 

Canada Lynx Conservation Assessment and Strategy

3rd Edition — August 2013

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Acknowledgments

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Chapter 1 - INTRODUCTION

Purpose and history of the Lynx Conservation Assessment and Strategy

The Lynx Conservation Assessment and Strategy (LCAS) was developed to provide a consistent and effective approach to conserve Canada lynx (*Lynx canadensis*), hereafter referred to as lynx, and to assist with Section 7 consultation under the Endangered Species Act (ESA) on federal lands in the contiguous United States. An action plan that identified the need for preparation of a lynx conservation strategy was approved by the affected Regional Foresters of the USDA Forest Service (FS), State Directors of the Bureau of Land Management (BLM), and Regional Directors of the U. S. Fish and Wildlife Service (FWS) on June 5, 1998. The National Park Service (NPS) joined the effort later that month.

In accordance with the action plan, an interagency Steering Committee was established to guide lynx conservation efforts. The Steering Committee selected a Science Team, led by Dr. Leonard Ruggiero, FS-Rocky Mountain Research Station, to assemble the best available scientific information on lynx, and appointed a Lynx Biology Team, led by Bill Ruediger, FS-Northern Region, to prepare a lynx conservation strategy applicable to federal land management in the contiguous United States.

The first edition of the LCAS was completed in January, 2000, with the second edition issued in August, 2000. Several amendments and clarifications were subsequently issued through the Steering Committee.

The LCAS is designed for application on federal lands. However, the information, concepts, and conservation measures could also be applied if desired when planning and managing lynx habitat on non-federal lands.

Synopsis of major changes from the previous edition

This edition of the LCAS provides a full revision, incorporating all prior amendments and clarifications, substantial new scientific information that has emerged since 2000 including related parts of the Lynx Recovery Plan Outline, as well as drawing on experience gained in implementing the 2000 LCAS. The document has been reorganized and condensed to improve readability and reduce redundancy.

Chapter 3, Lynx Geographic Areas, has been substantially revised to incorporate new information about lynx and lynx habitat. The map (Fig. 3.1) has also been updated.

Chapter 4, formerly titled Risk Factors, is here retitled as Anthropogenic Influences on Lynx and Lynx Habitat. The anthropogenic influences are grouped into 2 tiers based on the potential magnitude of effects on lynx and their habitats. For each anthropogenic influence, there is an explanation of how it may influence key drivers of lynx population dynamics: the snowshoe hare (*Lepus americanus*) prey base, direct mortality of lynx, and the risks associated with small population size.

The chapters that formerly described Planning Area and Project Level were eliminated in this edition. The original intent was to provide the perspective of a multi-tier spatial hierarchy in discussing status, trends, and concerns relative to lynx and lynx habitat. In retrospect, however, these 2 chapters were redundant to material already presented in the previous chapters.

Chapter 5, Conservation Strategy, incorporates concepts from the Canada Lynx Recovery Outline (U.S. Fish and Wildlife Service 2005). Specifically, conservation efforts for lynx are not to be applied equally across the range of the species, but instead more focus is given to high priority areas: the core areas. Further, we combined secondary areas and peripheral areas (which were also identified in the recovery outline) into one category, because they have similar characteristics and management recommendations. The intent is to place more emphasis on protection of the core areas, which support persistent lynx populations and have evidence of recent reproduction, and less stringent protection and greater flexibility in secondary/peripheral areas, which only support lynx intermittently. Chapter 5 presents conservation measures only for those anthropogenic influences that are within the authority of the federal agencies, and identifies areas where they should be applied.

Guidance provided in the revised LCAS is no longer written in the framework of objectives, standards, and guidelines as used in land management planning, but rather as conservation measures. This change was made to more clearly distinguish between the management direction that has been established through the public planning and decision-making process, versus conservation measures that are meant to synthesize and interpret evolving scientific information.

History of ESA listing actions and relationship to the LCAS

The FWS published a proposed rule on July 8, 1998 to list the lynx under the ESA of 1973, as amended (Federal Register Volume 63, No. 130, pp. 36994–37013). On March 24, 2000, the FWS published the final rule listing the Contiguous United States Distinct Population Segment (DPS) as a threatened species (Federal Register Vol. 65, No. 58, pp. 16052–16086). In its analysis of threats to the species, the FWS concluded that the single factor threatening the DPS was 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. The LCAS served as the foundation for review and amendment of those plans, as needed, to provide for the conservation of lynx.

The decision to list lynx as a single DPS and as threatened (rather than endangered) was challenged and the courts remanded the decision back to the FWS. On July 3, 2003, the FWS published a Notice of Remanded Determination of Status for the Contiguous United States Distinct Population Segment of the Canada Lynx (Federal Register Vol. 68, No. 28, pp. 40076–40101). In its finding (here referred to as the Remanded Rule), the FWS again evaluated the threats to lynx and reaffirmed its previous conclusion that endangered status was not warranted. The FWS indicated that many activities that may affect the lynx and its habitat have only local effects, which can vary depending on the quality and quantity of habitat available. The relative importance of each threat was also described for each geographic area. In the Remanded Rule, the FWS discussed the periodic immigration of lynx from Canada and its possible role in sustaining the smaller populations of lynx in the contiguous United States. These new understandings were incorporated into agency planning and management where appropriate.

A Recovery Outline for the Contiguous United States DPS of Canada Lynx (U.S. Fish and Wildlife Service 2005) was prepared by the FWS and made available on Sept. 14, 2005. A recovery outline is intended to provide interim guidance for consultation and recovery efforts until a formal recovery plan has been approved. No recovery plan has yet been developed for the lynx. This revision of the LCAS considered, incorporated, and in some cases modified or elaborated on the concepts that were put forward in the 2005 recovery outline.

Under the recovery outline, lynx habitat was stratified into core, secondary, and peripheral areas based on lynx occupancy, reproduction, and use as documented by historical and current records. The recovery outline did not establish recovery goals, but did identify a preliminary set of objectives and potential recovery actions for each area.

Core areas were identified by FWS where there was strong evidence of long-term persistence of lynx populations, including both historical records of lynx occurrence over time, and recent (within the past 20 years) evidence of presence and reproduction. A core area contains large, connected patches of boreal forest, encompassing at least 1,250 km^2 (480 mi^2). The term boreal forest is used here to include the true boreal forest, which is a zone extending south of the arctic tundra, as well as the southern transitional regions as described by Agee (2000) for the northeastern and Great Lakes regions (eastern hardwoods and temperate and boreal conifers) and the western United States (subalpine forests).

Secondary areas were identified by FWS where there were historical records of lynx presence, but fewer than in core areas, and no recent documentation of presence or reproduction; or where there were historical records of lynx, but current status is unknown due to lack of recent surveys.

Peripheral areas were identified by FWS where there were sporadic historical records of lynx, which generally correspond to cyclic population highs in Canada, and there was no evidence of reproduction. Because boreal forest in peripheral areas occurs in small and more isolated patches (such as an isolated mountain range), these areas are considered to be incapable of supporting self-sustaining populations of lynx.

Critical habitat for the lynx was designated on November 9, 2006 (Federal Register Vol. 71, No. 217, pp. 66008–66061). On July 20, 2007, the FWS announced that the final critical habitat rule would be reviewed in light of questions that had been raised about the integrity of the decision-making process. Based on this review, the FWS concluded that the final rule was improperly influenced by the then-Deputy Assistant Secretary of the Interior. On January 15, 2008, the U. S. District Court for the District of Columbia issued an order establishing deadlines for reissuing the critical habitat rule. The revised final rule designating critical habitat was published in the Federal Register, Vol. 74, No. 36, pp. 8616–8702 on February 25, 2009. Approximately 101,010 km^2 (39,000 mi^2) distributed in 5 units within the states of Maine, Minnesota, Montana, Wyoming, Idaho, and Washington were encompassed within the boundaries of the revised critical habitat. In July and September of 2010, the District Courts in Montana and Wyoming, respectively, took exception to parts of the revised critical habitat designation and again remanded the rule to the FWS. A proposed revised rule is scheduled for publication in September 2013 and a final rule within the following 12 months. The 2009 final rule will remain in effect until completion of the remanded critical habitat designation.

In this revision of the LCAS, the discussion of geographic areas and the development of conservation measures were informed by the Remanded Rule, the Recovery Outline, the revised final critical habitat rule, and other information that has become available since 2000.

Why the LCAS is still useful and needed

In response to the listing decision in 2000, the FS and the BLM entered into conservation agreements with the FWS. In these agreements, the agencies acknowledged the LCAS as one of the sources of the best available scientific information to assist in conservation of lynx. The agreements were to remain in place until such time as forest plans and land use plans could be amended or revised to incorporate management direction specific to conservation of lynx.

When the first edition of the LCAS was written, most lynx research had been conducted in Alaska and Canada, and little published literature was available regarding lynx in the contiguous United States (Ruediger et al. 2000). Since then, new research has been conducted throughout the range of the lynx and the body of scientific literature has expanded substantially. This revised LCAS provides an updated synthesis of the best available scientific information about lynx ecology and responses to management.

The LCAS continues to fulfill important roles in promoting conservation of the species on federal lands, particularly in the absence of an approved recovery plan, and in assisting biologists in supporting their determinations of effect and conducting ESA Section 7 consultation. In recognition of these ongoing roles, a revision of the LCAS was initiated in September, 2010. At the request of the Steering Committee, Dr. John Squires, FS-Rocky Mountain Research Station, led a review of the research and published scientific literature produced since 2000, and provided the Lynx Biology Team with a draft update of the assessment portion of the LCAS. The Lynx Biology Team built on that work to complete this revision of the LCAS.

Forest plans are prepared and implemented in accordance with the National Forest Management Act of 1976. Amendments or revisions to FS plans have been completed in the Eastern Region, Northern Region, Rocky Mountain Region, and Intermountain Region to better address conservation of the lynx. In the Pacific Northwest Region, forest plans for national forests with lynx habitat are currently being revised. The management direction contained in a forest plan guides project development and must be followed. The updated information and understandings in the revised LCAS may be useful for project planning and implementation, as well as helping to inform future amendments or revisions of forest plans.

The BLM and NPS continue to rely on the LCAS along with other sources of information to guide management of lynx habitat. The updated LCAS will assist these agencies in planning and designing their programs and projects.

Guiding principles

We relied on these guiding principles in developing and revising the LCAS:

- **Use the best scientific information available about lynx.** We relied on information from research throughout the range of the species, recognizing that behavior and habitat use may differ in various portions of its range. We incorporated information about the ecology of its primary prey species, snowshoe hare, and an alternate prey species, red squirrel (*Tamiasciurus hudsonicus*). As the basis for management recommendations, we relied primarily upon peer-reviewed publications. If no published sources were available on a given topic, we considered information from theses, dissertations, or other unpublished sources.
- **Address conflicting information.** In a few cases, different authors reached different or even opposing conclusions about a particular topic. In these situations we considered all the available information, assessed the rigor of the methods used in each study, and provided the rationale for the conclusions we reached.
- **Integrate a consideration of natural ecological processes and landscape patterns with knowledge of lynx habitat requirements**. Integrating knowledge about broad ecological processes and species-specific requirements is more likely to result in a strategy that is feasible to implement and sustainable over the long term.

How the document is organized

Chapters 2–4 of the document constitute the conservation assessment. These chapters provide a review and synthesis of the scientific foundation for the conservation of lynx. An overview of lynx ecology is presented in Chapter 2, followed by an assessment of lynx population status and habitat conditions for each of the geographic areas: Northeast, Great Lakes, Southern Rocky Mountains, Northern Rocky Mountains, and Cascade Mountains. Next we describe and prioritize the anthropogenic influences that may affect lynx or lynx habitat.

Based on the foundation of the conservation assessment, Chapter 5 presents the conservation strategy for lynx. The conservation measures contained in the strategy are compatible with the concepts and potential recovery actions put forward in the recovery outline (U.S. Fish and Wildlife Service 2005).

Chapter 6 summarizes information gained from past inventories and discusses the needs and priorities for future inventory of lynx populations and habitat. This chapter also describes important needs for future monitoring and research. Monitoring and applied research are essential to continue to adapt and improve management approaches that support lynx conservation.

Chapter 2 - OVERVIEW OF LYNX ECOLOGY

Description of lynx

Canada lynx are medium-sized cats, 75–90 cm (30–35 in) long and weighing 6–14 kg (13–31 lb; Quinn and Parker 1987, Moen et al. 2010*a*). They have large feet (Plate 2.1) adapted to walking on snow, long legs, tufts on the ears, and black-tipped tails (Plate 2.2).

Plate 2.1. Lynx have large furry feet, an adaptation for travel through deep, fluffy snow.

Plate 2.2. Canada lynx characteristics include a ruffed face, ear tufts, black-tipped tail, long legs, and large feet.

Lynx activity patterns

Circadian activity pattern. Kolbe and Squires (2007) reported on lynx activity patterns in Montana. Periods of activity varied by sex, season, and reproductive status, and were not consistently synchronous with the activity patterns of snowshoe hares. In winter, males were most active during daylight hours, with peaks in the afternoon or early evening; in summer, males tended to be more crepuscular in their activities. In contrast, female lynx that were rearing kittens during the summer months were most active during daylight hours, when the mean ambient temperature was highest. One female lynx without kittens had crepuscular patterns of activity similar to those of male lynx during summer.

Daily movements. Daily movements of lynx within their home ranges are centered on continuous forest, and they frequently use ridges, saddles, and riparian areas (Koehler 1990*a*, Staples 1995). Snow-tracking revealed that lynx avoid large openings (Staples 1995, Squires et al. 2010), either natural (Koehler 1990*a*) or created (Maletzke et al. 2008) when moving through their home ranges.

Fuller and Harrison (2010) found that daily movement distances of lynx in Maine varied by gender, season, and in relation to prey. The movement paths of female lynx raising kittens had higher sinuosity, apparently reflecting a preference to remain in habitats with dense horizontal cover and good accessibility to prey. In contrast, males appeared to make more linear movements, and tended to use skid trails and areas with less dense understory more frequently than females (Fuller and Harrison 2010).

In Minnesota, 3 female lynx used a foraging radius of approximately 2–3 km (1.2–1.8 mi) when kittens were at the den (Moen et al. 2008). In contrast, >50% of GPS collar locations were >2 km away from the den site during pre-denning and post-denning periods. Net displacement rates of 1–2 km/day (0.6–1.2 mi) were similar to rates reported from some other southern lynx populations (Apps 2000, Squires and Laurion 2000).

Squires et al. (2013) used global positioning system (GPS) collars programmed to record locations every 30 minutes every other day for 33 individual lynx during winter and 28 lynx during summer; the average daily movement rate of those lynx in Montana was 6.9 km/day (4.2 mi/day). Olson et al. (2011) monitored 4 denning females in Montana and reported that daily distances moved were shorter during the period from parturition until the kittens were 2 months old, as compared to movement distances before the kittens were born.

Ward and Krebs (1985), using VHF radio telemetry (to calculate the straight-line distance between locations on consecutive days) in southwestern Yukon, documented an increase in the radius of lynx daily movements as snowshoe hare densities decreased. Straight-line daily travel distance remained constant at about 2.2−2.7 km/day (1.3−1.6 mi/day) at hare densities above 1.0 hare/ha (0.4 hares/ac). Below 1.0 hare/ha (0.4 hares/ac), straight-line daily travel distances increased rapidly, reaching 5.5 km/day (3.3 mi/day) at 0.2 hares/ha (0.08 hares/ac). Below about 0.5 hares/ha (0.2 hare/ac), several lynx abandoned their home ranges and became nomadic, although they remained within the general study area. Parker et al. (1983) used VHF radio telemetry to relocate 1 adult female and reported the female's daily movement distance as 8.8 km (5.3 mi) in winter and 10 km (6.2 mi) in summer.

Exploratory movements. Aubry et al. (2000) defined exploratory movements as long-distance movements beyond identified home range boundaries, in which the animal returned to its original home range. Exploratory movements by lynx have been documented to occur within most of the geographic areas.

In Maine, lynx made long distance movements throughout the year from a study area in northwestern Maine, often returning to reoccupy their home range (Vashon et al. 2012). Distances of 52–403 km (31–242 mi) were recorded for movements into Quebec, and distances of 142–227 km (85–136 mi) were recorded for movements within the state of Maine.

In Minnesota, Moen et al. (2010*b*) reported lynx making long distance movements at all times of the year. Exploratory movements were greatest for males during the breeding season in March (Burdett et al. 2007). Resident lynx made long distance movements lasting days to a few months into Ontario and back during the predenning period.

In Montana, Wyoming, and southern British Columbia, exploratory movements by resident lynx during the summer months were documented by Squires and Laurion (2000), Squires and Oakleaf (2005), and Apps (2000), respectively. Distances of these exploratory movements in Montana ranged from about 15–40 km (9–25 mi), and duration away from the home range was 1 week to several months (Squires and Laurion 2000). In Wyoming, during 3 consecutive summers, a resident lynx was documented to travel a similar exploratory path (minimum path distance of 728 km [452 mi]) from its home range in the Wyoming Range, to the Wind River and Teton Ranges, and back (Squires and Oakleaf 2005).

Summer exploratory movements were not detected in north-central Washington (Koehler 1990*a*), nor have exploratory movements been recorded in the northern boreal forest (Mowat et al. 2000). It is unclear whether such movements did not occur, or were simply not observed due to the methods and frequency of monitoring employed in these studies.

Dispersal. Dispersal is the permanent movement of an animal to a new home range. Animals that are dispersing often cross areas such as frozen lakes, deserts, and farmland that are not typical lynx habitat (Ward and Krebs 1985). Mortality of dispersing lynx is speculated to be high, particularly for those individuals moving long distances through areas that lack adequate lynx habitat or resident populations (McKelvey et al. 2000*b*). However, this speculation is based primarily on trapping mortality information, rather than a study of the known fates of marked animals. Therefore, the extent to which dispersing lynx are able to successfully colonize new habitat is largely unknown.

It has been reported that female lynx tend to establish home ranges adjacent to their mother (Mowat and Slough 1998), while young males are more likely to disperse. However, an analysis of fine-scale genetic structure of lynx populations in Alberta, Canada suggested that dispersal distances did not significantly differ between males and females (Campbell and Strobeck 2006).

Dispersal distances of up to 1,000 km (620 mi) have been recorded for lynx (Mech 1980, Slough and Mowat 1996, Poole 1997). During dispersal, the minimum daily travel rate of 3 individual lynx was 1.7–8.3 km (1–5 mi) per day (Ward and Krebs 1985). Dispersing lynx did not appear to travel farther per day than resident lynx, but most movement was directional (Mowat et al. 2000).

In Canada, adult and subadult lynx of both sexes were documented making long-distance movements during periods of prey scarcity (Slough and Mowat 1996, Poole 1997). During the cyclic low of hare numbers in the Yukon, rates of emigration from established home ranges increased (O'Donoghue et al. 2001). Many of the lynx that were translocated to Colorado also made extensive movements (Devineau et al. 2010).

Lynx diet

Snowshoe hares (Plate 2.3) are the primary prey of lynx throughout their range (Mowat et al. 2000).

Plate 2.3. Across the range of lynx, snowshoe hares are the primary prey. The color of the fur changes seasonally, from white in winter to brown in summer.

