IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Conserving and managing carnivore populations is often one of the most challenging ecological and sociological problems facing wildlife biologists. Public opinion ranges from recognition that predator diversity and abundance are positive indicators of healthy ecosystems yet at the same time predation can create conflicts with livestock and impact on other wildlife species. For some time, wildlife ecologists have had a special interest in middle-sized carnivores (mesopredators) often because some are quite rare, or sometimes because their populations are naturally expanding. In Iowa, one of the first species to catch the attention of the Iowa Department of Natural Resources (DNR) was the bobcat (*Lynx rufus*). Bobcats are one of the most widely distributed cat species in the world, ranging from southern Canada into central Mexico. Historically, bobcats were found throughout Iowa, but they had nearly disappeared due to large-scale habitat loss and unregulated hunting and trapping that occurred during the century after Euro-American settlement. Until recently bobcats have been largely absent from the Corn Belt region of the Midwest. When Iowa established a Threatened and Endangered species list (T&E) in 1977, bobcats were listed as Endangered, and harvest was banned. But by the late 1990's reports of road-killed or incidental sightings of bobcats were becoming more frequent and though they were uncommon the species was down-listed to Threatened in 2001. By 2003, apparently more common though sparsely distributed in Iowa the species removed from T&E, and changed to simply Protected status. There is also federal protection because bobcats "look like" other species of spotted cats which are rare or endangered worldwide, so conservation of bobcats is also regulated by the U.S. Fish and Wildlife Service under the Convention on International Trade in Endangered Species (CITES).

Project Overview and Objectives

Biologists within the DNR and Iowa State University began wondering "where are these bobcats coming from and what can be expected about the future population dynamics." In 2003 a collaborative study was initiated that lasted about 10 years, one of the most comprehensive studies of bobcats that was ever done anywhere (Gosselink and Clark 2009, Gosselink et al. 2011). Among the first objectives of the project were to a) determine local home range and habitat selection by bobcats, especially in relation to the configuration of forest, grassland, and agricultural habitats. We also b) developed methods to efficiently assess statewide distribution and studied the potential for dispersal throughout Iowa. As we collected more data, we were able to c) evaluate recruitment (pregnancy and births) and survival (and causes of mortality). These vital rates were then used to derive estimates of the rate of population growth that could be used to direct conservation and management. A major objective was on d) population and landscape genetics, especially designed to understand the genetic connections of the Iowa population to other bobcat populations in the Midwest. Ultimately this part of the project expanded into an assessment of the genetic variation of bobcats across the nation.

This study laid the foundation for conservation and management of bobcats in Iowa and has become important to the conservation of the species across the continent. Many aspects of this research continue to the present day. The subsequent parts of this report highlight the results of the project and provide access to general information and scientific reports. If you wish to cite any of this information, please use the original science citations, rather than this summary. If you have further questions or more specific information you may contact:

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Bobcat Description and Life History

Bobcats are medium-sized carnivores, with males (~25 pounds) being larger than mature females (~18 pounds). Total body length is 25-35 inches. The largest bobcat we recorded in Iowa was 35 pounds. Bobcats get their name from the "bobbed" tail (~5 inches) which is black above and white below (Figure 1). They have a fluffy facial ruff and small ear tufts which are readily visible in the photos. Bobcats also have distinct white patches on the back of their ears, which is visible in some photos. Overall body coloration may range from grayish with spots (common in Iowa) to more reddish in other parts of the range (especially the Southwest). The underside is white with black spots and there is often distinctive spotting on the front and hind legs. Generally, bobcats from the southern parts of the range are paler colored and strongly distinctive underside spotting is most common in the northern Great Plains part of the species range.

Figure 1. Bobcat #154 collared in Iowa

Bobcats appear much larger than domestic cats because of the fluffy coat and facial ruff and longer legs. They have quick reflexes, but their common gait is a slow and deliberate path. Bobcat tracks are about the same length as width (overall print is a round shape), measuring approximately 2 inches by 2 inches. Generally, bobcat tracks can be recognized by the shape of the print, the lack of claw marks (because they have retractable claws), toes arranged "in front" of the interdigital "palm" pad, and the "M" shaped palm pad (with two lobes on front and three lobes on the rear) (Figure 2 and Figure 3). Many people confuse bobcat tracks with coyote or dog tracks. Canine tracks typically are longer than they are wide (diamond shaped) with two outside toes "below" the front toes, and the palm pad is triangular, with a single lobe on front and a double lobe on the rear. Canines most often show claw marks, though not always. The most reliable characteristic is the shape of the track and pads. Another useful feature is that canine paths tend to "wander" back and forth compared to the more direct path of bobcats. Bobcats are rarely seen because they are active between dusk and dawn, but they are readily captured on trail cameras.

Figure 2. Bobcat paw and comparison to coyote

Figure 3. Bobcat tracks in mud

Habitat Use, Diet, Social Structure, and Dispersal

We began the study in an 8-county area in southcentral Iowa where bobcat sightings were most common (Figure 4). The first task was to capture bobcats so that we could fit them with radio-telemetry collars to determine habitat use and movements. Initially we captured animals using live traps (the first bobcat #000 was caught in Lake Aquabi State Park) but we quickly realized this was very labor intensive (Figure 5).

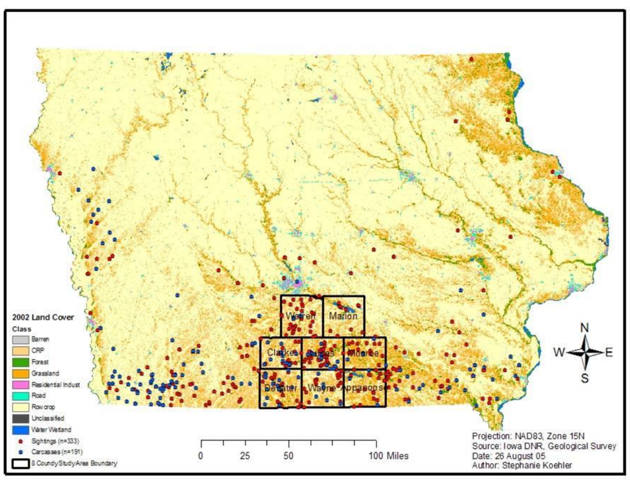

Figure 4. Location of study counties in Iowa

Figure 5. Capture of the first bobcat #000

Subsequently we trapped bobcats in properly set, padded foothold traps. The greatest success of our project was the cooperation of local trappers, which enabled us to mark a large sample of bobcats. Technicians were "on-call" every day to travel to the location of a captured bobcat, anesthetize the animal, check condition, and mark the animal. Once the animal was anesthetized, it was ear tagged, radio-collared, a tooth was extracted for aging, a tissue sample was taken for genotyping, and blood was drawn to check for diseases (all capture and animal handling procedures were approved by the Iowa State University Committee on Animal Care and Use, Gosselink et al. 2011). Collars were designed to last over 2 years, and some were designed to enable relocation via satellite.

Figure 6. Attaching ear tags and radio collar to anesthetized bobcat

Figure 7. Cooperating trapper with bobcat

<u>Home Range</u>: Between 2003-2008 we radio-marked 158 bobcats. By relocating each animal every other day, we could estimate home range (the area used by animals during 1 year) and also identified habitat used. When bobcats died, we recovered the carcass determined cause of death. When they dispersed long-distances we relocated them from an airplane (Koehler 2006).

