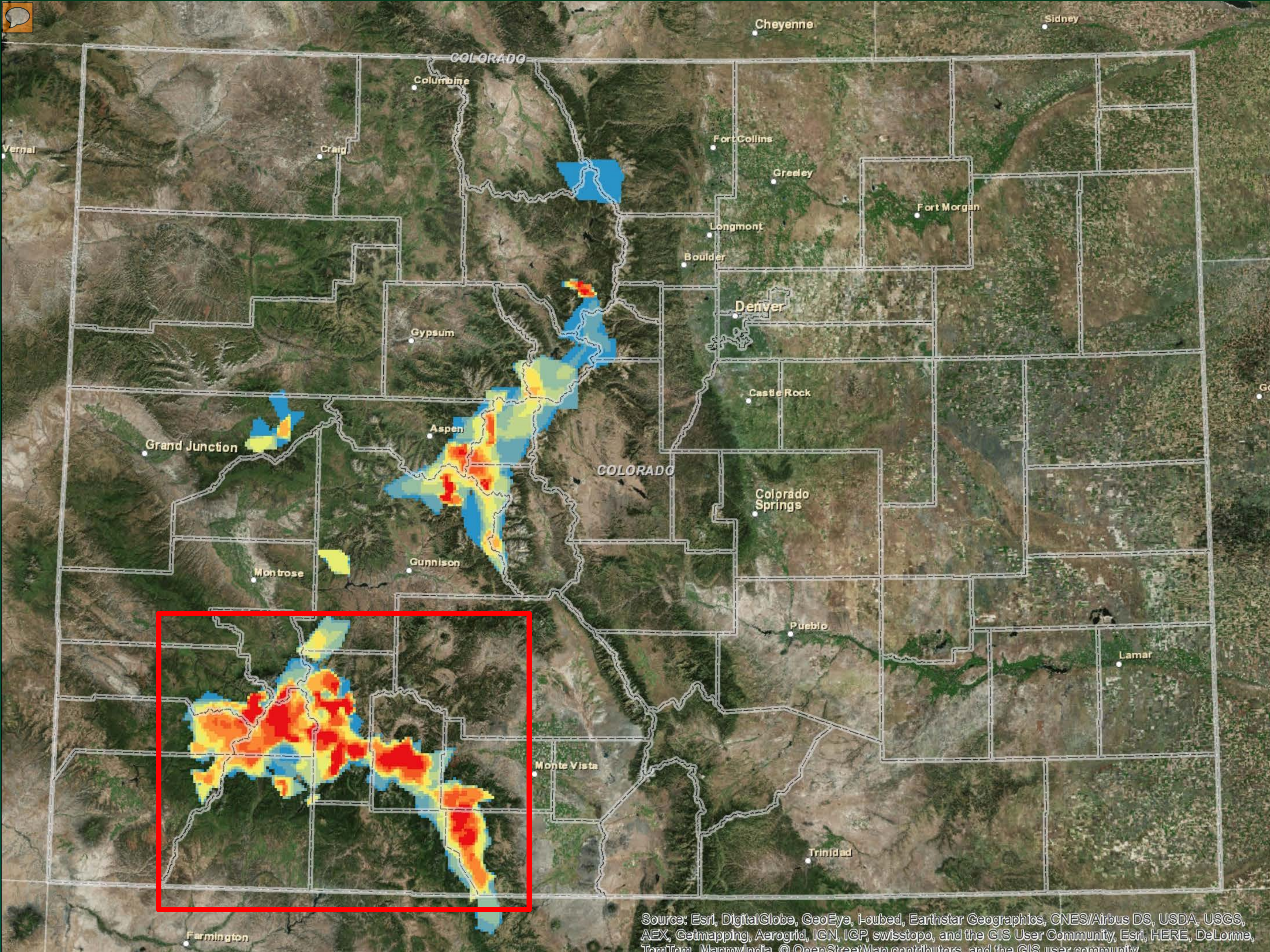
- *First den found 2003; 48 total through 2010*
- *3rd generation Colorado kittens*

Population Model

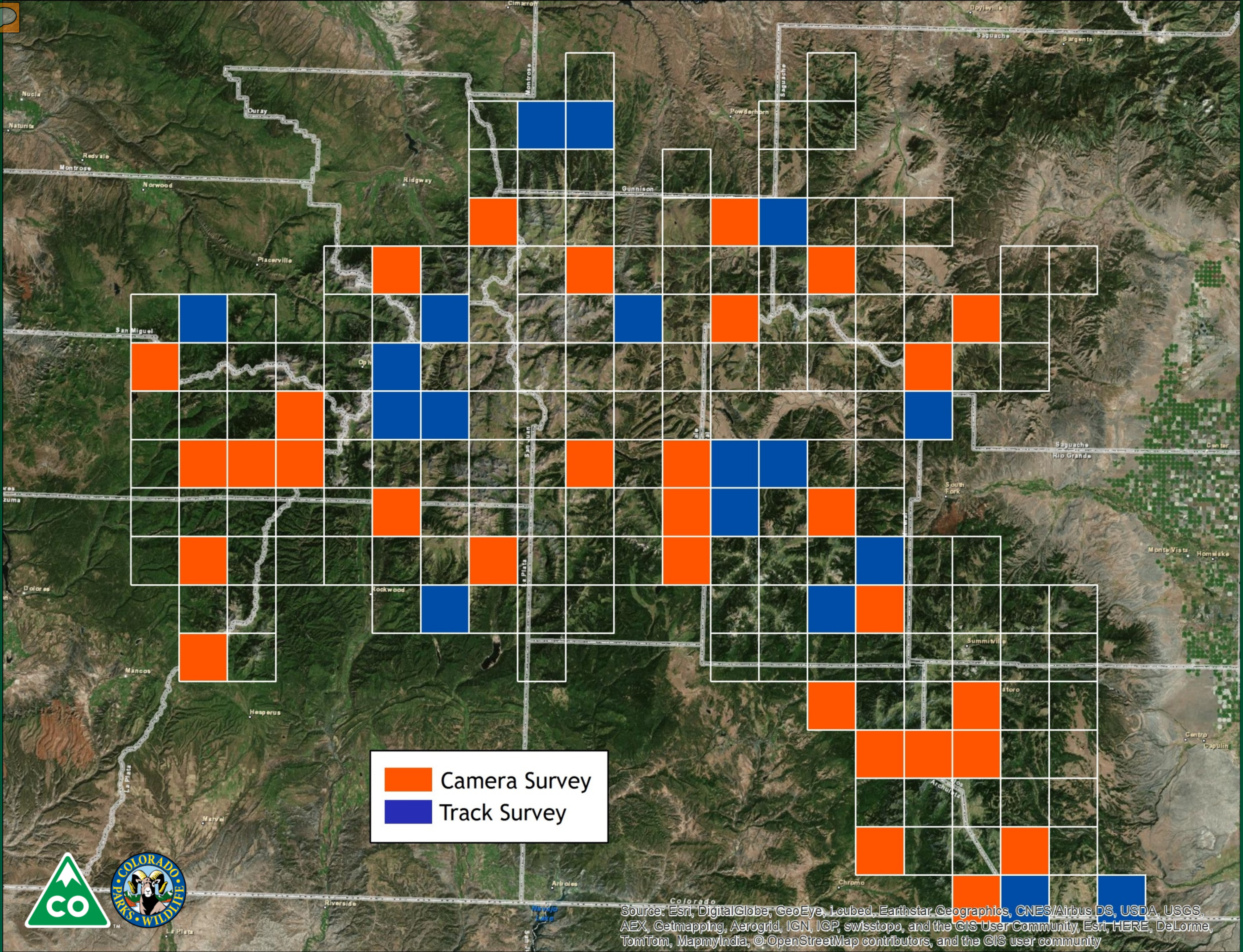


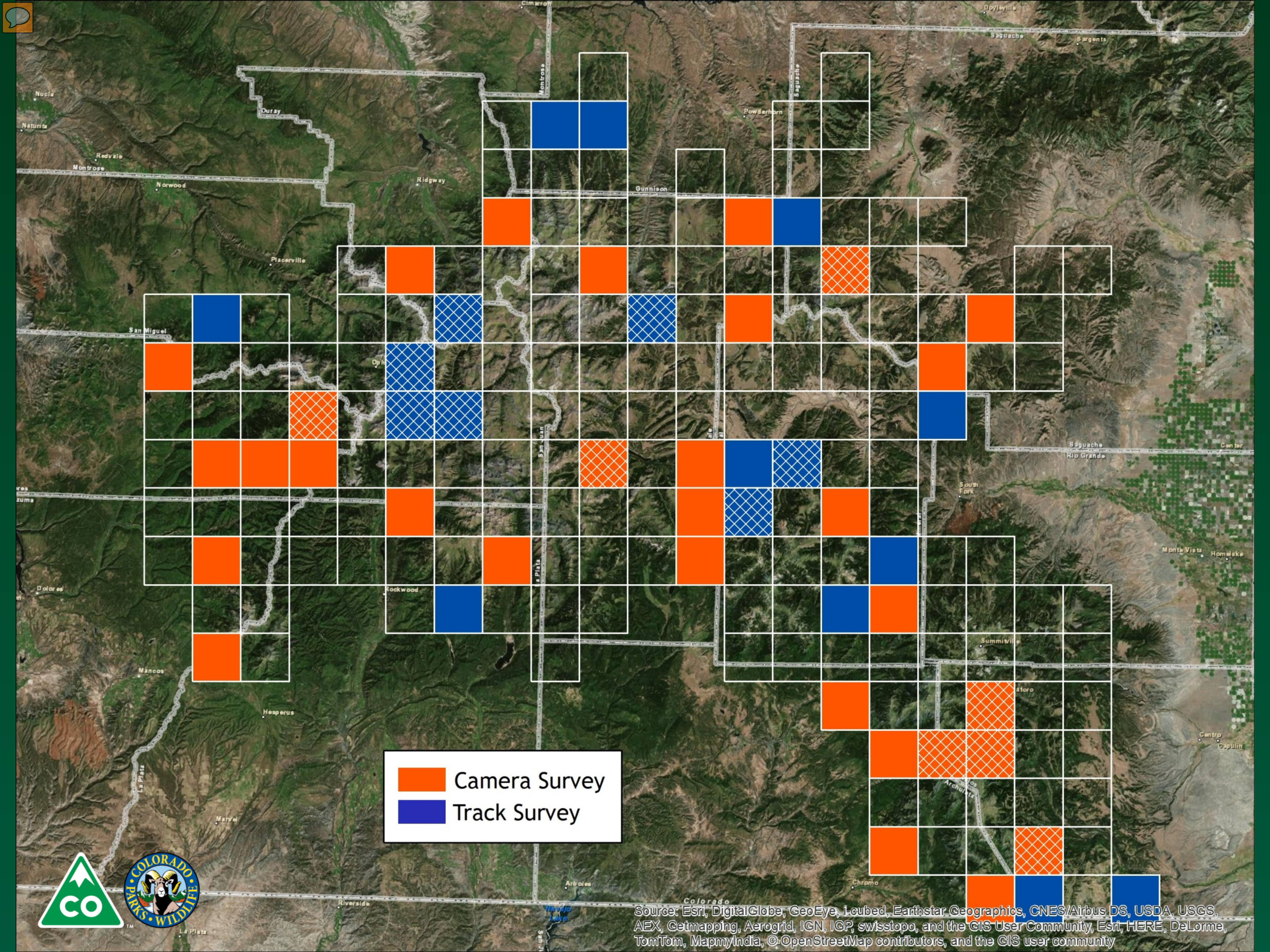
Status in 2015

- Occupancy monitoring
- Currently San Juans only; future potentially includes entire state
- Snow tracking surveys where possible; camera surveys otherwise
- Joint effort - Colorado Parks & Wildlife, U.S. Forest Service (83 people)



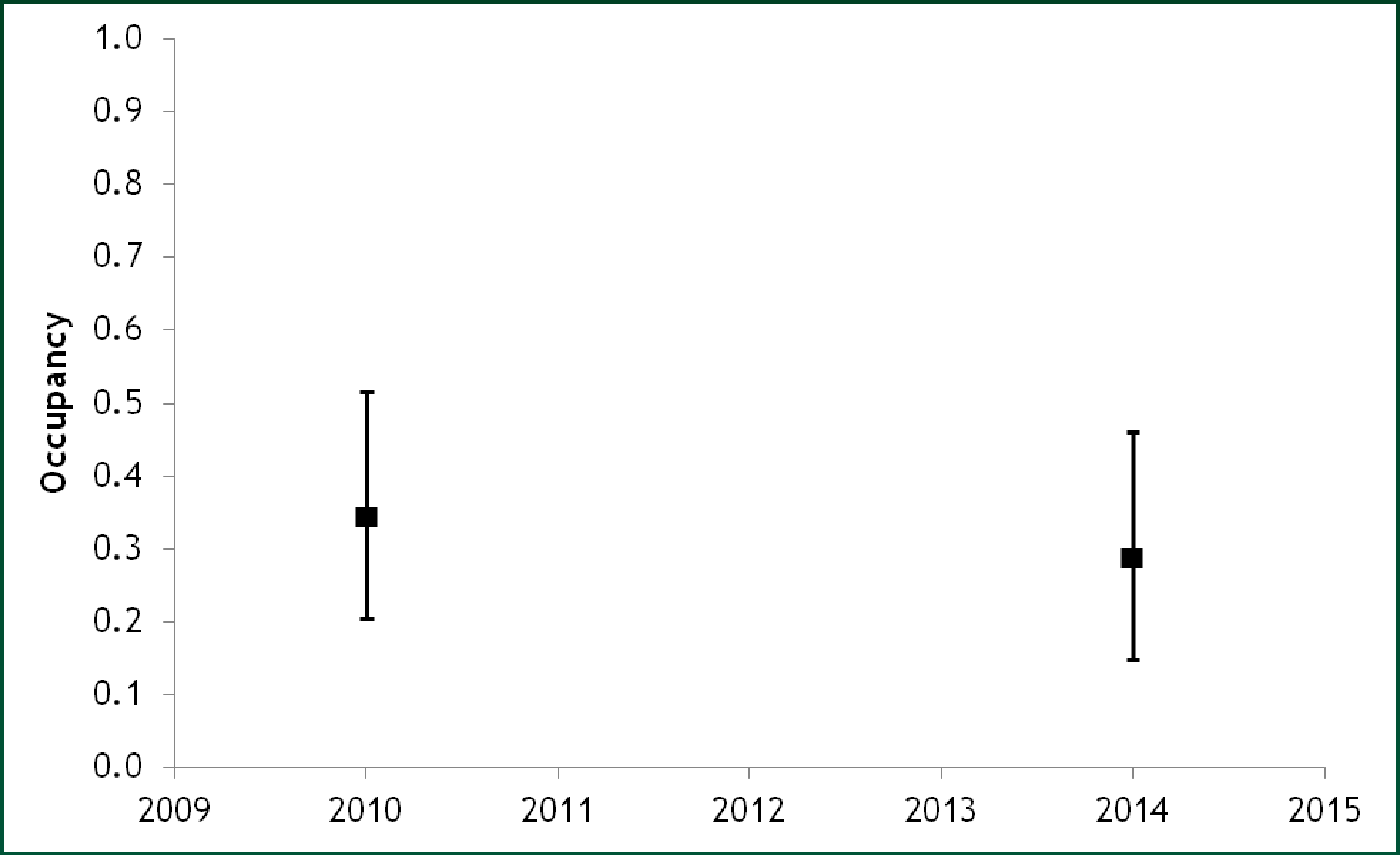
Cheyenne
Sidney
COLORADO
Columbine
Vernal
Craig
Fort Collins
Greeley
Fort Morgan
Longmont
Boulder
Denver
Gypsum
Castle Rock
Aspen
Grand Junction
COLORADO
Colorado Springs
Gunnison
Montrose
Pueblo
Lamar
Monte Vista
Trinidad
Farmington
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS,
AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme,


Camera Survey
Track Survey
Cimarron
Doyleville
Saguache
Sargents
Powderhorn
Gunnison
Ouray
Nucla
Naturita
Redvale
Montrose
Norwood
Ridgway
Placerville
San Miguel
Saguache
Rio Grande
South Fork
Center
Monte Vista
Homelake
Rockwood
Dolores
Summitville
Mancos
Hesperus
Platoro
Marvel
Chromo
Arboles
Riverside
La Plata
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community



Camera Survey
Track Survey
Source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Status in 2015



Status in 2015

- Evidence of continued reproduction:
  - Kittens captured on camera (with female) at 3 sample units during 2014-15 monitoring effort.
  - 38% of lynx captured during recent (2010-2015) USFS RMRS research projects in Colorado have been young and/or unmarked cats.
- Current survival: Unknown
- Status: Holding steady???