It is thought that the summer diet of lynx may include a greater diversity of prey species than in winter, due to the greater seasonal availability of prey (Quinn and Parker 1987, Koehler and Aubry 1994, Mowat et al. 2000). The summer diet of lynx has not been quantified in the southern portion of its range, although some anecdotal information is available.

Red squirrels (Plate 2.4) are reported to be the second most important food source for lynx in Alaska (Staples 1995) and the main alternate prey of lynx during periods of low hare abundance in Yukon Territory (O'Donoghue 1997). Other prey species taken across the range of the lynx include grouse (*Bonasa umbellus*, *Dendragopus* spp., *Lagopus* spp.), northern flying squirrel (*Glaucomys sabrinus*), ground squirrels (*Spermophilus parryii*, *S. richardsonii*, *Urocitellus columbianus*), porcupine (*Erethrizon dorsatum*), beaver (*Castor canadensis*), mice (*Peromyscus* spp.), voles (*Microtus* spp.), shrews (*Sorex* spp.), weasels (*Mustela* spp.), fish, and ungulates as carrion (Saunders 1963*a*, van Zyll de Jong 1966, Nellis et al. 1972, Brand et al. 1976, Brand and Keith 1979, Koehler 1990*a*, Staples 1995, O'Donoghue et al. 1998, Olson et al. 2011). Male lynx have opportunistically killed white-tailed deer (*Odocoileus virginianus*) and mule deer (*Odocoileus hemionus*) in the southern extent of their range, when deep snow hindered deer movements and increased their vulnerability to predation (Fuller 2004, Poszig et al. 2004, Squires and Ruggiero 2007).

Plate 2.4. Red squirrels are an important secondary prey for lynx in some parts of its range.

Snowshoe hare ecology

Description. Snowshoe hares generally average 40–44 cm (15.7–17.3 in) in length and 0.9–1.7 kg (2–3.7 lb) in weight (Kays and Wilson 2002). They have large hind feet and their pelage changes seasonally, from brown in summer to white in winter (Severaid 1945).

Snowshoe hares are widely distributed across North America, and are broadly associated with boreal and subalpine forests (Hall 1981). The species' historical range in North America extends from Alaska across most of Canada, and southward into portions of the contiguous United States. This includes the Cascades and Sierra Nevada Mountains (reaching into central California), the Rocky Mountains (reaching into southern Utah and northern New Mexico), the Great Lakes region, and the Appalachian Mountains (into North Carolina and Tennessee; Hodges 2000*b*, Hoffman and Smith 2005).

Activity patterns. Snowshoe hares forage primarily at dusk and dawn, remaining largely inactive during daylight hours (Foresman and Pearson 1999, Abele 2004). Lunar phases may influence foraging activity and movement patterns as well. Hares are less active under a full moon, particularly in the winter months when snow-reflected light likely would increase their susceptibility to predation (Gilbert and Boutin 1991, Griffin et al. 2005).

Home range. Home range size is 5–10 ha (12–25 ac); estimates vary depending on the sampling method (e.g., live-trapping vs. radio telemetry; Keith 1990, Hodges 2000*a*, Murray 2003). Although hares are non-migratory and generally occupy the same area throughout the year, short-distance seasonal movements between winter and summer foraging areas have been documented (Adams 1959, Bookhout 1965, Wolff 1980, Wolfe et al. 1982).

Dispersal. Dispersal from home ranges may be associated with intraspecific aggression resulting from overcrowding, competition for mates and food resources, or vulnerability to predation (Keith et al. 1993, Duffy and Belthoff 2001). Cyclic populations experienced higher dispersal rates during the late increase phase and the peak (Windberg and Keith 1976, Wolff 1980). Habitats with higher amounts of cover had lower rates of dispersal than habitats with little cover (Wirsing et al. 2002), as did larger habitat patches when compared to smaller habitat patches (Keith et al. 1993).

Habitat. Snowshoe hares occur in boreal forests across North America (Hodges 2000*b*). The density of horizontal cover, snow conditions, and presence of boreal forest vegetation appear to be important attributes of snowshoe hare habitat (Hodges 2000*a*).

Horizontal cover. The amount and density of horizontal cover strongly influence snowshoe hare abundance. Dense horizontal cover likely reduces exposure to predators, the proximate cause of most mortality (>90%) observed for hares in most populations studied (Sievert and Keith 1985, Rohner and Krebs 1996, Hodges 2000*a*, Murray 2003). Dense horizontal cover also provides better access to food resources and thermal protection during the critical winter period (Hodges et al. 2001), making it an important element of hare habitat (Belovsky 1984, Sievert and Keith 1985, Rohner and Krebs 1996, Wirsing et al. 2002, Murray 2003). Griffin (2004) documented higher hare survival in dense stands than in open stands in Montana. Hares also were more likely to select larger patches of densely-vegetated habitats when dispersing (Keith et al. 1993, Dufty and Belthoff 2001, Griffin 2004).

Stem densities ranging from 4,600–33,210 stems/ha (1,862–13,445 stems/ac) provide optimal forage and horizontal cover for snowshoe hares (Wolff 1980, Parker 1984, Litvaitis et al. 1985, Monthey 1986, Parker 1986, Koehler 1990*a*, Griffin 2004, Fuller and Harrison 2005, Robinson 2006, Scott 2009). Lewis et al. (2011) found that snowshoe hare densities were higher in areas where dense, horizontal cover patches were more contiguous or where similar patches were surrounded by other patches of similar structure.

In Maine, Fuller and Harrison (2005), Robinson (2006), Fuller et al. (2007), and Scott (2009) documented a close association between snowshoe hare density and horizontal cover density in conifer-dominated regenerating clearcuts.

In western Montana, Griffin (2004) monitored snowshoe hare densities in 4 forest stand structural stages: open mature (>150 years old and >76 cm [30 in] diameter at breast height [dbh]), open young (20–45 years old), dense mature, and dense young. During the summer (late June to mid-September), snowshoe hare densities were highest in the dense young, with the next highest hare densities in most years in the dense mature. In winter (mid-December to early April), snowshoe hare densities were highest in the dense mature (Griffin 2004).

In Wyoming, Berg et al. (2012) found hare densities (as measured by pellet counts) to be highest in young (30–70 year old) regenerating lodgepole pine (*Pinus contorta*) and mature, multi-story spruce-fir forests (Plate 2.5). While snowshoe hare density did not increase with increasing stem densities in the mature multi-story patches, hare density in the young, regenerating forests increased as stem densities increased (Berg et al. 2012). Ellsworth (2009) also highlighted the importance of young lodgepole pine stands with high sapling densities in northern Idaho.

Plate 2.5. Dense horizontal cover providing cover from predators, thermal protection, and adequate forage is required to support snowshoe hares across their range.

Snow conditions. Across northern boreal forests in Canada, conditions that favor hares are cold and dry, moderately deep (100–127 cm [39–50 in]) snow with relatively uniform depth (Kelsall et al. 1977). Studies documenting the relationship between snow depth and hare feeding patterns in Alberta (Johnstone 1981, Ives and Rentz 1993), British Columbia (Sullivan and Sullivan 1982), Colorado (Zahratka 2004), Montana

(Zimmer 2004), north-central Washington (Koehler 1990*b*), and northern Idaho (Wirsing and Murray 2002, Ellsworth 2009) showed that snow accumulation and persistence influence food availability, and consequently hare feeding patterns.

Boreal forest vegetation. In the northeastern United States, snowshoe hare populations occurred in all forested habitats at elevations of 0–1,800 m (0–5,500 ft). Coniferous and mixed-coniferous/deciduous forests dominated by white spruce (*Picea glauca*), black spruce (*Picea mariana*), red spruce (*Picea rubens*), balsam fir (*Abies balsamea*), eastern white pine (*Pinus strobus*), northern white cedar (*Thuja occidentalis*), eastern hemlock (*Tsuga canadensis*), sugar maple (*Acer saccharum*), aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*) were known to provide snowshoe hare habitat in this region (Hoving et al. 2004, Robinson 2006, Fuller et al. 2007, Vashon et al. 2008*b*, Scott 2009).

In the Great Lakes states, most snowshoe hare populations occurred in regenerating or young (25 years old or less) mixed deciduous and conifer forests (Plate 2.6; McCann and Moen 2011). Cover types in this region that support snowshoe hare include jack pine (*Pinus divaricata*), red pine (*Pinus resinosa*), balsam fir, black spruce, white spruce, northern white cedar, tamarack (*Larix laricina*), aspen, paper birch, as well as conifer bogs and shrub swamps (Burdett 2008, Moen et al. 2008).

Plate 2.6. Forest structure that provides dense horizontal cover is a common characteristic of snowshoe hare habitat across its range, but plant species composition varies. In the Great Lakes Geographic Area, a mix of coniferous and deciduous trees provide the best snowshoe hare habitat.

In the western United States, most snowshoe hare populations occurred within conifer forests at elevations ranging from 645–3,415 m (2,116–11,204 ft; Dolbeer and Clark 1975, Griffin 2004, Lewis et al. 2011, Berg and Gese 2012). Cover types that support snowshoe hares in this region include Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), mixed spruce-fir, mixed aspen and spruce-fir, and mixed lodgepole and spruce-fir and lodgepole pine (Hodges 2000*b*, Zahratka 2004, Zimmer 2004, Miller 2005, Berg et al. 2012).

<u>Diet</u>. Snowshoe hares feed on a variety of plant species, differing by region, plant community, and season (Hodges 2000*a*, 2000*b*; Ellsworth and Reynolds 2006; see Table 2.1). Energy expenditure and susceptibility to predation (Houston et al. 1993; Hodges and Sinclair 2003, 2005) also influence the diet.

Table 2.1. Food plants used by snowshoe hares in different regions, modified from Hodges (2000b).

Conifers	Deciduous trees	Shrubs	References
Eastern: Maritimes & Maine			
Abies balsamea	*Acer pennsylvanicum*	*Corylus cornuta*	Telfer 1972 (New Brunswick) Litvaitis 1984 (ME)
Picea spp.	*Acer rubrum*	*Gaylussaccia baccata*	
Picea rubens	*Acer saccharum*	*Hamamelis virginiana*	
Pinus strobus	*Acer spicatum*	*Kalmia* spp.	
Thuja occidentalis	*Alnus rugosa*	*Myrica gale*	
Tsuga canadensis	*Alnus crispa*	*Nemopanthus mucronata*	
	Betula alleghaniensis	*Rhododendron canadense*	
	Betula papyrifera	*Vaccinium* spp.	
	Betula populifolia	*Viburnum* spp.	
	Comptonia peregrina		
	Fagus grandifolia		
	Quercus rubra		
Eastern: Appalachians & Alleghenies			
Picea glauca	*Acer pennsylvanicum*	*Juniperus communis*	Cook & Robeson 1945 (NY) Brooks 1955 (VA) Walski & Mautz 1977 (NH) Brown 1984 (PA) Rogowitz 1988 (NY) Scott & Yahner 1989 (PA)
Picea rubens	*Acer rubrum*	*Kalmia latifolia*	
Pinus resinosa	*Acer saccharum*	*Rhododendron lapponicum*	
Pinus strobus	*Betula alleghaniensis*	*Rubus alleghaniensis*	
Pinus sylvestris	*Betula lenta*	*Rubus hispidus*	
Thuja occidentalis	*Betula lutea*	*Vaccinium erythrocarpum*	
Tsuga canadensis	*Betula papyrifera*	*Viburnum dentatum*	
	Fagus grandifolia		
	Fraxinus americana		
	Populus tremuloides		
Midwestern: Great Lakes			
Abies balsamea	*Acer pennsylvanicum*	*Amelanchier* spp.	Grange 1932 (WI) Bider 1961 (Quebec) de Vos 1964 (Ontario) Bookhout 1965 (MI) Johnson 1969 (MI) Conroy et al. 1979 (MI) Grigal & Moody 1980 (MN) Bergeron & Tardif 1988 (Quebec)
Larix laricina	*Acer rubrum*	*Chamaedaphne calyculata*	
Picea abies	*Acer saccharum*	*Corylus cornuta*	
Picea glauca	*Acer spicatum*	*Juniperus communis*	
Picea mariana	*Alnus crispa*	*Ledum groenlandicus*	
Pinus banksiana	*Alnus rugosa*	*Lonicera* spp.	
Pinus divaricata	*Betula alba*	*Rhamnus alnifolia*	
Pinus resinosa	*Betula papyrifera*	*Rosa* spp.	
Pinus strobus	*Betula pumila*	*Rubus* spp.	

Conifers	Deciduous trees	Shrubs	References
Midwestern: Great Lakes (cont.)			
Thuja occidentalis	*Fagus grandifolia*	*Salix* spp.	
Tsuga canadensis	*Ostrya virginiana*	*Shepherdia canadensis*	
	Populus grandidentata	*Viburnum* spp.	
	Populus pennsylvania		
	Populus tremuloides		
	Populus virginiana		
	Prunus pennsylvanica		
	Prunus serotina		
	Prunus virginiana		
	Pyrus malus		
	Quercus rubra		
	Sorbus americana		
	Ulmus americana		
Western: Rockies, Cascades & Intermountain West			
Abies lasiocarpa		*Amelanchier alnifolia*	Adams 1959 (MT) Black 1965 (OR) Radwan & Campbell 1968 (WA) Borrecco 1976 (WA) Sullivan and Sullivan 1983 (BC) Koehler 1990*a* (WA) Thomas et al. 1997 (WA) Wirsing and Murray 2002 (ID) Zahratka 2004 (CO) Zimmer 2004 (MT) Ellsworth and Reynolds 2006
Abies grandis		*Arctostaphylus uva-ursi*	
Larix occidentalis		*Ceanothus* spp.	
Picea engelmannii		*Juniperus scopulorum*	
Pinus contorta		*Mahonia repens*	
Pinus monticola		*Paxistima myrsinites*	
Pinus ponderosa		*Pteridium aquilinum*	
Pseudotsuga menziesii		*Rosa* spp.	
Thuja plicata		*Rubus* spp.	
Tsuga heterophylla		*Salix coulteri*	
		Shehperdia canadensis	
		Spirea betulifolia	
		Symphoricarpus albus	
		Vaccinium spp.	
Northern Boreal Forest			
Picea glauca	*Alnus crispa*	*Amelanchier alnifolia*	Wolff 1978 (AK) Bryant 1981 (AK) Smith et al. 1988 (Yukon)
Picea mariana	*Alnus rugosa*	*Betula glandulosa*	
	Betula papyrifera	*Corylus cornuta*	
	Populus balsamifera	*Ledum decumbens*	
	Populus tremuloides	*Rosa* spp.	
		Salix spp.	

Snowshoe hare ecology

Snowshoe hare activity levels are highest during the spring and summer, requiring the greatest level of energy intake; activity levels decrease to a moderate level during fall, and are lowest during winter (Abele 2004). Hares excrete soft pellets known as cecotropes (Pehrson 1983, Björnhag 1994). Once excreted, cecotropes are often re-ingested, enabling hares to recapture important components including vitamins, electrolytes and proteins (Björnhag 1994).

Herbaceous foods (deciduous shrubs and other leafy greens) are selected when available during spring through fall (Plate 2.7). Hares switch to woody browse (branches, twigs, small stems, and evergreen needles) during the winter in response to snow depth and changes in available food sources (Hodges 2000*a*, Wirsing and Murray 2002, Murray 2003, Zimmer 2004).

Plate 2.7. The diet of snowshoe hares provides energy-rich proteins necessary for growth and maintenance. The winter diet is largely restricted to buds and twigs of conifers, while the summer diet is more varied.

Snowshoe hares consume a variety of plant materials that when combined yield high nutritional content (Belovsky 1984, Sinclair et al. 1988, Rodgers and Sinclair 1997, Seccombe-Hett and Turkington 2008). Foraging strategies that maximize energy and protein intake and provide other necessary nutrients, while minimizing fiber and the need for secondary consumption, may explain selection of specific plant types (Ellsworth and Reynolds 2006, Seccombe-Hett and Turkington 2008). For example, buds or small twigs ≤4 mm (≤0.2 in) in diameter provide protein-rich resources (Pease et al. 1979, Wolff 1980, Fox and Bryant 1984, Hodges 2000*a*), while certain herbs and fungi provide increased sodium levels (Belovsky 1984). Lodgepole pine contains high levels of digestible protein (Holter et al. 1974, Ellsworth 2004) making it one of the most important winter food items for hares (Wirsing and Murray 2002, Ellsworth and Reynolds 2006).

Reproduction. The breeding season generally begins in winter (January–April) and ends in fall (July–October). Snowshoe hares are polygamous and can produce multiple litters during the breeding season (Ellsworth and Reynolds 2006). On average, snowshoe hares produce 2–4 litters per year, with 2–6 young per litter, for a total annual production of 6–13 offspring per adult female (Murray 2003).

In cyclic populations, pregnancy rate, litter size, and annual fecundity vary substantially between years (O'Donoghue and Krebs 1992, Hodges et al. 2001, Stefan and Krebs 2001). In Alberta, the mean number of young per adult female ranged from 7.5 during the cyclic low to 17.9 at the cyclic high (Meslow and Keith 1968, Cary and Keith 1979).

Non-cyclic snowshoe hare populations in the southern distribution have lower overall productivity, with some differences observed between eastern and western populations. It is speculated that increased stress levels caused by higher predation risk (Boonstra and Singleton 1993, Boonstra et al. 1998), shorter breeding seasons at higher elevations (Murray 2000), and reduced reproductive capabilities due to the smaller size of adult females (Nagorsen 1985) could be factors influencing the lower productivity of southern populations.

Snowshoe hare ecology

Snowshoe hares achieve adult body weight approximately 9–11 months following birth (Keith and Windberg 1978). The rate of juvenile dispersal varies between populations, ranging from <10% (Hodges 1998) to as much as 50% (Gillis and Krebs 1999).

Survival. Juvenile survival appears to be one of the most significant factors contributing to population decline, stability, or growth in both northern and southern populations (Green and Evans 1940, Meslow and Keith 1968, Dolbeer and Clark 1975, Keith 1981, Krebs et al. 1986, Hodges et al. 2001). Griffin (2004) used demographic modeling in Montana to evaluate population growth rates based on juvenile and adult survival, fertility rates of hare populations, and source/sink dynamics within various habitats. Annual survival appeared to have a greater influence on population growth than did reproduction rates. Similarly, Keith and Windberg (1978) found juvenile survival to be the most sensitive demographic parameter in a cyclic population in Alberta. In Colorado, juvenile survival rates of at least 16% contributed to population stability (Dolbeer and Clark 1975) while 28% juvenile survival was required for population growth in the Yukon (Hodges et al. 2001).

Mortality. Predation (Plate 2.8) is the leading cause of mortality for snowshoe hare throughout its range (Hodges 2000*a*). Of post-weaned mortality, 58–100% was attributable to predators in northern hare populations (Brand et al. 1975, Keith et al. 1984, Boutin et al. 1986, O'Donoghue 1994, Murray et al. 1997, Ferron et al. 1998, Gillis 1998, Hodges et al. 2001) and 80–100% in southern hare populations (Sievert and Keith 1985, Keith et al. 1993, Cox et al. 1997, Wirsing et al. 2002, Abele 2004, Bull et al. 2005).

Plate 2.8. Snowshoe hares are vulnerable to predation by many predators. Lynx are a primary predator, especially in winter.

