

The Spatial Ecology of *Lynx canadensis*

By

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Undergraduate departmental honors thesis
Bachelor of Arts – May 2011
Department of Geography
March 30, 2011

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Abstract

Lynx canadensis is a mammalian carnivore with a distribution spreading from Alaska to Newfoundland to Colorado. The latitudinal and anthropogenic alterations over this range provide many variations in lynx habitat, food source, and population characteristics. Studies from one part of the range do not necessarily extrapolate to another causing a widespread lack of knowledge regarding lynx requirements. This is especially pertinent to lynx in the contiguous United States where lynx were listed as threatened in 2000 according to the U.S. Endangered Species Act of 1973. To this end, I have analyzed research, focusing on those that occur in the lower half of lynx range, in order to determine lynx habits and the degree to which outside forces act upon them. Where possible, I have taken aspects from this research and applied it to lynx populations in Colorado. The result is a better understanding of lynx needs and preferences within the state, and a realization of where research gaps exist.

History

Lynx canadensis (lynx) is a North American carnivore with its prime habitat centered in the boreal forests of Canada and Alaska. Its historic range extends from Alaska to Nova Scotia with peninsular or island extensions (McKelvey 2000*b*) into the U.S. down the Rocky Mountains, the Cascade Range, and the Northeast and Great Lakes regions. In most research and in this paper, lynx in the contiguous United States and the border region of Canada are delineated as in their southern range, while populations in central to northern Canada are in the northern range. Colorado is the southernmost extent of the historic range (Devineau 2010*a*), but the last verified wild individual in the state was trapped in 1974 (Halfpenny 1974). In 2000, after having been extirpated from many U.S. states, the lynx was listed as a threatened species (USA Fish and Wildlife Service, 2000). With this listing a surge in research took place concerning lynx in the southern range. Prior to 2000 most information on the lynx was known due to studies undertaken in its northern range. These studies are good for general information, but are not necessarily applicable to lynx living in different habitats or climates, relying on other prey, or having a different population structure, such as those in the southern range. Since 2000 there have been many studies in the southern range, but many more are needed to better understand population needs in order to develop conservation plans.

In Canada lynx are abundant with trapping permitted throughout the western provinces. Lynx occur throughout most of the country, but are considered endangered in New Brunswick and are believed extirpated from mainland Nova Scotia and Prince Edward Island (Ruggiero 1994). Most studies on the lynx have taken place in Canada where, in comparison to the southern range, the boreal forest is homogenous, human

interference is minimal, prey is more abundant, and fewer types of competitors exist (Murray 2008). However, understanding lynx in the north is vital for understanding lynx in the south. Northern lynx are the core population and undergo an 8-11 year population cycle of highs and lows, which follows the cycle of their primary prey the snowshoe hare. During high and low lynx populations, individuals migrate long distances and may find their way into the southern range.