Threats

- Climate Change
- Bark beetle epidemics
- Fire
- Recreation
- Highways

Threats – Climate Change

- Colorado State Wildlife Action Plan:
- Climate modeling: USGS Fort Collins Science Center, North Central Climate Science Center
- Based on 2nd-highest emissions scenario (RCP6)
- Used 12 climate models
  - averaged over 1980-2005 = historic normal
  - averaged over 2035-2060 = mid-century projection

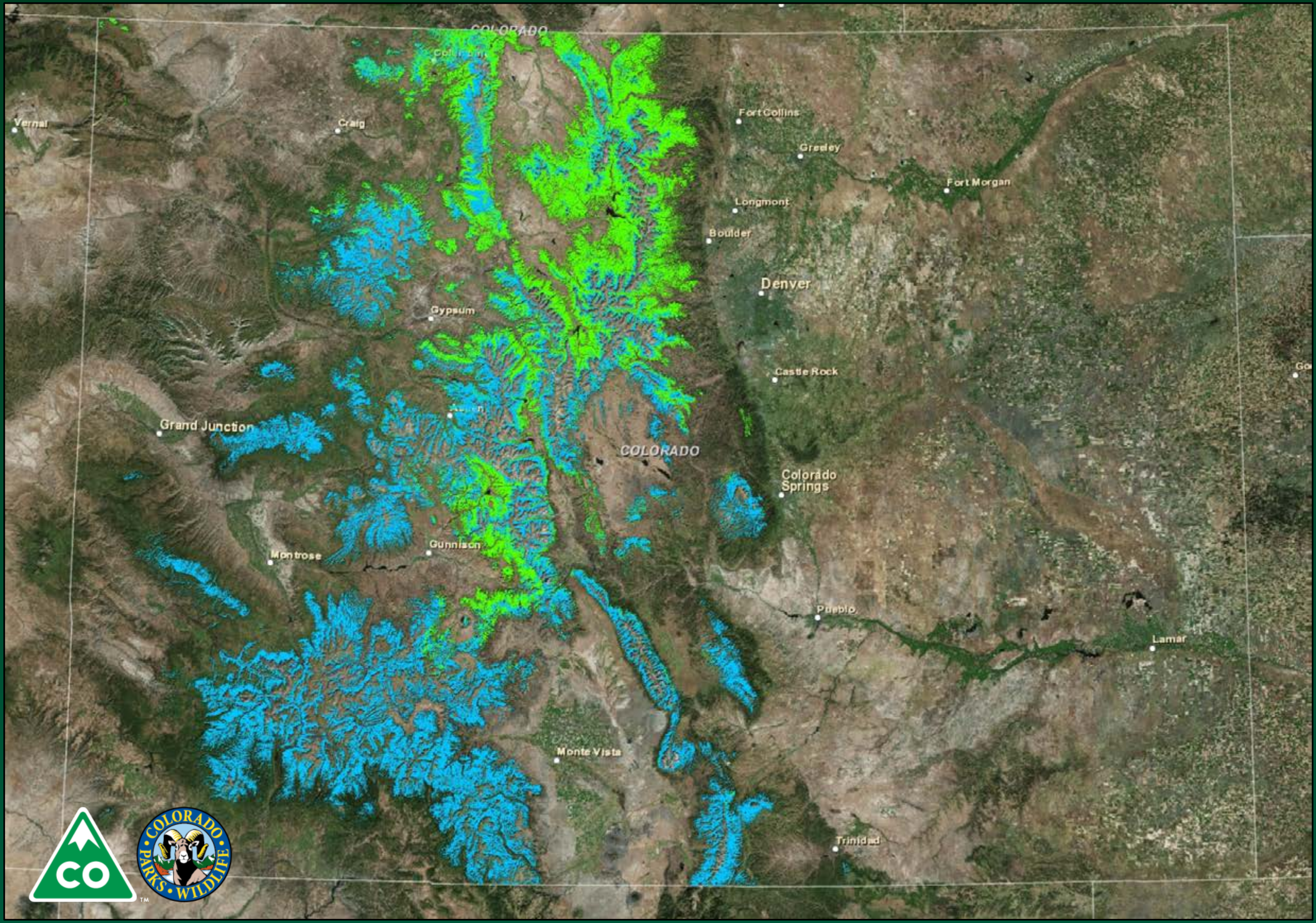
Threats – Climate Change

- System rankings:
  - exposure-sensitivity
  - resilience-adaptive capacity
- Overall vulnerability ranks:
  - Low
  - Moderate
  - High
  - Very high

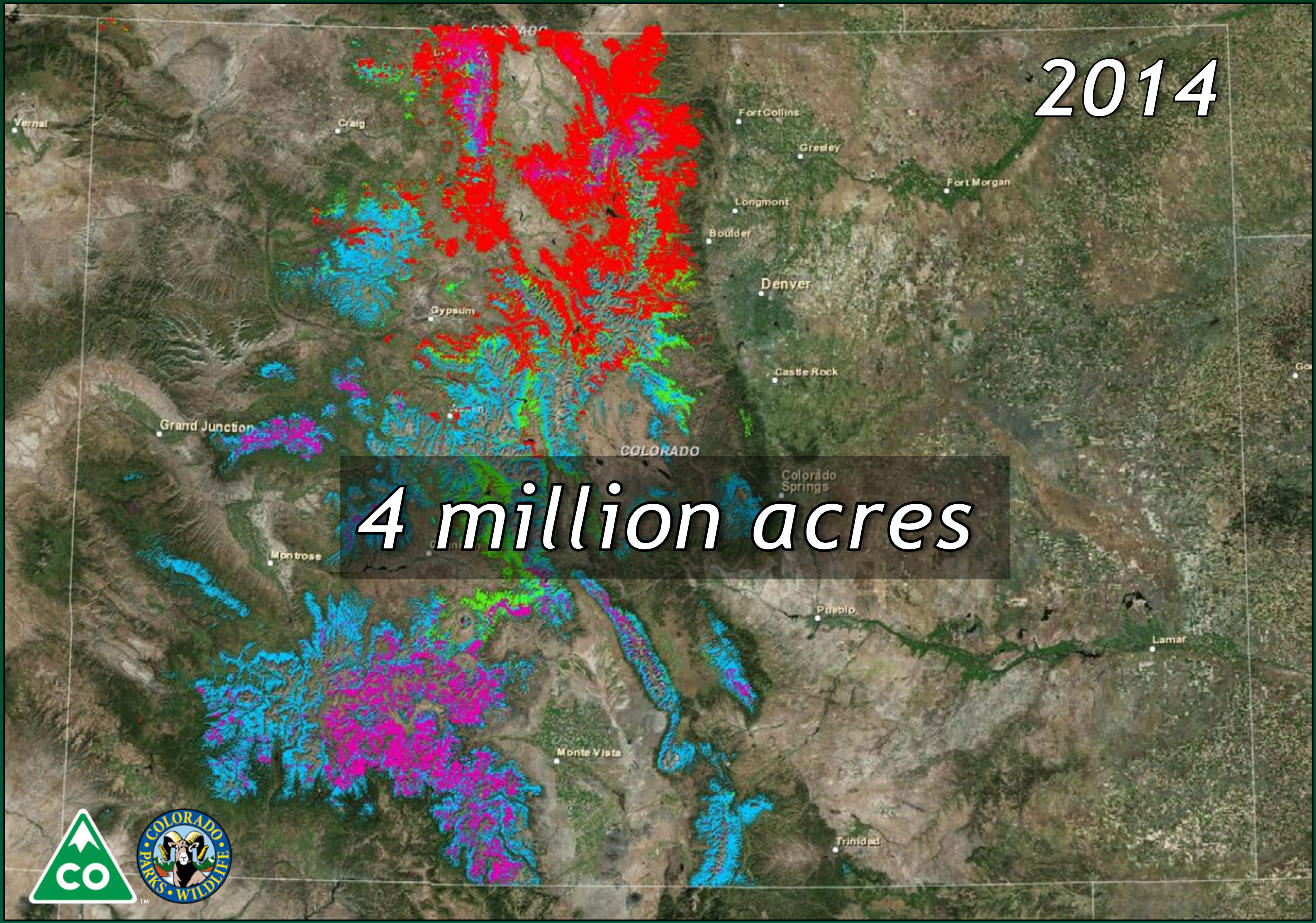
Threats – Climate Change

- RESULTS (Spruce/Fir):
  - Overall vulnerability = moderate
  - Mean temps expected to increase 2°C
  - Decreased precipitation in San Juans & southern mountains
  - Increased precipitation in north-central mountains
  - Habitat will migrate upslope, 50-100 year lag behind climate conditions