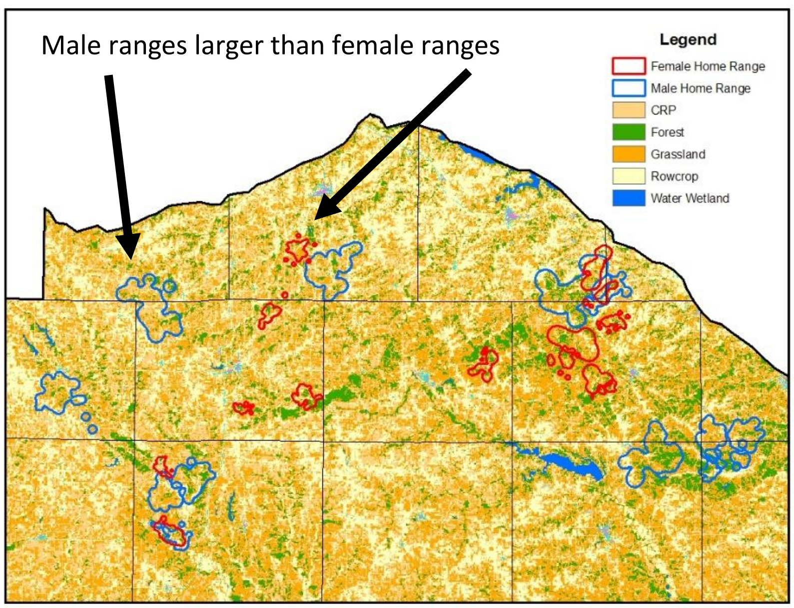

Figure 8. Example home ranges across the study counties

Figure 8 shows examples of home ranges of males (blue) and females (red). Male bobcats are generally solitary, with an average home range area of 22 square miles. Female home ranges averaged about 7 square miles when they had kittens and then expanded to about 10 square miles as the kittens became more active with age. Male home ranges often overlapped 2-3 females, whereas females excluded other females. Bobcats mark the home range with scent posts along frequently used travel routes. Bobcats were primarily nocturnal with peaks of activity around dusk and dawn. They hunt by stalking and ambushing prey (cottontails, mice and voles, squirrels) in brushy forest and along habitat edges. Bobcats used forested habitat most frequently, but their activity encompassed the full range of habitats, including pastures, Conservation Reserve grasslands, and agricultural areas. Although radioed bobcats were sometimes located in corn and soybean fields, they crossed such areas quickly and usually followed waterways or field edges as they did so. As Figure 8 shows, an average home range consisted of multiple patches of forest, where the largest patch comprised about 8% of the home range. Forest patches were surrounded by grasslands, not row crops, and the largest row-crop patch comprised less than 3% of the home range. Although home ranges were not necessarily shaped by stream corridors, the areas used commonly contained streams or ditches. In the home range core, where 50% of telemetry locations were found, forest comprised about 20% and pasture/grassland comprised about 40%. Forest and grassland patches are widely scattered in the southern Iowa landscape and home range area increased as the fragmentation of the landscape increased. However, in areas dominated by row crops, home ranges became smaller and simpler in shape to conform to the limited preferred habitat. Females with kittens were found in dense forest patches and were often associated with brush piles that enabled them to avoid disturbance, particularly by coyotes (Tucker et al. 2008). Annual home ranges shift over the course of an animal's lifetime, which wildlife ecologists refer to as lifetime home range. Adult female home ranges shift relatively little in the landscape, whereas adult males may sometimes relocate home ranges as much as 10-20 miles. In contrast, young bobcats eventually disperse away from the home range where they were born (see below). We were able to recapture and refit collars on many bobcats so that we could recalculate home ranges over a lifetime. This map shows annual home ranges of the Aquabi female (#000) from 2003 to 2007 (total lifetime home range). This female drowned with two kittens, in the park sewage lagoon. Another 1-year-old female that we marked in 2006 was legally trapped in 2016 less than 1 mile from where we tagged it, having survived 10 trapping seasons.

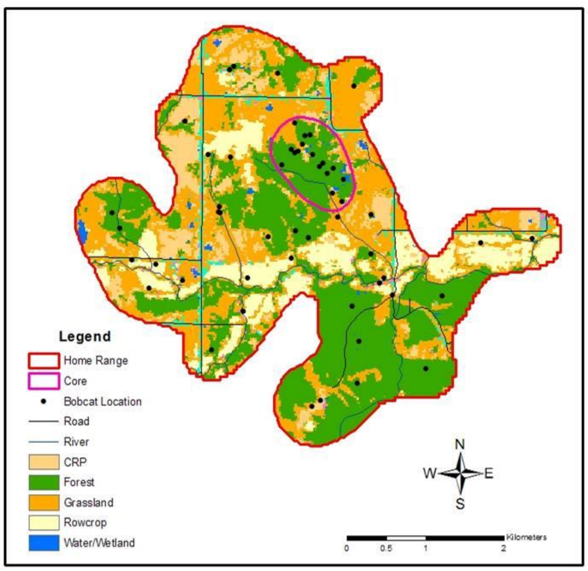

Figure 9. Home range and core habitat

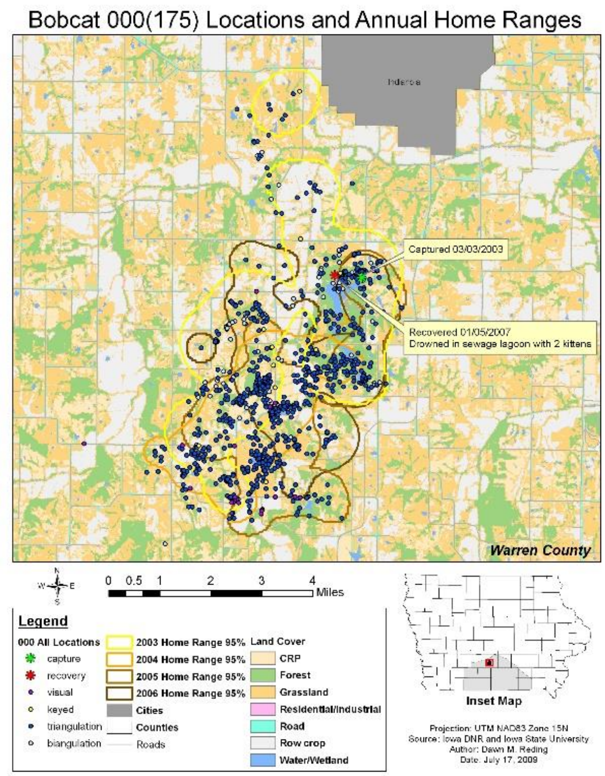

Figure 10. Home ranges of female #000 over 4 years

Besides suitable land cover, another component of habitat is preferred prey. Iowa DNR collected carcasses from road-killed and harvested bobcats that provided a lot of essential biological data, including dietary data. Bobcats are highly adapted carnivores with large canines, shearing teeth, and strong jaws. We examined the stomachs of 100 bobcats (male and female, adult and juvenile) that were primarily collected October to May. Like reports from other places, bobcat diets in Iowa were >95% mammal prey. Sixty percent of stomachs contained cottontail rabbits, 20% mice and voles, and 15% fox squirrels. We found turkey and pheasant in only 2 stomachs, and only one other bird species. There was evidence of deer in 12 stomachs, but it was primarily hair and that plus the small volume suggests it was likely consumed as carrion (Brockmeyer and Clark 2007). The significance of cottontail rabbits as prey was further enhanced by the importance of the roadside counts of cottontails as a predictor variable in statewide distribution of bobcats in Iowa (Linde 2010). Although there have been questions about the impact of bobcats on game birds and deer, no study anywhere in the United States has concluded that bobcats are a limiting factor on populations of game animals.