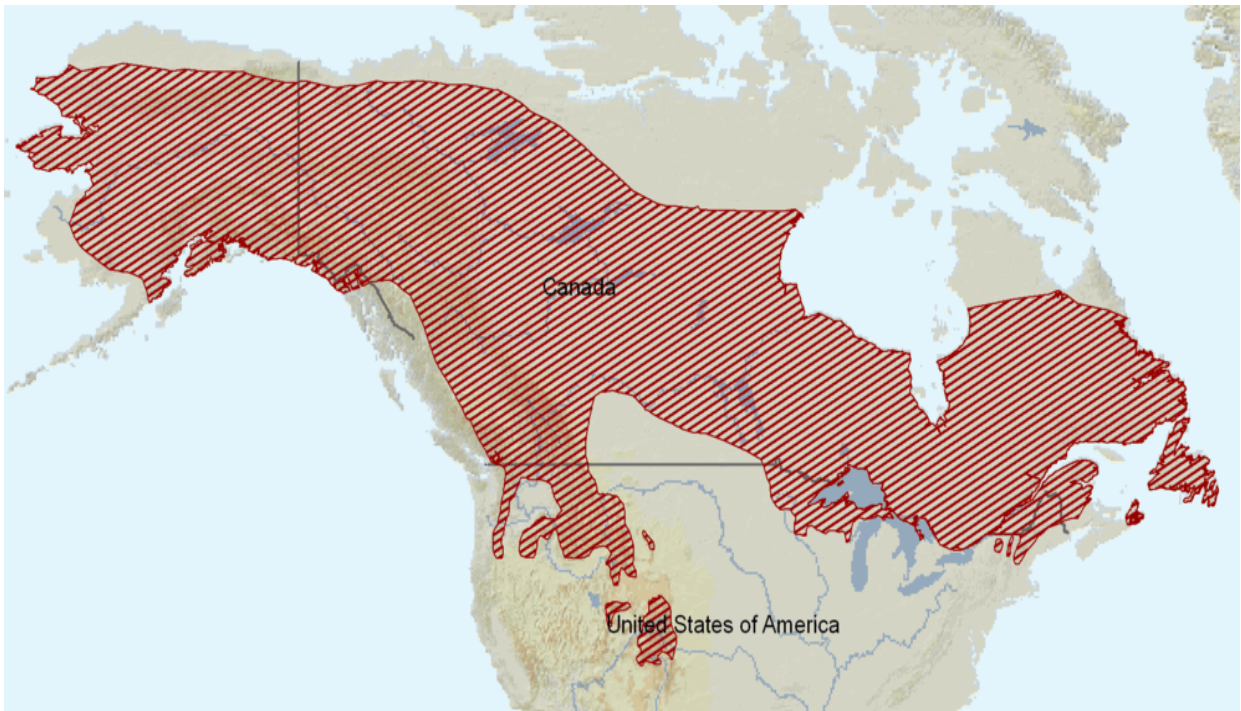


Figure A. Lynx canadensis range. The IUCN Red List of Threatened Species. Lynx canadensis. 3/30/11 <http://www.iucnredlist.org/apps/redlist/details/12518/0/rangemap>

In 1997 Colorado began a lynx reintroduction program. Captured lynx from Alaska, British Columbia, Manitoba, Quebec, and Yukon were brought to a rehabilitation center in southwest Colorado to acclimatize (Devineau 2010a). Between 1999 and 2006 218 lynx were released within 40 km of the Rio Grande Reservoir. The goal of the project was to establish a “self-sustaining lynx population within Colorado” (Devineau 2010a). To evaluate progress, the program used these objectives:

- 1) “Reintroduced lynx demonstrate a high rate of survival in the critical first months after release.
- 2) Released adult lynx demonstrate low mortality rates over the longer term, particularly in good habitat.
- 3) Lynx remain in good habitat at densities sufficient for breeding.
- 4) Reintroduced lynx successfully reproduce.
- 5) Lynx born in Colorado survive and also successfully reproduce (“recruitment”).
- 6) On balance, lynx recruitment equals or exceeds mortality over an extended period of time (CDOW 2010)”.

As of June 2010 the project is viewed by the state as a success because all of these goals have been met. Indeed, after ten years the program has been a short-term success, but in order to determine long-term success it will take more time and more knowledge of lynx behavior. These goals are only useful for short-term success as the first, second, and fourth only apply to reintroduced individuals and goals five and six have no requirements regarding amount of reproduction or recruitment. Lynx in Colorado have reproduced and been recruited, but for a carnivore with a large home range, low population density, and high offspring mortality, reproduction and recruitment should be much higher than mortality (McKelvey 2000*a*).

The reintroduction has taken place under the care of the Colorado Department of Wildlife (CDOW), which continues to monitor and collect data on the lynx. Knowledge of lynx habitat, migration patterns, prey, and population structure are important for a statewide and regional conservation plan. Studies by CDOW are currently under way, including one discerning lynx habitat and distribution through occurrence data (Eric Odell, personal email). But researching lynx is difficult because they occur at low

densities, have large ranges, and live in habitats that are difficult to access. Colorado is a unique portion of lynx range because individuals occur at the highest elevations and populations are the most disjunct from other populations out-of-state. In time, the most beneficial course for understanding lynx in Colorado would be multiple studies in varying seasons, habitats, and regions. Until that time it would be helpful if studies from out-of-state could be applied to lynx in Colorado. This paper reviews research on the lynx and uses their applicable aspects to describe habitats, population structure, denning sites, prey types, and migration tendencies of lynx in Colorado.

There are several reasons why Colorado is used as the region of interest as opposed to a natural boundary. First, the reintroduction was a state project. The goal of the project is to establish a self-sustaining population within Colorado and has done so without aid from neighboring states. Second, the historic population core of lynx occurring in Colorado was situated in the west-central portion of the state and lay mostly within state boundaries (Fig 1). Lynx habitat in this area is disjunct from similar areas in Utah and Wyoming by 150 km and is, therefore, an island population with unknown connections to adjacent populations (Fig 2, McKelvey 2000*b*).