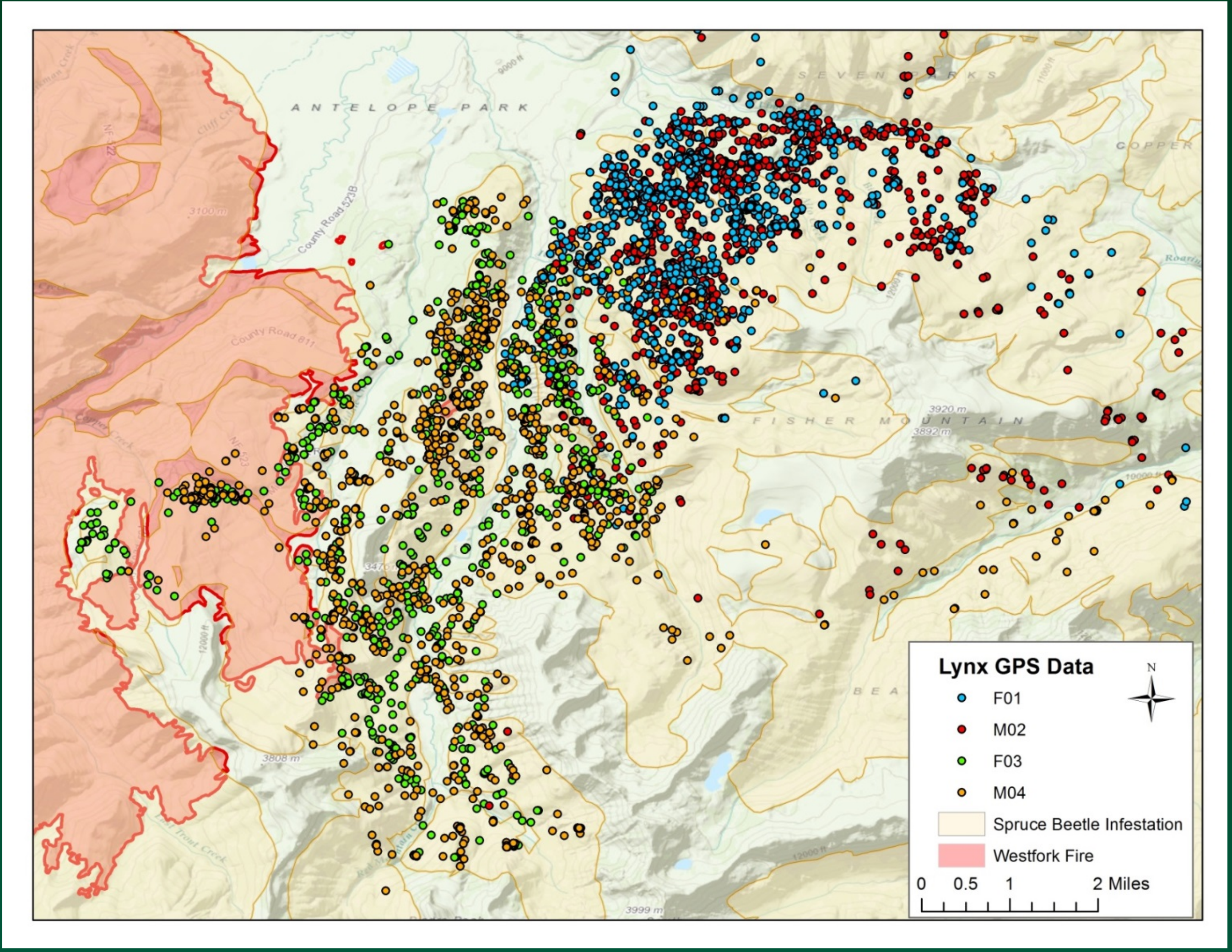
Threats – Bark Beetles



Threats – Bark Beetles

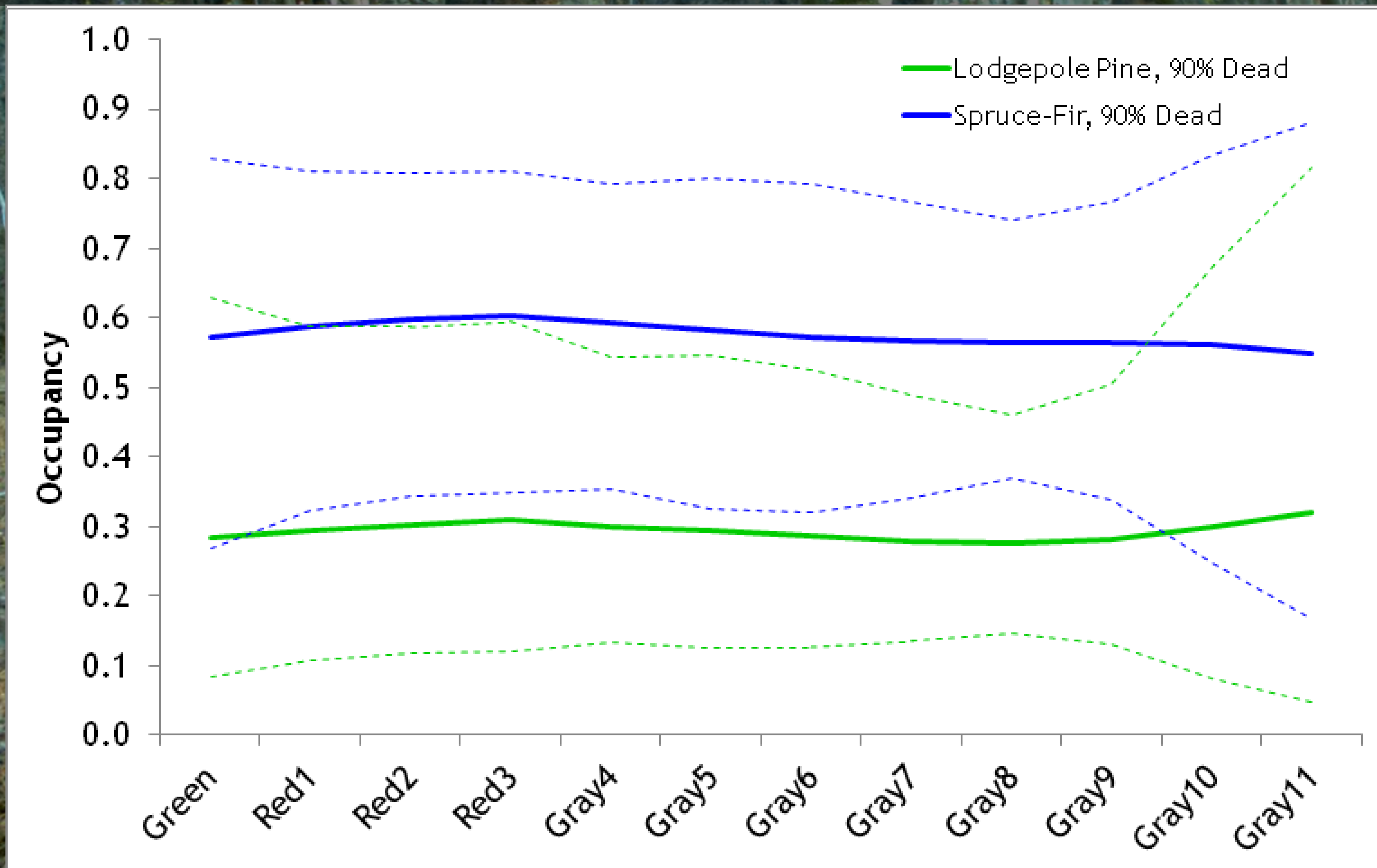


Threats – Bark Beetles



2013-07-08 7:02:28 PM M 2/3 65°F

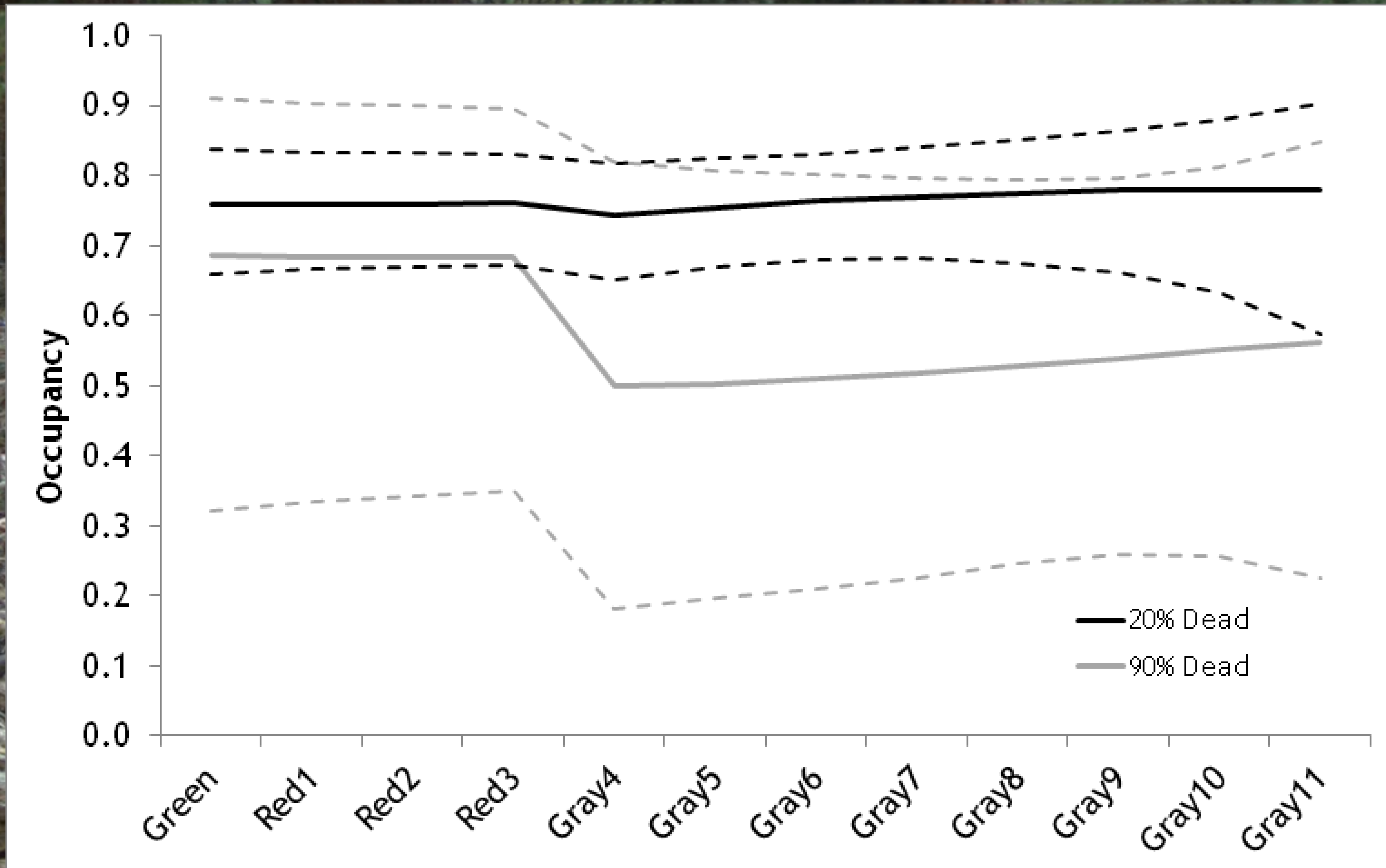
Snowshoe Hare



LP100

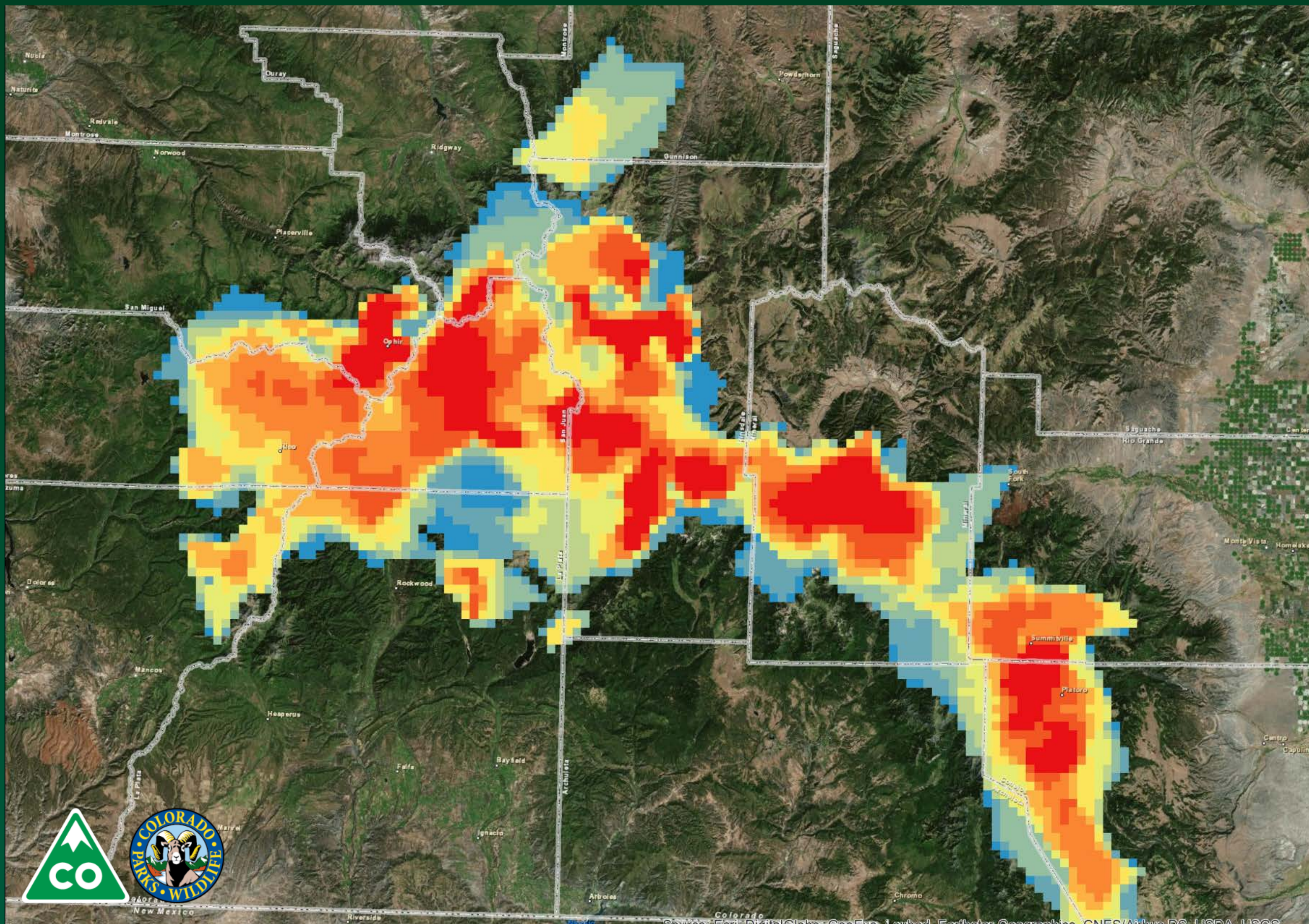
RECONYX

Red Squirrel

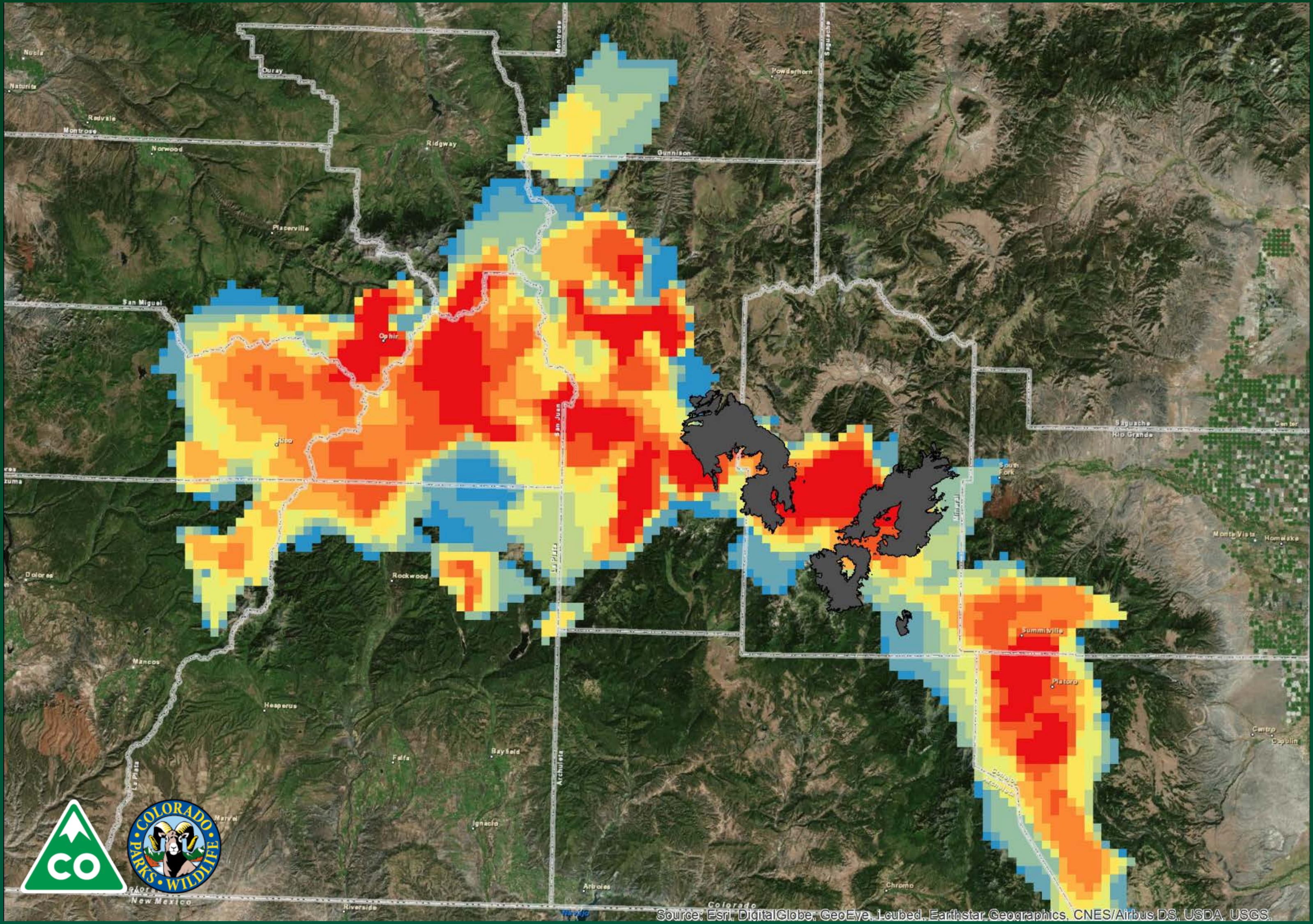


Threats - Fire

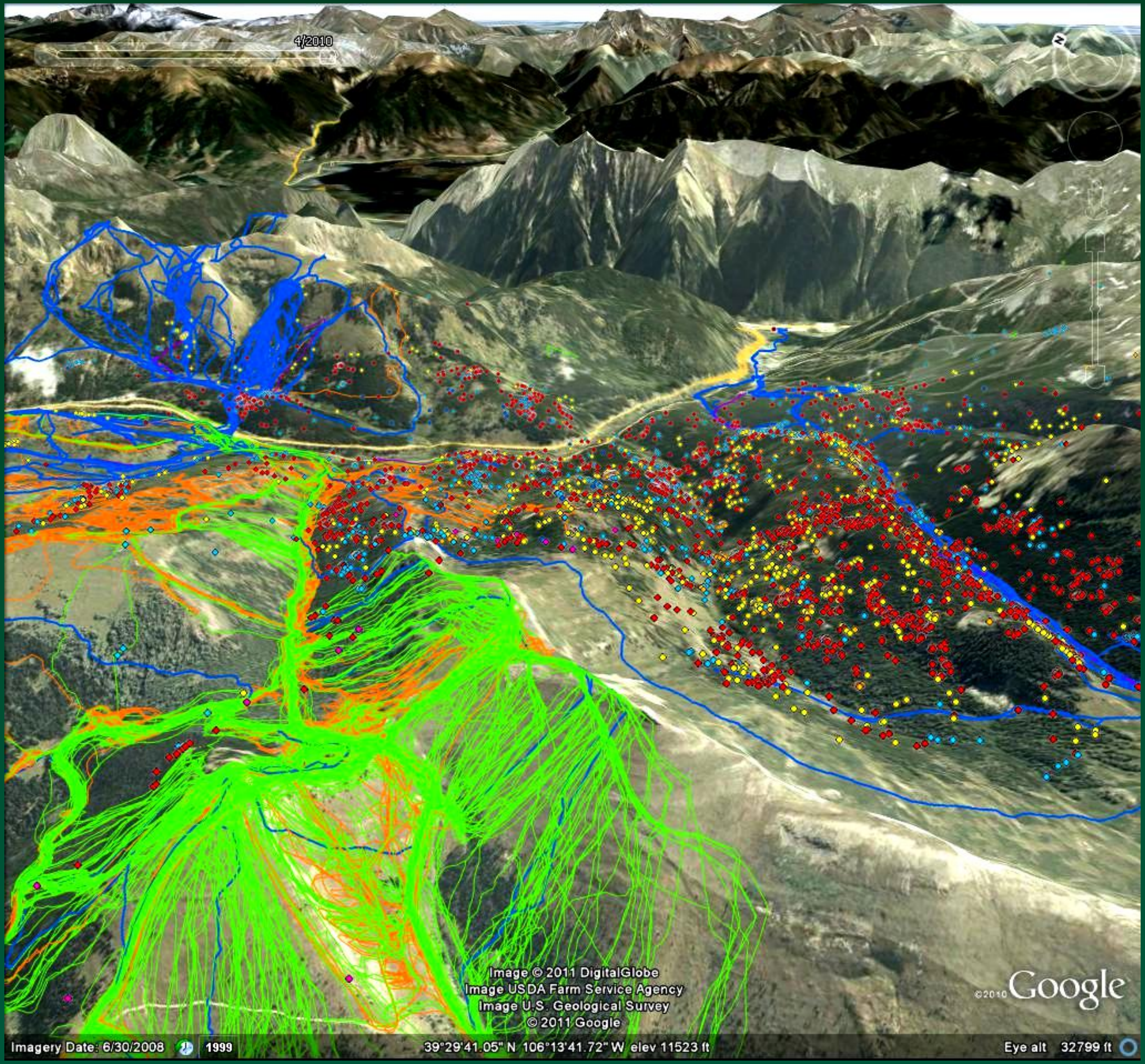
Threats – Fire



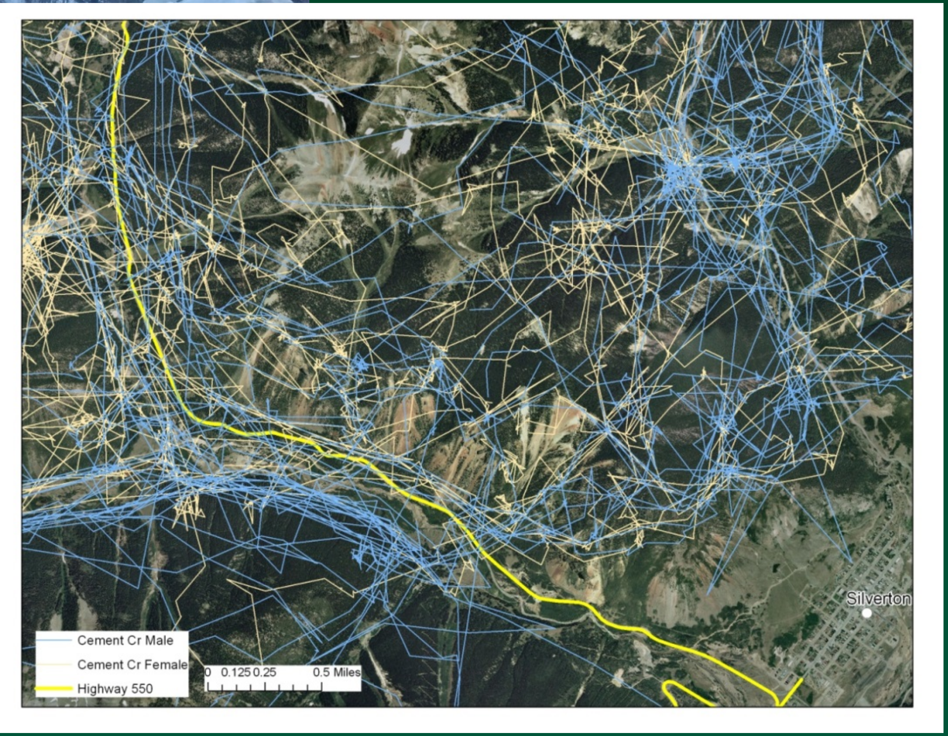
Threats - Fire



Threats – Recreation



Threats – Highways



Threats – Highways

- Lynx frequently crossed 2-lane paved highways in home ranges (0.6 crossings/day).
- Lynx cross roads more at dusk and night, coincident with lower traffic volumes.
- Forest was predictive of lynx highway crossings at fine and landscape scales.
- Remotely-sensed covariates predicted lynx highway crossings validated with independent data.

Baigas, P.E., J. R. Squires, L. E. Olson, J. S. Ivan, and E. K. Roberts. In Review. Landscape and Urban Planning.

Questions?

Lynx EE figures

Jonathan Cummings

February 26, 2016

Contents

Introduction

This R markdown file contains code to process the results of the October 13-15 Lnyx expert elicitation workshop. The input data are the responses collected in response to the questions asked of the expert panel at the workshop. See the Canada Lynx Expert Elicitation Workshop Report for a description of the workshop and the questions asked. What follows is a description of the r code used to generate summary figures to accompany the workshop report.

Lynx Status

Expert responses were collected for each of the 3Rs used in species status assessment. The code below is grouped by the 3Rs, Representation, Redundancy, and Resiliency.

R initialization

Prior to analyzing the data r is initialized with packages needed for the response summaries. #### Load packages

```
# Clear workspace
rm(list=ls())

# Load libraries
# ----Packages for Manipulating & Visualizing Data-----------
library(reshape2) # package for manipulating data
library(ggplot2) # package for plotting data