Predators of adult snowshoe hares include lynx, bobcats (*Lynx rufus*), red foxes (*Vulpes vulpes*), coyotes (*Canis latrans*), gray wolves (*Canis lupus*), fishers (*Martes pennanti*), American martens (*Martes americana*), mink (*Mustela vison*), wolverines (*Gulo gulo*), mountain lions (*Felis concolor*), northern goshawks (*Accipiter gentilis*), red-tailed hawks (*Buteo jamaicensis*), golden eagles (*Aquila chrysaetos*), northern hawk-owls (*Surnia ulula*), great gray owls (*Strix nebulosa*), great horned owls (*Bubo virginianus*), barred owls (*Strix varia*), and common ravens (*Corvus corax*; Adams 1959, Earhart and Johnson 1970, Rausch and Pearson 1972, Keith et al. 1977, Raine 1987, Kuehn 1989, Keith 1990, Poole and Graf 1996, Rohner and Krebs 1996, O'Donoghue et al. 1997, Stenseth et al. 1997, McIntyre and Adams 1999, Hodges et al. 2001, Wirsing et al. 2002). Predators of juvenile hares also include red squirrels, arctic ground squirrels (*Spermophilus parryii*), short-tailed weasels (*Mustela erminea*), boreal owls (*Aegiolus funereus*), and American kestrels (*Falco sparverius*; O'Donoghue 1994, Stefan 1998, Hodges et al. 2001). Predation risk may vary by season, influencing the species of predators that are present and their hunting efficiency (Ellsworth and Reynolds 2006).

Competition with other browsers. Dodds (1960), Bookhout (1965), and Krefting (1975) considered the potential for competition between snowshoe hares and native ungulates. Moose and snowshoe hares appeared to concentrate their use in different areas and did not limit the other's population through overbrowsing (Dodds 1960). The potential for competition was also lowered due to differences in browse heights between ungulates and hares (Dodds 1960, Bookhout 1965, Oldemeyer 1983). Still, Telfer (1972) found some overlap between browsing of white-tailed deer and snowshoe hare in Nova Scotia and New Brunswick. The vertical distribution of winter browsing by snowshoe hares, between 0.6–1.5 m (2–5 ft), was the same as white-tailed deer browsing during the fall and spring (Telfer 1974). However, in all of these studies it is unlikely that co-occurring herbivores resulted in population limitation of hares.

Population cycle. The snowshoe hare cycle is thought to be generated by an interaction between hares, their winter food supply, and predation (Keith et al. 1977, Akcakaya 1992, Royama 1992, Krebs et al. 1995, Stenseth 1995). Keith (1990) summarized the results of several studies on the snowshoe hare population cycle and food supply in northern boreal forests. Overwinter browse estimates during the hare peak and post-peak indicated a shortage of food. Weight losses of hares were significantly negatively correlated with browse availability. Hares suffering from malnutrition or starvation showed symptoms of low body mass and depressed levels of blood sugar and liver glycogen. Lower rates of reproduction, growth, and survival followed winters of high weight loss. In food manipulation experiments, mean winter weights were lower and overwinter weight losses greater for hares in food-scarce treatments. In addition, food scarcity led to shorter breeding seasons and a decrease in mean natality. Keith (1990) concluded that food shortage at a regional rather than local scale controlled the hare cycle.

Several subsequent studies indicated that while hares reduced shrub biomass (Smith et al. 1988, Krebs et al. 2001*a*, Krebs 2011), it was unlikely that populations were limited by food quantity at any time during their cycle (Krebs et al. 2001*a*, Krebs 2011). Krebs et al. (1986) found that food additions may increase hare densities, but did not prevent the decline phase of the cycle. The quality of the diet was shown to limit populations by reducing reproduction and juvenile survival (Keith et al. 1984, Boutin et al. 1986, Aubry et al. 2000, Mowat et al. 2000, Hodges et al. 2001).

Boonstra and Singleton (1993) and Boonstra et al. (1998) suggested that the main mechanism causing the cycle may be decreased survival and reproduction during the decline phase of the cycle, due to a lag time when predator numbers are still increasing and predation rate is heightened. Hares are then thought to avoid high-risk areas by selecting dense cover, which may provide poorer quality food resources (Hik 1994, 1995), resulting in lowered reproduction rates (Boonstra and Singleton 1993, Boonstra et al. 1998). Sherriff et al. (2009) also suggested that stress related to predation may be responsible for hare population crashes by influencing reproduction.

Boonstra et al. (1998) found evidence that risk of predation causes hares to be chronically stressed, which may increase hare vulnerability to predation and decrease hare fecundity. This indicated the snowshoe hare population cycle is driven by an interaction between food and predation (Krebs et al. 1995).

As a specialist predator in the northern boreal forest, lynx populations help to maintain the snowshoe hare population cycle (Anderson and Erlinge 1977, Korpimäki et al. 1991, Hanski et al. 2001). In more southern latitudes, the greater abundance and diversity of generalist predators are thought to have a stabilizing effect because of their ability to "prey switch" when a given prey item becomes scarce (Ellsworth and Reynolds 2006). The interaction of habitat patchiness with more abundant and diverse predator guilds may explain why southern snowshoe hare populations lack cyclicity (Dolbeer and Clark 1975, Wolff 1980, Wolff 1981, Buehler and Keith 1982, Keith et al.

1993, Wirsing et al. 2002). Hodges (2000*b*) discussed 2 models that may explain the lack of cyclicity of snowshoe hares in the southern distribution: the refugium model and the facultative predator model. The refugium model involves 5 components: higher survival by hares in refuge habitats (i.e., dense horizontal cover), hare distribution changes during the cycle (a higher proportion of hares in refugium during the low), lower reproductive rates in refugium, lower survival in non-refugium habitats, and lower overall survival of hares in the southern part of the range. The facultative predator model is driven by higher mortality of snowshoe hares and a higher proportion of mortality by facultative predators than in northern populations.

<u>Importance of snowshoe hare to lynx</u>. The distributions of snowshoe hare and lynx overlap across much of North America (Bittner and Rongstad 1982, McCord and Cardoza 1982). Snowshoe hares are the primary prey of lynx, composing 35–97% of the diet throughout the range of the lynx (Saunders 1963*a*, van Zyll de Jong 1966, Brand and Keith 1979, Parker et al. 1983, Quinn and Parker 1987, Koehler and Aubry 1994, Apps 2000, Mowat et al. 2000, O'Donoghue et al. 2001, Squires and Ruggiero 2007, Burdett 2008, Hanson and Moen 2008, Maletzke et al. 2008, Shenk 2009). Lynx habitat selection largely reflects that of hares, both seasonally as well as through the hare population cycle (O'Donoghue et al. 1998, Mowat and Slough 2003, Squires and Ruggiero 2007, McCann and Moen 2011).

During the low of the snowshoe hare cycle in the northern boreal forest, the proportion and importance of other prey species such as red squirrels increase in the diet of lynx (Brand et al. 1976, O'Donoghue et al. 1998, Apps 2000, Mowat et al. 2000). Although lynx populations rely more heavily on alternate prey during lows in the hare cycle or in areas where hare population densities are naturally low, Roth et al. (2007) found that hares still make up >50% of the biomass of lynx diets for all populations studied.

In Maine, 98% (40 of 41) of lynx kills located while backtracking lynx were snowshoe hare; the exception (1 of 41) was a red squirrel (Fuller 2006, Fuller et al. 2007, Vashon et al. 2012). Hare remains were found in 76% of the lynx scats in Minnesota (Hanson and Moen 2008), and 92% of the kills documented via snow-tracking were snowshoe hare (Burdett 2008). In Montana, Squires and Ruggiero (2007) reported that even in areas with consistently low densities (0.1–0.6 hares/ha [0.04–0.02 hares/ac]), snowshoe hares still accounted for 96% of biomass in the lynx diet, with red squirrels and grouse accounting for only 2% each of the biomass in lynx diets during winter. In Colorado, 66.4±5.6% of annual documented kills by lynx (n=604) were hares, varying annually from 30.4–90.8%, while an average of 22.6±5.7% were red squirrels (Shenk 2009). In Washington, 81% (17 of 21) of the kills located along lynx trails were snowshoe hare, while 14% (3 of 21) were red squirrels (Maletzke et al. 2008).

Energetic analysis suggests that lynx should consume 0.4–0.5 hares per day to satisfy caloric needs (Nellis et al. 1972). In the northern portion of its range, lynx consumption rates averaging 0.5–1.2 hares per day were calculated using various methods (Saunders 1963*a*, Brand et al. 1976, Keith et al. 1977, Parker 1981, O'Donoghue et al. 1998).

Red squirrel ecology

<u>Description</u>. The red squirrel is the most widespread species of tree squirrel in the genus *Tamiasciurus* (Obbard 1987). It is a small tree squirrel, with head and body 18–20 cm (7–8 in) in length and tail 10–15 cm (4–6 in) in length (Plate 2.4).

Red squirrels range from Alaska, Yukon Territory, Northwest Territories and Quebec southward to the Rocky Mountains of New Mexico in the west, and to the southern Appalachian Mountains of South Carolina in the east

(Miller and Kellogg 1955, Hall and Kelson 1959, Peterson 1966, Walker 1968, Banfield 1974, Honacki et al. 1982). Their range is closely associated with boreal forests of Alaska and northern Canada, subalpine montane coniferous forests of western Canada and the United States, and mixed-coniferous and hardwood forests of the eastern United States and Canada (Peterson 1966, Walker 1968, Rowe 1972, Banfield 1974).

Activity patterns. Red squirrels are active year-round and are primarily diurnal (Godin 1977). During winter, red squirrels often are most active during the warmer mid-day period (Layne 1954, Smith 1968*a*, Pauls 1978). When temperatures fall below -32°C (-25°F), red squirrels are seldom active above the snow surface (Pruitt and Lucier 1958, Smith 1968*a*). Especially in northern portions of its range, red squirrel activity is often subnivean or subterranean during extremely cold winter periods (Pruitt and Lucier 1958, Zirul 1970).

Home range. In coniferous forests, red squirrels occupy solitary, non-overlapping contiguous territories that are defended from conspecifics of either sex (Gordon 1936, Clarke 1939, Hatt 1945, Kilham 1954, Smith 1968*a*). In deciduous forests, red squirrel home ranges overlap broadly, and no exclusive territories are evident (Layne 1954, Yahner 1980). This may reflect a more abundant and diverse food base in deciduous forests, which eliminates the dependence on a cached food supply (Kemp and Keith 1970, Rusch and Reeder 1978).

Habitat. Red squirrel densities tend to be highest in older, closed-canopy forests that have substantial quantities of coarse woody debris, and lower in young stands that lack cone production (Layne 1954, Obbard 1987, Klenner and Krebs 1991). Population densities are highest (250–400/km^2 [96–154/mi^2]) in spruce forests, lower (100–200/km^2 [38–77/mi^2]) in mixed conifers and mixed-conifer/hardwoods, and lowest (25–100/km^2 [10–38/mi^2]) in pines and hardwoods (Obbard 1987). Lachowski (1997) found red squirrels to be abundant across all forest types in Maine during spring, but more abundant in conifer and mixed forest during winter. Sullivan and Moses (1986) showed that red squirrel densities and recruitment were significantly higher in young (20 year-old) unthinned lodgepole pine stands (stem density of 20,000–35,000/ha [8,000–14,000/ac]), than in thinned stands (stem density 850–2,300/ha [350–900/ac]) in interior British Columbia.

Where available, spruce is used by red squirrels as nest trees. Other conifers with a high branch density are also utilized (Hatt 1945, Fancy 1980). Where cavities in coniferous trees are not available, underground nests and outside tree (leaf) nests are commonly used (Fancy 1980). In eastern hardwood forests, tree cavities offer preferred nest sites, but underground and outside tree nests are also used (Hatt 1929, Hamilton 1939, Layne 1954). Tree nests are usually located in contact with the trunk in dense stands with high canopy closure (Rothwell 1979).

Dense conifer clumps, especially those with snags or fallen logs, provide important shade and protective cover for food caches (Vahle and Patton 1983).

Diet. Conifer seeds are the basis of the red squirrel's year-round diet, but deciduous and coniferous buds are also important components during winter and spring (Smith 1968*a*, *b*; Kemp and Keith 1970, Reichard 1976, Rusch and Reeder 1978). Squirrels cut and cache newly matured conifer cones to help assure a year-round food supply (Smith 1968*a*, 1981; Gurnell 1984).

The activity center of each territory is the midden where seeds are cached (Larsen and Boutin 1995). Caches often accumulate over several years and provide food during cone crop failures (Smith 1968*b*).

Large species of fungi are eaten fresh as well as cached in the canopy for later consumption (Seton 1910, Klugh

1927, Hatt 1929, Layne 1954). In deciduous forests, red squirrels utilize and cache a large variety of seeds and mast from species such as oaks (*Quercus* spp.), hickory (*Carya* spp.), maple (*Acer* spp.), elm (*Ulmus* spp.), and beech (*Fagus grandifolia;* Seton 1910, Hatt 1929, Williams 1936, Layne 1954, Kemp and Keith 1970). However, these caches do not normally accumulate from year to year (Hatt 1929).

Red squirrels also prey on young hares. During highs in the hare population cycle in the Yukon, squirrel predation was a major source of mortality on young hares, which may have slowed hare population growth (Boonstra et al. 2001).

Reproduction. Females are reported to accept males onto their territories only during their 1-day estrous cycle (Smith 1968*a*, Rusch and Reeder 1978). Throughout most of its range, 1 litter per year is typical (Obbard 1987). However, in the southern and eastern portion of its range, 2 litters may be produced each year (Hamilton 1939, Layne 1954, Wrigley 1969, Lair 1985). Average litter size is about 3 to 5 young (Obbard 1987), depending on annual food supply (Smith 1968*a*, Kemp and Keith 1970, Rusch and Reeder 1978).

Mortality. Red squirrels are preyed upon by a variety of predators. Among the most common mammalian predators are fishers (Hamilton and Cook 1955, Brown and Will 1979) and martens (Marshall 1946, Quick 1955, Soutiere 1979, Lachowski 1997). The most common avian predator is northern goshawk (Meng 1959), although great horned owls (Rusch et al. 1972), red-tailed hawks (Luttich et al. 1970), broad-winged hawks (*Buteo platypterus*; Rusch and Reeder 1978), and Cooper's hawks (*Accipiter cooperi*; Meng 1959) have also been noted to prey upon red squirrels.

Importance of red squirrels to lynx. Red squirrels appear to be the most important alternate prey for lynx throughout the northern portion of their range (Brand et al. 1976, O'Donoghue et al. 1998, Apps 2000). Red squirrel remains occurred in 56% (10 of 18) of lynx winter scats from the Northwest Territories (More 1976) and 9% (2 of 23) of the summer digestive tract samples from northern Alberta and the Northwest Territories (van Zyll de Jong 1966). Red squirrel densities appeared to fluctuate independently of the snowshoe hare cycle during a 10-year project in the Yukon (Krebs et al. 2001*b*).

Koehler (1990*a*) reported that red squirrels occurred in 24% of lynx scats in north-central Washington. In contrast, Burdett (2008) and Hanson and Moen (2008) analyzed 87 lynx scat samples collected during winter in Minnesota and found no red squirrel remains. Red squirrels do not appear to be an important alternate prey in that area. Squires and Ruggiero (2007) located 86 lynx kills that included 7 prey species in their Montana study area. Snowshoe hares accounted for 69 of the kills and 11 were red squirrels. Red squirrels were only 2% of the biomass of the winter diet (Squires and Ruggiero 2007). Shenk (2007) reported that red squirrels made up 16.5% of the annual lynx diet while snowshoe hares made up 75% in Colorado.

Koehler (1990*a*) suggested that a diet of red squirrels alone might not be adequate to ensure lynx reproduction and survival of kittens. Rather, lynx populations appear to be limited by the availability of snowshoe hare prey, particularly during the winter months.

Lynx hunting behavior

The morphological and behavioral adaptations of felids generally accentuate visual recognition of prey and short, quick pursuits (Kleiman and Eisenberg 1973). Lynx use 2 basic methods to hunt snowshoe hares: ambushing from a hunting bed during nocturnal hours when hares are most active, and moving through hare habitat to stalk and flush hares from cover during the day (Kolbe and Squires 2007, Squires and Ruggiero 2007, Fuller et al. 2007).

In Canada, O'Donoghue (1997) reported that lynx captured red squirrels opportunistically when hares were abundant, but actively hunted red squirrels when hares were scarce. In Montana, red squirrels were taken opportunistically (Squires and Ruggiero 2007).

Although cover is important to lynx when searching for food (Brand et al. 1976), lynx often hunt along the edges of forests (Plate 2.9; Kesterson 1988, Staples 1995, Mowat et al. 2000) and dense riparian willow stands (Major 1989, Shenk 2008). Less dense stands may improve visibility for lynx and increase the vulnerability of hares (O'Donoghue et al. 1998, Fuller et al. 2007). Lower stem density may be more important than hare abundance in determining hunting success (Fuller et al. 2007).

Laurel Peelle

Plate 2.9. Lynx foraging habitat is moderately dense, allowing pursuit and capture of prey while also providing dense horizontal cover for snowshoe hares.

In Maine, lynx focused their hunting in regenerating clearcuts (Plate 2.10; 11–26 years post-harvest) and in established partially-harvested stands (11–21 years postharvest; Fuller et al. 2007). However, lynx avoided the stands with the highest stem density (14,000 stems/ha [5,668 stems/ac]) and preferentially hunted in patches with intermediate to high snowshoe hare density (Fuller and Harrison 2010). Roads and their associated edges (30 m [100 ft] on either side of roads) were selected against within lynx home ranges (Fuller et al. 2007).

In Minnesota, Burdett (2008) reported that lynx selected regenerating forests for hunting and resting sites during the winter months. Female lynx used a foraging radius of approximately 2–3 km (1.2–1.8 mi) when kittens were at the den (Moen et al. 2008).

In Montana, Squires et al. (2010) reported that horizontal cover was denser at lynx kill sites than along travel paths. They further reported that lynx kill sites were associated with a higher proportion of spruce-fir overstory than lodgepole pine overstory, and that neither snow depth nor snow penetrability influenced lynx kill sites.

Berg et al. (2012) speculated that lynx in the Greater Yellowstone Ecosystem would likely not avoid hunting in young, dense (3,194.16±553.05 stems/ha [1,293±223.9 stems/ac]) lodgepole pine patches. In this area, the stem density does not reach the 14,000 stems/ha (5,668 stems/ac) that was reported by Fuller and Harrison (2010) to be too dense for effective hunting by lynx.

Plate 2.10. Young, dense conifers provide excellent lynx foraging habitat in Maine.

Lynx distribution

The historical range of Canada lynx extends from Alaska across much of Canada (except for coastal forests), with southern extensions into parts of the western United States, the Great Lakes states, and New England (McCord and Cardoza 1982). Lynx distribution is closely aligned with the distribution of snowshoe hares (Bittner and Rongstad 1982, McCord and Cardoza 1982) and boreal forests (McCord and Cardoza 1982, Koehler and Aubry 1994, Agee 2000, McKelvey et al. 2000*b*, Mowat et al. 2000). Boreal forests extend southward from the arctic tundra in the far north, to boreal/hardwood forest ecotones in the Midwest and eastern United States, and to subalpine forests in the western United States (Agee 2000).