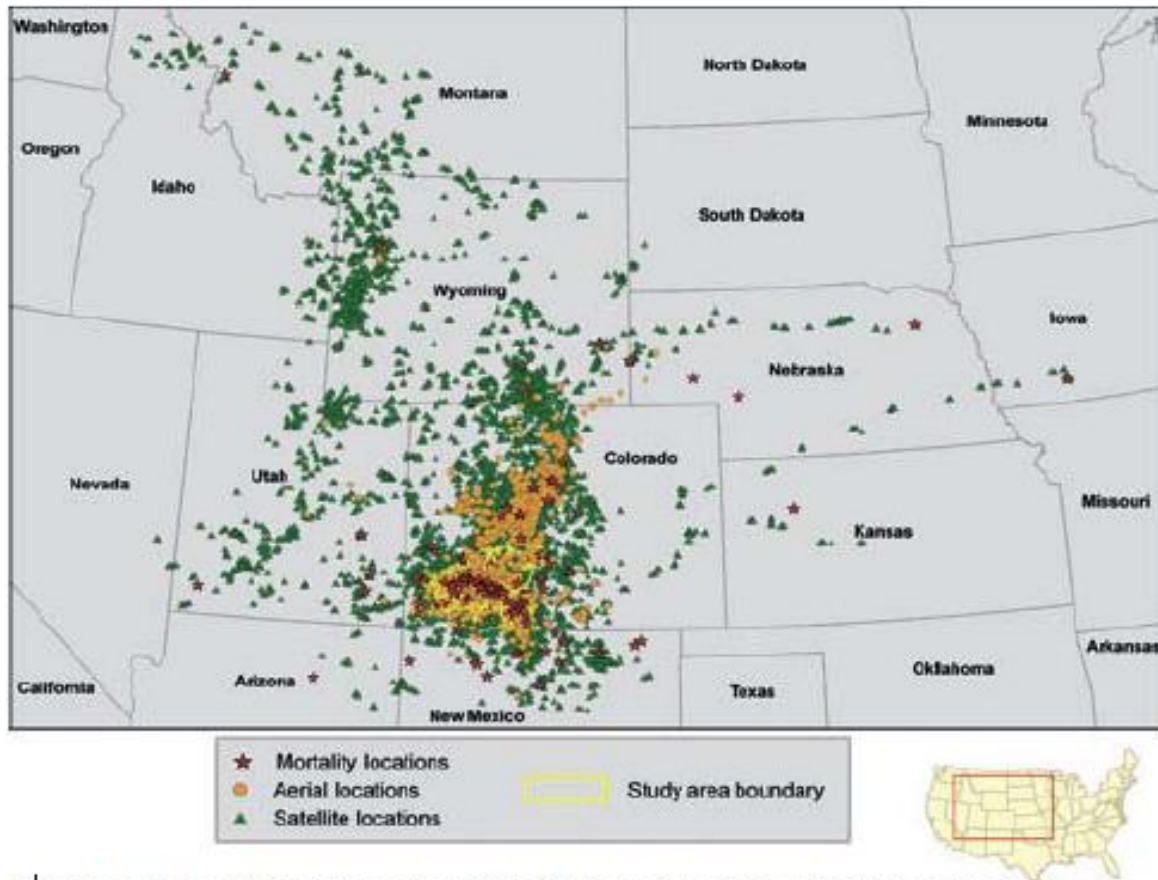


Figure 1. Map outlining the core reintroduction and main monitoring area, and showing locations obtained by either satellite or aerial radio telemetry for the 218 Canada lynx reintroduced into Colorado from February 1999 to November 2007. Figure reproduced from Devineau *et al.* (2010).

Devineau, Olivier, Shenk, Tanya M., White1, Gary C., Doherty Jr, Paul F., Lukacs Paul M. and Kahn, Richard H. "Evaluating the Canada lynx reintroduction programme in Colorado: patterns in mortality". *Journal of Applied Ecology*. 2010, 47, 524–531

Physical description

Lynx canadensis is one of three felids held in common between the U.S. and Canada, along with bobcats (*Lynx rufus*) and cougars (*Puma concolor*). Females generally weigh 8.5 kg and are 82 cm in length; males 10 kg and 85 cm (Ruggiero 1994). Lynx are much smaller than cougars and slightly larger than bobcats. The winter fur of lynx is grayish-brown on the back, and grayish-white on the belly, legs, and feet. Their summer fur has more red, gray, and brown. Lynx have notable tufts of fur protruding

above the ear and a flared facial ruff. Lynx look very similar to bobcats, but have a few distinguishing features. Lynx have a small tail with a black tip on all sides, compared to bobcats, which have a black tip only on the top portion. The fur color on the backs of lynx is fairly uniform, while the bobcats are spottier. Lynx have long legs for their body size and their hinds are longer than their fores. They have proportionally large paws, which act similarly to snowshoes. The morphology of the legs and paws help the lynx hunt effectively in deep snow and give them a winter advantage over bobcat and cougars.

Competition with bobcats, cougars, and coyotes may be a challenge to the survival of lynx in the southern range. Cougars and bobcats compete with lynx by interference, where they drive lynx from habitat with threatening behavior (Buskirk 2000). Cougars may kill lynx if the two come in contact (Buskirk 2000). Coyotes and bobcats compete by exploitation, where they prey on similar species and force lynx out of habitat due to food shortage (Buskirk 2000). The winter advantage lynx have over the three competitors is only useful where snow is deep, which causes concerns over global warming and the northward movement of the competitors. Habitat fragmentation may aid coyotes and challenge lynx. Studies document that coyotes utilize snow packed roads and snowmobile trails to enter forests that would otherwise be inaccessible (Buskirk 2000).

Methods

This paper is a review of studies that occurred in the southern range or are applicable to the southern range. Many of these studies took place in Maine, Washington, and Montana. Others took place across the continent from Alaska to eastern

Canada. The goal of this paper is to analyze research from these different regions and determine if any of their aspects are applicable to lynx in Colorado. If there are applicable aspects it would show the possibility of inferring information on a species from one part of its range and applying it to populations living in another. Though this does not replace the benefits of local data, it serves as a useful, temporary, and inexpensive replacement in the absence of direct data. This absence of information is the situation that now exists in Colorado. CDOW actively collects telemetric occurrence figures, but has not yet shared their raw data.