```

Representation

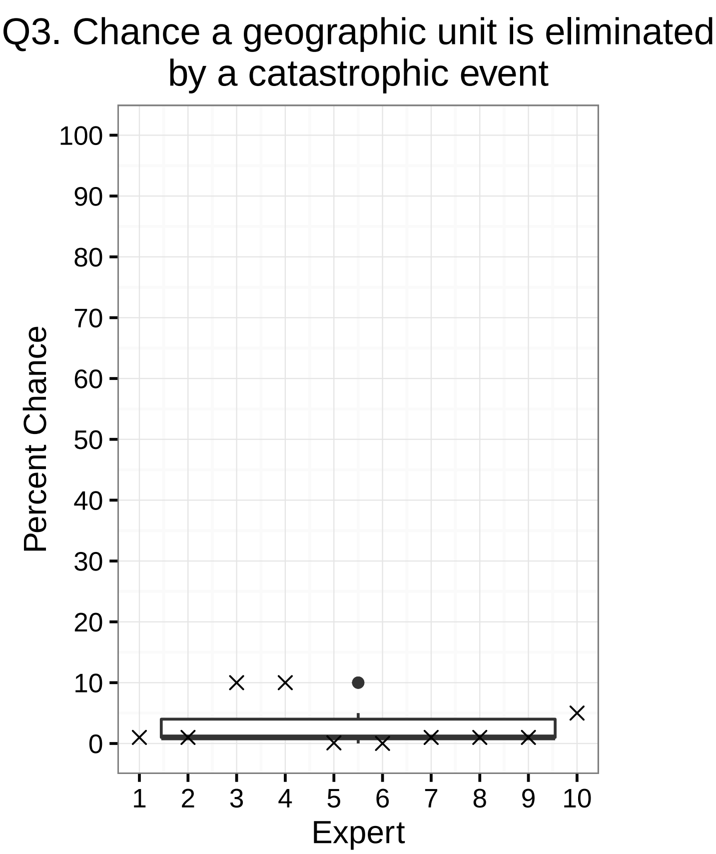
There are no figures associated with the responses to the representation questions.

Redundancy

This section processes the responses to redundancy questions for lynx populations in the lower 48 US states.

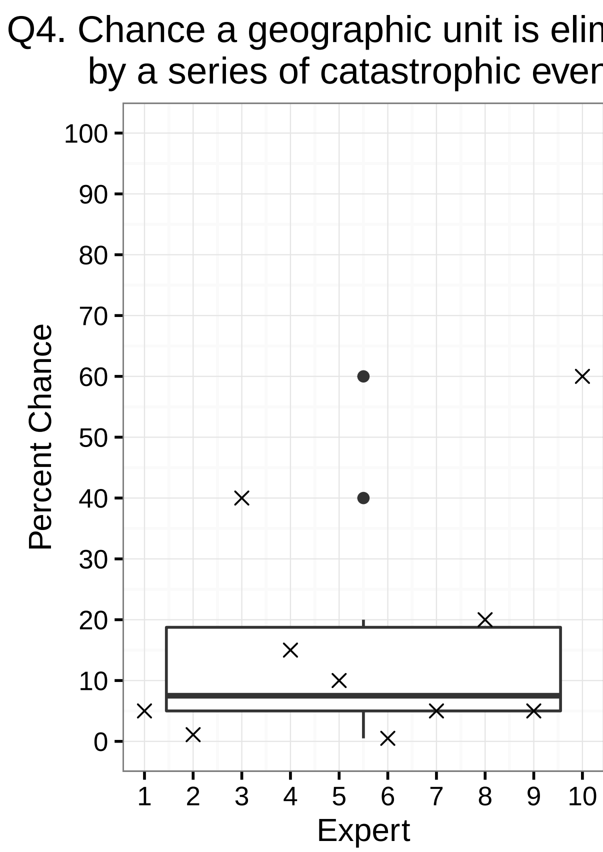
```
# Responses to redundancy question 3, entered by hand from the response files
redundancy3<-data.frame(expert<-c(1,2,3,4,5,6,7,8,9,10),Q3<-c(1,1,10,10,0.1,0.01,1,1,1,5))
# Name the data columns for data on question 3
names(redundancy3)<-c("Expert","Q3")

# Create the plot for the responses to redundancy question 3
plot.Q3<-ggplot(redundancy3,aes(Expert,Q3))
Q3<-plot.Q3 + geom_boxplot() + geom_point(size=2,shape=4) +
  scale_x_continuous(breaks=seq(1,10,1)) + theme_bw()+
  ylab("Percent Chance")+xlab("Expert")+scale_y_continuous(limits=c(0,100),breaks = seq(0,100,10))+
  ggtitle("Q3. Chance a geographic unit is eliminated\nby a catastrophic event") +
  coord_fixed(0.125)
# ggplot is the ploting function, geom_boxplot creates the boxplot and geom_jitter adds data points to

#Plot
Q3
```

```
## Warning: Continuous x aesthetic -- did you forget aes(group=...)?
```



```r
# Responses to redundancy question 4, entered by hand from the response files
redundancy4<-data.frame(expert<-c(1,2,3,4,5,6,7,8,9,10),Q4<-c(5,1.1,40,15,10,0.5,5,20,5,60))
# Name the data columns for data on question 4
names(redundancy4)<-c("Expert","Q4")

# Create the plot for the responses to redundancy question 4
plot.Q4<-ggplot(redundancy4,aes(expert,Q4))
Q4<-plot.Q4 + geom_boxplot() + geom_point(size=2,shape=4)+
  scale_x_continuous(breaks=seq(1,10,1)) + theme_bw() +
  ylab("Percent Chance")+xlab("Expert")+scale_y_continuous(limits=c(0,100),breaks = seq(0,100,10))+
  ggtitle("Q4. Chance a geographic unit is eliminated\nby a series of catastrophic events") +
  coord_fixed(0.125)
# Same plot a for question 3, different data
# Plot
Q4
```

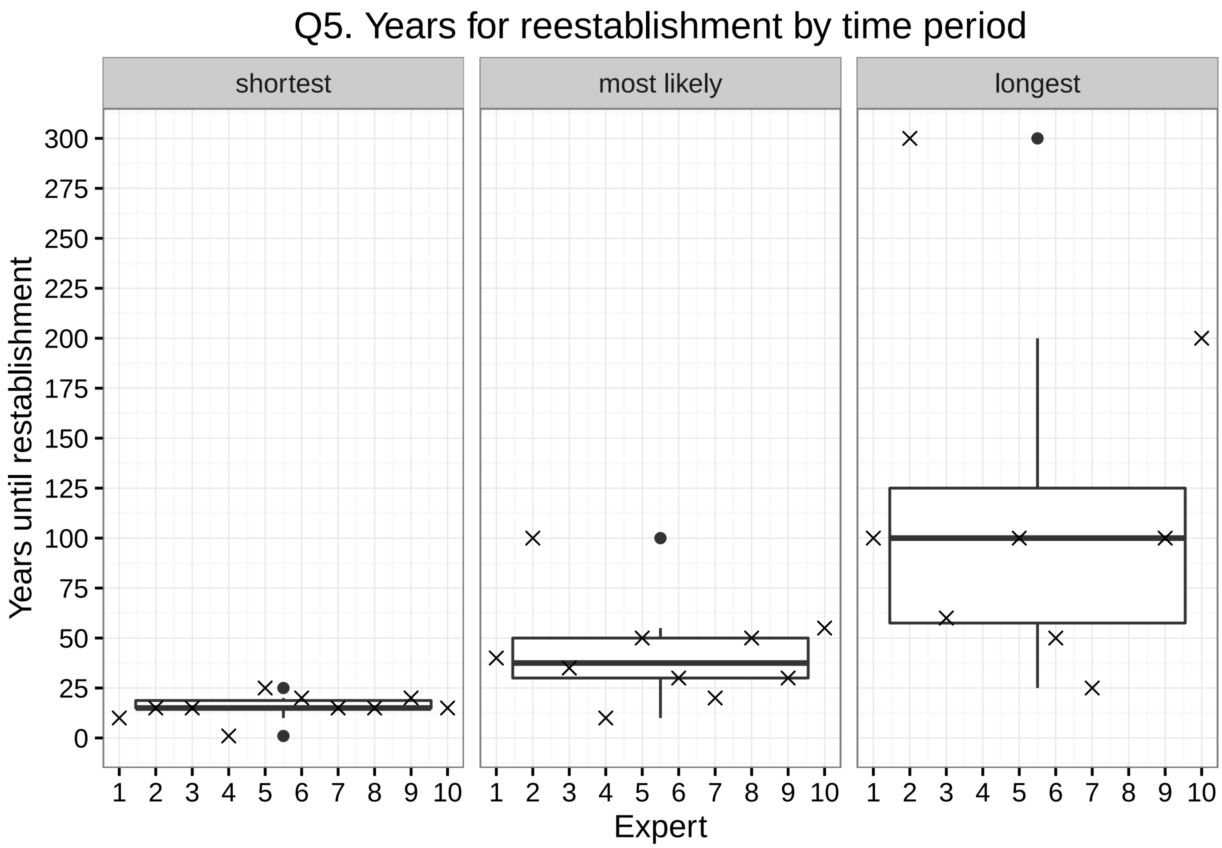
```
## Warning: Continuous x aesthetic -- did you forget aes(group=...)?
```