States with verified records of lynx

McKelvey et al. (2000*b*) summarized the locations of documented lynx occurrences, which were found in 24 states. A "verified record" was defined as a museum specimen or a written account in which a lynx was either in someone's possession or observed closely, e.g., killed, photographed, trapped and released, or treed by dogs.

The National Lynx Survey, using a detection protocol developed by McKelvey et al. (1999), was conducted between 1999 and 2003 to determine the presence of lynx on federal lands. Approximately 70 sampling grids were deployed in the survey of 22 national forests. Lynx were detected on 6 of the national forests surveyed: the Okanogan-Wenatchee National Forest in Washington, the Boise and Targhee National Forests in Idaho, Shoshone National Forest in Wyoming, and Lolo and Gallatin National Forests in Montana, as well as Glacier National Park in Montana (K. McKelvey, USDA Forest Service, Rocky Mountain Research Station, unpublished data). Subsequent surveys, using a modified protocol, detected lynx in Maine and on the Superior National Forest in Minnesota.

A number of recent studies of lynx improved our knowledge of lynx distributions in specific regions (Hoving et al. 2003, 2005; Fuller et al. 2007; Koehler et al. 2008; Maletzke et al. 2008; Vashon et al. 2008*a*, *b*; Moen 2009;

Simons 2009; Fuller and Harrison 2010; Squires et al. 2013). These studies generally found that lynx are more abundant in Maine, but rarer and more patchily distributed across the western and Great Lakes regions of the United States than previously thought. This refinement in our understanding of lynx distribution is described in greater detail for each geographic area in Chapter 3.

States with verified records but not thought to support resident populations of lynx

There is substantial uncertainty about the historical distribution of lynx in the northeast (McKelvey et al. 2000*b*). However, recent regional-scale habitat models suggest New York, Vermont, and New Hampshire receive insufficient snow levels or contain too much deciduous-dominated landscape to support viable populations of lynx (Hoving et al. 2005). Small numbers of breeding lynx were documented in northern New Hampshire and Vermont between 2009–2011 (M. McCollough, U.S. Fish and Wildlife Service, personal communication 2012). The long-term persistence of these small populations is unknown.

Records from 1940–1997 showed an increase in lynx occurrences during the 1960s in Michigan's Upper Peninsula, a period when extensive dispersals from Canada occurred. Beyer et al. (2001) conducted track surveys that yielded no evidence of lynx in the region, and habitat models suggested there is insufficient suitable habitat or densities of snowshoe hare to support a viable population of lynx in Michigan (Linden 2006). Wisconsin is not believed to support lynx habitat or resident populations either.

Lynx presence has been recorded in North Dakota, South Dakota, Illinois, Nebraska, Kansas, and Indiana, where lynx habitat does not exist (Adams 1963, Gunderson 1978, Hoffman and Genoways 2005, Devineau et al. 2010). Most of these occurrences appear to be animals dispersing southward from Canada during lows in the snowshoe hare population cycle (McKelvey et al. 2000*b*) or following translocation to Colorado (Devineau et al. 2010).

There are sporadic lynx records from northeast Oregon, which are generally consistent with the time periods when there were large numbers dispersing from Canada (McKelvey et al. 2000*b*). There is no evidence that lynx breed and reproduce in Oregon.

Lynx population density and home range size

Lynx densities vary across the southern periphery of its range. In Maine, densities during a likely population peak ranged from 9.2–13.0 lynx/100 km^2 (23.8–33.7 lynx/100 mi^2); if only adults are included, the density averaged 4.3 adults/100 km^2 (11.1 adults/100 mi^2; Vashon et al. 2008*a*). The density in nearby Gaspé Peninsula, Quebec was estimated to be 10 lynx/100 km^2 (25.9 lynx/100 mi^2; Ray et al. 2002). These are much higher than the density estimate of 2.3 lynx/100 km^2 (6.0 lynx/100 mi^2) for north-central Washington (Koehler 1990*a*).

Reported lynx home range sizes are also quite variable (Table 2.2). Methods used to estimate home range area have not been standardized, and some of the differences in reported home range sizes reflect the home range estimator employed, type of telemetry monitoring system used (VHF, GPS, or Argos), and number of relocations of individuals. Generally, home ranges in the western United States are larger than those reported from the eastern United States or from northern Canada during peaks in snowshoe hare abundance (Aubry et al. 2000).

In Canada, average winter home ranges of 3 lynx in Newfoundland were about 18 km^2 (7 mi^2; Saunders 1963*b*). In Riding Mountain National Park, Manitoba, home ranges for 2 females with kittens averaged 156 km^2 (60 mi^2), while that of a male was estimated at 221 km^2 (85 mi^2; Carbyn and Patriquin 1983). In southwestern Yukon, Ward and Krebs (1985) found a clear trend of increasing lynx home range size as hare densities declined. Four

Table 2.2. Mean annual home range size of Canada lynx in southern boreal forests.

Location	Latitude (°N)	Male		Female		Method	Reference
		n	X ± SD	n	X ± SD		
Northern Maine	46	11	54 ± 5 km^2 (21 ± 2 mi^2)	11	26 ± 4 km^2 (10 ± 2 mi^2)	85% Fixed Kernel	Vashon et al. 2008*a*
Northeastern Minnesota	48	4	267 ± 73 km^2 (103 ± 28 mi^2)	2	21 ± 2 km^2 (8 ± 1 mi^2)	95% MCP	Burdett et al. 2007
Northeastern Minnesota	48	2	194 km^2 (75 mi^2)	2	87 km^2 (34 mi^2)	95% MCP	Mech 1980
Southern Canadian Rockies	51	3	277 ± 71 km^2 (107 ± 27 mi^2)	3	135 ± 124 km^2 (52 ± 48 mi^2)	95% MCP	Apps 2000
West-central Wyoming	43	1	137 km^2 (53 mi^2)	1	114 km^2 (44 mi^2)	95% MCP	Squires and Laurion 2000
Southern Colorado	37	4	103 ± 40 km^2 (40 ± 15 mi^2)	19	75 ± 16 km^2 (29 ± 6 mi^2)	90% Fixed Kernel	Shenk 2008
Northwestern Montana	47	4	238 ± 99 km^2 (92 ± 1 mi^2)	2	115 ± 50 km^2 (44 ± 19 mi^2)	95% MCP	Squires and Laurion 2000
North-central Washington	49	5	69 ± 28 km^2 (27 ± 11 mi^2)	2	39 ± 2 km^2 (15 ± 1 mi^2)	100% MCP	Koehler 1990*a*

home ranges corresponding with high hare densities (15 hares/ha [6 hares/ac]) averaged 13 km^2 (5 mi^2) in size, while 7 home ranges at lowest hare densities (<1 hare/ha [<0.4 hares/ac]) averaged 39 km^2 (15 mi^2) in size. In the Northwest Territories, Poole (1994) reported average home range size of about 17 km^2 (7 mi^2) for 23 male and female lynx in a year of peak hare abundance, increasing to 44 km^2 (17 mi^2) for 2 males and 62 km^2 (24 mi^2) for 2 females in the second year of the snowshoe hare decline.

Description of lynx habitat

Lynx habitat characteristics. Lynx typically inhabit gentle, rolling topography (Maletzke et al. 2008, Squires et al. 2013). Across its range, dense horizontal cover, persistent snow, and moderate to high snowshoe hare densities (>0.5 hares/ha [0.2 hares/ac]) are common attributes of lynx habitat. The elevation at which lynx habitat occurs depends on local moisture patterns and temperatures, and varies across the range of the species. Spruce-fir forests are the primary vegetation type that characterizes lynx habitat in the contiguous United States (Koehler 1990*a*, Apps 2000, McKelvey et al. 2000*b*, Koehler et al. 2008, Moen et al. 2008, Vashon et al. 2008*a*, Squires et al. 2010).

The following describes general characteristics of boreal forest vegetation, snow conditions, and snowshoe hare prey base that constitute lynx habitat. More detailed information is provided for each geographic area in chapter 3.

Boreal forest vegetation. In the northeastern United States, most lynx occurrences are within the Mixed Forest-Coniferous Forest-Tundra vegetation type, at elevations of 250–500 m (820–2,460 ft; McKelvey et al. 2000*b*). Lynx have been documented to use both coniferous and mixed-coniferous/deciduous vegetation types dominated by white, black, and red spruce, balsam fir, pine, northern white cedar, eastern hemlock, sugar maple, aspen, and paper birch (Plate 2.11; Hoving et al. 2004, Fuller et al. 2007, Vashon et al. 2008*a*). Mature deciduous stands and forest openings are avoided by lynx at all spatial scales.

In the Great Lakes Geographic Area, most lynx occurrences (88%) are within the Mixed Deciduous/Conifer Forest (McKelvey et al. 2000*b*). Coniferous and mixed-coniferous/deciduous vegetation types dominated by pine, balsam fir, black and white spruce, northern white cedar, tamarack, aspen, paper birch, conifer bogs and shrub swamps provide lynx habitat in this geographic area (Plate 2.12; Burdett 2008, Moen et al. 2008, McCann and Moen 2011).

In the western United States, most lynx occurrences (83%) are associated with Rocky Mountain Conifer Forest, and most (77%) fall within the 1,500–2,000 m (4,920–6,560 ft) elevation zone (McKelvey et al. 2000*b*), except in Colorado where elevations are higher. Engelmann spruce, subalpine fir and lodgepole pine forest cover types occurring on cold, moist potential vegetation types provide habitat for lynx (Plate 2.13; Aubry et al. 2000). Dry forest cover types (e.g., ponderosa pine, dry Douglas-fir) do not provide lynx habitat (Koehler et al. 2008, Maletzke et al. 2008, Squires et al. 2010).

Snow conditions. Across the northern boreal forests of Canada, snow conditions are very cold and dry. Snow depths are relatively uniform and only moderately deep, with total annual snowfall of 100–127 cm (39–50 in; Kelsall et al. 1977). In contrast, in the southern portion of lynx range, snow depths are generally deeper, with deepest snows in the mountains of southern Col-

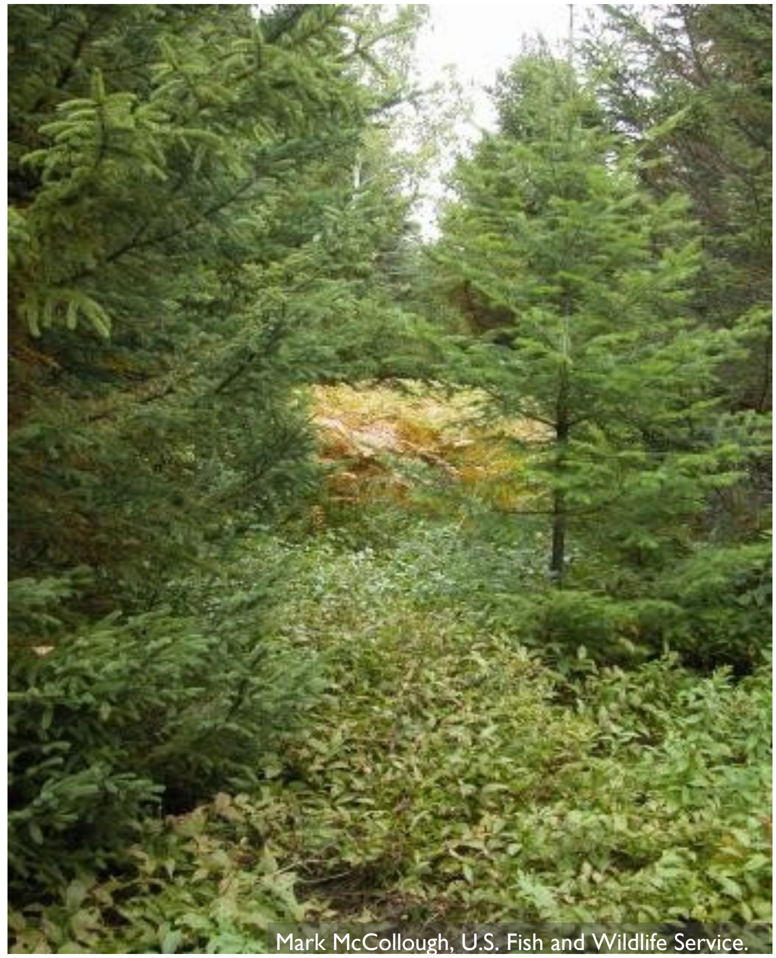

Plate 2.11. Lynx habitat in the northeastern United States is dominated by white, black, and red spruce, white cedar, sugar maple, and aspen.

Plate 2.12. Lynx habitat in the Great Lakes area is dominated by balsam fir and white spruce.

orado. Snow in southern lynx habitats may be subjected to more freezing and thawing than in the northern portion of lynx range (Buskirk et al. 2000*b*), although this varies with elevation, aspect, and local weather conditions. It has been suggested that crusting or compaction of snow may reduce the competitive advantage that lynx have in soft snow because of their long legs and low foot loadings (Buskirk et al. 2000*a*).

Plate 2.13. Lynx habitat in the western United States is dominated by Engelmann spruce, subalpine fir, and lodgepole pine.

Snowshoe hare prey base. A landscape density of >0.5 hares/ha (0.2 hares/ac) has been suggested to be necessary to sustain lynx within their home ranges (Mowat et al. 2000, Ruggiero et al. 2000*b*). A density of <0.3 hares/ha (0.12 hares/ac) correlates with observations of adult lynx emigrating from their home ranges in Canada and is thought to be too low to support lynx survival (Mowat et al. 2000).

Steury and Murray (2004) indicated that a density of >1.5 hares/ ha (0.6 hares/ac) would be necessary to enable a reintroduced lynx population to persist. However, snowshoe hare densities across the southern range are consistently below this density (Keith 1990, Hodges 2000*b*, Murray 2000). Murray et al. (2008) acknowledged that this may be an overly conservative estimate for a threshold density, given differences in population dynamics between northern and southern populations of hares and lynx.

Plate 2.14. In the western United States, mature multi-story forests with dense horizontal cover and lower live limbs at the snow surface provide good lynx foraging habitat during winter.

Lynx occurrence in northern Maine is strongly associated with landscape-scale hare densities of >0.74 hares/ha (0.39 hares/ac; Simons 2009, Simons-Legaard et al. 2013). Stands that had snowshoe hare densities of >1.5 hares/ha (0.6 hares/ac) supported female lynx accompanied by kittens and a 78% kitten survival rate (Vashon et al. 2008*a*). Lynx did not occupy areas where landscape-scale hare densities were <0.5 hares/ha (0.2 hares/ac; Simons-Legaard et al. 2013).

Seasonal variation in lynx habitat use. In the western United States in winter, lynx selected for mature multi-story stands dominated by Engelmann spruce and subalpine fir (Plate 2.14; Koehler et al. 2008, Squires et al. 2010). These stands consisted primarily of large diameter trees where limbs reached the snow at ground level and contributed to dense horizontal cover (Squires et al. 2010). In Montana, the proportion of overstory size classes of trees in forests used by lynx in winter were 5% saplings (2.5–8 cm [1–3 in] dbh), 19% pole (8–18 cm [3–7 in] dbh), 42% mature (18–28 cm [7–11 in] dbh), and 29% large (>28 cm [>11 in] dbh). Regenerating stands composed of small diameter saplings <10 cm (<4 in) dbh in dry forest types, recent clear-cuts, and forest openings across all spatial scales were generally avoided during winter (Koehler et al. 2008, Maletzke et al. 2008, Squires et al. 2010). Lynx remained near the forest edge when crossing forest openings, and the average crossing distance was 117 m (384 ft) with a range of 40–379 m (131–1,243 ft; Squires et al. 2010).

In contrast to habitat use by lynx in winter, Squires et al. (2010) found forest stands in Montana with mature and large diameter trees were used less often during summer. Lynx broadened their selection to include younger regenerating stands composed of Engelmann spruce and subalpine fir with abundant small diameter and pole sized trees (8–18 cm [3–7 in] dbh), abundant total shrubs, and high horizontal cover (Squires et al. 2010). The proportion of overstory size classes of trees in forests used by lynx in summer were 66% pole (8–18 cm [3–7 in] dbh), 21% mature (18–28 cm [7–11 in] dbh), and 6% large (>28 cm [>11 in] dbh). Lynx generally avoided forest types with high proportions of Douglas-fir, grass in the understory, or snags. Elevations used by lynx were 136±24 m [446±79 ft] higher in summer than during the winter but still occurred in the montane zone between the alpine zone and the dry forests of the lower montane zone (Squires et al. 2010).

Foraging habitat. In the contiguous United States, lynx focus their foraging in conifer and conifer-hardwood habitats that support their primary prey of snowshoe hares. Winter habitat may be more limiting for lynx (Squires et al. 2010). Dense saplings or mature multi-layered stands are the conditions that maximize availability of food and cover for snowshoe hares at varying snow depths throughout the winter.

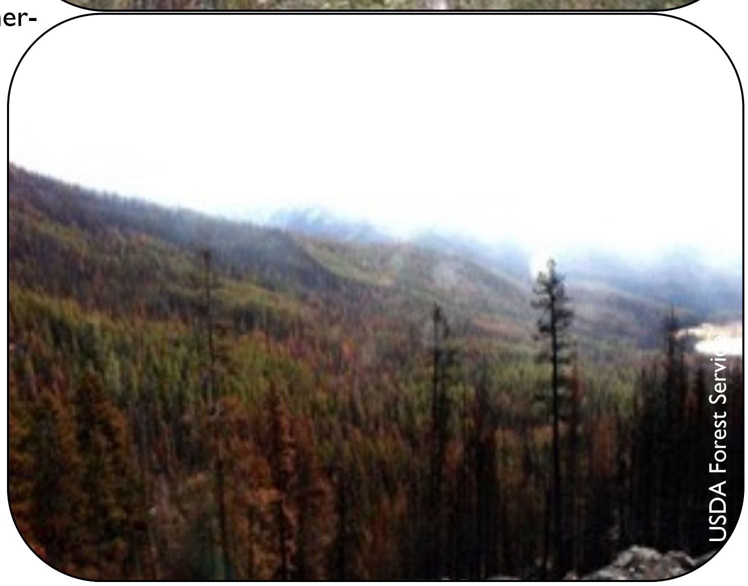

Plate 2.15. Natural disturbance processes, including wildfire, wind events, and insect outbreaks, create early seral forest structure that can develop into the dense structure used by snowshoe hares.

Natural disturbance processes that create early successional stages exploited by snowshoe hares include fire, insect infestations, wind throw, and disease outbreaks (Plate 2.15; Kilgore and Heinselman 1990, Veblen et al. 1998, Agee 2000). Both timber harvest and natural disturbance processes provide foraging habitat for lynx when the resulting stem densities and stand structure meet the habitat needs of snowshoe hare (Plate 2.16; Keith and Surrendi 1971; Fox 1978; Conroy et al. 1979; Wolff 1980; Parker et al. 1983; Litvaitis et al. 1985; Bailey et al. 1986; Monthey 1986; Koehler 1990*a*, *b*).