Figure 11. Bobcat skull-note canines and shearing back teeth

Figure 12. Cottontail rabbit remains from a bobcat stomach

Dispersal: The radio-collared and ear-tagged individuals enabled us to determine dispersal over both short and very long distances. Young-of-the-year bobcats tend to remain with the adult female through autumn and their first winter. Dispersal behavior may begin in the spring before they turn age 1 year but is a gradual wandering behavior that may take place over as much as a year before they settle in suitable habitat. The average age of dispersal in our population was about 17 months. Sixty five percent of males moved at least 1 home range diameter from the edge of their natal home range whereas only 26% of females did so. On average juvenile males dispersed 43 straight-line miles, whereas juvenile females dispersed only 14 miles. Dispersal distance was more variable among males compared with females. Bobcats that successfully dispersed established home ranges in landscapes with essentially the same composition of forest, grassland, and agriculture as their natal home range (Hughes et al. 2019). During dispersal bobcats jump from patch to patch, follow natural paths such as corridors along drainages, quickly cross large areas of row crops, and use temporary home ranges (Reding et al. 2013). As the map of the dispersal of male 154 illustrates, large cities like Des Moines are barriers to movement. The narrow river corridors, predominance of row crop agriculture in northern Iowa, and perhaps lack of conspecifics was unsuitable, and 154 returned southward after a period of 3-4 months of wandering (Gosselink et al. 2011). The most extreme dispersal we observed among our marked bobcats was by a male that was recovered in Cass County, Nebraska over 150 miles from our study area. We regularly observed movements of marked animals from southern Iowa into Missouri.

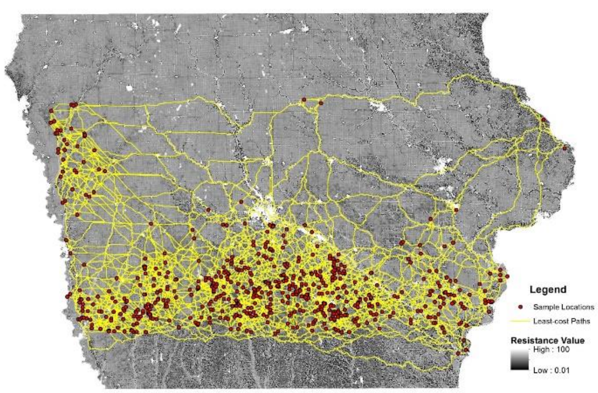

Figure 13. Potential least cost dispersal paths in Iowa

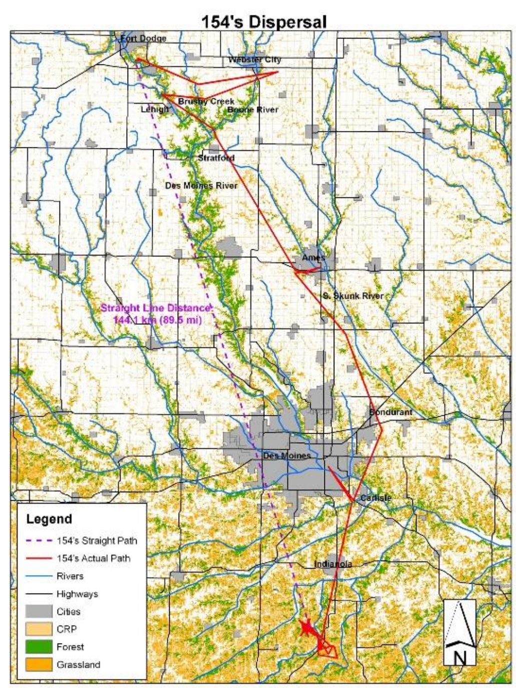

Figure 14. Brief movement of #154 from southern Iowa northward before return

In addition to the data from marked animals, we used genetics to study the regional connections of Iowa bobcats with other states in the Midwest region (Reding 2011, see details below). We described potential dispersal paths from southern Iowa by connecting sampled bobcat genotypes linked by the least cost dispersal paths using suitable habitat across the landscape (Figure 14). In both Figure 13 and Figure 14, it is apparent that lack of suitable habitat impedes connectivity with bobcat populations north of our study area (Reding et al 2013).

Statewide Distribution

To fully understand the dynamics of bobcats it was necessary to study how local habitat selection and dispersal influenced populations across Iowa and even regionally. DNR biometrician S. Roberts and W. Clark developed the Bowhunter Observation Survey (BOS) as a repeatable and cost-effective method to survey bobcats (and other mesocarnivores) across the state (Gosselink and Clark 2009). Bowhunters (archery deer hunters) are ideal observers of wildlife because they are knowledgeable and spend many quiet hours pursuing deer at their favorite hunting locations, on both public and private land across the state. A survey diary was sent to about 9000 hunters (about 90/each county) on which the hunter recorded the counties where they hunted, the number of hours they hunted during each trip, the number of deer, turkeys, and mesocarnivores that they saw. The survey was started in 2004 and continues to the present. It provides input from about 2000 hunters each year, who make over 20,000 unique trips, and over 70,000 hours of observations across the state. The results are summarized as the number of bobcats observed/1000 hunter-hours (Figure 15), which illustrates that bobcats are relatively common in the southern tiers of counties but much rarer in the northern part of the state (https://www.iowadnr.gov/hunting/population-harvest-trends).

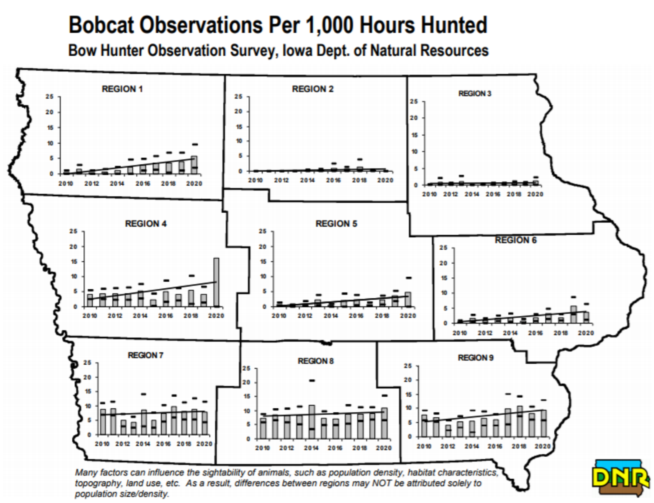

Figure 15. Bowhunter Observation Survey designed during the bobcat research project

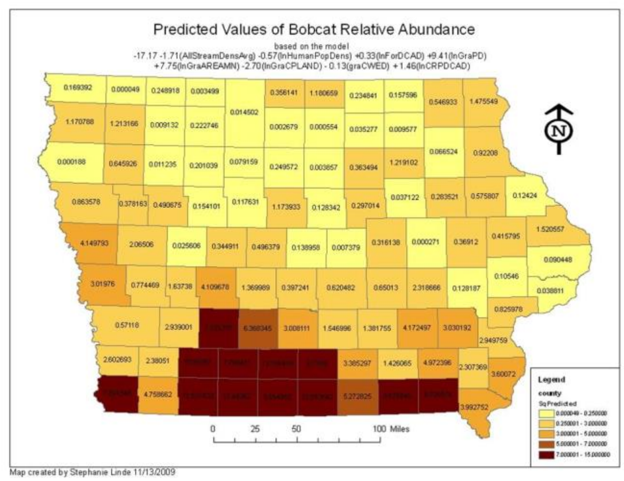

Figure 16. Predicted relative abundance of bobcats based on the BOS

From these observations we can calculate that an average bowhunter in southcentral Iowa might expect to see a bobcat about every 2+ years whereas a hunter in the northcentral region might not see one for 20 years! Using BOS data from 2004-2009, Linde (2010, Linde et al. 2012) developed models that linked variables of landcover composition and configuration (e.g. forest patches, edge configurations) human factors (e.g. population density), and interspecific interactions (e.g. coyote and cottontail abundance) and predicted the expected BOS counts for comparison to the observed counts. Forest and grassland patch density, area of grassland including CRP were variables that positively affected counts. Counts were negatively affected in landscapes with sharp edges between forest and agricultural fields (the opposite of soft edges of forests with transitional edges with grassland) and those with higher human population density. There was a significant but weak positive association with cottontail rabbit abundance but no significant negative association between bobcat and coyote counts. Linde et al. (2012) validated that the predicted values accurately reflected the observed BOS counts. Therefore, we could use these models to link habitat suitability to the expected relative abundance of bobcats in each county across Iowa (Figure 16).