Studies Applied to Colorado

The spatial ecology of lynx is a function of latitude, topography, and human induced alterations. For lynx in Alaska compared to lynx in Colorado, this means prime habitat is in forest stands of different species, prey make-up depends on availability, and demographic characteristics are linked to prey. The goal is to determine the patterns at work and fit Colorado lynx into their niche.

In 2000 the United States Forest Service published an assessment on southern lynx ecology. The purpose of this project was to reassess lynx distribution, data, and theory and to encourage additional research where information gaps existed (Ruggiero 2000). One of the questions considered was why lynx did not occur in all southern coniferous forests that seem to provide necessary conditions, such as Colorado in 1999. The assessment says, “conventional wisdom holds that a landscape dominated by coniferous forest will support lynx if it: 1) produces adequate numbers of snowshoe hares, 2) includes a small amount of old forest needed for den sites, and 3) includes a

mixture of forest age classes dominated by early successional stands” (Ruggiero 2000). The 2000 assessment was successful in that new research has shown the flaws in these beliefs and highlighted the problem of producing guidelines under assumptions based on northern populations. In each of the next sections I will set out to define the conditions under which Colorado lynx exist in order to determine their needs.

Prey

Lynx of the boreal forest are thought to be prototypical specialist predators due to their dependence on the snowshoe hare as primary prey (Mowat 2000). Hare, like the lynx, have proportionally large feet, which spreads the foot load of the individual and is useful for walking on deep snow. In winter, with other prey options like mice and squirrel mostly under snow moving via tunnels, lynx focus on the more accessible hare. They have become so dependant on hare that a synchronous cyclic population phenomenon has developed. However, during lynx and hare population lows lynx are known to diversify their diet and eat more red squirrel and other types of prey (Roth 2007). This brings about the question of whether or not lynx are truly specialists or actually generalist predators. Of course in the north, because of the cyclicity of both populations, lynx are specialists during the rise, peak, and, downturn in hare populations, but when hare numbers are at their lowest the lynx may become a generalist predator.

Roth et al (2007) in their study of carbon and nitrogen isotopes in lynx, hare, and red squirrels across the lynx range found that a geographic gradient exists where lynx rely less on hare in the south and west (Roth 2007). They describe the lynx as facultative specialists whereby lynx have the ability to hunt alternative types of prey other than the

hare, though it is not yet known if this is due to the southerly increase in prey diversity or the decrease in hare density. One implication of this finding is in determining the minimum necessary hare density needed for lynx to survive. Much of the past lynx ecological theory depends on their reliance on hare, but hare in the southern range occur at lower densities than in the north. The connection between lynx reproduction, kitten survival, and hare density is vital and might be the main cause of lynx cyclicity (Steury & Murray 2004) because as hare density sinks below a threshold female reproduction shuts down (Vashon 2008).

Steury & Murray (2004) modeled populations of lynx and hare and found the necessary density for the survival of translocated lynx to be 1.1 to 1.8 hares per hectare. CDOW used this threshold as part of their evaluation to determine the most suitable region in the state to reintroduce lynx (Devineau 2010a). However, this threshold only applies to translocated lynx after release and not their long-term persistence. The model was based on northern hare and lynx and it assumed lynx would retain their hunting habits. Other studies have determined minimum hare densities of 0.5 hares/ha in northern Canada (Ruggiero 2000), but there is no definitive number in the south.

There have been several studies in the southern range that have calculated hare density. The densities are not useful for comparison because they occurred in different seasons and were calculated with different methods. They are useful for showing areas of low hare density where lynx subsist. In southeastern British Columbia from 1996-1998, Apps (2000) found 0.01-0.47 hares per hectare. Hodges' (2000a) compilation of hare studies found densities of 0.09 to 2.7 hares per hectare in coniferous landscapes with the average well below one hare per hectare. Zahratka & Shenk (2008) in Colorado

found 0.08-1.32 hares/ha in Engelmann spruce-subalpine fir stands and 0.06 to 0.34 hares/ha in lodgepole pine. Other studies in the U.S. Rocky Mountains by Dolbeer and Clark (1975), Andersen et al (1980), and Griffin found averages of 0.73, 0.5, and 0.6 hares/ha respectively (Zahratka & Shenk 2008). The trend is of comparatively low hare densities in the southern to the northern range where densities vary between 0.09 and 11.8 hares/ha (Hodges 2000*a*). The densities during population lows in the north are similar to the relatively stable rate of the south and has led, along with reproduction data and home range sizes, to the belief that southern lynx behavior can be compared and modeled after northern lynx during hare scarcities (Apps 2000, Aubry 2000). In regards to prey, the problem with this comparison is that hare population lows are brief and lynx react by migrating away, focusing on other food sources, or expiring. The set of lynx that would be useful for comparison, those that remain, can adapt to reduced hare numbers, but since hare will quickly rebound to higher densities this situation tells little on the likelihood of long term persistence of lynx in areas of low hare density.