Landscapes containing a mix of forest age classes are more likely to provide lynx foraging habitat throughout the year (Poole et al. 1996, Griffin and Mills 2004, Squires et al. 2010). In winter, lynx do not appear to hunt in openings, where lack of cover limits habitat for snowshoe hares (Mowat et al. 2000, Maletzke et al. 2008, Squires et al. 2010). Areas with recent timber harvest and areas recently burned can contribute herbaceous summer foods for snowshoe hares, and woody winter browse will develop on older sites (Fox 1978). Multi-story stands may provide a greater availability of browse as snow depths vary throughout the winter.

Plate 2.16. Regrowth following stand-replacing wildfires can develop dense horizontal cover that supports high densities of snowshoe hares.

In the eastern United States, lynx habitat selection at the home range scale includes extensive areas of regenerating spruce-fir stands 15–35 years after clearcut or other even-aged harvest, with >50–60% canopy closure and intermediate (7,000–11,000 stems/ha [2,834–4,453 stems/ac]) to high (up 14,000 stems/ha [5,668 stems/ac]) stem density (Fuller et al. 2007, Vashon et al. 2008*b*, Scott 2009, Simons 2009). The highest hare densities were found where stem densities exceeded 14,000 stems/ha (5,668 stems/ac), but lynx selected stands with intermediate stem density and intermediate to high hare densities for hunting (Fuller et al. 2007). Simons-Legaard et al. (2013) found the probability of lynx occurrence exceeded 90% when a density of >0.74 snowshoe hares/ha (0.39 hares/ac) and >10% mature conifer forest were present.

In Minnesota, Burdett (2008) reported that lynx selected regenerating forest, dominated by conifer with extensive forest edge; lynx beds (resting and hunting) and kill sites were associated with regenerating and mixed forest. McCann and Moen (2011) found snowshoe hare densities were highest in regenerating forests.

In the western United States, development of a high density >11,250/ha (>4,500/ac) of young conifer stems and branches protruding above the snow was found to provide foraging habitat for lynx within about 10–40 years following disturbance, depending on site productivity, forest type and intensity of disturbance (Sullivan and Sullivan 1988, Koehler 1990*a*). This habitat is temporary, as the tree stems and branches eventually grow out of reach of snowshoe hares and shade out understory saplings and shrubs. Mature multi-story conifer forests with low limbs and a substantial understory of young trees and shrubs provide stable lynx foraging habitat (Murray et al. 1994, Koehler et al. 2008, Squires et al. 2010, Ivan 2011*a*). In north-central Washington, high snowshoe hare densities (>1.0 hares/ha [0.4 hares/ac]) were associated with sapling (<10 cm [<4 in] dbh) densities of 2,784±281 stems/ha (1,127±114 stems/ac) and medium-sized (10–28 cm [4–11 in] dbh) tree densities of 712±80 stems/ha (288±32 stems/ac; Walker 2005).

Lynx denning habitat and den site characteristics. Natal and maternal den sites are used until kittens reach about 6–8 weeks of age (Slough 1999, Moen et al. 2008). For denning habitat to be functional, it must be in or adjacent to foraging habitat (Plate 2.17; Moen et al. 2008). Maternal dens are generally located close to natal dens (median distance of 107 m [351 ft]) and are similar in forest structure characteristics (Slough 1999, Squires et al. 2008). Kittens are left alone at den sites while the female lynx hunts (Slough 1999, Moen et al. 2008, Olson et al. 2011). Coarse woody debris provides kittens with protection from extreme temperatures, precipitation, or predators (Boutros et al. 2007, Moen et al. 2008).

Plate 2.17. Lynx denning habitat is structurally complex, typically located near foraging habitat and containing a high volume of large down logs.

The common components of natal and maternal den sites appear to be large woody debris (Plate 2.18; down logs or root wads) and dense horizontal cover (Koehler 1990*a*, Mowat et al. 2000, Squires and Laurion 2000, Moen et al. 2008, Organ et al. 2008, Squires et al. 2008). Dens have occasionally been located under ledges in boulder fields (individual boulders >1 m [>3.3 ft] diameter), under live vegetation such as alder

Plate 2.18. The majority of lynx dens in the contiguous United States are associated with large, down logs in mature conifer forests.

(*Alnus* spp.) and Pacific yew (*Taxus brevifolia*), or in slash piles (Moen et al. 2008, Squires et al. 2008). Den sites typically are situated within older regenerating stands (>20 years since disturbance) or in mature conifer or dense regenerating mixed-conifer-deciduous (typically spruce/fir or spruce/birch) forests (Koehler 1990*a*, Slough 1999, Moen et al. 2008, Organ et al. 2008, Squires et al. 2008). Stand structure appears to be more important than forest cover type (Mowat et al. 2000). The availability of den sites does not appear to be limiting (Gilbert and Pierce 2005, Moen et al. 2008, Organ et al. 2008, Squires et al. 2008).

In Maine, lynx dens were primarily located in stands of sapling-sized trees dominated by conifers, where blown-down trees provided cover and the canopy opening promoted understory growth and dense horizontal cover (Organ et al. 2008). In Minnesota, Moen et al. (2008) reported that sites selected by female lynx for denning had lower stem densities than surrounding areas, with >80% of tree stems being coniferous species including white or black spruce, balsam fir and northern white cedar, The amount of regenerating forest increased in areas surrounding these dens at a distance of 100–500 m (328–1,640 ft; Moen et al. 2008). In Montana and Colorado, lynx primarily denned in mature Engelmann spruce and subalpine fir stands in concave drainages or basins with dense horizontal cover and abundant coarse woody debris (Shenk 2008, Squires et al. 2010).

Lynx population dynamics

Reproduction. Breeding occurs during March and April in the northern part of the range of lynx (Quinn and Parker 1987). Male lynx may be incapable of breeding during their first year (McCord and Cardoza 1982). Males are not known to help rear young (Eisenberg 1986).

In the Yukon near Whitehorse, the timing of kitten births differed somewhat by age class of female lynx.

Adult females delivered kittens on May 23±6 days, while yearlings gave birth from 1–3 weeks later on June 17th ± 7 days (Slough 1999). Kittens were born in May to June in south-central Yukon (Slough and Mowat 1996). Kittens were born in early May in Minnesota (Moen et al. 2008), and from 26 April to 23 May in Montana (Olson et al. 2011). In Maine, 1 female that may have lost her first litter appeared to have had a second litter in August (Vashon et al. 2012).

In Montana, female lynx stayed in natal dens on average for 21±17 days, and subsequently used an average of 3±2 maternal dens in a given year (Olson et al. 2011). Nine female lynx exhibited roughly equal levels of activity from dawn to dusk when they had newborn to 2-month-old kittens. Females caring for kittens were more active during the day compared to pre- or post-denning periods, and they travelled shorter daily distances than before their kittens were born (Olson et al. 2011).

Kitten production and survival. Litter size of adult females averages 4–5 kittens during periods of hare abundance in the northern boreal forest (Mowat et al. 1996). Based on snow-tracking in the Yukon, O'Donoghue et al. (2001) found evidence of family groups with 1–6 kittens. In Canada during the low phase of the hare cycle, few if any live kittens are born, and few yearling females conceive (Brand and Keith 1979, Poole 1994, Slough and Mowat 1996). However, some lynx recruitment may still occur when hares are scarce and this may be important in maintaining the lynx population through the cyclic low (Mowat et al. 2000).

In Maine, during years of high hare populations (1999–2005), 89% of radio-collared females of breeding age had kittens, and average litter size was 2.74 kittens (Plate 2.19; Vashon et al. 2012). During years of low hare populations (2006–2010), 30% of breeding age females had kittens with litter size averaging 2.25 kittens (Vashon et al. 2012). During both time periods (1999–2010), 78% of kittens were with their mother the following January or February after birth (Vashon et al. 2012). This high productivity and survival rate is be-

Plate 2.19. Lynx natal dens are typically located under large logs that provide protection for kittens. Litter size is generally 2–3 kittens in the contiguous United States, but can be as many as 5.

lieved to be indicative of good habitat quality and prey abundance in the study area (Vashon et al. 2008*a*).

In Minnesota, 5 dens were monitored from 2004–2006. Four of 5 females had litters in consecutive years; the 9 litters ranged from 2–5 kittens (average 3.22±0.97; Moen et al. 2008). One radio-collared female bred and had a litter at 2 years of age (Moen et al. 2008).

In Wyoming, 1 female produced 4 kittens in 1998 and 2 kittens in 1999 (Squires and Laurion 2000). In Montana, Squires and Laurion (2000) reported that 1 female produced 2 kittens in 1998, and in 1999, 2 of 3 females produced litters of 2 kittens each. From 1999–2006, 57 dens of 19 female lynx were located in the Seeley Lake, Garnet Range, and Purcell Mountains in western Montana (Squires et al. 2008); litter size data from this study are not yet available.

In Colorado, the number of dens that were located peaked in 2005 (n=17 dens while monitoring 42 females), and subsequently decreased to 4 dens in 2006. No dens were located in 2007 or 2008 while monitoring 34 and 28 females, respectively (Shenk 2008). The average number of kittens per litter was 2.78 and the sex ratio of males to females was 1:1.14 (Shenk 2008).

In north-central Washington, 2 radio-collared females had litters of 3 and 4 kittens in 1986, and each had at least 1 kitten in 1987 (Koehler 1990*a*). Of these litters, only 1 kitten survived to its first winter. However, during 2001-2004, snow tracking showed females to be accompanied by 1–3 kittens in their first winter, but dispersal and survival rates were unknown (von Kienast 2003, Maletzke 2004, Maletzke et al. 2008). Koehler (1990*a*) suggested that the relatively low number of kittens produced in north-central Washington was comparable to northern populations during periods of low snowshoe hare abundance.

Mortality. The most commonly reported causes of mortality are starvation, especially of kittens (Quinn and Parker 1987, Koehler 1990*a*, Vashon et al. 2012), and human-caused mortality (Ward and Krebs 1985, Bailey et al. 1986, Moen 2009). Longevity records indicate lynx live up to 16 years in the wild (Kolbe and Squires 2006). Life spans could vary between regions due to different sources and rates of mortality.

In Maine, 26% (17 of 65) of the mortalities of radio-collared lynx were from starvation, even during times when hare populations were high (Vashon et al. 2012). Other sources of mortality included predation and suspected predation (42%, 27 of 65), legal and illegal harvest both in Maine and Canada (15%, 10 of 65), vehicles (3%, 2 of 65), and disease (2%, 1 of 65; Vashon et al. 2012).

In Minnesota, half of 14 animals radiocollared in the 1970s were shot or trapped, and all recorded mortalities were associated with human causes (Mech 1980). Of lynx that were radiocollared from 2003-2008, Moen (2009) reported that 75% of the mortalities were associated with humans.

In the reintroduced population in Colorado, the primary sources of known mortality were shooting (14 known and 5 probable of 102 mortalities), vehicle collisions (13 of 102), and starvation (10 of 102; Devineau et al. 2010). Other confirmed causes were predation (3 known and 3 probable of 102), disease (7 or 102), illness (2 of 102), and other trauma (8 of 102). Plague was diagnosed as the cause of the 7 lynx mortalities attributed to disease, which was apparently contracted after release in Colorado (Wild et al. 2006). The cause of mortality did not appear to differ between males and females (Devineau et al. 2010).

In cyclic lynx populations of the northern boreal forest, most natural lynx deaths are attributed to starvation during years of low hare abundance (Poole 1994, Slough and Mowat 1996). Hunger-related stress is also thought to induce dispersal, which may increase the exposure of lynx to other forms of mortality such as trapping and highway collisions (Brand and Keith 1979, Carbyn and Patriquin 1983, Ward and Krebs 1985, Bailey et al. 1986).

Predation on lynx by mountain lion, coyote, wolverine, gray wolf, fisher, and other lynx has been confirmed (Plate 2.20; Berrie 1974, Koehler et al. 1979, Poole 1994, Slough and Mowat 1996, O'Donoghue et al. 1997, Apps 2000, Squires and Laurion 2000, O'Donoghue et al. 2001, Vashon et al. 2012). In Maine, 14 of 18 lynx that died of predation were killed by fishers, which were suspected at 4 additional predation events (Vashon et al. 2012). Squires and Laurion (2000) reported 2 of 6 mortalities of radio-collared lynx in Montana were due to mountain lion predation. In Colorado, 3 of 102 lynx mortalities were confirmed as predation (Devineau et al. 2010).

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Plate 2.20. Cougars have been documented as predators of lynx in the western United States, while fishers have been documented killing lynx in the northeast.

Population cycles. Based on the Hudson's Bay Company fur trading records, Elton and Nicholson (1942) documented cyclic 8–11 year oscillations of northern lynx populations, corresponding to similar fluctuations in snowshoe hare abundance. Since then, many studies in northern boreal forests have provided further evidence that lynx populations there are tightly linked to the cyclic abundance of snowshoe hares, with the 2 species exhibiting largely synchronous 8–11 year cycles across Canada and Alaska (Keith et al. 1977, Sinclair et al. 1993, Poole 1994, Mowat et al. 2000, Murray et al. 2008). Stenseth et al. (1999) suggested that lynx population dynamics are synchronized by climatic patterns typical of the Pacific, Continental, and Atlantic zones that are affected by the North Atlantic Oscillation. Stenseth et al. (2004) used a model to test the effect of climate forcing as a synchronizer of regional density fluctuations, and suggested that climate forcing could result in synchrony within regions and asynchrony between regions.

Lynx typically exhibit a 1–2 year delay in peak abundance following a peak in hare abundance (Elton and Nicholson 1942, Keith 1963, O'Donoghue et al. 1997). During a cyclic decline in hare numbers, lynx demonstrate lower survival than during any other phase in the cycle (O'Donoghue et al. 1997). In Alberta, Keith et al. (1977) found that lynx responded to the increase in hare numbers with approximately 4-fold increases in their population sizes, followed by a 3–4-fold decrease during the decline phase of the cycle. In the Northwest Territories, Poole (1994) documented a 10-fold reduction in lynx density during the decline of hare populations. In south-central Yukon, Slough and Mowat (1996) found that lynx numbers fluctuated 10–17-fold over the cycle.

Lynx density, home range size, dispersal patterns, reproductive parameters, and survival rates are strongly correlated to snowshoe hare abundance (Nellis et al. 1972, Brand and Keith 1979, Ward and Krebs 1985, Poole 1994). When hares reach their peak abundance in the cycle, the lynx population exhibits high productivity and recruitment, low mortality, and individuals use smaller home ranges. When hare populations decline, lynx exhibit lower productivity and higher mortality, and demonstrate increased movements and home-range sizes (Ward and Krebs 1985, O'Donoghue et al. 1997).

Evidence of lynx and snowshoe hare cyclicity in their southern distribution has been mixed, but population cycles and synchrony in both species appear to diminish with decreasing latitude (Keith 1963, Smith 1983, Keith 1990, Ranta et al. 1997, Hodges 2000*b*, Wirsing et al. 2002, Hodges et al. 2009, Scott 2009). Koehler (1990*b*) and Strohm and Tyson (2009) suggested that the natural patchiness of habitat in the southern portion of the range may contribute to a dampening of cyclic population dynamics of lynx and snowshoe hares.

In general, hares occur at lower densities in their southern range than in the north (Koehler and Aubry 1994). Peak densities reported in the north are 4–6 hares/ha (1.62–2.43 hares/ac; reported in Hodges 2000*a*). Hare densities in Maine range from 1.0–2.4/ha (0.6–0.97/ac; Robinson 2006, Fuller et al. 2007, Homyack et al. 2007, Vashon et al. 2008*a*, Scott 2009); Minnesota hare densities range from 0.3–2.0/ha (McCann 2006); and densities in the western United States range from <1.0–4.85/ha (<0.4–2.02/ac; Koehler 1990b, Hodges 2000*b*, Lewis et al. 2011, Berg and Gese 2012).

Genetic variation across the range of lynx

Periodically, influxes of dispersing lynx have occurred in the northern United States during lows in the snowshoe hare cycle in Canada (McKelvey et al. 2000*b*). Schwartz et al. (2002) used microsatellite DNA markers to estimate gene flow from lynx samples collected across the lynx's geographic range. The analysis revealed a high degree of gene flow despite separation by distances greater than 3,100 km (1,925 mi). This supported the hypothesis that immigrating lynx have been able to successfully colonize southern areas, and highlighted the need for management actions to maintain connectivity with the core of the lynx's geographic range in Canada.

Row et al. (2012) conducted a similar analysis of microsatellite DNA markers from lynx from Alaska to Newfoundland and came to a similar conclusion. They found low levels of population genetic structure in mainland North American lynx populations (Newfoundland populations were unique) suggesting high levels of dispersal. In contrast, Rueness et al. (2003) found significant genetic differentiation between the British Columbia and Alaska-Yukon-Northwest Territory regions and eastern Ontario-Quebec populations (possibly because different microsatellite loci were used). Despite these differences, Row et al. (2012) concluded that all these studies support the concept that the Rocky Mountains do not provide a strong barrier to gene flow for lynx although there may be subtle restrictions in gene flow between eastern and western North American populations.

Schwartz et al. (2003) compared genetic variation across the range of lynx. Using their operational definition (the outer 165 km [103 mi] band of the species' geographic range, based on home range size), they found less genetic variation in the periphery than in the center of the range.

Hybridization with bobcats

Canada lynx-bobcat hybridization was first documented in 3 of 20 lynx in northeastern Minnesota through genetic analysis of hair and scat samples (Schwartz et al. 2004). Lynx-bobcat hybrids were also detected in Maine (Plate 2.21; n=2) and New Brunswick (n=2) from samples collected from 1986 to 2003 (Homyack et al. 2008). All hybrids were the offspring of male bobcats and female lynx (Schwartz et al. 2004). Hybrids were capable of reproducing successfully based on observations of a hybrid female lynx with 3 kittens, and placental scars in the reproductive tract of another hybrid (Homyack et al. 2008).

Hybrids had ear tufts similar in length to lynx at >2.5 cm (>1 in) and their tails were black with a few white hairs interspersed. Hind feet of 2 hybrids were 17.5 and 20.0 cm (7 and 8 in) long, respectively (Homyack et al. 2008) and intermediate between those of a bobcat at 17.0 cm (6.7 in; Lariviere and Walton 1997) and a lynx at 20.3 cm (8 in; Tumlison 1987). The pelage of the hybrids tended to be reddish brown with a few spots and generally more like bobcats in appearance (Homyack et al. 2008).

To date, hybridization has been documented only in Minnesota, Maine, and New Brunswick where low topographic relief and variability in winter severity may allow more interaction between the 2 species during the breeding season. There was no evidence of hybridization in the 120 lynx studied in Montana (J. Squires personal communication 2012). Further research is needed to identify areas where lynx-bobcat hybridization is occurring, to determine the factors in lynx habitat that favor bobcats, and to assess whether hybridization may hinder lynx recovery (Schwartz et al. 2004).

Plate 2.21. Lynx and bobcat hybridization has been documented in Minnesota, Maine, and New Brunswick. Note that on this lynx-bobcat hybrid, the tail is not completely black-tipped, the front foot is smaller than that of a lynx, and the fur is more spotted as seen on the leg.

Interspecific relationships with other carnivores

Predation on lynx. Mountain lion predation was a source of 3% of the confirmed mortality observed among lynx reintroduced in Colorado (Devineau et al. 2010) and also was observed in lynx populations in Montana (J. Squires, personal communication 2012) and Washington (Koehler 1990*a*). As noted above, documented predators of lynx include mountain lion, coyote, wolverine, gray wolf, fisher and other lynx. The magnitude of predation on lynx and the extent to which it may influence lynx population structure and dynamics are unknown.