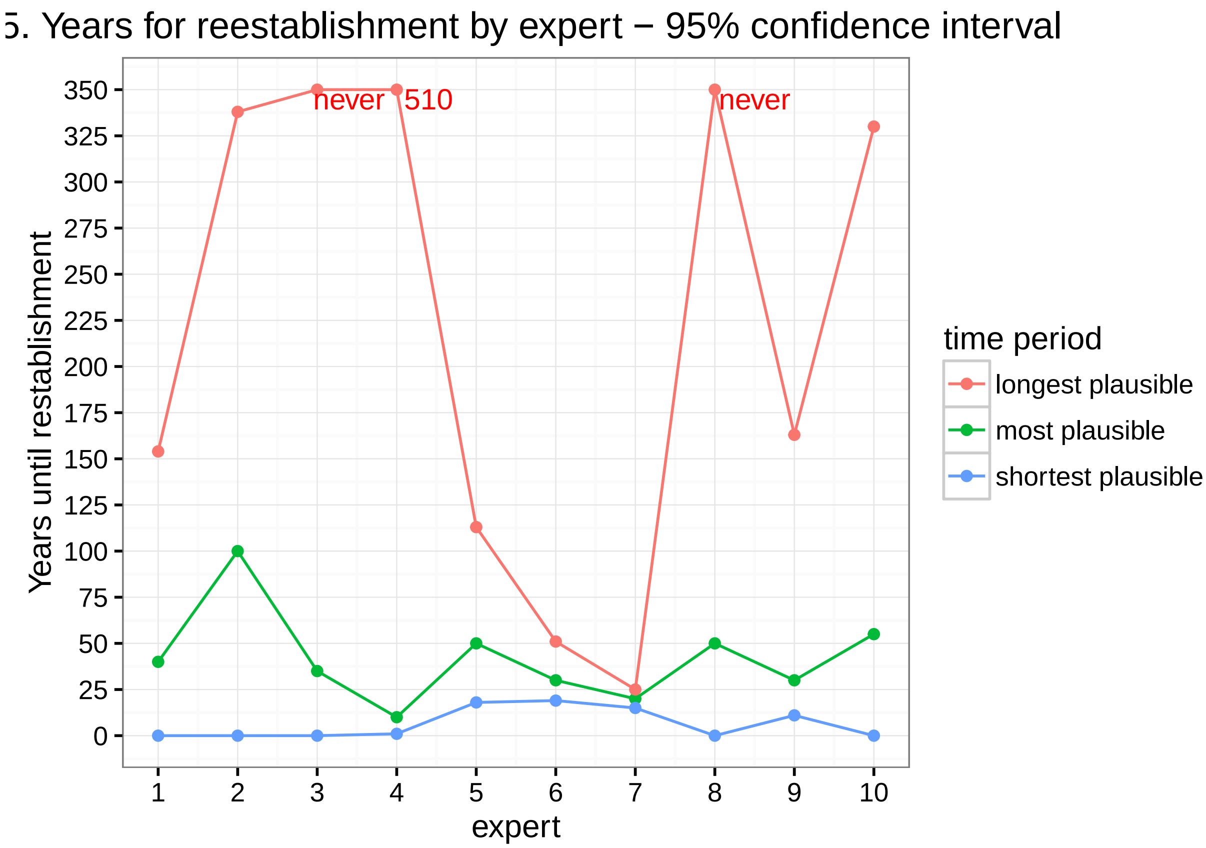

```r
# Responses to redundancy question 5, entered by hand from the response files
redundancy5<-data.frame(expert<-rep(c(1,2,3,4,5,6,7,8,9,10),4),
                        point<-c(rep("longest",10),rep("shortest",10),rep("most likely",10),rep("confide
                        value<-c(100,300,60,NA,100,50,25,NA,100,200,10,15,15,1,25,20,15,15,20,15,
                                 40,100,35,10,50,30,20,50,30,55,50,80,5,100,75,90,90,40,50,50))
# Name the data columns for data on question 4
names(redundancy5)<-c("expert","point","value")
```

```
# Manipulate data to ease calculations
redundancy.df<-dcast(redundancy5,expert~point)

# Compute 95% confidence bound for shortest time period
redundancy.df$shortest.95<-round(((redundancy.df$shortest-redundancy.df$most)/redundancy.df$confidence)*
# Compute 95% confidence bound for longest time period
redundancy.df$longest.95<- round(((redundancy.df$longest-redundancy.df$most)/redundancy.df$confidence)*9

# Manipulate data again to ease figure production
redundancy5<-melt(redundancy.df,id.vars="expert")
redundancy5$value[redundancy5$value<0]<-0
redundancy5$variable<-factor(redundancy5$variable)
redundancy5$variable<-factor(redundancy5$variable,levels(redundancy5$variable)[c(6,4,3,2,5,1)])

# Create the boxplot for the responses to redundancy question 5
plot.Q5.box<-ggplot(redundancy5[c(11:40),],aes(x=expert,y=value))
Q5.box<-plot.Q5.box +  geom_boxplot() +geom_point(size=2,shape=4) + ylab("Years until restablishment") +
  scale_y_continuous(limits=c(0,300),breaks = seq(0,300,25)) + scale_x_continuous(breaks = seq(0,10))+fa
#Plot
Q5.box
```

```
## Warning: Continuous x aesthetic -- did you forget aes(group=...)?

## Warning: Removed 2 rows containing non-finite values (stat_boxplot).

## Warning: Removed 2 rows containing missing values (geom_point).
```




```
# replace large and NA values with 350 for plotting purposes
redundancy5$value[is.na(redundancy5$value)]<-350
redundancy5$value[redundancy5$value>350]<-350

# Create the 95% confidence interval lineplot for the responses to redundancy question 5
plot.Q5<-ggplot(redundancy5[c(21:30,41:60),],aes(x=expert,y=value,group=variable))
Q5<-plot.Q5 + geom_line(aes(colour=variable)) + geom_point(aes(colour=variable)) +
  ylab("Years until restablishment") +
  scale_x_continuous(limits=c(1,10),breaks = seq(1,10,1))+theme_bw() +
  scale_colour_discrete(name="time period",labels=c("longest plausible","most plausible",
    "shortest plausible")) +
  scale_y_continuous(limits=c(0,350),breaks = seq(0,350,25)) + annotate("text", x = 3.4, y = 345,
    label = "never", colour="red") +
  annotate("text", x = 4.4, y = 345,label = "510", colour="red") +
  annotate("text", x = 8.5, y = 345,label = "never", colour="red") +
  ggtitle("Q5. Years for reestablishment by expert - 95% confidence interval")
#Plot
Q5
```



Resiliency

This section processes the responses to the resiliency questions for lynx populations in the lower 48 US states.

Resiliency by Geographic Unit

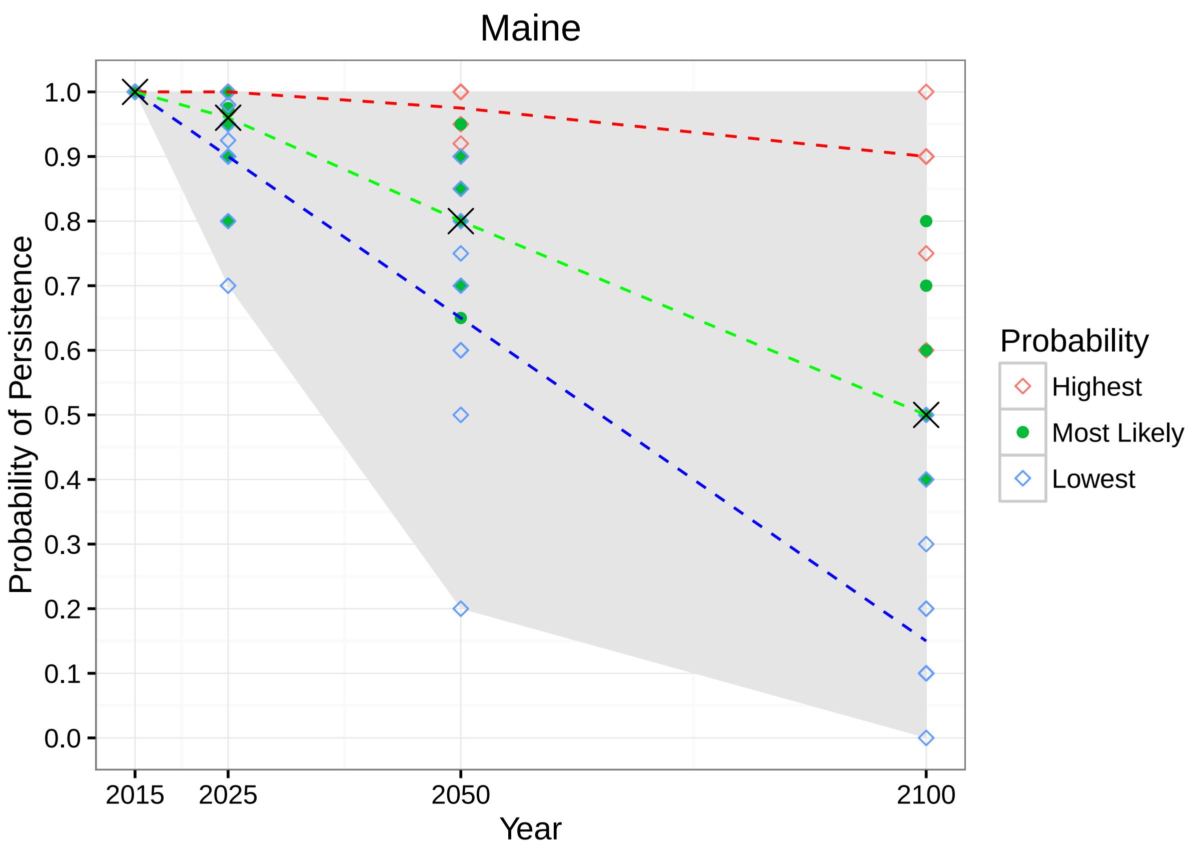
This section reads in the resiliency response file, reorganizes that data, and produces a summary figure of the responses for each geographic unit.

```
# read in resiliency data and organize it
resiliency.data<-read.csv("Resiliency Responses.csv") # read in data file from workhop
# name the columns of data
names(resiliency.data)<-c("Geographic.Unit","Expert","Time.Period","Highest","Most Likely","Lowest")
# reorganize the data and reassign names
resiliency.data<-melt(resiliency.data,c("Geographic.Unit","Expert","Time.Period"))
names(resiliency.data)<-c("Geographic.Unit","Expert","Time.Period","Probability","value")
# make the expert column a factor for use in plotting
resiliency.data$Expert<-as.factor(resiliency.data$Expert)

# Filter by geographic unit
r.ME<-resiliency.data[resiliency.data$Geographic.Unit=="Maine/NE",]
r.MN<-resiliency.data[resiliency.data$Geographic.Unit=="MN/Lakes States",]
r.MT<-resiliency.data[resiliency.data$Geographic.Unit=="Northwest MT/ NE Idaho",]
r.WA<-resiliency.data[resiliency.data$Geographic.Unit=="Washington",]
```