In another analysis, Linde (2010) built models that predicted the probability of the presence across the landscape (Figure 17). The data for these models was simply the mapped the presence from confirmed locations of sightings, road kills, and trapped animals. Like the county-level models, amount and configuration of grassland, forest, and amount of forest/grassland edges increased likelihood of presence, and human density and area in row crops decreased the probability of presence. Viewed at the watershed scale, the results provide insight into landscape ecology in ways that are not obvious from the county maps.

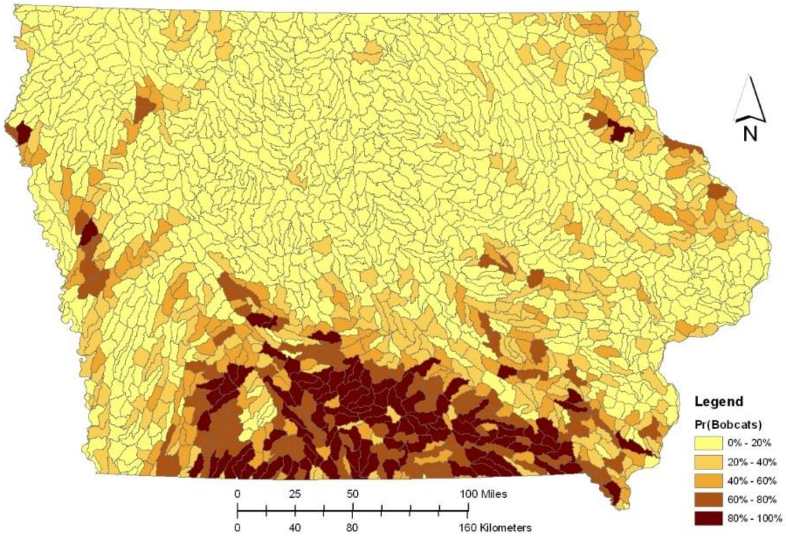

Figure 17. Predicted presence of bobcats within watersheds of Iowa

For example, you can visualize the potential effects of river corridors for enhancing distribution. You can also identify watersheds in northeastern Iowa (where bobcats were essentially absent at the time of the analyses) that have similar habitat characteristics to those areas in southern Iowa where bobcats were common.

Demographics: Reproduction, Survival, Population Projection, and Harvest

Reproduction: The primary source of data on reproduction and age structure of bobcats was taken from carcasses that were accidentally or legally trapped or road-killed in Iowa. We extracted teeth from these carcasses (also from live-captured individuals) that we then aged by examining the cementum annuli (like tree rings). During necropsy we examined the uterus of females from which we could determine pregnancy rate and litter size of females of each age class. We collected over 1000 carcasses that could be accurately aged and examined reproductive tracts of 292 adult females. Bobcats may begin breeding as early as February but most breeding in Iowa takes place in March through April. Females give birth about 60 days later which means that most young are born in April to June. Juvenile bobcats are not mature in their first winter of life, so they do not breed until their second winter, when they are aged 1 year and approaching their second birthday. We observed litters from 1-7 kittens, with the most common litter size of 3. Sixty percent of females in age class 1-2 were pregnant which is less than the pregnancy rate of 85% of females 2-3 years old and older. Taken together the pregnancy and litter size data emphasize that adult females in the 2-3- and 3-4-year age classes produce most of the kittens in the population (Gosselink et al. 2011).

Figure 18. Bobcat kittens in a hollow stump in Iowa

Survival: We estimated survival rates in two ways. We calculated survival from the distribution of ages among tooth sections taken from 476 female and 556 male carcasses (Figure 19). There was no significant difference in the observed age distribution between males and females, so the sexes were combined in these age analyses. Because of variation in sampling, we fit a smoothed curve to the observed age data (note that the kitten age class 0 is not included in the figure). Surviving proportions drop steeply from age 1 through 3. Estimated survival rate of age 1 (yearlings) was 69%, age 2 was 31%, and age 3 was 18%. Less than 3% of the bobcats in Iowa are expected to live ≥ 5 years. The oldest female we examined was age 9 and the oldest male was age 13.

Figure 19. Observed (dots) and smoothed (curve) age distribution of Iowa bobcats

We marked and released 158 bobcats from 2003-2009 and logged over 20,000 relocations (Tucker et al. 2008, Gosselink and Clark 2009). In any given year we had as many as 58 radio-collared bobcats simultaneously active. We recorded the date and cause of mortality from these animals and then used these data to calculate survival from 1 April (the peak breeding point) to the next year (Figure 20). The survival patterns of radioed females and males were similar, despite the differences between the sexes in habitat use and behavior that we described above. Fig. 20 is the survival rate estimated from the telemetry data for 1-2-year-olds (red line) and 3-5 year olds (black line). Note that the timeline starts at 1 April. The vertical line indicates the start of the Iowa trapping season (~ 1 November). It is important to be careful with the interpretation of the illustrated patterns. First, the estimates do not separate data collected before 2007 (when trapping was first allowed) from data after that year. Regardless, it is clear from the steep decline in survival of both age groups that much mortality is somehow associated with the fall and winter season when trapping is allowed. Whether the two age groups are equally vulnerable to trapping was not determined. Also looking at the black line, we can see that the survival rate from 1 April to the beginning of trapping season (i.e. only natural mortality) declines more gradually than after the season opens. Looking at the red line, the very gradual change in survival rate among the 1-2-year-olds after 1 April is biased because bobcats could not be radioed until they were about 6 months old. In fact, combining the estimated "red-line" survival with our crude estimate of kitten survival indicates that survival to age 1 is about 59%, which is nearly identical to the "black-line" survival of 60% of older bobcats (Gosselink et al. 2011). One final point is that the survival estimated from these telemetry data is lower than the rates estimated from the age structure analyses.

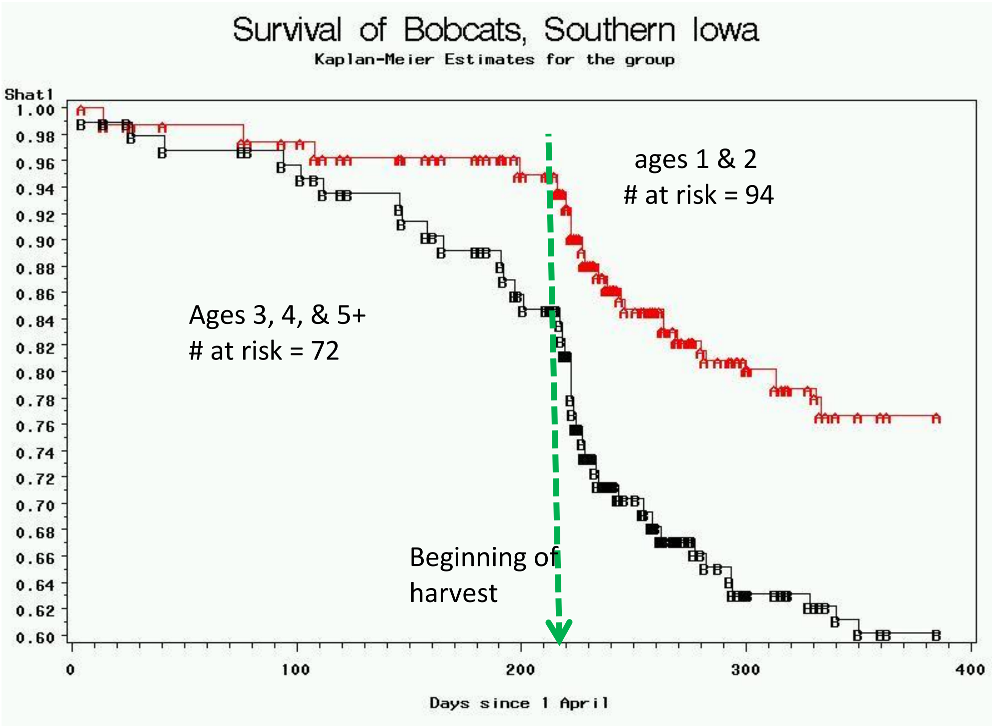

Figure 20. Annual survival rates estimated from radio-collared bobcats in Iowa

From telemetry we were able to conclude cause of death in 62 cases. Natural mortality (drowned, predation including dogs, disease) accounted for only 8%. Most mortality is human caused. Illegally shot or trapped (i.e. not during a designated open harvest season) ranked first (23%) among human-caused mortality, followed by road-killed (21%), accidentally trapped (i.e. non-target take during legal trapping season for other species or after the bobcat quota was reached (18%), legally harvested (18%). Sometimes the radio-collar or a skeleton was recovered with little evidence of a cause. After the study, when a harvest season was opened, illegal and non-target take have declined, though ~80% of mortality remains human-related (https://www.iowadnr.gov/hunting/population-harvest-trends).