Competition – dietary overlap. Buskirk et al. (2000*a*) defined 2 possible competition impacts to lynx as exploitation (competition for food) and interference (avoidance). Exploitation competition could contribute to lynx starvation and reduced recruitment. Of several predators examined (raptors, coyote, gray wolf, mountain lion, bobcat, and wolverine), coyotes were deemed the most likely to pose local or regionally important exploitation impacts to lynx. Coyotes, bobcats, and mountain lions are possibly capable of imparting interference competition effects on lynx. Interference would be most probable during summer, and during winter in areas lacking deep, unconsolidated snow.

Parker et al. (1983) discussed anecdotal evidence of competition between bobcats and lynx. On Cape Breton Island, Nova Scotia, lynx were common over much of the island prior to bobcat colonization. Following colonization by bobcats, lynx densities declined and their presence on the island became restricted to the highlands where bobcats did not occur.

Robinson (2006) documented that the absence of bobcats was a significant factor along with hare density in explaining the distribution of lynx occurrence in Maine. In townships where both species were present, lynx used suboptimal habitats and bobcats were found in the areas having the highest hare densities. Lynx have a lower foot loading and longer limb length than bobcats (Buskirk 2000, Hoving et al. 2003) and likely have a competitive advantage in deep, fluffy snow conditions. Bobcats in Maine are physically stressed during harsh winters that have deep snow, and these conditions likely limit their northern distribution (Litvaitis et al. 1986).

Five geographic areas are identified: Northeast, Great Lakes, Southern Rocky Mountains, Northern Rocky Mountains, and Cascade Mountains. These geographic areas were delineated in the 2000 LCAS based on lynx occurrence records and the distribution of appropriate forest vegetation (e.g., spruce-fir forests).

In 2005, FWS developed a Canada Lynx Recovery Outline (U.S. Fish and Wildlife Service 2005), which provides preliminary recovery objectives and actions for the contiguous United States DPS of lynx until a recovery plan is completed. Based on the examination of historical and recent evidence of lynx habitat and occurrence, the recovery outline identified core areas, secondary areas, and peripheral areas (Fig. 3.1). Core areas are the areas with the strongest long-term evidence of the persistence of lynx populations supported by a sufficient quality and quantity of habitat. The recovery outline recommends focusing lynx conservation efforts on core areas to ensure the continued persistence of lynx in the contiguous United States. FWS hypothesized that secondary areas and peripheral areas may contribute to lynx persistence by enabling successful dispersal and recolonization of core areas, but their role in sustaining lynx populations remains unknown.

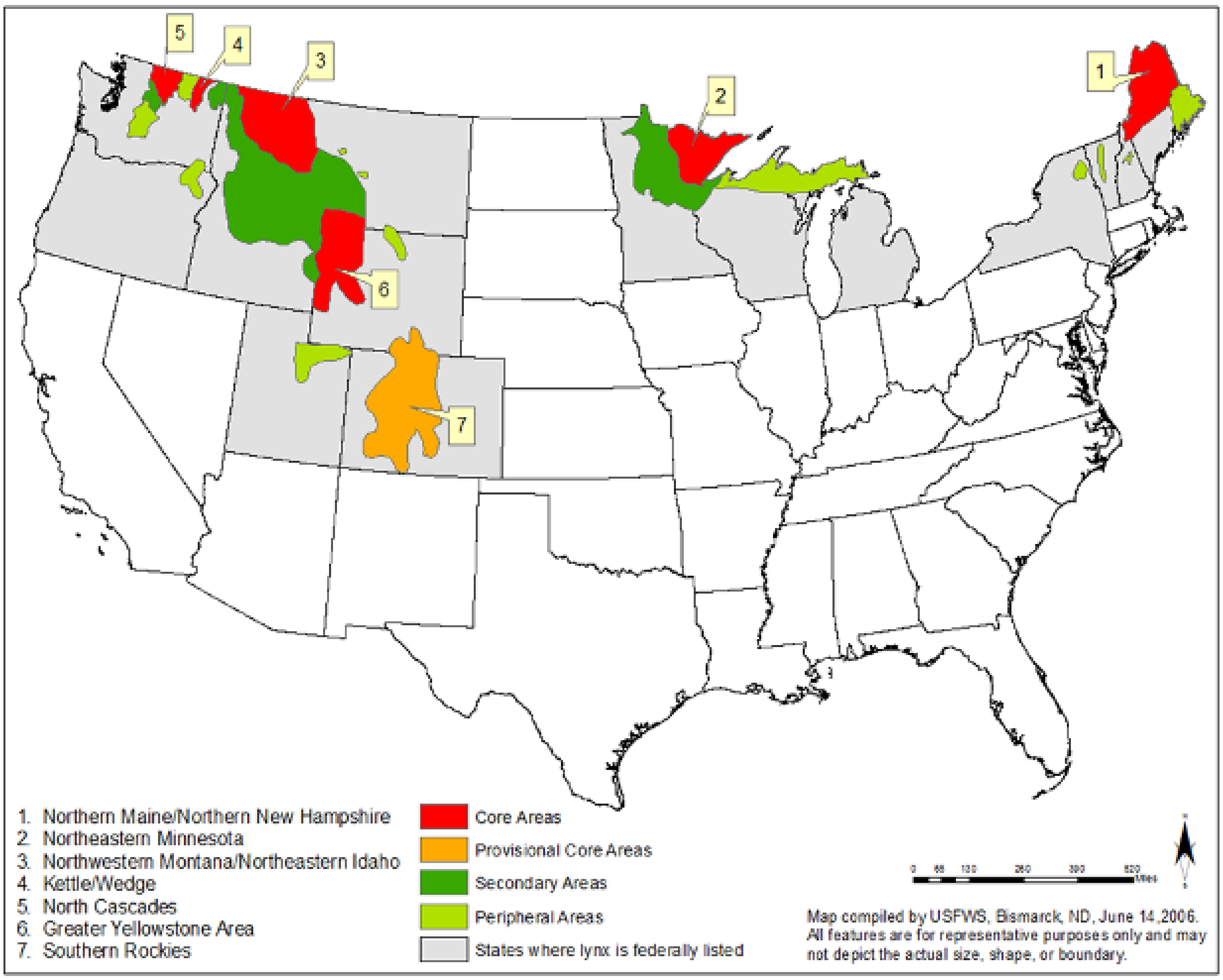

Figure 3.1. Areas identified as core, secondary, and peripheral as depicted in the Canada Lynx Recovery Outline across the states where the lynx is listed (U.S. Fish and Wildlife Service 2005).

The recovery outline (U.S. Fish and Wildlife Service 2005) identified 6 core areas: Northern Maine/Northern New Hampshire, Northeastern Minnesota, Northwestern Montana/Northeastern Idaho, Kettle/Wedge, North Cascades, and Greater Yellowstone Area. The Southern Rockies was identified as a "provisional core" because it contains a reintroduced population, and at that time it was too early to determine whether a self-sustaining population of lynx would result. In this document, the provisional core is treated the same as the core areas.

All of the core areas, secondary areas, and peripheral areas identified in the recovery outline (U.S. Fish and Wildlife Service 2005) are encompassed within the 5 geographic areas (Fig. 3.1). As new information continues to be developed, the delineations may be modified. For example, the Southern Rocky Mountains Geographic Area was not subdivided into core, secondary, and peripheral areas in the recovery outline. As the pattern of occupancy by the reintroduced population becomes clearer over time, it is possible that some further subdivision may occur. Our intent is that LCAS geographic areas will be adjusted if needed to encompass the areas identified in the recovery outline or in a future recovery plan.

A crosswalk between geographic areas and the core areas is shown in Table 3.1. The table also includes an estimate of the size of each core area taken from the rule designating critical habitat (Federal Register vol. 74, no. 36, pp. 8616-8702), the Southern Rockies Lynx Amendment (USDA Forest Service 2008), and the Washington Lynx Recovery Plan (Stinson 2001).

Table 3.1. Cross-walk between geographic areas and core areas and estimated size of core areas.

Geographic Area Name	Core Area Name	Core Area Size km^2 (mi^2)
Northeast	Northern Maine/Northern New Hampshire	24,597 km^2 (9,497 mi^2)
Great Lakes	Northeastern Minnesota	20,888 km^2 (8,065 mi^2)
Southern Rocky Mountains	Southern Rockies	27,328 km^2 (10,551 mi^2)
Northern Rocky Mountains	Northwestern Montana/Northeastern Idaho Greater Yellowstone Area Kettle/Wedge	36,096 km^2 (13,937 mi^2) 13,492 km^2 (5,209 mi^2) 1,167 km^2 (451 mi^2)
Cascade Mountains	North Cascades	4,755 km^2 (1,836 mi^2)

The geographic areas vary in important ways that may influence lynx populations and their prey. In this chapter, we address the population status and distribution of lynx and features of their habitat, as well as the distribution and habitat of snowshoe hares, in each geographic area. For each area, we discuss connectivity of lynx populations and their habitat, and the potential influence of relevant human activities and developments that are occurring or are likely to occur. Potential changes in habitat conditions due to climate change are also described, in order to assess the relative capability and importance of areas within the geographic area to sustain lynx populations into the future.

Northeast Geographic Area

Geographic extent

The Northeast Geographic Area boundary encompasses Maine, northern New Hampshire, northern Vermont, and northeastern New York. The previous delineation in 2000 also included much of New Hampshire and Vermont, small portions of northwestern Massachusetts, and the very northeastern corner of Pennsylvania. Based on more recent information including documented records of reproduction by lynx, these more southern areas are no longer included in the geographic area.

This geographic area falls within the Adirondack-New England Mixed Forest-Coniferous Forest-Alpine Meadow Province (McNab and Avers 1994). The province is composed of 5 sections, as described by McNab and Avers (1994). Current information indicates that lynx inhabit only the White Mountains Section.

> *White Mountains Section (M212A)*: This section extends across the western one-half of Maine from north to south and the northeastern corners of New Hampshire and Vermont. The potential vegetation types occurring on this section include northern hardwoods forest, northern hardwood-spruce forest, and northeastern spruce-fir forest (Kuchler 1964).

The Acadian forest ecoregion is an ecological transition zone between northern boreal forests and southern temperate deciduous-dominated forests (Seymour and Hunter 1992). The province is composed of subdued glaciated mountains and dissected plateaus of mountainous topography. Elevations range from 150–1,220 m (500–4,000 ft) with a few isolated peaks higher than 1,525 m (5,000 ft). Any glacially broadened valleys have glacial outwash deposits and contain numerous swamps and lakes.

The climate in the area is characterized by warm summers. Winters can be cold; mean temperatures in January in western Maine are -17° C (+1° F; Homyack et al. 2006), but it is less cold near the ocean. Average annual snowfall is more than 250 cm (100 in) with a steep gradient of snowfall increasing from the coast to the interior forest in northwest Maine (Jacobson et al. 2009).

Tree species composition and growth form are similar to the forests found to the north in Canada, but red spruce tends to replace white spruce. Valleys contain hardwood forests with the principal tree species being sugar maple, yellow birch (*Betula alleghaniensis*), and beech, with a mixture of hemlock. Low mountain slopes support a mixed forest of spruce, fir, maple, beech, and birch. Above the mixed-forest zone lie pure stands of balsam fir and red spruce. Alpine meadows exist above timberline (Bailey 1995).

Lynx population status and distribution

Historical records of lynx exist from Maine, New Hampshire, Vermont, and New York; however, with the exception of Maine, recent records of lynx from the Northeast are rare (McKelvey et al. 2000*b*, Hoving et al. 2003, Krohn and Hoving 2010). Lynx are currently considered present in Maine, the White Mountains of New Hampshire, and the Green Mountains of Vermont. Modeling based on lynx occurrence data concluded that areas in the northeastern United States that receive <270 cm (<106 in) of snowfall or are dominated by deciduous forests are unlikely to support lynx (Hoving et al. 2005).

Anecdotal reports suggest that lynx were breeding in Maine during the 1960s and 1970s (McKelvey et al. 2000*b*, Hoving et al. 2003, Vashon et al. 2012). Lynx snow tracking surveys, using a detection protocol established by the Maine Department of Inland Fisheries and Wildlife, were conducted in Maine from 1995–1999 across 126 townships and from 2003–2008 across 60 townships to determine the presence of lynx on private forest lands. Lynx were detected in 10 townships in 1995–1999 and 35 townships in 2003–2008 (Vashon et al. 2012). Data from these surveys were used to model lynx occurrence and habitat in northern Maine (Hoving 2001, Simons 2009), which predicted lynx habitat to be widespread and relatively abundant throughout northern Maine. Lynx reproduction was confirmed in 1999 when a radio-collared female produced 2 kittens (Vashon et al. 2012). During a period of high hare populations (>2hares/ha [0.8 hares/ac]), 89% percent of available adult females (older than 2 years) produced litters, and litter size averaged 2.74 kittens (Vashon et al. 2012). Lynx are state-listed as a species of special concern in Maine.

Regional modeling based on vegetation and annual snowfall indicates that Acadian forest habitat in New Hampshire, Vermont, and New York is no longer contiguous with existing lynx populations in Maine, New Brunswick, and the Gaspé Peninsula of Quebec (Hoving et al. 2005). In New Hampshire, the lack of lynx captures by trappers or of vehicle-related mortalities since 1967, and the subsequent failure to detect lynx tracks during an extensive survey of the White Mountain National Forest in 1986 are considered evidence that a viable population of lynx no longer exists there (Litvaitis et al. 1991). However, small numbers of breeding lynx were discovered in northern New Hampshire and Vermont in 2007 and have persisted through 2011 (M. McCollough, U.S. Fish and Wildlife Service, personal communication 2013). Lynx are state-listed as endangered in Vermont and New Hampshire. The lynx is considered extirpated in New York.

Lynx populations in Maine are contiguous with lynx populations in the Gaspé region of southern Quebec and northern New Brunswick, Canada. Lynx also occur on Cape Breton Island, Nova Scotia. It is thought that dispersing lynx from the north may periodically supplement resident populations in the United States (Litvaitis et al. 1991, Hoving et al. 2003, Vashon et al. 2012).

In Quebec, populations are trapped according to a management strategy implemented in 1995 (Ministère de l'Environement et de la Faune 1995). Southern Quebec is divided into Fur Management Units. Harvest limits vary from 1–4 lynx in most units adjacent to northern Maine and New Brunswick. The lynx population density is estimated to be 10 lynx/100 km^2 (3.86 lynx/100 mi^2) at the peak of the hare cycle, 2 lynx/100 km^2 (0.77 lynx/100 mi^2) at the trough, and 4–6 lynx/100 km^2 (1.5 lynx–2.3/100 mi^2) on average (Ray et al. 2002). Harvest limits are adjusted according to hare populations. Annual harvest in the entire province of Quebec from 2004–2011 ranged from 1,734 to 3,155 lynx. The annual harvest in southern Quebec Fur Management Units (south of the St. Lawrence River and adjacent to the United States) during the same time period ranged from 339 to 744 lynx.

Lynx are listed as endangered by the provinces of New Brunswick and Nova Scotia; there is no harvest and no estimate of population density or abundance in these provinces at this time. Lynx are considered extirpated from the Upper St. Lawrence Valley (Alvo 1998).

Lynx habitat

Lynx habitat within the Northeast Geographic Area is distributed in a mostly contiguous block of forest in the Acadian forest ecotone between boreal forest and deciduous forest, primarily associated with northern spruce-fir forest and northern hardwood-spruce forest communities. This habitat is similar to, and contiguous with, forested areas in Quebec and New Brunswick, Canada (Hoving et al. 2005).

The current range of lynx in the Northeast is most strongly associated with areas of deep snowfall (Hoving et al. 2004), large (100 km^2 [40 mi^2]) forested landscapes, and areas with a high proportion of regenerating conifer-dominated forest that had previously been treated with herbicides to suppress hardwoods (Hoving 2001). The majority of current lynx populations and lynx habitat in the Northeast Geographic Area are located on private industrial forest lands in Maine (Harper et al. 1990, Hoving et al. 2004, Simons 2009, Federal Register Vol. 74 pp. 8616–8701).

In the northeast prior to European settlement, lynx habitat was created and maintained by small-scale, frequent forest gap dynamic events and large-scale, infrequent (stand-replacing) forest disturbances (Seymour et al. 2002, Lorimer and White 2003). Higher elevation forests are often characterized by an even-aged windthrow phenomenon known as fir-waves (Sprugel 1976). The extent of these areas is limited and little is known about hare densities and lynx use within them. Large, stand-replacing events (fire, wind and ice storms, insect outbreaks) are rare (interval of several hundred to several thousand years) and highly variable in size (Seymour et al. 2002, Lorimer and White 2003). Spruce budworm, spruce beetle, beech bark disease, and sugar maple defoliators have been important influences affecting forest landscape patterns (McNab and Avers 1994). The frequency and intensity of spruce budworm outbreaks, the most likely insect to affect lynx habitat, have been highly variable in Maine and eastern Canada in recent centuries (Blais 1983). In this geographic area, wildfire is less significant as a natural agent of disturbance. The typical fire regime is infrequent surface fires in the dormant season in the hardwood forests, and slightly more frequent but long-interval fires in conifer forests (Kilgore and Heinselman 1990, Seymour et al. 2002, Lorimer and White 2003). For the past several decades, early successional forests in northern Maine, New Brunswick, and southern Quebec have been created almost exclusively by forest management (Lorimer and White 2003).

Large-scale, intensive forest management in Maine created the regenerating softwood-dominated habitat conditions that have recently been favorable for lynx (Hoving et al. 2005). Forested habitats in New Hampshire, Vermont, and New York are highly fragmented and are believed to lack the conifer component needed to produce high enough snowshoe hare densities to support viable populations of lynx (Hoving et al. 2005).

In general, landscape scale and home range scale habitat selection by lynx on industrial forest lands reinforce the importance of dense regenerating conifer forest along with a component of mature conifers (Hoving et al. 2004, Vashon et al. 2008*a*, Simons 2009, Simons-Legaard et al. 2013). Simons-Legaard et al. (2013) found the probability of lynx occurrence was >90% when snowshoe hare landscape densities were >0.74 hares/ha (0.39/ac) and there was >10% mature conifer forest. In Maine, lynx selected softwood-dominated (spruce and fir) regenerating stands (Fuller et al. 2007; Vashon et al. 2008*a*, *b*) and adjacent older (11–21 years post-harvest) partial-harvested stands (Fuller et al. 2007). Lynx were more likely to occur in landscapes with regenerating forest, and less likely to occur in landscapes with recent clearcut or partial harvest (Hoving et al. 2004). Regenerating stands used by lynx typically developed 15–30 years after harvest (Hoving et al. 2004), and were characterized by high stem density and dense horizontal cover within 1 m (3 ft) of the ground (Robinson 2006, Scott 2009, Fuller and Harrison 2010). These habitats supported high snowshoe hare densities (Homyack 2003, Fuller and Harrison 2005, Vashon et al. 2008*a*). At a landscape scale, lynx habitat selection did not differ between sexes; however, at a home range scale, males tended to use more mature forest dominated by conifers than females, and both male and female lynx tended to avoid mature forests that had a high deciduous component (Vashon et al. 2008*a*). The mean landscape density of hares in occupied lynx areas in northern Maine was 0.74 hares/ha (Simons-Legaard et al. 2013).