CDOW's research on hare in the state has found density rates typically lower than 1 hare/ha (Devineau 2010*b*), and comprising 65–90% of the winter diet of reintroduced lynx (Devineau 2010*b*, Shenk 2009). Young lodgepole pine had the highest density, spruce/fir the next highest, but spruce/fir also had the highest survivability rate. One of the challenges in determining hare density is determining if the population is a source or sink. An area can have a high density and also be a sink, which would not be ideal for supporting a lynx population (Devineau 2010*b*). Spruce/fir has the highest hare survivability, a medium hare density, and represents a large portion of Colorado forest. It is, therefore, CDOW's forest of main concern for protecting the lynx (Devineau 2010*b*).

Of Colorado lynx, we know that hare occur at low densities, which likely causes lynx to increase their range size, rely more on alternative prey, and also occur at low densities. Table 4 (below) shows that hare is the most important prey for Colorado lynx. It would tell even more if it combined hare and red squirrel densities for the same years.

FIELD SEASON	N	PREY (%)			
		SNOWSHOE HARE	RED SQUIRREL	COTTONTAIL	OTHER
1999	9	55.56	22.22	0	22.22
1999-2000	83	67.47	19.28	1.20	12.05
2000-2001	89	67.42	19.10	8.99	4.49
2001-2002	54	90.74	5.56	0	3.70
2002-2003	65	90.77	6.15	0	3.08
2003-2004	37	67.57	27.03	2.70	2.70
2004-2005	78	83.33	10.26	0	6.41

TABLE 4. NUMBER OF KILLS FOUND EACH WINTER FIELD SEASON THROUGH SNOW-TRACKING OF LYNX AND PERCENT COMPOSITION OF KILLS OF THE THREE PRIMARY PREY SPECIES.

Shenk, T. M., R. H. Kahn, G. Byrne, D. Kenvin, S. Wait, J. Seidel, and J. Mumma. 2009. Canada lynx (*Lynx canadensis*) reintroduction in Colorado. Pages 410-421 in Vargas, Astrid, Breitenmoser, Christine, Breitenmoser, editors. *Iberian Lynx Ex situ Conservation: An Interdisciplinary Approach*. Fundacion Biodiversidad, Madrid, Spain.

Cyclicality

In the northern range hares undergo an 8-11 year cycle of population highs and lows. The refugia hypothesis suggests that during increasing population phases, hares drift out of prime habitat due to overcrowding. As hare numbers continue to rise lynx numbers follow suit. The hares that live outside the protection provided by their prime habitat become easy targets and hare numbers crash (Wolff 1980, Hodges 2000b). Lynx numbers mirror the hare, but with a 1-2 year lag extending out like a wave from the center of the range (Murray 2008). This delayed synchronous relationship in the north

has been well documented (Murray 2008), but a consensus on the trends in southern lynx populations has yet to be reached (Hodges 2000*b*). Researchers originally believed cyclicality was absent in the South (Hodges 2000*a*), while more recent studies have found southern hare cyclicality to be attenuated or absent with the causes unknown (Hodges 2000*b*). Some proposals are the patchiness of hare habitat, which amplifies the rapid die off that occurs in the north (Hodges 2000*b*, Zahratka & Shenk 2008), increased hare competition, and increased diversity of predators, all of which diminish population bursts (Apps 2000).

Research that has shown attenuated or absent cyclicality of hare in the south is not necessarily site specific to Colorado. Colorado habitat is somewhat of an island with an unknown amount of connectivity to out-of state populations. Determining the presence or absence of cyclicality of lynx in Colorado would tell more of the level of connectivity between populations. Furthermore, cyclicality of hare can be harmful to low-density populations of lynx (McKelvey 2000*a*).

Denning

One distinction that should be made when attempting to discern lynx habits is between a preference and a need. For example, lynx prefer hare over alternative prey, but they hunt and rely on alternative prey when necessary. It is known that hare are a preference and it would be helpful to know more of the degree to which they are a need. The needs of lynx are less well known than the preferences because they are more difficult to study. Concerning den sites, research has shown the needs to be horizontal coverage close to foraging habitat (Moen 2008, Organ 2008, Squires 2008). The research

I have found focuses on preferences. Three recent studies in Maine, Minnesota, and Montana used telemetric collars to track lynx and locate den sites.

Moen et al (2008) measured the movement distances of 10 females before denning, during denning, and after denning and also recorded the species, diameter at breast height, and status of all stems ≥ 5 cm around the den site. All the dens used a downed tree whether it was branches, root wads, trunks, or logging slash. Their conclusion is that horizontal cover is more important than type of forest cover and the den must be within an area within foraging distance.