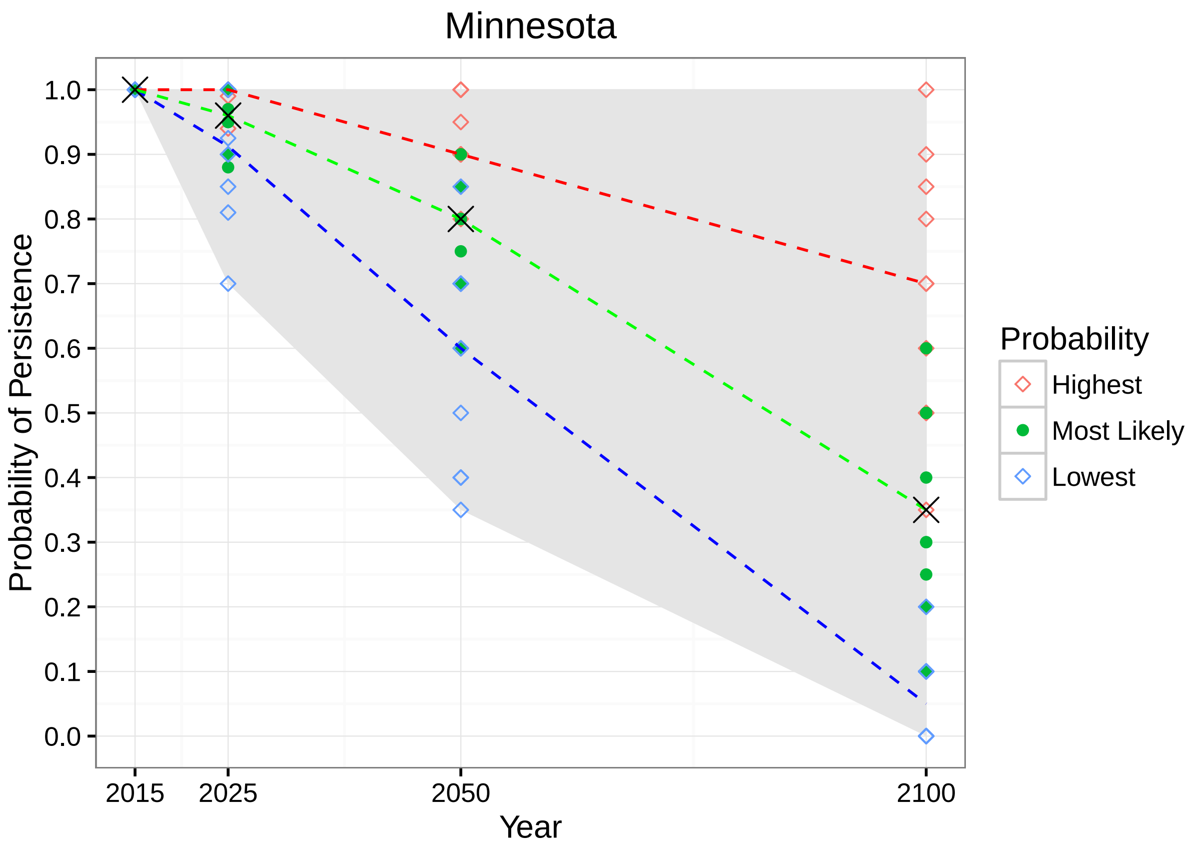
```r
r.GYA<-resiliency.data[resiliency.data$Geographic.Unit=="Greater Yellowstone Area",]
r.CO<-resiliency.data[resiliency.data$Geographic.Unit=="Colorado",]

# Create plot for each geographic unit
#Maine/NE (ME)
res.plot.ME <- ggplot(r.ME, aes(y=value, x=Time.Period,)) + theme_bw() +
  scale_x_continuous(breaks=c(2015,2025,2050,2100)) + scale_y_continuous(limits=c(0,
    1),breaks=c(0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1)) +
  ylab("Probability of Persistence")+xlab("Year") +
  stat_summary(geom="ribbon", fun.ymin="min", fun.ymax="max",fill="grey90") +
  geom_point(data=r.ME,aes(x=Time.Period,y=value, shape=Probability,
    colour=Probability,group=interaction(Probability,Expert))) +
  scale_shape_manual(values=c(5,19,5)) +
  stat_summary(data=r.ME[r.ME$Probability=="Highest",],geom="line",
    fun.y="median",linetype="dashed",colour="red") +
  stat_summary(data=r.ME[r.ME$Probability=="Lowest",],geom="line",
    fun.y="median",linetype="dashed",colour="blue") +
  stat_summary(data=r.ME[r.ME$Probability=="Most Likely",],geom="line",
    fun.y="median",linetype="dashed",colour="green") +
  stat_summary(data=r.ME[r.ME$Probability=="Most Likely",],geom="point",
    fun.y="median",shape=4,size=4) + ggtitle("Maine")
#MN/Lakes States(MN)
res.plot.MN <- ggplot(r.MN, aes(y=value, x=Time.Period,)) + theme_bw() +
  scale_x_continuous(breaks=c(2015,2025,2050,2100)) + scale_y_continuous(limits=c(0,
    1),breaks=c(0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1)) +
  ylab("Probability of Persistence") + xlab("Year") + stat_summary(geom="ribbon",
    fun.ymin="min", fun.ymax="max",fill="grey90") +
  geom_point(data=r.MN,aes(x=Time.Period,y=value, shape=Probability,
    colour=Probability,group=interaction(Probability,Expert))) +
  scale_shape_manual(values=c(5,19,5)) +
  stat_summary(data=r.MN[r.MN$Probability=="Highest",],geom="line",
    fun.y="median",linetype="dashed",colour="red") +
  stat_summary(data=r.MN[r.MN$Probability=="Lowest",],geom="line",
    fun.y="median",linetype="dashed",colour="blue") +
  stat_summary(data=r.MN[r.MN$Probability=="Most Likely",],geom="line",
    fun.y="median",linetype="dashed",colour="green") +
  stat_summary(data=r.MN[r.MN$Probability=="Most Likely",],geom="point",
    fun.y="median",shape=4,size=4) + ggtitle("Minnesota")
#Northwest MT/ NE Idaho
res.plot.MT <- ggplot(r.MT, aes(y=value, x=Time.Period,)) + theme_bw() +
  scale_x_continuous(breaks=c(2015,2025,2050,2100))+scale_y_continuous(limits=c(0,
    1),breaks=c(0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1)) +
  ylab("Probability of Persistence")+xlab("Year") +  stat_summary(geom="ribbon",
    fun.ymin="min", fun.ymax="max",fill="grey90") +  geom_point(data=r.MT,
    aes(x=Time.Period,y=value, shape=Probability, colour=Probability,
    group=interaction(Probability,Expert))) + scale_shape_manual(values=c(5,19,5)) +
  stat_summary(data=r.MT[r.MT$Probability=="Highest",],geom="line",
    fun.y="median",linetype="dashed",colour="red") +
  stat_summary(data=r.MT[r.MT$Probability=="Lowest",],geom="line",
    fun.y="median",linetype="dashed",colour="blue") +
  stat_summary(data=r.MT[r.MT$Probability=="Most Likely",],geom="line",
    fun.y="median",linetype="dashed",colour="green") +
  stat_summary(data=r.MT[r.MT$Probability=="Most Likely",],geom="point",
```

```
    fun.y="median",shape=4,size=4) + ggtitle("NW Montana & NE Idaho")
#Washington
res.plot.WA <- ggplot(r.WA, aes(y=value, x=Time.Period,)) + theme_bw() +
  scale_x_continuous(breaks=c(2015,2025,2050,2100)) + scale_y_continuous(limits=c(0,
    1),breaks=c(0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1)) +
  ylab("Probability of Persistence") + xlab("Year") +
  stat_summary(geom="ribbon", fun.ymin="min", fun.ymax="max",fill="grey90") +
  geom_point(data=r.WA,aes(x=Time.Period,y=value, shape=Probability,
    colour=Probability,group=interaction(Probability,Expert))) +
  scale_shape_manual(values=c(5,19,5)) +
  stat_summary(data=r.WA[r.WA$Probability=="Highest",],geom="line",
    fun.y="median",linetype="dashed",colour="red") +
  stat_summary(data=r.WA[r.WA$Probability=="Lowest",],geom="line",
    fun.y="median",linetype="dashed",colour="blue") +
  stat_summary(data=r.WA[r.WA$Probability=="Most Likely",],geom="line",
    fun.y="median",linetype="dashed",colour="green")+
  stat_summary(data=r.WA[r.WA$Probability=="Most Likely",],geom="point",
    fun.y="median",shape=4,size=4) + ggtitle("Washington")
#Greater Yellowstone Area
res.plot.GYA <- ggplot(r.GYA, aes(y=value, x=Time.Period,)) + theme_bw() +
  scale_x_continuous(breaks=c(2015,2025,2050,2100)) + scale_y_continuous(limits=c(0,
    1),breaks=c(0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1)) +
  ylab("Probability of Persistence")+xlab("Year") + stat_summary(geom="ribbon",
    fun.ymin="min", fun.ymax="max",fill="grey90") + geom_point(data=r.GYA,
    aes(x=Time.Period,y=value, shape=Probability,colour=Probability,
    group=interaction(Probability,Expert))) + scale_shape_manual(values=c(5,19,5)) +
  stat_summary(data=r.GYA[r.GYA$Probability=="Highest",],geom="line",
    fun.y="median",linetype="dashed",colour="red") +
  stat_summary(data=r.GYA[r.GYA$Probability=="Lowest",],geom="line",
    fun.y="median",linetype="dashed",colour="blue") +
  stat_summary(data=r.GYA[r.GYA$Probability=="Most Likely",],geom="line",
    fun.y="median",linetype="dashed",colour="green") +
  stat_summary(data=r.GYA[r.GYA$Probability=="Most Likely",],geom="point",
    fun.y="median",shape=4,size=4) + ggtitle("Greater Yellowstone Area")
#Colorado
res.plot.CO <- ggplot(r.CO, aes(y=value, x=Time.Period,)) + theme_bw() +
  scale_x_continuous(breaks=c(2015,2025,2050,2100)) + scale_y_continuous(limits=c(0,
    1),breaks=c(0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1)) +
  ylab("Probability of Persistence") + xlab("Year") +
  stat_summary(geom="ribbon", fun.ymin="min", fun.ymax="max",fill="grey90") +
  geom_point(data=r.CO,aes(x=Time.Period,y=value, shape=Probability,
    colour=Probability,group=interaction(Probability,Expert))) +
  scale_shape_manual(values=c(5,19,5)) +
  stat_summary(data=r.CO[r.CO$Probability=="Highest",],geom="line",
    fun.y="median",linetype="dashed",colour="red") +
  stat_summary(data=r.CO[r.CO$Probability=="Lowest",],geom="line",
    fun.y="median",linetype="dashed",colour="blue") +
  stat_summary(data=r.CO[r.CO$Probability=="Most Likely",],geom="line",
    fun.y="median",linetype="dashed",colour="green") +
  stat_summary(data=r.CO[r.CO$Probability=="Most Likely",],geom="point",
    fun.y="median",shape=4,size=4) + ggtitle("Colorado")

#show plots
```

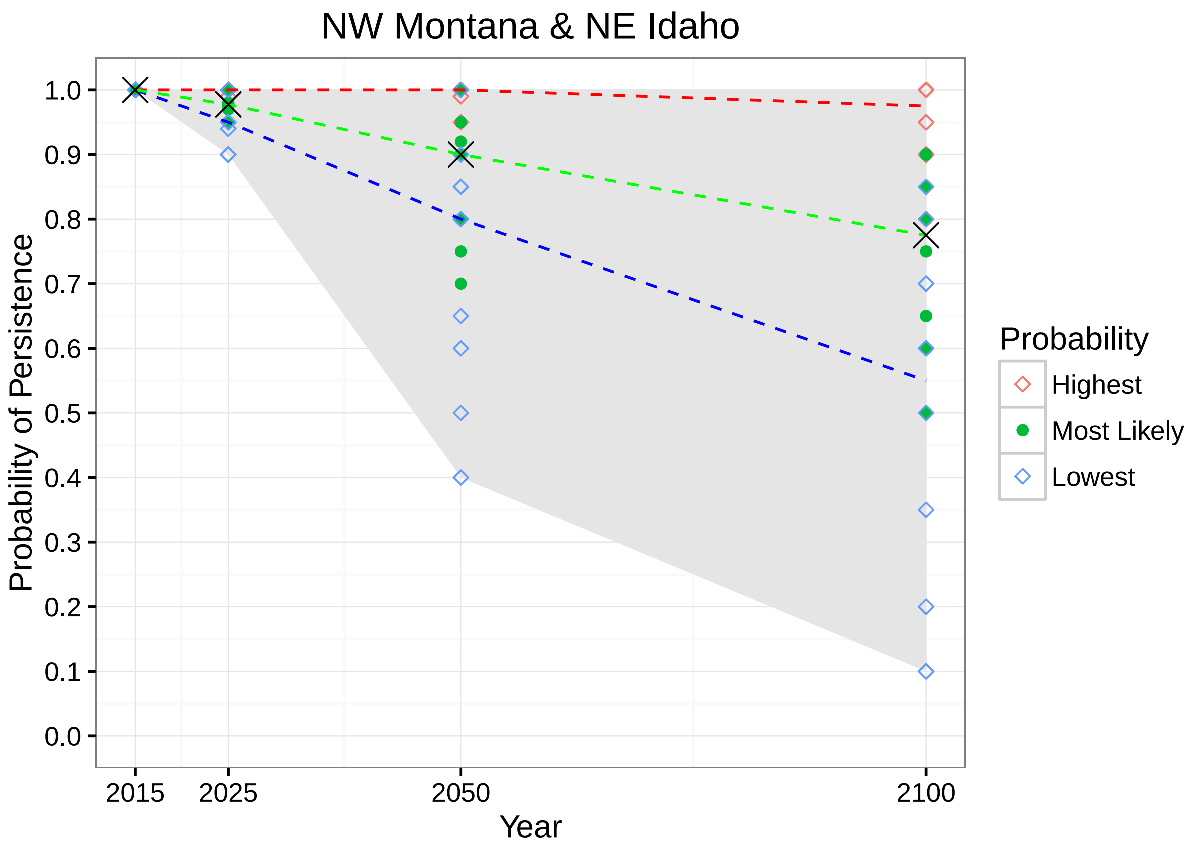
```
res.plot.ME
```




```
res.plot.MN
```

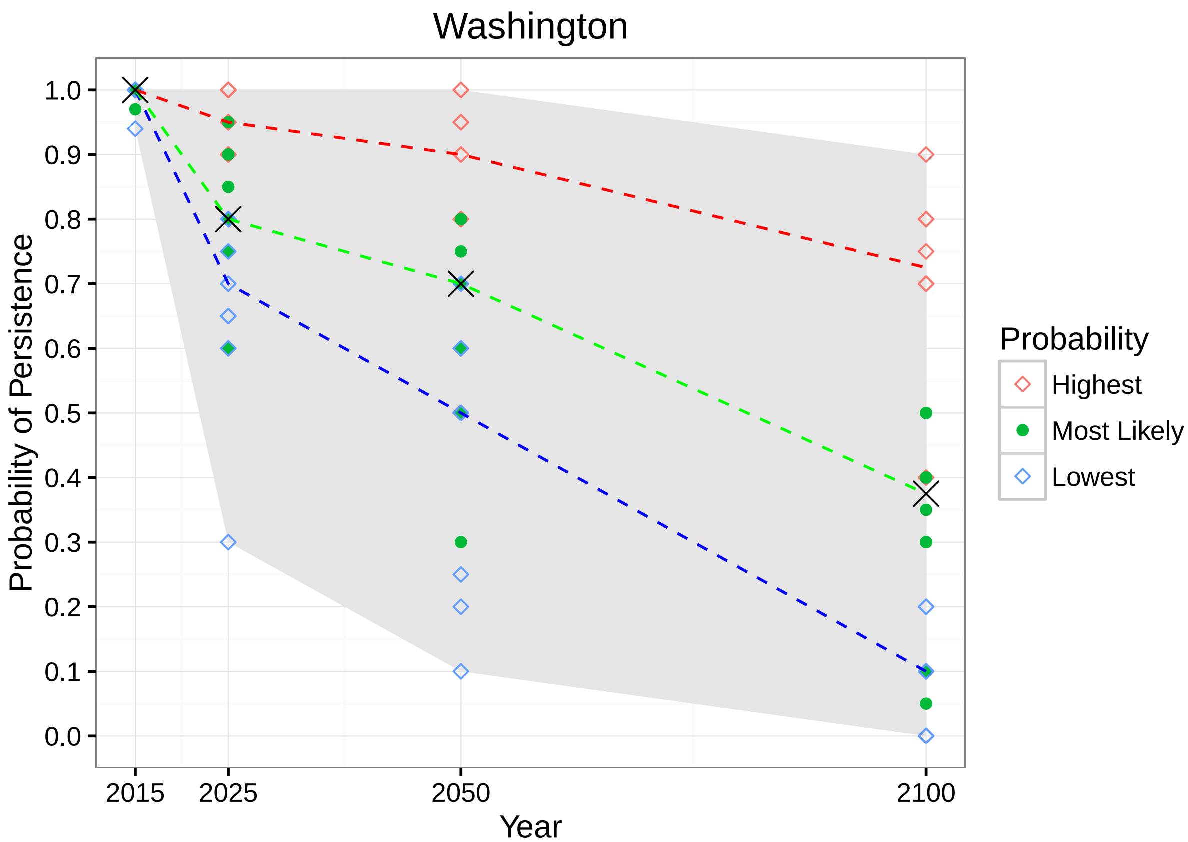

Minnesota
Probability of Persistence
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2015
2025
2050
2100
Year
Probability
Highest
Most Likely
Lowest

```
res.plot.MT
```