During winter, lynx primarily selected tall (4.4–7.3 m [14.5–24 ft]) regenerating clear-cuts and partially harvested stands that were 11–21 years post-harvest (Fuller et al. 2007). Lynx avoided mature stands (>40 years old) and short (3.4–4.3 m [11–14 ft]) regenerating clear-cut or partial harvested stands <10 years post-harvest (Fuller et al. 2007). Further research of year-round habitat use yielded similar results, with lynx preferentially using conifer-dominated sapling stands that were 3.4–7.3 m (11–24 ft) in height and supported high densities of snowshoe hares (Vashon et al. 2008*b*). Lynx tended to forage in areas with intermediate to high snowshoe hare densities (tall regenerating or older partial harvest stands), which afforded lynx with greater mobility and where snowshoe hares were more vulnerable to predation, rather than in the densest stands (short regenerating stands; Fuller and Harrison 2010).

Denning habitat was provided by blowdown, deadfalls, and root wads. In northern Maine, the majority of natal dens (12 of 26) occurred in conifer-dominated sapling stands, and 6 dens were found in mature or mixed multi-story forest stands dominated by conifers (Organ et al. 2008).

Forest management created Maine's current lynx habitat (Hoving et al. 2004, Scott 2009). Natural stand-replacing disturbances are rare and infrequent and, other than spruce budworm outbreaks, are unlikely to significantly affect future habitat conditions (Hoving et al. 2004). Current habitat was created by extensive softwood regeneration created by salvage harvest (clearcutting) on private land in the 1970s and 1980s; a portion of these units were subsequently sprayed with herbicide to reduce deciduous competition (Scott 2009). The resulting vegetation was dominated by balsam fir and red or black spruce (Scott 2009). Over 95% of cutting that occurs now in northern Maine in 2005 is partial harvesting (selective cutting, patch cuts) compared to only 59% in 1988 due to implementation of the Maine Forest Practices Act (Scott 2009, Simons 2009, Simons-Legaard et al. 2013). This new cutting regime supports lower densities of snowshoe hares (Fuller 1999, Homyack 2003, Robinson 2006, Scott 2009) and is projected to result in a reduced population of lynx in Maine (Simons 2009).

Connectivity of lynx populations and habitat

The current distribution of lynx in the Northeast Geographic Area (northern Maine) is continuous with large areas of lynx habitat in Canada (Hoving et al. 2005, Carroll 2007). Maintaining connectivity with occupied lynx habitats in Canada may be critical to maintaining viable populations of lynx in the northeastern United States (Hoving et al. 2005). International cooperation to this end will be essential to the long-term conservation of the species in the United States.

Snowshoe hare population distribution and habitat

Snowshoe hares were historically resident in Maine, New Hampshire, Vermont, New York, Massachusetts, and Pennsylvania. Only in Maine, northern New Hampshire, and northern Vermont are snow depth and quality, adequate conifer-dominated forest, and densities of snowshoe hares likely to be sufficient to support lynx.

Hare density estimates in Maine vary according to stand composition, age, and the silvicultural practices that created the stand. Throughout Maine, snowshoe hare densities are associated with dense regenerating stands (Monthey 1986, Fuller 1999, Hoving 2001, Robinson 2006, Scott 2009) with understory density being more important than vegetation composition (Litvaitis et al. 1985). Litvaitis et al. (1985) reported that dense softwood understories supported a greater density of hares than hardwood stands, due to their superior cover from predators and climatic extremes.

Average hare densities in forest stands (during a period of high hare population) range from 0.25 hares/ha (0.1 hare/ac) in mature softwood and conifer forests to 2.0 hares/ha (0.8 hares/ac) in conifer and mixed regenerating forest (Scott 2009). Hare densities were highly correlated with understory density (Litvaitis et al. 1985, Robinson 2006, Scott 2009). At their highest, snowshoe hare densities in Maine were similar to hare densities in the middle phases of the cycle in the northern boreal forest (Apps 2000, Hodges 2000*a*, Homyack et al. 2007, Scott 2009).

Hare populations fluctuate and may be cyclic in Maine. From 2006–2012, hare densities declined by about 50% in all regenerating conifer-dominated stands (24–39 years post-clearcutting) in northern Maine (D. Harrison, University of Maine, unpublished data). Synchronous declines occurred in Maine and the neighboring Gaspé region of Quebec from 2001–2006 (Assells et al. 2007, Scott 2009). The fluctuation in hare numbers in Maine and the adjacent Gaspé region of southern Quebec was not synchronous with the Temiscamingue region of southwestern Quebec, which peaked in 2002 followed by a low in 2005 (Assels et al. 2007). Hare populations in the Chaudiere-Appalaches region of Quebec, west of Maine, fluctuated in a cyclic pattern with very low amplitude (Godbout 1999).

Human activities and developments in the Northeast

Climate change is likely to affect the distribution and quality of lynx habitat in the northeastern United States and eastern Canada (Hoving 2001, Carroll 2007, Gonzales et al. 2007). In association with cooling during the Little Ice Age, spruce-fir forests proliferated in the last 500 years (Schauffler and Jacobson 2002). Warmer temperatures due to climate change could result in a contraction of the distribution of spruce-fir forests. Winter precipitation due to climate change is expected to increase 10–15% in Maine (Jacobson et al. 2009). However, the duration of snow cover as predicted under low emission scenarios could stay the same, or under high emission scenarios it could decrease by up to 50% (Hayhoe et al. 2007).

Vegetation management for timber production is the dominant land use within northern Maine and influences the amount and distribution of lynx habitat. Following a major spruce budworm outbreak, previous timber management practices that emphasized clearcutting produced the abundant, dense understory that is currently beneficial for lynx and snowshoe hares. However, with a shift to partial harvest forest management practices, lynx densities in northern Maine are projected to decline (Simons 2009, Simons-Legaard et al. 2013). There are no comprehensive agreements with the forest industry in Maine to manage lynx, although lynx forestry management guidelines (http://www.fws.gov/mainefieldoffice/PDFs/Canada%20lynx%20habitat%20management%20guidelines%20for%20Maine%209.13.07.pdf) are being used by several landowners enrolled in the Healthy Forest Reserve Program.

The lynx trapping season has been closed in the Northeast Geographic Area since the lynx was listed as a threatened species under the Endangered Species Act. Carroll (2007) modeled lynx populations in the Northeast and demonstrated that increased trapping pressure in Quebec could have a negative effect on protected lynx populations in Maine and New Brunswick. The Maine Department of Inland Fisheries and Wildlife is seeking an incidental take permit from FWS to provide coverage in case lynx are incidentally trapped during legal trapping of other furbearers or predators. Since 2000, 59 lynx are known to have been captured in traps set for other species and 6 of those were killed (Vashon et al. 2012).

Wind power development has increased in Maine since 2008. As of 2012, 1 project operates in lynx habitat, 3 others are in permit review, and 5–6 others are being considered. Although effects on lynx are unknown, wind development may fragment and reduce lynx habitat, increase road density and human activity, and create noise. Construction of associated transmission lines may temporarily affect habitat.

Great Lakes Geographic Area

Geographic extent

The Great Lakes Geographic Area encompasses northeastern and north-central Minnesota, northern Wisconsin, and the Upper Peninsula of Michigan. The Great Lakes Geographic Area is located in a southern extension of the Canadian Shield boreal forest region described by Larsen (1980), and falls within the southern boreal-northern hardwood forest border (Pastor and Mladenoff 1992). A direct connection with lynx habitat in Canada is important to maintain emigration of lynx out of and immigration of lynx into this geographic area.

The Great Lakes Geographic Area largely falls within the Laurentian Mixed Forest Province (McNab et al. 2005). This is a highly diverse geographic area both in terms of landform and vegetation mix. Most of the province is characterized by low-relief hilly landscapes with glacial features such as lakes, poorly drained depressions, bogs, moraine hills, drumlins, eskers, and outwash plains. Elevations range from sea level to 730 m (2,400 ft). Compared with lynx habitat elsewhere in the United States, the Great Lakes Geographic Area has much more water in the form of lakes, rivers, ponds and wetlands interspersed through the upland forested areas. Rock outcrops are common.

Forest vegetation is transitional between the boreal forests of Canada and northern Minnesota and the broadleaf deciduous forests of Wisconsin and Michigan. Forested stands vary from mixtures of conifers to pure stands of conifer or hardwood species (Bailey 1995). Fire and windthrow are the major natural disturbance processes in boreal forests and northern hardwood forests, respectively.

Climate in the area is characterized by moderately long and somewhat severe winters, with snowfall remaining on the ground all winter. Large lake influences produce more snow along Lake Superior. Although snow is present all winter, this region receives the majority of its precipitation in the summer.

Lynx population status and distribution

The lynx population in the Great Lakes Geographic Area is an extension of the larger population of lynx in Ontario, Canada. Northeastern Minnesota contains the core lynx population and habitat in this geographic area. Outside of this portion of Minnesota, lynx appear to be occasional visitors (transients). Suitable habitat is limited in northern Wisconsin and the Upper Peninsula of Michigan and there is no current evidence of reproduction in either area.

Historical evidence shows that lynx populations in the Great Lakes area, particularly Minnesota, were regularly supplemented by dispersing lynx from Canada (Harger 1965). Many lynx records, particularly from the 1960s and 1970s, are highly correlated with lynx population peaks in Canada (McKelvey et al. 2000*b*).

<u>Minnesota</u>: The lynx population in Minnesota is geographically restricted. Most recent and historical records are from the northeastern part of the state, especially in the Northern Superior Uplands Ecological Section. Currently, a breeding population of lynx exists in northeastern Minnesota. It appears that Minnesota supports a resident population of lynx, and that periodic invasions from adjacent Canadian provinces occur when the snowshoe hare population crashes (Moen 2009). Radiotelemetry has documented lynx movements between Minnesota and Ontario (Moen et al. 2008, Moen et al. 2010*b*).

Reproduction and maintenance of home ranges by lynx were first documented in the early 1970s (Mech 1973, 1980). From 2003–2008, reproduction by radiocollared lynx was documented and 10 dens were located (Moen et al. 2008). Few kittens born in Minnesota have been recruited into the adult population, but this is balanced by movement of lynx into Minnesota from Ontario. Emigration to Ontario also occurred, with 6 of 35 lynx radiocollared in Minnesota dying in Ontario, and several others with a last-known location in Ontario (Moen 2009).

In Minnesota, there is a long record of lynx harvest, with annual harvests exceeding that of any other state (Henderson 1978, Erb 2012). The average harvest in Minnesota from 1929–1969 of 177 lynx per year is at least 40 times higher than the average reported harvest or the verified records of every other state south of Canada except Montana (Moen 2009). Harvest data between 1930–1976 (before the cessation of legal trapping) show that lynx harvest ranged from 0–400 animals per year (Henderson 1978). Only 3 verified lynx records are known from the early 1990s after the closure of the legal trapping season (McKelvey et al. 2000*b*). Between 2000–2006, there were 63 verified and 161 probable reports of lynx (Minnesota Department of Natural Resources 2006). Genetic analyses of scat and hair samples collected between 2000–2009 along lynx snow trails and from tissue samples confirmed the presence of 104 unique lynx genotypes (Catton and Loch 2010).

Over the last decade there have been 3 lynx sightings confirmed through DNA analysis in Voyageurs National Park (Moen et al. 2012). There were no detections of lynx in Voyageurs National Park through the National Lynx Survey (Route et al. 2009), or with surveys using remote cameras or snow-tracking (Moen et al. 2012). Snowshoe hare pellet counts in and near Voyageurs National Park indicated a snowshoe hare population too low to support a viable population of lynx (Moen and Windels 2009, Moen et al. 2012). Despite the low prey populations, 1 female lynx was observed with a kitten in 2010, but was the only probable resident lynx confirmed near Voyageurs National Park from 2001 to 2010. There were no lynx detected during snow tracking surveys west of Highway 53 in northern Minnesota in 2006 (Moen et al. 2006).

Snow depth and quality of snowpack are thought to separate the distributions of lynx and bobcat within the Great Lakes Geographic Area. Hybridization between lynx and bobcat has been documented in Minnesota (Schwartz et al. 2002).

Wisconsin: There are few verified reports of lynx in Wisconsin. McKelvey et al. (2000*b*) found 29 reports of lynx between 1870–1992, 16 of which were associated with unprecedented cyclic highs that occurred throughout Canada in the early 1960s and 1970s. Between 2000–2003, no lynx were detected during extensive snow tracking surveys in potential lynx habitat in northern Wisconsin (S. Hassett, personal communication 2003). There are no records of lynx breeding in Wisconsin. Lynx found in Wisconsin are likely dispersers and not resident animals (U.S. Fish and Wildlife Service 2005).

Michigan (Upper Peninsula): McKelvey et al. (2000*b*) located 38 verified records of lynx from the mid-1800s to 1983. Beyer et al. (2001) documented 39 verified records of lynx between 1940 and 1997; 27 of these records correlate with an extreme cyclic high in Canada in the early 1960s. There is no evidence of lynx breeding in Michigan. Lake Superior nearly isolates the Upper Peninsula of Michigan from source populations in Canada, limiting the potential to successfully establish a population via immigration (U.S. Fish and Wildlife Service 2005). Beyer et al. (2001) concluded a resident lynx population does not occur in the Upper Peninsula and that dispersers occur only occasionally.

Ontario: Trapping in Ontario, adjacent to the Great Lakes Geographic Area, occurs on registered traplines. The open season for lynx is from 25 October until the last day of February.

Lynx habitat

Lynx habitat in the Great Lakes Geographic Area is embedded within the ecotone between boreal and mixed deciduous forests. This landscape contains a mix of upland conifer and hardwood interspersed with lowland conifer, shrub swamps and bogs. Conifer species include white and black spruce; balsam fir; northern white cedar; jack, white, and red pine; hemlock, and tamarack. Deciduous species include aspen, paper birch, and mixtures of northern hardwoods and lowland hardwoods. Of the non-forested types, shrub swamps and bogs are generally considered lynx habitat. Shrub swamps consist mainly of alder or willow. Bogs typically have components of black spruce, tamarack or other lowland conifers. Northeastern Minnesota contains by far the most suitable lynx habitat in the geographic area. Northern Wisconsin and the upper peninsula of Michigan contain only small patches of habitat and large areas that are not lynx habitat.

McKelvey et al. (2000*b*) found that most historical occurrences (88%) of lynx in the Great Lakes Geographic Area fell within the Mixed Deciduous/Conifer Forest province. Most (66%) of the lynx locations from a telemetry study in Minnesota were in areas classified as either lowland conifer, upland conifer, or regenerating forest (Moen et al. 2008). A conifer component in forest stands appears to be a critical factor for suitability of lynx habitat in this geographic area. Large stands of pure northern hardwoods are not considered suitable.

Fire, wind, and insects are the primary natural disturbance factors that maintain forest composition and successional patterns in this landscape. Three distinct fires regimes were found by Kilgore and Heinselman (1990) in pre-settlement forests:

- Jack pine and spruce-fir forest sustained very large (>101,171 ha [>250,000 ac]) stand-replacement crown fires or severe surface fires at 50–250 year intervals;
- Red pine and white pine forests have combinations of moderate intensity surface fires at 20–40 year intervals, with more intense crown fires at 150–300 year intervals; and
- Mixed aspen-birch-conifer forests have high-intensity surface or crown fires at 70–110 year intervals.

Larger blowdowns due to wind shear and tornadoes occur infrequently, but often cause extensive localized disturbance. Smaller, localized wind events created concentrations of downed logs, providing suitable denning habitat for lynx. Insect infestations such as those caused by spruce budworm contribute to large areas of tree mortality, and may create conditions conducive to subsequent large fires. These disturbance events create diverse, early-successional forests that provide habitats preferred by snowshoe hare, and thus important foraging areas for lynx.

Natural disturbances and timber harvest are important factors in maintaining the conifer understory component throughout much of this area.

<u>Minnesota</u>: The best lynx habitat is found in the Superior National Forest (including the Boundary Waters Canoe Area Wilderness) in Minnesota and Quetico Provincial Park in Ontario. Recent research in northeastern Minnesota indicated lynx selected for regenerating forest with a dominant conifer component and high densities of forest edges (Burdett 2008). Hare densities were highest in regenerating forests (McCann 2006, McCann and Moen 2011). Resting beds, kill sites, and hunting beds were found most often in regenerating and mixed forest while none were found in lowland conifer forests (Burdett 2008). Although lowland conifer did not appear to be important foraging habitat during winter, it was selected by females for denning habitat because of the forest structure that resulted from blowdown and fallen snags (Moen et al. 2008). Upland conifer and mature mixed-conifer/hardwood cover types were used as available on the landscape. Lynx habitat in the Great Lakes region may be managed by using timber harvest and fire to create early-successional forest, to maintain interspersed mature and lowland conifer forest for denning, and to create edge effects (Burdett 2008).

The lowland conifer cover types were used most often for denning in northern Minnesota (Moen et al. 2008), but other forest cover types were used if recent blowdowns were present (Moen and Burdett 2009). Female lynx with young kittens used a foraging radius of approximately 2–3 km (1.2–1.8 mi) around the den. Denning areas had significantly higher amounts of regenerating stands and upland conifer forest adjacent to the denning habitat (Moen et al. 2008).

<u>Wisconsin and Michigan</u>: As inferred from the historical record (McKelvey et al. 2000*b*), lynx are irregularly recorded in Wisconsin and Michigan's Upper Peninsula. Mapping of historical vegetation shows only small patches of boreal forest occur along the south shore of Lake Superior in extreme northern Wisconsin (S. Hassett, personal communication 2003; Wisconsin Department of Natural Resources, personal communication 2003). No lynx habitat is currently mapped on national forest system lands in Wisconsin. Habitat models of pre-settlement and current vegetation conditions in the Upper Peninsula of Michigan suggest that these areas lack the dense understory conditions favorable to snowshoe hares (Linden 2006), with low stem cover and resulting low hare densities across most forest stands (Linden et al. 2011). The few historical records from Michigan also indicate a low probability of supporting lynx populations (Beyer et al. 2001).

Connectivity of lynx populations and habitat

Habitat connectivity with Ontario is an important consideration for continued existence of a viable lynx population in the Great Lakes Geographic Area. Although lynx are capable of making long-distance dispersal movements (Mech 1980, Ward and Krebs 1985, Moen et al. 2010*b*), these movements are more likely to be made over land than across large lakes. Lake Superior interrupts the connectivity of habitat between the Upper Peninsula of Michigan and northern Wisconsin with lynx populations and habitat in Ontario. Over-land routes that exist around Lake Superior are a mix of forested areas and non-habitat such as urban development (e.g., Duluth and Sault Saint Marie) and the St. Louis and St. Mary's Rivers; and intersect several major highways including Highways 35, 53, and 61 in Minnesota; Highways 2 and 53 in Wisconsin; and Highway 75 in Michigan.