Squires et al (2008) tracked females and located 57 natal and maternal den sites in Montana. They used three spatial scales: an 11.2 m, a 100 m, and a 1 km radius circle centered at the den. They recorded species, diameter of trees, slope, aspect, and distance to water; estimated tree basal area, horizontal cover, canopy cover, and hare abundance; and counted conifer saplings and deciduous stems. They found, "Lynx denned in preexisting sheltered spaces created by downed logs (62%), root-wads from wind-thrown trees (19%), boulder fields (10%), slash piles (6%), and live trees (4%)" (pg 1497). They compared this data to random locations within the individual's home range and found that, "Female lynx selected den areas with greater spruce-fir tree basal area, higher horizontal cover, and larger-diameter trees compared to random locations within their home range." (pg 1497).

Organ et al (2008), in an area of abundant denning habitat, used telemetric collars to locate den sites and sample the surrounding plots. They, "estimated volume of coarse woody debris (CWD) by species, decay class, size class, and whether on or off the ground" (1515), as well as visual obscurity, softwood and hardwood stem density, and

canopy cover. They compared four models to determine the variables that led to the selection of the site by the lynx and found visual obscurity and tip-up mounds of blown down trees to be the best predictors of dens, which suggests that denser cover is their preference.

The challenge in applying this information to Colorado is determining whether denning habitat can be a limiting factor for distribution or survivability. Needs for denning habitat are dense horizontal cover, proximity to foraging habitat, little human disturbance, and stands at least 1 hectare in size (Ruggiero 1994). Halfpenny et al (1979) evaluated several lynx tracks in Colorado that were found after it was believed lynx were extirpated. The tracks were found in central Colorado and all of the tracks were associated with rocky outcrops, which they hypothesized were being used as dens. Recently, tracking of reintroduced lynx in southwestern Colorado found dens mostly in coarse woody debris downfall in Engelmann spruce/subalpine fir stands averaging 3,354 meters in elevation (Shenk 2009). To what degree den selection is affected by the reintroduction and region of the state is unknown.

The research areas in the three studies did not encounter this problem, but Colorado habitat is in the subalpine zone, which is patchy, separated by valleys, alpine zones, and human development. This, along with low hare density and disconnection with out-of-state populations, are challenges for lynx viability in Colorado. Lynx historically occur in the state, but it is not known if the population was permanent (Ruggiero 1994). The existing lynx were mostly reintroduced since 1999 and have survived and reproduced (CDOW 2009). Lynx are utilizing denning habitat, but recruitment of carnivores with large home ranges and low densities needs to be much

higher than mortality in order to avoid stochastic events (McKelvey 2000a). 126 kittens have been born in Colorado since the beginning of the project (CDOW 2009), while 122 adult lynx have died (Devineau 2010b). This count does not include kitten mortality, so lynx death rate is probably still below death rate, and well below the required rate for viability.

Habitat

Lynx habitat is generally cool coniferous forest (Ruggiero 1994). In Canada and Alaska lynx use the boreal forest that extends east to west from coast to coast. Traveling into the lower latitudes of the southernmost part of the range, the typical boreal forest rises in elevation and changes to the subalpine zone. In Colorado the subalpine zone is around 2,740 to 3,350 meters and comprised mostly of Engelmann spruce, subalpine fir, and lodgepole pine (Agee 2000).

The habitat needs of the lynx are forests with unique characteristics that each provide for adequate snowshoe hare, denning sites, and cover for travel (Aubry 2000). For hunting, lynx use habitat that supports the snowshoe hare, which is mostly mid-successional forests with moderate to abundant understory cover and high stem density (Mowat 2000, Murray 2008). In Colorado it was found that hare prefer stands of young, densely-stocked conifers and mature, uneven-aged conifers (Devineau 2010b). The highest densities of hare were in small (young) lodgepole pine. Medium densities and the highest survival rates of hare were in spruce-fir stands (Devineau 2010b). Shenk et al (2009) tracked reintroduced lynx in southwestern Colorado and found Engelmann spruce to be the dominant used cover type and a mixture of Engelmann spruce, subalpine fir, and

aspen as the second most used. Lodgepole pine was not used because it was not abundant in the region.

For denning, we know that lynx need dense horizontal cover, which could be provided by blown down, diseased, or mature stands, or by rocky outcrops. For travel that is not dispersal, lynx will use a variety of stands not considered prime, such as sparse canopy and understory cover or shrub habitats, and will mostly move in non-meandering paths (Aubry 2000). In Washington, it was found that lynx preferred moderate canopy and understory cover and avoided openings, recent burns, open canopy cover, open understory cover, and steep slopes (Koehler 2008). In Maine, lynx avoided stands that had the highest stem densities even when they contained higher hare densities (Fuller 2006).

Lodgepole pine, subalpine fir, and Engelmann spruce stands account for 25,227 km² or 26% of Colorado forests (Colorado Statewide Forest Resource Assessment), but the natural patchiness and human induced fragmentation is a challenge to lynx survival. Fragmentation is, “a reduction of total area, increased isolation of patches, and reduced connectedness among patches of natural vegetation” (Buskirk 2000). Non-dispersing lynx avoid open spaces as observed in Washington where lynx did not cross openings >150 m (Koehler 2008). Humans fragment habitat by cutting forests, building roads, and creation or disruption of disturbances. Reduction of hare habitat reduces hare numbers by eliminating forage and allowing access to a greater suite of predators. Patchiness is any area without a canopy, such as valleys, meadows, and alpine zones. These natural and human caused barriers make it more difficult to reproduce and forage for food. Additionally, roads create fragmentation by direct vehicle mortality and by supporting

edge-preferring predators (Buskirk 2000). Thirteen percent of reintroduced lynx deaths before 2007 were caused by vehicle collisions (Devineau 2010a), though that rate may diminish as offspring of reintroduced individuals are more accustomed to vehicles than their parents.