We also made a special effort to determine if disease was a potential cause of mortality by assessing the prevalence of antibodies in the blood samples. Disease of could potentially be important in limiting population growth of bobcats, especially if they showed signs of infection by agents commonly associated with domestic cats (*Felis catus*) which are widespread in association with humans. Some infectious agents carried by bobcats may be transmitted to other wildlife, domestic pets, or humans. There is particular interest in feline immunodeficiency virus (FIV), the coccidian protozoan *Toxoplasma gondii*, and cat scratch disease (*Bartonella)* which is spread by arthropod bites. We sent a total of 155 frozen samples (26 whole blood and 135 serum/plasma) to colleagues at Colorado State University (Fort Collins, Colorado USA) for analysis of antibodies. The results of the screening for antibodies to various feline infectious diseases was remarkably uninformative with very few positives for any of the tests (Gosselink et al. 2011). Antibodies to *Toxoplasma* were found in 2.3% of the samples. This low seroprevalence of *Toxoplasma* in Iowa bobcats is particularly striking because prevalence rates in other wildlife and domestic cats in Iowa in the mid-1980‟s ranged from 15% in raccoons to 80% in domestic cats (Hill et al. 1998). Seroprevalence of *Bartonella* was similarly low, only detected in 1.6% of the samples. FIV was completely undetected in the Iowa bobcats. The absence of FIV is perhaps not expected because FIV strains are highly species-specific, and it rarely undergoes effective transmission between felid species. We were unable to test for feline leukemia virus (FeLV) nor did we do complete necropsy to check for internal parasites such as tapeworms. But based on these data, we conclude that mortality from disease is not presently a major factor in Iowa bobcat dynamics. And in the opposite sense, bobcats are unlikely to be a source of domestic cat or human disease transmission because they are unlikely to become highly abundant in urban and suburban areas where transmission is most likely.

<u>Population projection</u>: We had two sources of information to calculate the rate of population growth: a) the combined reproduction and survival data, and b) the trends in the BOS survey. A simple way to express the rate of population growth is as a percent increase (e.g. a population that increased from 100 to 105 from one year to the next has a rate of

increase of 5% per year). But wildlife populations often fluctuate, in some years increasing (e.g. +5%) and in others declining (e.g. -5%), so we estimated long-term averages of expected growth.

First, we combined our field data on reproductive and survival rates into mathematical models to calculate an average potential rate of growth of the southern Iowa bobcat population. We used the reproductive rates, age structure, and survival rates in models to project potential population growth. Gosselink et al. (2011) reported the details used to test this projection modeling. Given the average estimates of reproduction and survival with no variation, we estimated the expected long-term average growth rate to be 5.5% each year. From the model we calculated that the expected long-term age distribution is weighted to young ages; 53% young of the year (0-1), 28% yearlings (1-2), and 12% aged 2-3), which closely matches the observed age data. The analyses also highlight that females ages 1-2 and 2-3 contribute many offspring to the population each year because they are abundant in the population. But females greater than 3 have a large importance to long-term growth and future genetic changes in the population.

Applying such models in a realistic way to conservation and management requires we make realistic assumptions, accounting for the sampling variation and the natural variation in birth and death, both of which will affect our final estimate of growth. Also, in an expanding population we tried to account for potential dispersal into vacant habitat. In our analyses (Gosselink et al. 2011) we incorporated variation in reproduction and survival, and identified the vital rates that were most influential to changes in the population growth rate. For example, we assumed that below average conditions for reproduction and survival occur relatively infrequently in this colonizing population and given that assumption estimated that the average rate of growth per year was 8.5%. But the statistical interval on that estimate ranged from slight decline (-1%) to rapid increase (19%). In Figure 21 you can see the effect of incorporating this variation—projected populations fluctuate, some remaining relatively level and some declining or increasing greatly over 15 years. We determined that population dynamics is most sensitive to variation in yearling female survival, more than twice as influential on growth rate as variation in reproduction of yearling and older females. By the end of our research, we had data on survival and reproduction based on large sample sizes that enabled thorough analyses of likely population growth of bobcats in Iowa and potential effects of hunting and trapping.

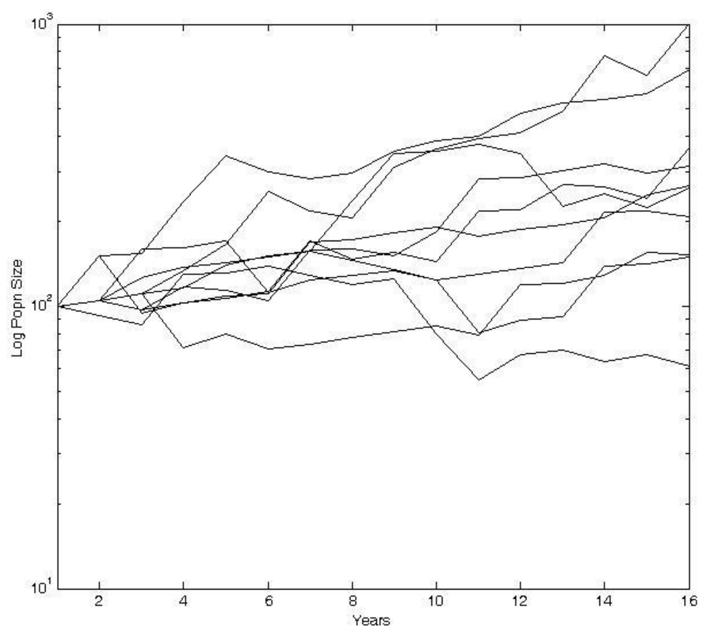

Figure 21. Simulated population trends of Iowa bobcats over 15 years

A second way we could estimate population growth was to use the BOS trends to compare to the projection projections. The BOS average trend in the South Central region, the location of our study area, was equivalent to 3% increase per year, lower than the two estimates discussed above but consistent with the slow, sustained rates that have continued (https://www.iowadnr.gov/hunting/population-harvest-trends). Trends in the Southeast and Northwest appear steepest; at the time of the study Central was equivalent to 13% and in the Southeast is equivalent to 25%, as large or larger than the upper confidence limit of simulated growth. Such rates would be consistent with rapidly colonizing populations. In the northern regions of Iowa, the survey indicates that there have been only trivial increases in sightings of bobcats. The projected and observed rates across southern Iowa are almost constant, reflecting conditions when the population has reached carrying capacity of the landscape. In Central and Western Iowa, the population analyses are consistent with continuing colonization, and those in Northern and Northeastern Iowa consistent with population dynamics of sparse populations.