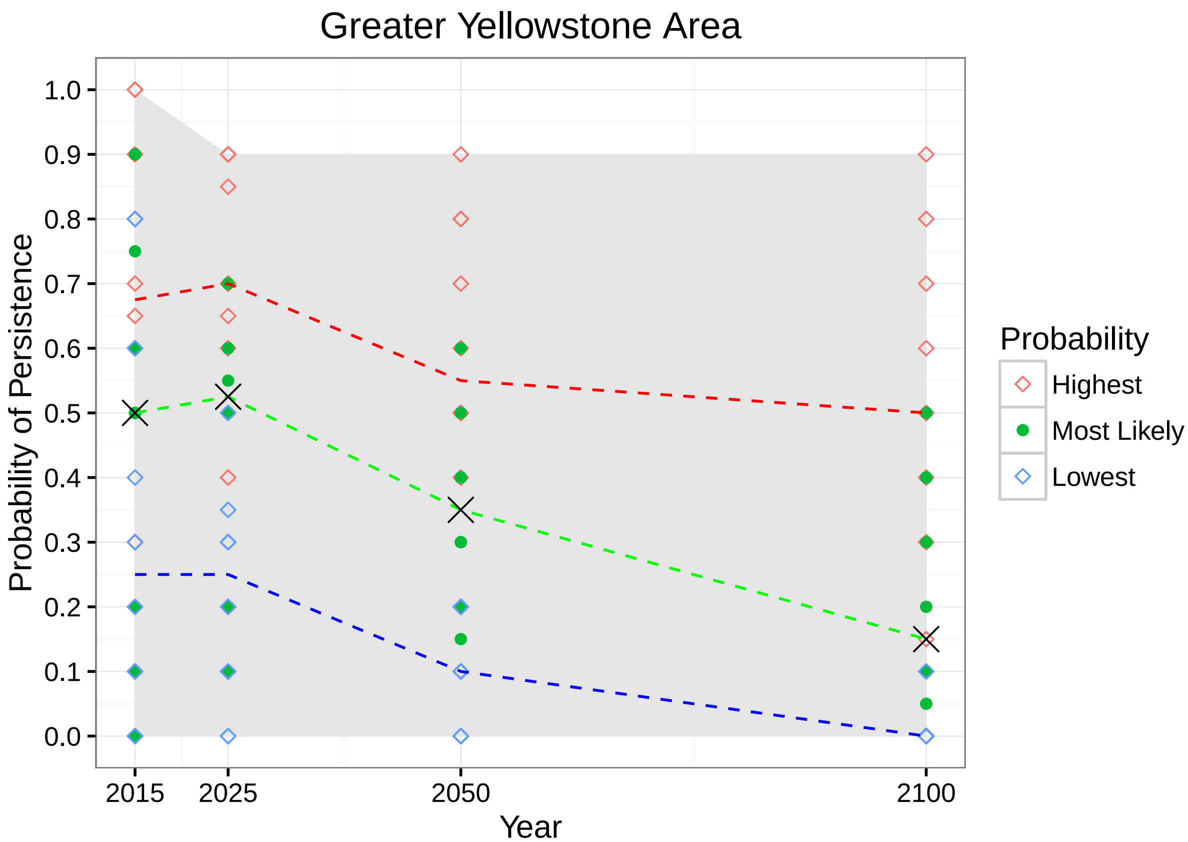



```
res.plot.WA
```

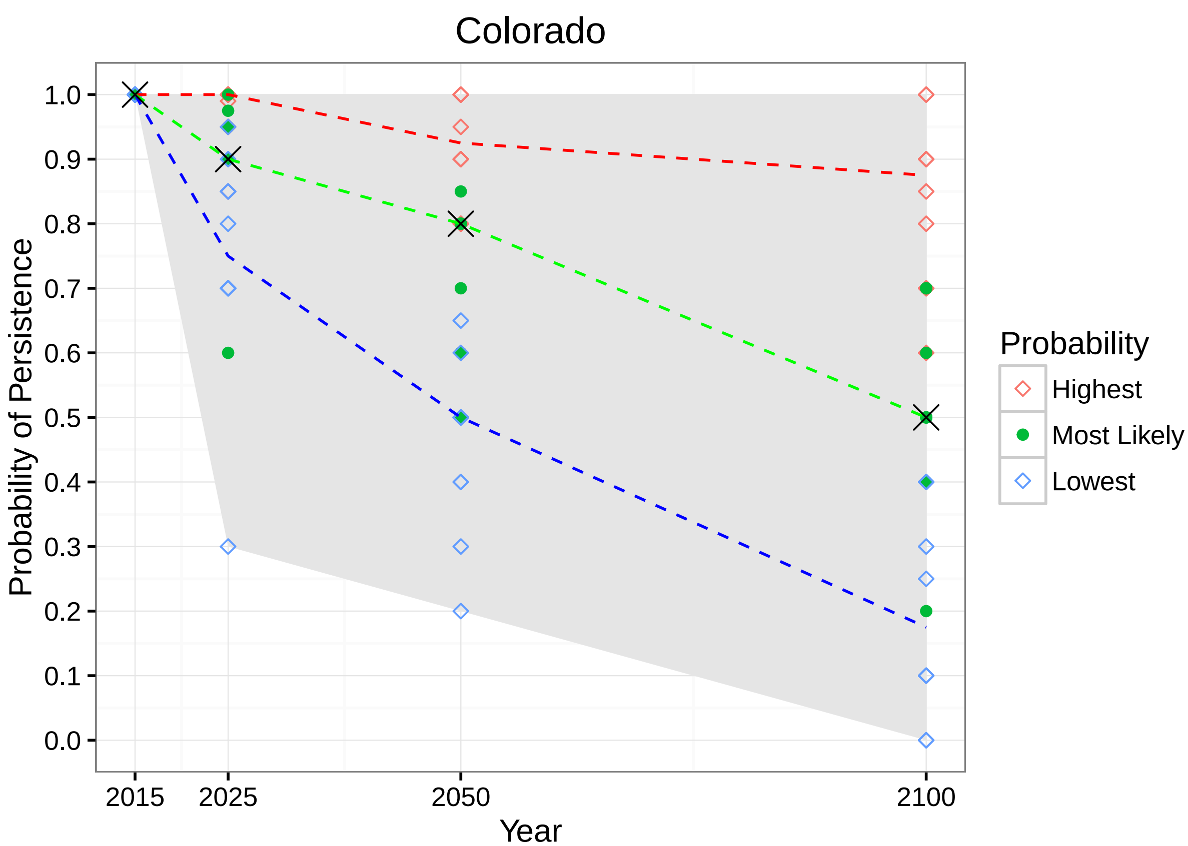
```
## Warning: Removed 3 rows containing non-finite values (stat_summary).

## Warning: Removed 1 rows containing non-finite values (stat_summary).

## Warning: Removed 1 rows containing non-finite values (stat_summary).

## Warning: Removed 1 rows containing non-finite values (stat_summary).

## Warning: Removed 1 rows containing non-finite values (stat_summary).

## Warning: Removed 3 rows containing missing values (geom_point).
```


Washington
Probability of Persistence
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2015
2025
2050
2100
Year
Probability
Highest
Most Likely
Lowest

```
res.plot.GYA
```


Greater Yellowstone Area
Probability of Persistence
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2015
2025
2050
2100
Year
Probability
Highest
Most Likely
Lowest

```
res.plot.CO
```



Resiliency across Geographic Units This section uses the binonomial probability of persistence in each unit and combines them to determine the resulting probability of persistence across units. Some terminology: "Highest_High" is the probability of persistence generated by selecting the highest probability of persistence across experts from the highest probability response in each geographic unit.
"Median_High" is the probability of persistence generated by selecting the median probability of persistence across experts from the highest probability response in each geographic unit. "Highest_Likely" is the probability of persistence generated by selecting the highest probability of persistence across experts from the most likely probability response in each geographic unit. "Median_Likely" is the probability of persistence generated by selecting the median probability of persistence across experts from the most likely probability response in each geographic unit. "Lowest_Likely" is the probability of persistence generated by selecting the lowest probability of persistence across experts from the most likely probability response in each geographic unit. "Median_Low" is the probability of persistence generated by selecting the median probability of persistence across experts from the lowest probability response in each geographic unit. "Lowest_Low" is the probability of persistence generated by selecting the lowest probability of persistence across experts from the lowest probability response in each geographic unit.

```
# Create summary graph across geographic units
# create empty vector to bind results to
r.summary<-0

# loop through data to compute median of response and find max and min response across experts for each
for (i in unique(resiliency.data$Geographic.Unit)){ # loop through geographic units
  for (j in unique(resiliency.data$Time.Period)){ # loop through time periods
    for (k in unique(resiliency.data$Probability)){ # loop through probability (high, low, most likely)
      # Create new array containing the geographic unit, time period, probability, and the median, max,
      r.summary<-rbind(r.summary,c(i,j,k,"median",
        median(resiliency.data[resiliency.data$Geographic.Unit==i&
```

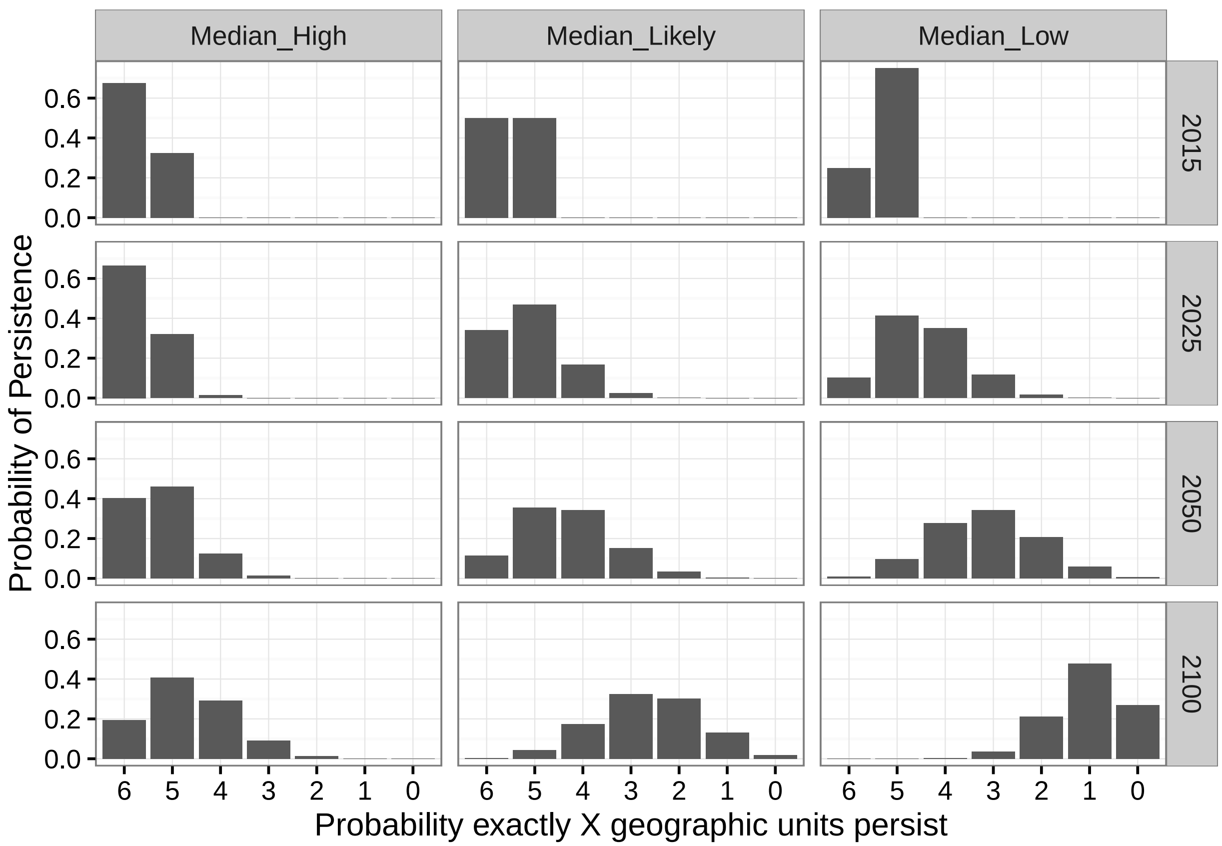
```
          resiliency.data$Time.Period==j&resiliency.data$Probability==k,"value"],
          na.rm=T),"max",
        max(resiliency.data[resiliency.data$Geographic.Unit==i&
          resiliency.data$Time.Period==j&resiliency.data$Probability==k,"value"],
          na.rm=T),"min",
        min(resiliency.data[resiliency.data$Geographic.Unit==i&
          resiliency.data$Time.Period==j&resiliency.data$Probability==k,"value"],
          na.rm=T)))
    }
  }
}

# Remove empty first row
r.summary<-r.summary[-1,]
# Convert to data.frame and name columns
r.summary<-data.frame(Geographic.Unit=r.summary[,1],Time.Period=r.summary[,2],
  Probability=r.summary[,3],median=r.summary[,5],max=r.summary[,7],min=r.summary[,9])
# Organize for easier processing and graphing
r.summary<-melt(r.summary,id.vars=c("Geographic.Unit","Time.Period","Probability"),
  measure.vars=c("median","max","min"))
```

```
## Warning: attributes are not identical across measure variables; they will
## be dropped
```

```
# Remove unwanted rows
r.summary.big<-r.summary[!(r.summary$Probability=="Highest"&r.summary$variable=="min"),]
r.summary.big<-r.summary.big[!(r.summary.big$Probability=="Lowest"&r.summary.big$variable=="max"),]
# order the data by time period, variable, and probability
r.summary.big<-r.summary.big[order(r.summary.big$Time.Period,r.summary.big$variable,r.summary.big$Probal
# number the rows
row.names(r.summary.big)<-1:nrow(r.summary.big)

# Compute the independent binomial probabilities of a total number of persisting geographic units based
convolve.binomial <- function(p) {
  # p is a vector of probabilities of Bernoulli distributions.
  # here p is response for the probability of each geographic unit persisting
  # The convolution of these distributions is returned as a vector
  # `z` where z[i] is the probability of i-1, i=1, 2, ..., length(p)+1.
  n <- length(p) + 1
  z <- c(1, rep(0, n-1))
  sapply(p, function(q) {z <<- (1-q)*z + q*(c(0, z[-n])); q})
  z
}

n<-1:nrow(r.summary.big) # variable for rows in results
#Create a list to store results
p.results<-list(name=character(0),p=matrix(NA,max(n)/6,7))
r.summary.big[]<-lapply(r.summary.big,as.character) # convert the list structure to character
# Name the results in the first element of the list and assign the results of the convolve function to
for (i in n[seq(1, length(n), 6)]){
  j<-(i+5)/6
  p.results$name[j]<-paste(r.summary.big[i,2],".",r.summary.big[i,3],".",r.summary.big[i,4])
  p.results$p[j,]<-convolve.binomial(as.numeric(r.summary.big[i:(i+5),5]))
```