The needs for Colorado lynx habitat are a mosaic that provides high stem density and moderate to abundant understory for hare, moderate canopy and connectedness of forest for lynx, and some type of horizontal cover for dens. More research is needed to determine stand characteristics that lead to lynx usage within the state. Two publications by CDOW, one concerning stand and landscape scales and the other on denning habitat, are in progress (Devineau 2010b).

Population Structure

Prior to the reintroduction, lynx were extirpated from Colorado in 1974 when the last verifiable individual was killed (Halfpenny 1979). Little is known on this historic population and so there is little to model the current population after. Records on lynx in the state are based on reported sightings, trapping records, and museum specimens. Trapping records and museum specimens may be paired with locational data, but very few of both exist. Visual sightings are unreliable as an individual may be over-reported or mistakenly reported. The state-by-state survey conducted by McKelvey et al (2000b) determined Colorado had just 154 physical, visual, and track-based occurrences of lynx between 1842 and 1998. This lack of information coupled with the location of Colorado at the southern tip of lynx range indicates that the area probably did not support a permanent population (Ruggiero 1994). It is more likely lynx in the state were arranged

as part of a metapopulation (McKelvey 2000a). A metapopulation is variously defined, but at its core is a set of spatially separated populations of a species connected through migration. Subpopulations within a metapopulation may dwindle in numbers and be rescued or may die off and be recolonized, but the metapopulation remains intact. The important link is that the populations remain connected; otherwise it is likely they will permanently fail (McKelvey 2000a). If a population's birth rate is below the death rate then the population is a sink. Colorado rates seem to drift around parity (McKelvey 2000a), but the timeframe of measurement is short.

Lynx habitat in the U.S. is arranged as islands and peninsulas. Extensions from the Canadian population reach down the Cascade Range and Rocky Mountains and into the Great Lakes and Northeast regions. Colorado, Wyoming, Utah, and Idaho habitat are mountainous and discontinuous. Colorado habitat is disjunct from habitats in Utah and Wyoming by 150 km (McKelvey 2000b). Lynx will travel distance this long through suboptimal habitat only when migrating (McKelvey 2000b, Appendix A, Figure 1). The chance of success for dispersal is increased with more dispersers, shorter distances, less obstacles, and larger targets (McKelvey 2000a). Humans decrease chances by creating barriers or obstacles and destroying habitat.

In a metapopulation, it is not unusual for a subpopulation to be extirpated. Therefore, the current protection effort may be misguided as Colorado lynx may not survive. It was CDOW's opinion that the only manner in which a lynx population would reestablish itself was a reintroduction (Devineau 2010a). Another method more suited for long-term persistence, albeit more difficult and time consuming, could have been a federal effort to protect the corridors that connect Colorado habitats with similar areas to

the west and north through to Canada. Over time a population would have reestablished itself to the extent that successful dispersal allowed for. In combination with the reintroduction, this would give Colorado lynx a good opportunity to survive.

For persistence in Colorado, lynx and their habitat must be protected along their migration corridors within and outside the state, as well as in the source areas of Canada. One hypothesis regarding cyclicity of southern lynx is that it is fueled not by the cyclicity of southern hare, but instead by the flux of migrant lynx from Canada in search of food (Murray 2008). Steury and Murray, in their model of minimum hare densities (2004) and review of lynx research needs (Murray 2008), suggest that the southern range does not provide adequate hare for lynx to survive and that dispersalists from the north are necessary to support southern populations. Schwartz et al (2002) sampled DNA from hair specimens taken at 17 locations along the northwest and southwest corridor of lynx range. Their results, showing high gene flow, supports the hypothesis that lynx are highly connected throughout their range.

Home Range

Aubry et al (2000) compiled articles that calculated home range sizes for lynx across their range. The results show that lynx in the north during high hare densities have the smallest ranges. Lynx in the north during low hare densities and lynx in the south have larger and more variable range sizes. The results may not be comparable due to small sample sizes, different analyses, and status of the individuals (Aubry 2000), but they show a latitudinal trend.

	Median male range (km ²)	Median female range (km ²)	Source
Northern lynx, high hare density	37.5	15	Aubry (2000)
Northern lynx, low hare density	81.5	39.5	Aubry (2000)
Southern lynx	90.5	66	Aubry (2000)
Colorado reproductive	102.5	75.2	Shenk (2009)
Colorado non-reproductive	387	703.9	Shenk (2009)
Maine	53.6	25.7	Vashon (2008)

Northern lynx expand their range when hares become scarce (Aubry 2000). Southern lynx have larger home ranges because the low hare density and naturally patchy habitat (Aubry 2000). Vashon et al's (2008) research in Maine shows populations to be more similar to northern lynx than western lynx. This suggests that the gradient over the lynx range is caused more by topography than latitude.