<u>Harvest potential</u>: Harvesting a wildlife population while at the same time ensuring that the population is conserved must be based on sufficient scientific data. A familiar analogy is living off the interest on a bank account while never depleting the capital investment. But compared to banking with consistent returns, wildlife population variability makes managing removal with fixed harvest quotas notoriously difficult. Another complication about bobcats is that reproduction occurs over about two months in spring, survival changes seasonally (Figure 20), and harvest seasons occur in fall and winter. We had to incorporate these factors into the modeling. The Iowa DNR began considering opening a bobcat season during Phase I of the project and opened a limited season in 2007. At a minimum, setting harvestable limits requires an estimate of the rate of population growth and an estimate of population size, both of which we refined as this study continued. Estimating the population size is the most difficult; in fact, there is no way to directly measure total population over areas as large as a state. However, we had solid scientific data to indirectly estimate the population with confidence. Using the BOS, Linde et al. (2012) and Linde (2010) estimated relative population size of bobcats based on habitat across all the counties in Iowa, and as Figure 16 and Figure 17 illustrate the greatest population is in southern Iowa. Tucker et al. (2008) and Koehler (2006) provided the home range area needed by each female and male bobcat. We assumed that eventually all available habitat would be utilized and calculated maximum population density for all counties. For example, in Clarke County, with an area of 431 square miles, there would be habitat for as many as 46 adult females and 19 adult males. Accounting for reproduction and survival of kittens yields an estimate of 157 bobcats at the end of October. That density is about 0.36 bobcats per square mile, or 13 bobcats/township (36 square miles). By accounting for the estimated variances in the home ranges, litter size, and survival, along with variation in the BOS estimates, we calculated that the Clarke County population could range from 111 to 184 bobcats. In 2007 when the Iowa DNR proposed a season, we applied the relative abundance estimates across the 21 included counties and estimated the total population estimate of approximately 1155 bobcats.

Finally, using the data on rates of growth and population size we estimated the potential rate of harvest and a target harvest quota. Recalling that the harvest season comes in the fall and winter, toward the end of the biological year, the estimated sustainable harvest rate is slightly lower than the projected growth. Effectively the underlying concept is that the population would have enough surviving adults to reproduce and sustain a steady population size. With liberal assumptions about variation, we approximate the sustainable harvest rate as 7.8%. Using the averaged parameters, the rate would be about 5%. Applying these rates of sustainable harvest to the 21-county area we estimated that harvesting between 58 and 92 bobcats would be sustainable. By the time of the 2010 season the population had expanded further, and we had more complete data on dynamics. We estimated 2812 bobcats for the 35-county open zone with confidence intervals between 1987 and 3637. The estimated quota on a population of 2812 would be 140 or 224.

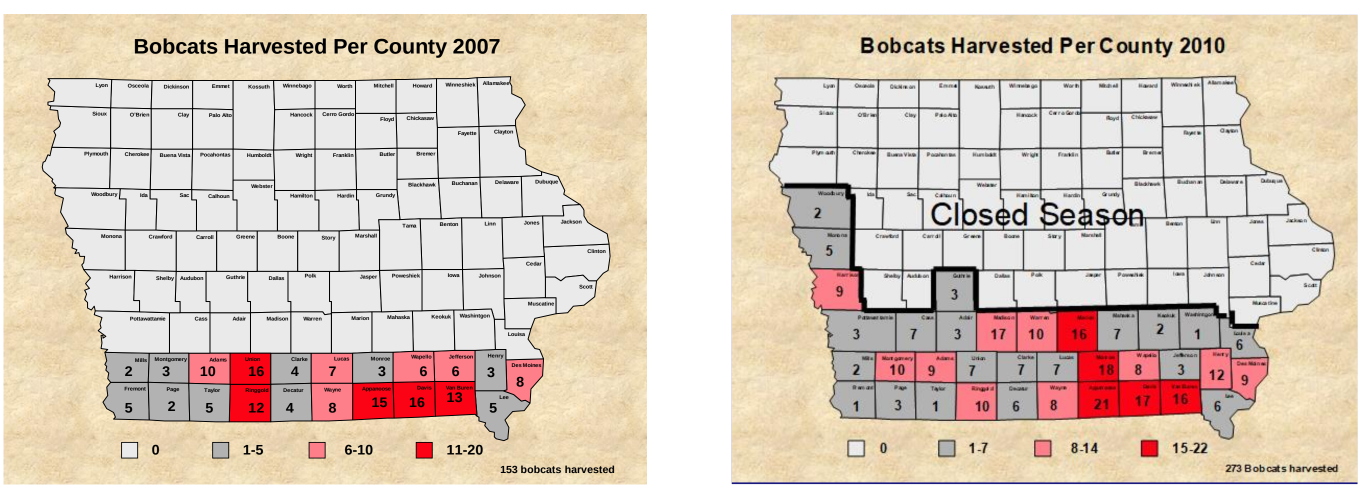

Figure 22. Actual harvest of bobcats in two of the early seasons under the recommended quota system

We recommended a conservative approach based on the lower estimates of population size and sustainable growth. In 2007 the quota was 150 bobcats and 154 were harvested (2.6% over target). By 2010 the quota was 250 bobcats and 274 bobcats were harvested (9.6% over). This relatively conservative approach adopted in the early years of open harvest accomplished both the goal of a sustainable harvest and continued expansion of bobcats in Iowa (https://www.iowadnr.gov/hunting/population-harvest-trends).

Population and Landscape Genetics

As we noted at the outset a major motivation for this research was to understand the population and landscape genetics, particularly to determine the connections of the Iowa population to other bobcat populations in the Midwest. Genetic methods have become so common that the public is aware of their use in research and management of wild animal populations. Examining DNA can be done non-invasively to determine the sex of individuals, assign paternity, track dispersal, and identify relatedness at local, regional, and continental scales. On the local scale, we examined the social and population structure within Iowa to understand whether expanses of row crop agriculture, major highways, cities, and large rivers act as barriers, limiting distribution within Iowa (Figure 14). At the regional scale we used genetics to investigate whether the population in Iowa is separate and self-sustaining, or if it is part of a broader subpopulation that includes bobcats in surrounding states. The regional connections might be particularly important to predicting how conservation in surrounding states may impact Iowa's bobcat population, and vice versa. We were so successful at obtaining tissue samples from regional cooperators that we expanded analyses to landscape genetics of bobcats across the continent.

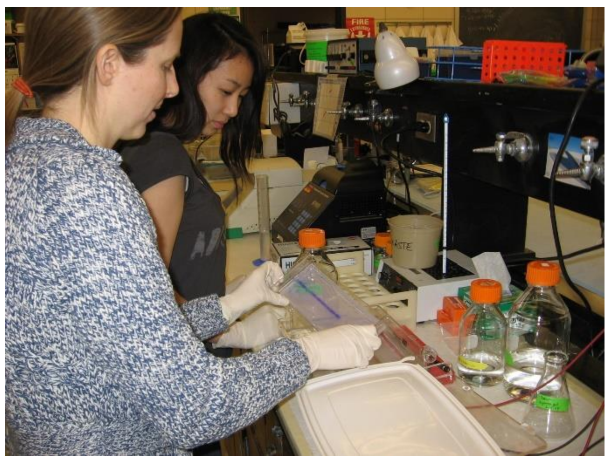

Figure 23. Dawn Reding examines a gel from bobcat DNA extraction

We collected tissue from the bobcats we captured during the telemetry studies, from carcasses of those that were road-killed, accidentally killed, and legally harvested. We also received tissue samples taken by cooperating agencies and fur-harvest facilities all over the continent. During the study we extracted and amplified DNA from tissue samples of over 2000 bobcats. We based our analyses on microsatellites, which are short repeated DNA sequences at various locations throughout the genome of an animal. They are good indicators of genetic similarity or variation. We benefited from the fact that other researchers were also using microsatellites identified from bobcats, Canada lynx, and domestic cats. We used DNA found in the mitochondria within cells (inherited maternally) and the nucleus (inherited maternally and paternally). Our analyses characterized genetic variation by identifying alternative sequences at specific microsatellite locations on the genes (called alleles), across 15-19 microsatellites (i.e. in popular terms, their DNA "fingerprint"). Individuals were clustered into the same subpopulation when the observed proportion of similarity of their genotype was >75% (Reding 2011, Reding et al. 2012).