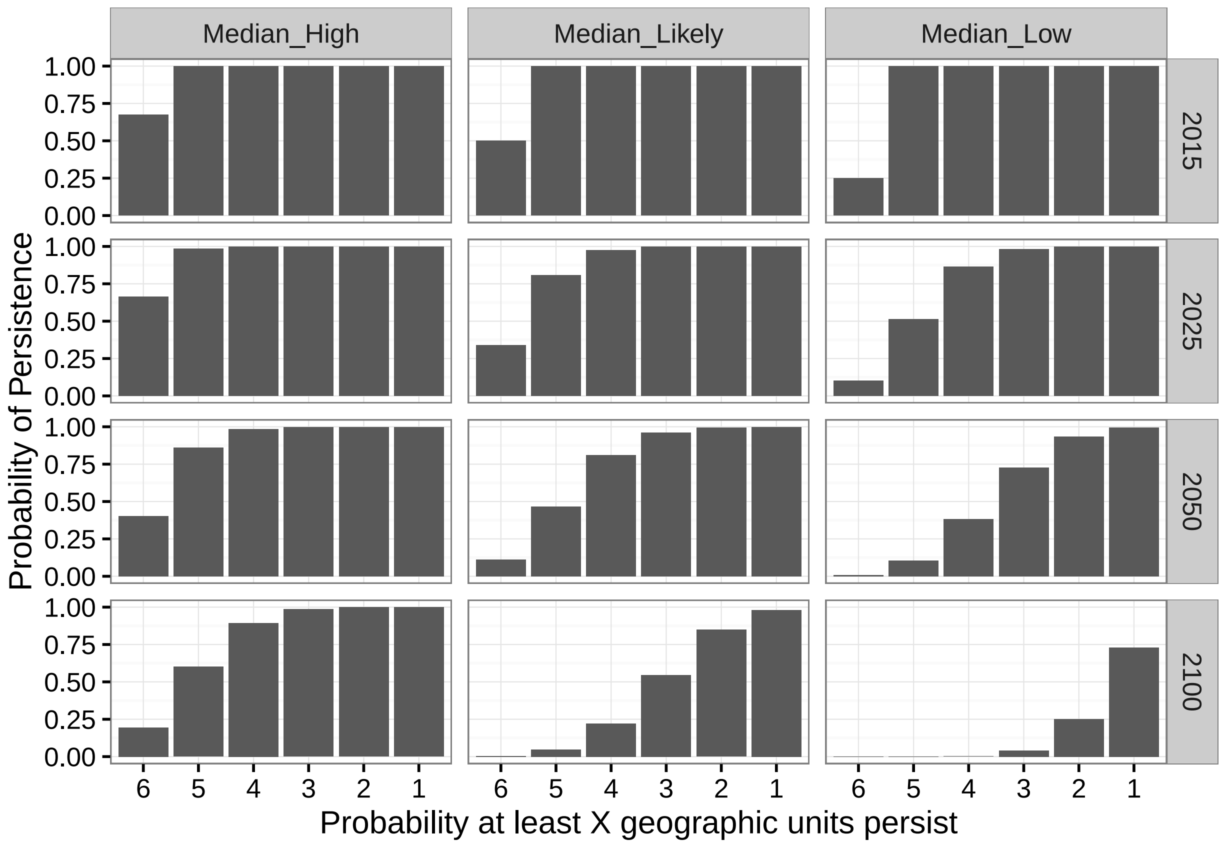
```r
}

#Manipulate the results
# flip the resulting persistence probabilities from the convolve function horizontally to order from 6 f
p.results$p<-p.results$p[,ncol(p.results$p):1]
# Name the columns
colnames(p.results$p)<-c(6,5,4,3,2,1,0)
# Name the rows
rownames(p.results$p)<-p.results$name
# drop the name portion of the list and retain the matrix only
p.results<-p.results$p
# Compute cumulative probabilities of persistence
c.results <- t(apply(p.results, 1, cumsum))

p.results<-melt(p.results) # Reorganize the results
names(p.results)<-c("name","Units", "Probability") # add names to the columns
# edit the text in the results, extracting the time period
Time.Period <- sub(" .*","", p.results[,1])
# combine them
p.results<-cbind(p.results,Time.Period)
# edit the text of the first column
p.results[,1]<-gsub(" . ",".",p.results[,1])
p.results[,1]<-substr(p.results[,1],6,100)
p.results[,1]<-gsub(" ","",p.results[,1])
# label the result probability type
p.results$Variable<-rep("Probability",nrow(p.results))

# Repeat for the cumulative probability results
c.results<-melt(c.results)
names(c.results)<-c("name","Units", "Probability")
Time.Period <- sub(" .*","", c.results[,1])
c.results<-cbind(c.results,Time.Period)
c.results[,1]<-gsub(" . ",".",c.results[,1])
c.results[,1]<-substr(c.results[,1],6,100)
c.results[,1]<-gsub(" ","",c.results[,1])
c.results$Variable<-rep("Cumulative Probability",nrow(c.results))

# Combine the results
res.summary.data<-rbind(p.results,c.results)
# Convert the unit column to a factor, change the names, and order the factors for the figure
res.summary.data$Units<-as.factor(res.summary.data$Units)
res.summary.data[res.summary.data$name=="Highest.max","name"]<-"Highest_High"
res.summary.data[res.summary.data$name=="Highest.median","name"]<-"Median_High"
res.summary.data[res.summary.data$name=="MostLikely.max","name"]<-"Highest_Likely"
res.summary.data[res.summary.data$name=="MostLikely.median","name"]<-"Median_Likely"
res.summary.data[res.summary.data$name=="MostLikely.min","name"]<-"Lowest_Likely"
res.summary.data[res.summary.data$name=="Lowest.median","name"]<-"Median_Low"
res.summary.data[res.summary.data$name=="Lowest.min","name"]<-"Lowest_Low"
res.summary.data$name<-factor(res.summary.data$name)
res.summary.data$name<-factor(res.summary.data$name,levels(res.summary.data$name)[c(1,5,2,6,3,7,4)])

# For all summaries
res.summary.data.all<-res.summary.data
```

```r
# Summaries for medians only
res.summary.data<-rbind(res.summary.data[res.summary.data$name=="Median_Low",],res.summary.data[res.summ

# Plot the probability of persistence across the six geographic units
res.plot.summary.p <- ggplot(data=res.summary.data[res.summary.data$Variable
    =="Probability",],aes(y=Probability,x=Units)) + geom_bar(stat="identity") +
  facet_grid(Time.Period~name) + scale_x_discrete(limits=c("6","5","4","3","2","1",
    "0"),labels=c("6","5","4","3","2","1","0")) +
  xlab("Probability exactly X geographic units persist") + ylab("Probability of Persistence") + theme_bw
# select the data for the probability density figure, assign the x and y variables for ploting, make a

# Show the figure
res.plot.summary.p
```

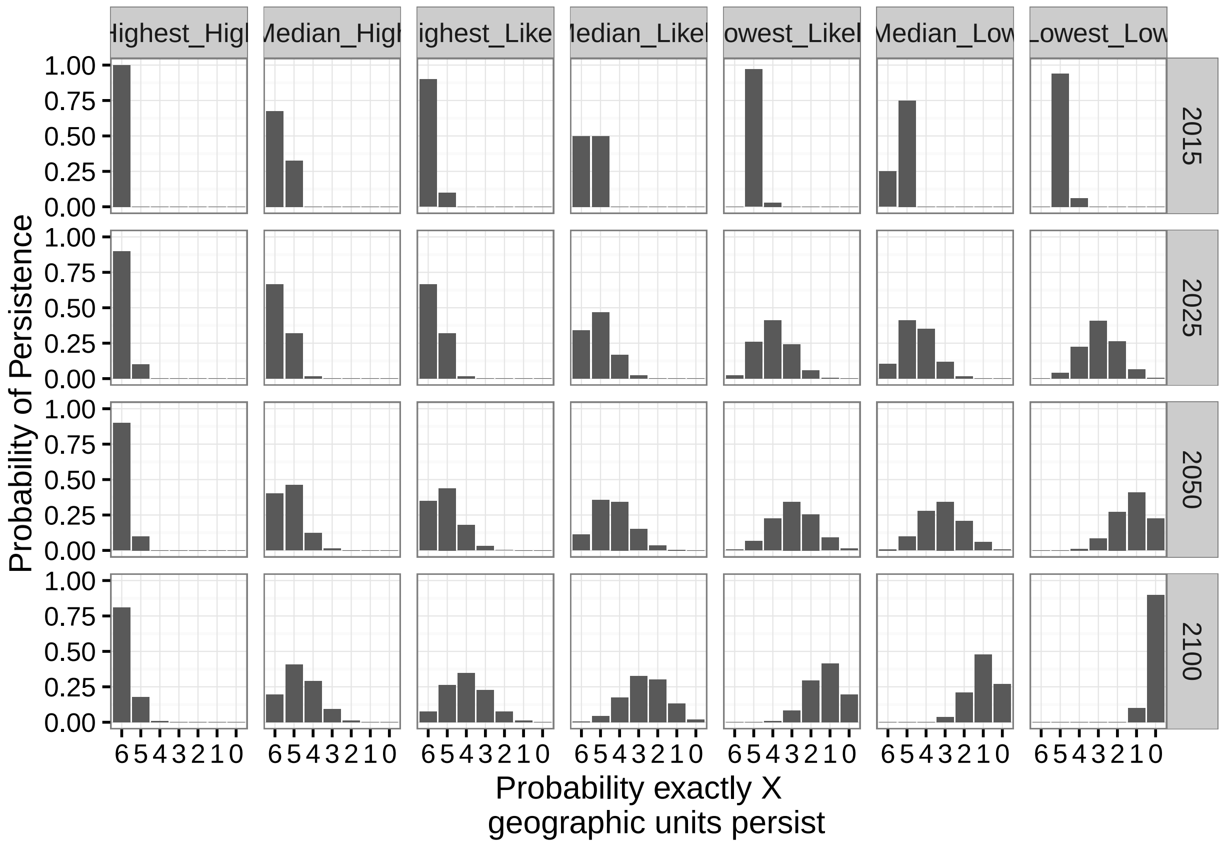



```r
# Plot the cumulative probability of persistence across the six geographic units
res.plot.summary.cp <- ggplot(data=res.summary.data[res.summary.data$Variable==
    "Cumulative Probability",],aes(Probability,x=Units)) + geom_bar(stat="identity")+
  facet_grid(Time.Period~name) + scale_x_discrete(limits=c("6","5","4","3","2",
    "1"),labels=c("6","5","4","3","2","1")) +
  xlab("Probability at least X geographic units persist") + ylab("Probability of Persistence") + theme_
# As above, but select the cumulative probability data and limit the x axis to positive values

# Show the figure
res.plot.summary.cp
```

```
## Warning: Removed 12 rows containing missing values (position_stack).
```

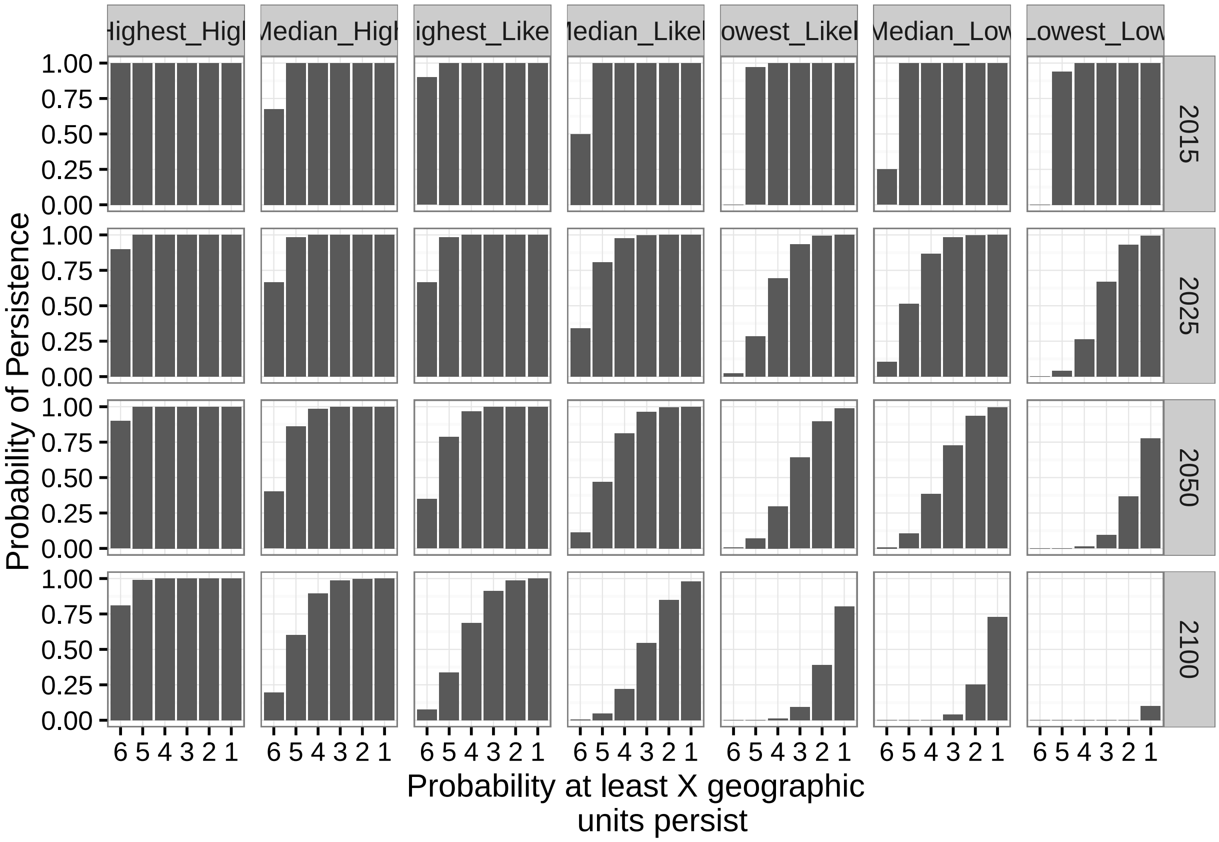



```
# Plots for all summaries.  This produces the same figures as the sections above, but with all summarie
# Plot the probability of persistence across the six geographic units
res.plot.summary.all.p <- ggplot(data=res.summary.data.all[res.summary.data.all$Variable
    =="Probability",],aes(y=Probability,x=Units)) + geom_bar(stat="identity") +
  facet_grid(Time.Period~name) + scale_x_discrete(limits=c("6","5","4","3","2","1",
    "0"),labels=c("6","5","4","3","2","1","0")) + xlab("Probability exactly X
    geographic units persist")+ylab("Probability of Persistence") + theme_bw()
# select the data for the probability density figure, assign the x and y variables for ploting, make a

# Show the figure
res.plot.summary.all.p
```




```
# Plot the cumulative probability of persistence across the six geographic units
res.plot.summary.all.cp <- ggplot(data=res.summary.data.all[res.summary.data.all$Variable==
    "Cumulative Probability",],aes(Probability,x=Units)) + geom_bar(stat="identity")+
  facet_grid(Time.Period~name) + scale_x_discrete(limits=c("6","5","4","3","2",
    "1"),labels=c("6","5","4","3","2","1")) + xlab("Probability at least X geographic
      units persist") + ylab("Probability of Persistence") + theme_bw()
# As above, but select the cumulative probability data and limit the x axis to positive values

# Show the figure
res.plot.summary.all.cp
```

```
## Warning: Removed 28 rows containing missing values (position_stack).
```



Highest_High
Median_High
Highest_Likely
Median_Likely
Lowest_Likely
Median_Low
Lowest_Low
2015
2025
2050
2100
1.00
0.75
0.50
0.25
0.00
Probability of Persistence
6 5 4 3 2 1
Probability at least X geographic units persist