Estimates of home range within Colorado can be helpful in combination with total area of continuous habitat and amount of overlap between individuals. This would give lynx density and show the best fitting population size for the state. A GIS could be used to select polygons of continuous habitat of 75.2 and 102.5 km² for females and males respectively. However, the population within the state is not old enough nor has it utilized all the suitable habitat in order to calculate an accurate density.

Discussion

Lynx needs in Colorado can be identified by combining and comparing research throughout the range. This process has shown its strengths and limitations in describing the characteristics of a young population generated from a reintroduction project. Some information can be inferred throughout the range or from similar populations, such as

denning and habitat landscapes and stands. Other types of information can only be found with in situ data collection. This type of within stand and location specific data requires time and funding. As the lynx population within Colorado ages and more research is published, it will be instructive for similar future mammalian carnivore reintroductions.

Appendix A

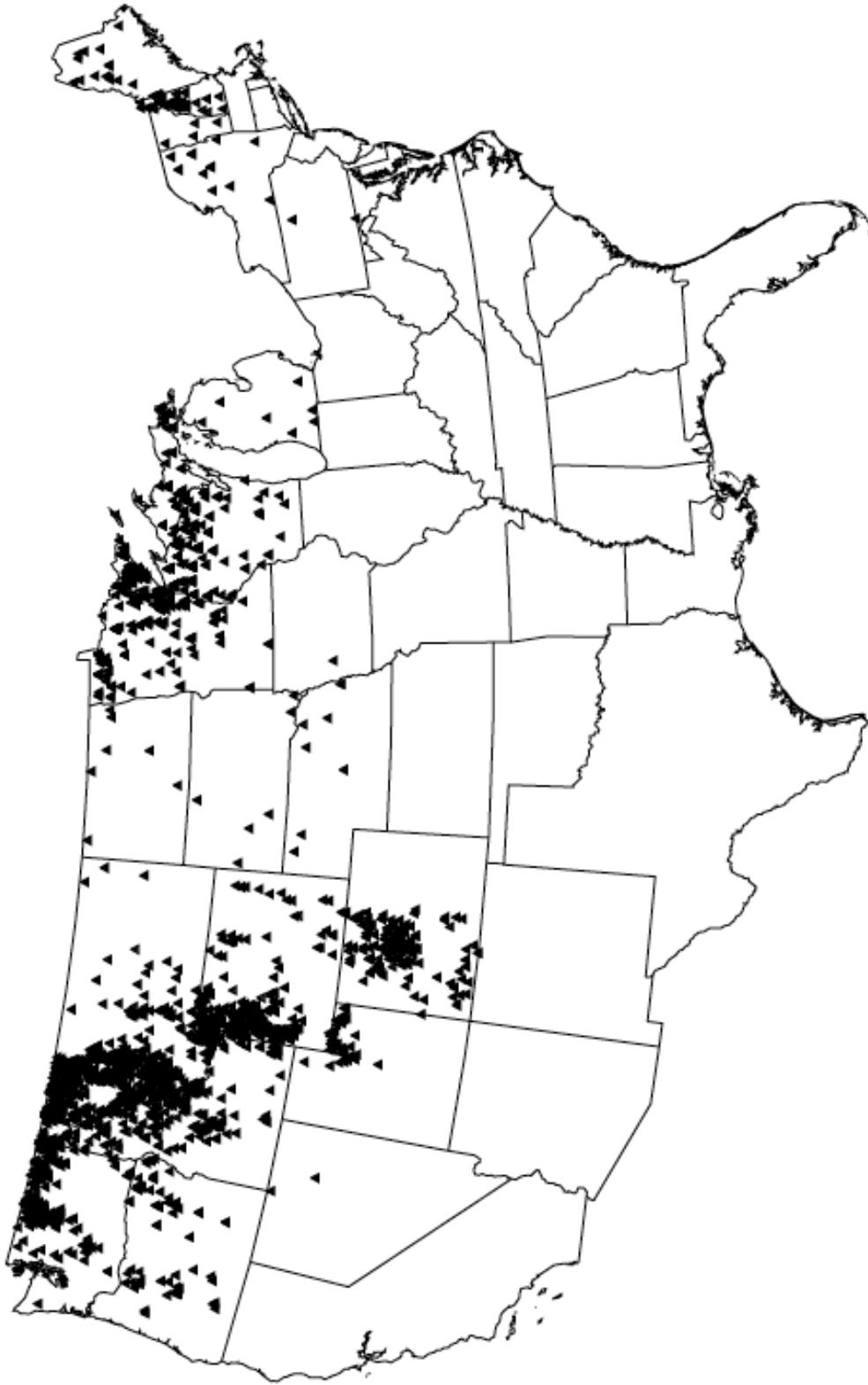


Figure 8.17—Spatial distribution of lynx occurrence data from 1842 to 1998 (Table 8.1).

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