<u>Regional subpopulations</u>: At the regional level bobcats in Iowa are part of a subpopulation including northern Missouri, Kansas, and southern Nebraska (red) (Figure 24). There is a large gap in distribution across the intensively agricultural Corn Belt separating the Iowa subpopulation from other subpopulations in Minnesota/Wisconsin (purple) and lower Michigan (blue). The "red" subpopulation remains distinct from the "green" and "yellow" populations, even though there are no obvious physical barriers like the Corn Belt. However, the observed patterns are likely related to ecoregional differences in habitat. The distribution of the "red" subpopulation suggests adaptation to the open habitats of the "Prairie Peninsula" of the Central and Southern Plains. The "green" subpopulation lives in habitat of the Eastern

Temperate Forest. Asterisks denote samples where the genotype was somewhat mixed between subpopulations. We draw attention to the samples intermediate between eastern Iowa and Wisconsin, which suggests that dispersing individuals might begin to bridge the gap across the Corn Belt through that area.

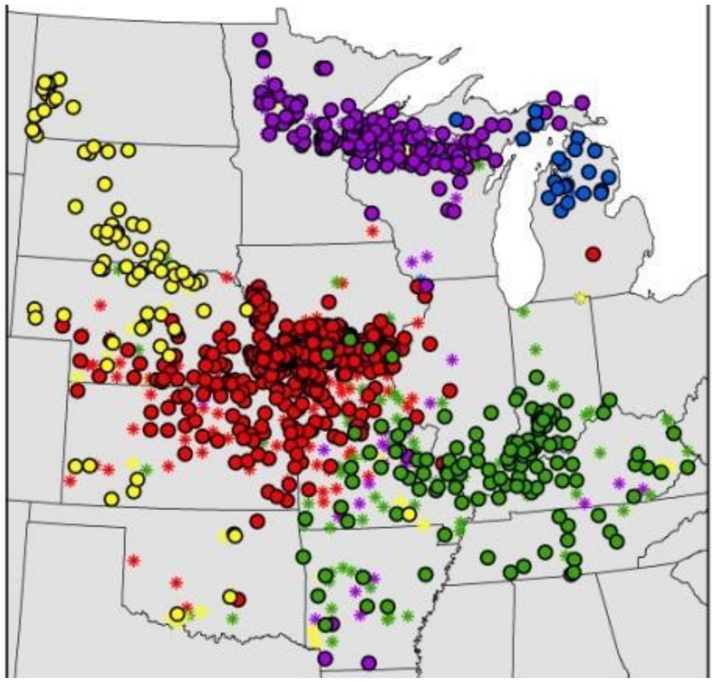

Figure 24. Subpopulations in the midwestern USA identified by genetic analyses

Continental subpopulations: As we noted at the beginning, bobcats are distributed coast to coast and from southern Canada to Mexico. Original description of subspecies was based on color and spotting of the pelage and morphological characteristics like head size and length of limbs. Morphological descriptions separated bobcats into as many as 12 subspecies. The regional analyses of variation stimulated us to investigate whether there were deeper evolutionary divergences related to landscape ecological factors across the continent. Starting with the DNA inherited maternally enabled us to examine the evolutionary history back to the time of the last glacial maxima. These analyses distinguished bobcats in the eastern USA from those in the western half (Figure 25), even though there is no obvious current physical barrier separating them. Instead, the data support a scenario of a historical midcontinent barrier. During the Pleistocene glaciation, bobcat populations in the east and west were apparently isolated in the southern parts of the continent. They remained separated for thousands of years by the relatively arid and treeless conditions in the midcontinent Great Plains. The dashed line indicates this suture zone (Figure 25). We estimated that expansion northward may have begun between 28,000 and 67,000 years ago, as suitable habitat became more widely available (Reding 2011, Reding et al. 2012). But bobcats didn't populate the northern states until the glacial ice completely receded about 12-15 thousand years ago.

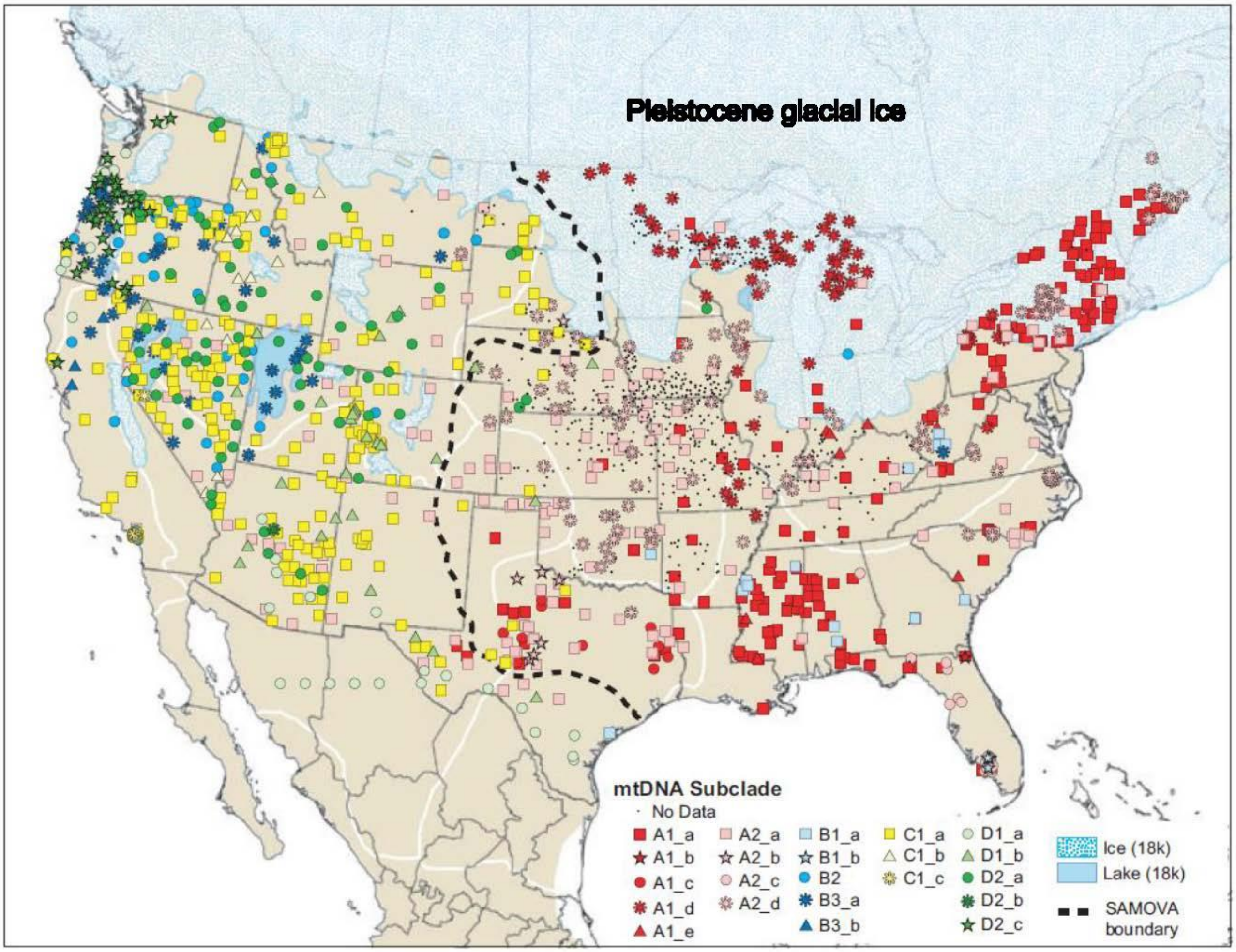

Figure 25. Ancestral clades (basal lineages) of bobcats across North America, identified through analyses of maternally inherited DNA

Using the DNA inherited both maternally and paternally we resolved additional substructure within the two main bobcat lineages (Figure 26). Habitat loss and extirpation during Euro-American settlement in places such as the Midwest and mid-Atlantic region seem to have contributed to population genetic structure. Lower peninsula Michigan is isolated by the barriers of agriculture and urbanization and the Great Lakes. Founder effects are evident in the North and East (with reduced genetic diversity) as bobcats expanded into regions previously covered by glacial ice. Considering the mountainous terrain of the West there was less variation than we expected, except for the Oregon/Washington difference west of the Cascade Mountains. There is an isolated population in the Everglades of Florida. However, two prominent topographic features - the Mississippi River and Rocky Mountains - were not supported as significant genetic barriers. Ecological regions and environmental variables explained a small but significant proportion of genetic variation across the bobcat range.

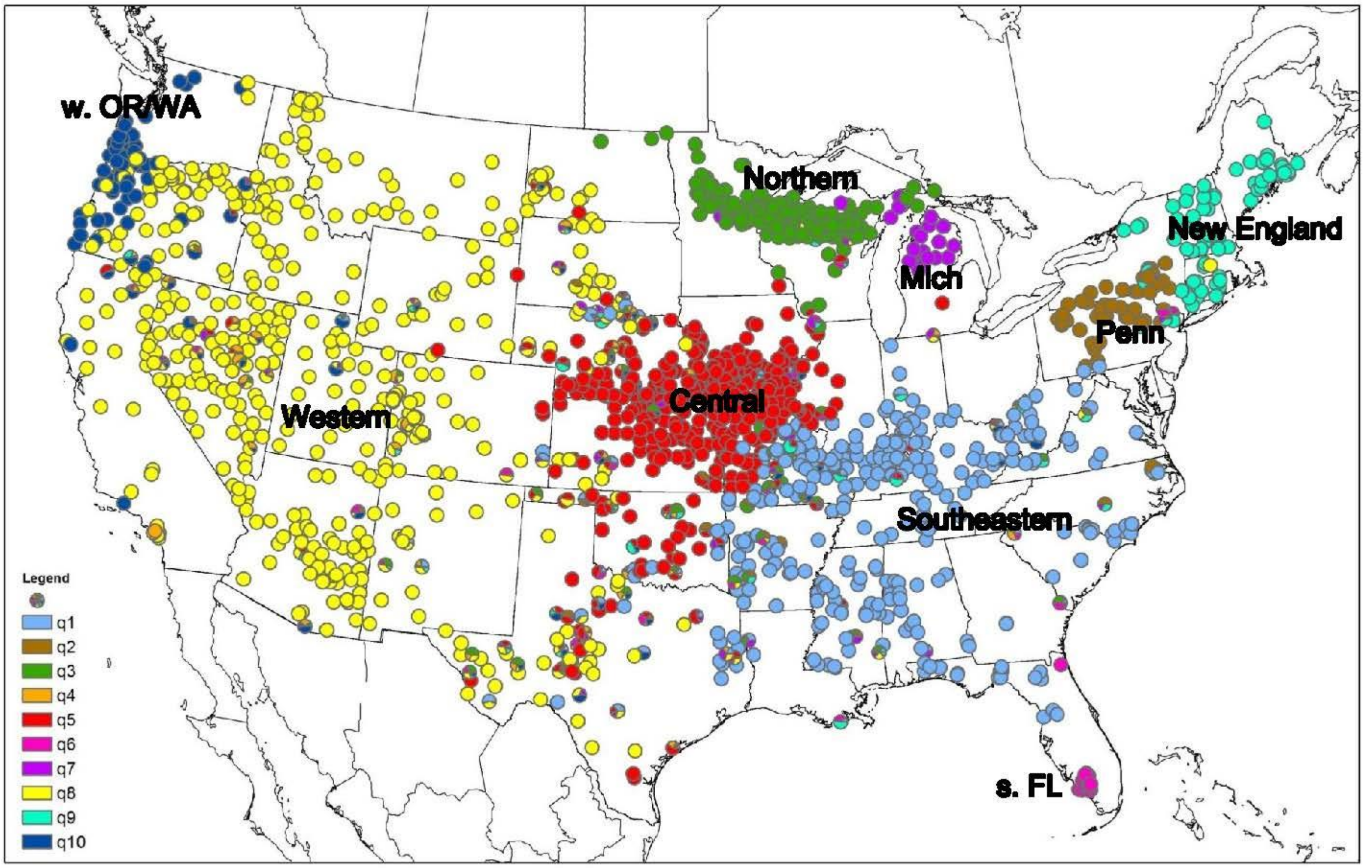

Figure 26. Subpopulations of bobcats across the USA, identified by analyses of DNA inherited both maternally and paternally

Although we only had a few samples from Mexico, they had unique genetic sequences, suggesting additional investigation of subspecific distinctiveness of Mexico's bobcat population. Based on this research (Figure 25, Reding 2011, Reding et al. 2012), the Cat Specialist Group of the International Union for the Conservation of Nature (Kitchener et al. 2017) recognized only two subspecies of bobcats in the USA; (*Lynx rufus rufus*) east of the Great Plains, and (*Lynx rufus fasciatus*) west of the Great Plains. They also encouraged investigation of potential subspecies in Mexico. Interestingly, the pattern of broad delineation of carnivore subspecies across the mid-continent has also recently been made evident by studies of gray fox (Reding et al. 2021).

Outreach, Collaborations, and Funding

The project attracted lots of interest from the public. We held many public meetings in southern Iowa to inform people about the project and to encourage trapper cooperation. Staff and students collectively made hundreds of presentations to schools, conservation organizations, civic clubs, and county conservation boards. The project received media attention from newspapers and magazines across Iowa, media attention including KCCI television. The Missouri Department of Conservation included the Iowa bobcat project in a documentary they made regarding the importance of research as the basis for conservation planning and management of bobcats.

Figure 27. Todd Gosselink talks to the public at a meeting at Red Haw State Park

The principal investigators who designed and led the project were Dr. William R. Clark, Department of Ecology, Evolution and Organismal Biology, Iowa State University, and Dr. Todd Gosselink, Wildlife Research Biologist, Iowa Department of Natural Resources (DNR). Initially the project was motivated by Ron Andrews, formerly Furbearer Biologist with the DNR, supported by Dr. Terry Little, Research Supervisor for the DNR. James Coffey, DNR Wildlife Research Technician, oversaw much of the daily operation, including radio-telemetry, carcass collections, and liaison with DNR officers and county conservation boards.

Figure 28. Dawn Reding explains the project to DNR Deputy Director, Pat Boddy, Director Rich Leopold, and DNR Commissioner Kim Francisco at a "carcass necropsy gathering."

Three students earned advanced degrees during this study. **Stephanie Koehler Tucker**, MS, initiated the telemetry field work and analyzed home range and habitat selection; she is now the Furbearer Biologist and Game Management Section Leader of North Dakota Game and Fish Department in Bismarck. **Stephanie A. Linde**, MS, modeled the statewide distribution and abundance; she now is a GIS Specialist for the Climate Adaptation Center at the University of Minnesota, Twin Cities. **Dawn M. Reding**, PhD, led the research on landscape genetics. Dr. Reding was co-advised in the laboratory of Dr. Anne M. Bronikowski, also in the Department of Ecology, Evolution and Organismal Biology, Iowa State University. Dr. Reding is now a Professor at Luther College, Decorah, Iowa.

This project could not have been accomplished without the hard work of many technicians who spent countless hours in the field, literally 24/7/365, including holidays. Many went on to graduate study and have careers with wildlife conservation, research and management agencies throughout the U.S. and Canada. Technicians: Derek Broman, Chad Holy, Alicia Andes, Eric Schroder, Dan Fredrickson, Kristy Bellinger, Jaclyn Comeau, Jennifer Timmer, Jim Kauffman, Chad Tucker, Scott Williams, Sara Hansen, Jennifer Kanine, Jessica Parkhurst, Kelcey Brockmeyer, Heather Stricker, Megan Jones, Jessica Davis, Beth Orning, Jessica Bolis, Matt Purvis, Calvin Duncan, Nick McCann.

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