Habitat connectivity within and between portions of northeastern Minnesota and Canada appears functional based on movement data from radio-collared lynx in northeastern Minnesota from 2003–2009 (Moen et al. 2010*b*). Six of 12 lynx made long-distance movements through the Superior National Forest including the Boundary Waters Canoe Area and Wilderness into Ontario, Canada and then returned to Minnesota. Several other lynx have moved from Minnesota into Ontario after being radio-collared (Moen 2009). Three radio-collared lynx moved across northeastern Minnesota and Ontario, ending up near the northeastern corner of Lake Superior (Moen et al. 2010*b*).

Exploratory movements occurred throughout the year and were not strongly correlated to vegetation composition or topography. Males tended to leave their home ranges and then return, while females tended to disperse and establish a new home range (Moen et al. 2010*b*).

The current vegetation and forest structure in the Voyageurs National Park do not appear to support sufficient prey populations or provide the habitat necessary to support a population of lynx (Moen et al. 2012). However, certain areas within the Voyageurs National Park may provide sufficient prey resources to support transient lynx dispersing through the area.

Snowshoe hare population distribution and habitat

Snowshoe hare populations occupying the Great Lakes area historically showed density fluctuations based on pellet count data (Fuller and Heisey 1986), but these fluctuations have not been observed since the 1990s (Hodges 2000*b*). Snowshoe hare habitat in the Great Lakes Geographic Area primarily consists of conifer forests with dense low-growing understories, lowland shrub and conifer bogs, sapling, and older sawlog stands. Conifer bogs or lowland conifer forests may be especially important during low points in hare cycles by acting as refugia for hares. Early regenerating or pole-sized stands are not used as much as in other portions of their range, although older regeneration stands were used frequently in Minnesota (McCann 2006). However, sapling-sized aspen adjacent to conifer cover may provide functional snowshoe hare habitat.

<u>Minnesota</u>: McCann and Moen (2011) mapped the distribution of predicted snowshoe hare habitat across northeastern Minnesota. In northeastern Minnesota, edge habitats and regenerating conifer stands appeared to be important for snowshoe hare populations (Burdett 2008, McCann 2006), as were dense habitats containing balsam fir, white spruce, and cedar (Fuller and Heisey 1986). Pietz and Tester (1983) found that the presence of snow resulted in a decreased use of deciduous upland habitats. Hare density in parts of northeastern Minnesota appears to be sufficient to support a viable lynx population (Moen et al. 2008), ranging between 0.3–2.0 hares/ha (0.12–0.8 hares/ac; McCann 2006).

<u>Wisconsin</u>: In Wisconsin, snowshoe hare use red pine, jack pine, aspen, and dense black spruce and cedar bogs with sufficiently dense cover between 3–5 m (9–15 ft) in height (Buehler and Keith 1982, Sievert and Keith

1985). Winter foods consist of bark, twigs and tree buds from aspen, willow, birch, maple, sumac and alder. Populations occur primarily in the northern third of Wisconsin (Buehler and Keith 1982, Sievert and Keith 1985), with the distribution apparently limited by predator-caused mortality, which is influenced by conifer cover and snowfall (Buehler and Keith 1982). Sievert and Keith (1985) reported that predators killed 87% of the 67 radio-collared hares that died; survival was higher in areas where cover concealed hares or obstructed predators. Populations in Wisconsin are no longer believed to cycle due to loss of multi-story stands and forest maturity (Buehler and Keith 1982).

Michigan: In Michigan, Conroy et al. (1979) found that snowshoe hares preferred red maple and speckled alder in lowland habitats, but shifted to aspen and pine in upland habitats and clear cuts. However, lack of a dense understory in most parts of Michigan (especially the Upper Peninsula region) and low disturbance levels (limited timber management and wildland fires) indicate that conditions are not favorable to provide snowshoe hare populations adequate to support a viable lynx population (Beyer et al. 2001, Linden 2006). Isle Royale National Park, a 53,418-ha (132,000-ac) island located in Lake Superior, may contain suitable snowshoe hare densities to support lynx (Isle Royale Canada Lynx Feasibility Study Meeting, April 19, 2012, Ashland WI).

Human developments and activities in the Great Lakes

Most climate change simulations for the Great Lakes-St. Lawrence Basin predict reduced precipitation and lower lake levels (Inkley et al. 2004). Gonzalez et al. (2007) suggested the Superior National Forest in northern Minnesota may provide a refugium for lynx under various climate models, based on snow persistence and vegetation composition in this area.

The current composition and spatial distribution of early-successional and mature forests are considerably different from those formed by the natural disturbances that occurred prior to European settlement (Agee 2000). Timber harvest increased the proportion of early-successional forests, while fire suppression increased the distribution of balsam fir across the landscape. State and federal land management plans that govern management of lynx habitat emphasize maintaining and restoring boreal forest conditions and increasing the conifer component on the landscape.

Interest in biomass harvest (removal of small-diameter understory vegetation) in Minnesota, for energy as well as for fuels reduction, increased from 2000–2012. This is driven by higher energy prices and state-supported incentives to produce renewable energy (Minnesota Statutes chapter 216B, section 2424). Biomass harvest reduces horizontal cover important for snowshoe hares and lynx. However, with declining energy prices in the last few years, biomass harvest removal is not currently a significant factor affecting lynx habitat in Minnesota.

Lynx habitat in Minnesota is contiguous with habitats in southern Ontario, and radiocollared lynx successfully move back and forth across the border. Significant areas within historical lynx range in northern Wisconsin, central Minnesota, and upper Michigan have been converted to forest conditions that do not provide quality lynx habitat; however, this does not appear to create a barrier to lynx movements (Moen et al. 2010*b*).

Because this geographic area has relatively high forest road and highway densities that intersect lynx habitat, mortality due to vehicle collisions could be of concern. Several radiocollared lynx in Minnesota inhabited home ranges that were bisected by highways. Six lynx mortalities were documented on highways over the past 11 years in Minnesota (U.S. Fish and Wildlife Service 2012). These mortalities were located on the edges of lynx range in Minnesota. Deaths on roads due to motor vehicle collisions have occurred less frequently within the central lynx range and within the Superior National Forest.

Before the lynx harvest was closed in the 1980s in Minnesota, about half of the harvest was by trapping and half was from shooting (Henderson 1978). Currently, it is not legal to trap or shoot lynx within the Great Lakes Geographic Area because the species is protected under the Endangered Species Act. Emigration of lynx from Minnesota to Ontario may expose lynx to trapping and shooting that is allowed in accordance with regulated harvest in Canada. At least a third of the animals radiocollared in Minnesota spent time in Ontario; 4 radiocollared lynx were legally harvested (trapped) in Canada between 2003–2010 (U.S. Fish and Wildlife Service 2012).

The FWS in Minnesota maintains a database of known incidental lynx trapping, shooting, and other causes of death or injury (U.S. Fish and Wildlife Service 2012). Of the 23 known trapping incidents recorded since 2001, 13 resulted in lynx mortalities (U.S. Fish and Wildlife Service 2012). It is probable that there are additional incidental catches that are not reported each year (Moen 2009). The documented incidents largely occurred during trapping that targeted fox, bobcat, coyote, and marten, and involved a variety of traps including foot-holds, body gripping traps, and snares (U.S. Fish and Wildlife Service 2012). In response to a 2008 court ruling, the Minnesota Department of Natural Resources (MN DNR) drafted a plan to address incidental take of lynx that may result from otherwise legal trapping in the state. This plan, designed to reduce the likelihood of incidental take from trapping, is still under development by the MN DNR with review by the FWS.

Bobcat harvest in northeastern Minnesota has been increasing over the last decade (Erb 2012). Where lynx and bobcat overlap, there is potential for accidental shooting of lynx, or for bobcat hunting with dogs to harass or harm lynx. Since 2001, 6 lynx are known to have been shot and killed, 2 of which were radiocollared (U.S. Fish and Wildlife Service 2012).

Predator control activities occur in this area. Very limited agriculture occurs here; however, 1 farm is located within the center of lynx habitat in Minnesota where nuisance wolves were occasionally trapped as part of the animal damage control program. However, this particular farm is not likely to be a concern for lynx mortality.

Forest and backcountry roads, trails, and railroads may have both beneficial and negative impacts on lynx in this geographic area. Lynx use backcountry roads, trails, and railroads for travel, and presumably for hunting (Terwilliger and Moen 2012). Radiocollared lynx on average occurred about 300 m (984 ft) from a road or trail within their home range (Terwilliger and Moen 2012). When making long-distance movements to Ontario, lynx were located on average <200 m (656 ft) from a road or trail (Moen et al. 2010*b*). These linear pathways provide efficiency of movement and may support a higher density of prey; however, use of these routes also exposes lynx to risk of human-caused mortality. Since 2001, 1 lynx mortality due to a vehicle collision along a low-level gravel road and 2 lynx mortalities due to collisions with trains were documented (U.S. Fish and Wildlife Service 2012). Backcountry roads and trails also provide greater human access, which may increase the potential for incidental trapping and illegal shooting of lynx.

Mineral exploration and development is increasing in portions of the Great Lakes Geographic area, particularly for hard rock (non-ferrous) minerals. Some of the area of interest for minerals overlaps with lynx habitat in northeastern Minnesota and designated critical habitat. Mineral exploration may result in short-term displacement of lynx. Mining activities and associated development may result in an irreversible loss of habitat or increased mortality risk. The specific effects to lynx and their habitat will depend on the scale and type of each project.

Utility corridors (except in cases where utility corridors intersect backcountry roads) have little to no impact on lynx. Utility corridors located within lynx habitat tend to be for lower voltage power and phone lines.

Lynx are known to use utility corridors for travel and hunting.

Livestock grazing does not occur on public lands and grazing that occurs on private lands tends to be on small allotments and family farms that are generally not suitable lynx or hare habitat.

Southern Rocky Mountains Geographic Area

Geographic extent

The Southern Rocky Mountains Geographic Area encompasses the mountainous regions of Colorado, south-central Wyoming, and north-central New Mexico. The southern Rockies are separated from the rest of the Rocky Mountain chain by sagebrush and desert shrub communities in the Wyoming Basin and the Red Desert of southern and central Wyoming, and the arid Green and Colorado River plateaus of western Colorado and eastern Utah.

Throughout much of the Pleistocene epoch, the southern Rockies appear to have been connected with the rest of the Rocky Mountains through continuous forested habitats, across what are now open shrub-steppe communities (Armstrong 1975). Although the continental ice sheets of the Pleistocene never reached Colorado, the climate of the southern Rockies in that period was substantially cooler. Summer mean temperatures were estimated to be about 9° C (16° F) cooler, resulting in extensive alpine valley glaciation, high-altitude ice caps, and a lowering of the life zones 900–1,220 m (3,000–4,000 ft) below their current elevation limits. This would have lowered the spruce-fir/lodgepole pine forest to 1,500–2,150 m (5,000–7,000 ft) in elevation, encompassing much of the area between the southern Rockies and the rest of the Rocky Mountain chain (Armstrong 1975). During the last 15,000 years, the climate began a general trend of warming and drying, causing a northward retreat of the boreal forest and the raising of mountainous life zones to their current elevation limits (Armstrong 1972). It was during this interval that the southern Rockies became ecologically separated from the rest of the Rocky Mountains, isolating its remnant high-elevation boreal forests and the species characteristic of these forests (Armstrong 1975, Fitzgerald et al. 1994). The climate may have reached its thermal maximum 4,000–6,500 years ago (Oosting 1956). Based on pollen studies by Pennak (1963), mountainous vegetation communities appear to have remained relatively stable over the past 3,000 years.

The Southern Rocky Mountains Geographic Area falls within the Southern Rocky Mountain Province (Bailey et al. 1994, McNab and Avers 1994), and includes the following sections:

- Southern Parks and Mountain Ranges (M331F)
- South Central Highlands (M331G)
- North Central Highlands and Rocky Mountain (M331H)
- Northern Parks and Ranges (M331I)

Lynx population status and distribution

Historically, lynx appear to have been distributed sparsely in Colorado in areas above 2,700 m (9,000 ft) in the Park, Gore, San Juan, and La Plata Mountains and on the White River Plateau (Armstrong 1972). McKelvey et al. (2000*b*) reported 17 verified records of lynx from Colorado during the period 1878–1974. Verified records from southeastern Wyoming included a single specimen from 1865 in the Medicine Bow Range and one from the Laramie Range in 1963. Verified records after the 1920s are rare in Colorado and southern Wyoming, with most records coming from central Colorado. In 1973, 2 lynx were trapped on Vail Mountain in Eagle County, CO. A statewide lynx survey conducted from 1978–1980 by the Colorado Division of Wildlife, now known as Colorado Parks and Wildlife (CPW), concluded that a small lynx population persisted in Eagle, Pitkin, Lake, and Clear Creek Counties with evidence of lynx occurrence in Grand and Park Counties, based on tracks and visual observations. However, the lynx population was thought to be too small to be self-sustaining.

In 1999, CPW initiated a program to reintroduce lynx from Canada and Alaska to re-establish a self-sustaining breeding population throughout the southern Rockies. A total of 218 animals were transplanted into the San Juan Mountains from 1999 to 2006 (Devineau et al. 2010). To evaluate the near-term success of the lynx reintroduction, CPW established benchmarks to track progress towards establishing a self-sustaining population in Colorado. In 2010, after completing more than a decade of monitoring, CPW announced that all of the following benchmarks for a successful lynx reintroduction had been met:

- Reintroduced lynx demonstrated a high rate of survival in the critical first months after release;
- Released adult lynx demonstrated low mortality rates over the longer term, particularly in good habitat;
- Lynx remained in good habitat at densities sufficient for breeding;
- Reintroduced lynx successfully reproduced;
- Lynx born in Colorado survived and also successfully reproduced ("recruitment" into the population); and
- On balance, lynx recruitment equaled or exceeded mortality over an extended period of time.

As of 2007, the average probability of survival for reintroduced lynx was 0.9315±0.0325 within the study area in the San Juan Mountains and 0.8219±0.0744 outside the study area boundary (Devineau et al. 2010). Although 30% of known mortalities were due to human causes (being shot or hit by a vehicle), the estimate of survival within the study area was higher than those reported for natural, lightly trapped populations of Canada lynx in the Yukon (0.75–0.90; Slough and Mowat 1996, O'Donoghue et al. 1997) or in the Northwest Territories (~0.90; Poole 1994). Successful reproduction, including by females born in Colorado, has been documented (Shenk 2008).

Plague, a flea-borne disease caused by the bacterium *Yersinia pestis*, which is not native to North America, was reported for the first time in lynx in Colorado (Wild et al. 2006). Pneumonic plague appeared to be the direct or indirect cause of death of 6 reintroduced lynx between 2000 and 2003. When translocated from Canada and Alaska, none of the lynx had antibody titers to *Y. pestis*; it appears likely that lynx were exposed to plague by infected prey after their release in Colorado.

Of the transplanted animals, a majority (152/218) remained within the study area in the San Juan Mountains of southern Colorado. Additional small population centers have been established in several locations farther north in Colorado. Based on radiotelemetry location data, lynx presence was verified on all national forests in Colorado, the Medicine Bow National Forest in Wyoming, and Rocky Mountain National Park (Shenk 2008).

Most individuals have been detected outside of the 20,684 km^2 (7,986 mi^2) study area at least once. Some lynx dispersed widely over an area >1,000,000 km^2 (>386,103 mi^2) in size, including Kansas, Iowa, Nebraska, South Dakota, Wyoming, Montana , Idaho, Utah, Nevada, Arizona, and New Mexico (Devineau et al. 2010).

New Mexico is not included in the list of states in the historical range of the species (Federal Register Vol. 65, No. 58, pp. 16052-16086). There are no verified historical records of occurrence of lynx in New Mexico (McKelvey et al. 2000*b*). However, high-elevation montane forest that is contiguous with occupied habitat in Colorado does occur in New Mexico (Shenk 2008). It is possible that lynx occurred in New Mexico historically but were extirpated prior to being documented by scientists (Frey 2004, 2006). On the other hand, an analysis of the Carson and Santa Fe National Forests and Valles Caldera National Preserve in New Mexico, which evaluated potential vegetation, snow depth and persistence, records of lynx, occurrence of prey species, presence of competing predators, and the potential impacts of climate change, concluded that conditions in New Mexico are not adequate to maintain a self-sustaining population of lynx (USDA Forest Service 2009). In 2009, citing the movement of lynx from the reintroduced population in Colorado into northern New Mexico, the FWS determined that changing the boundary of the lynx listing to include New Mexico was warranted (Federal Register Vol. 74, p. 66937); the final decision is still pending.

Lynx habitat

Lynx habitat in the southern Rockies is found within the subalpine and upper montane forest zones. In the upper elevations of the subalpine zone, forests are typically dominated by subalpine fir and Engelmann spruce. As the subalpine zone transitions to the upper montane, spruce-fir forests begin to give way to lodgepole pine and aspen. On cooler, mesic mid-elevation sites, Engelmann spruce may retain dominance, intermixed with aspen, lodgepole pine, and Douglas-fir. Lodgepole pine reaches its southern limits in the central parts of the geographic area, while southwestern white fir occurs only in the San Juan Mountains. The lower montane zone is dominated by ponderosa pine and Douglas-fir, with pines typically dominating on lower, drier, more exposed sites, and Douglas-fir occurring on the more sheltered sites. Lower montane forests do not support snowshoe hares and seldom would be used by lynx.

Lynx habitat was mapped across federal lands in the southern Rockies based largely on current forest cover types. About 2.8 million ha (7 million ac) of lynx habitat was estimated to occur across the Southern Rockies Geographic Area (USDA Forest Service 2008).

Broad-scale lynx habitat use was documented from more than 9,400 daytime aerial telemetry locations by CPW from February 1999–June 2007. Shenk (2008) used these data to characterize lynx habitat use throughout the year. Mature Engelmann spruce/subalpine fir forests with total canopy cover of 42–65%, of which 15–20% was contributed by conifer understory tree canopies, were the most commonly used areas, followed by mixed forests of Engelmann spruce/subalpine fir/aspen. Riparian and riparian-mix was the third most-used cover type, with a pattern of increasing use beginning in July, peaking in November, and dropping off in December. Large or medium willow/alder carrs and willow riparian communities provided important habitat for snowshoe hare, grouse, ptarmigan (winter), and other prey species that could be utilized by lynx.

The telemetry data collected by CPW were re-analyzed to better predict the statewide distribution of lynx habitat. As a first step, Theobald and Shenk (2011) described the types of areas that were known to be used by reintroduced lynx from 1999–2010. Most of the data were collected in the core study areas in the San Juan Mountains of southwest Colorado and the Sawatch Range in the central part of the state. Ivan et al. (2012) extended the work of Theobald and Shenk (2011) by producing a statewide map of predicted lynx use. The telemetry data were not collected for the purpose of constructing a predictive map, and suffer from at least 2 shortcomings. First, the locations were not precise. Ivan et al. (2012) attempted to account for this imprecision by modeling at a 1.5 km (0.93 mi) scale, but matching covariates, response variables, and predictions at this scale reduces the clarity of relationships and weakens the model. Second, the bulk of the reintroduction research effort, from which these data originated, was conducted in the southern and central portions of Colorado. Lodgepole pine only occurs in the northern 2/3 of the state, and is dominant there. Thus, predicting lynx habitat use in northern Colorado is difficult because the landscape is very different, yet few data are available to predict lynx use of that landscape. Extrapolation beyond the range of covariates used to fit the models is tenuous, and caution must be exercised in interpreting results north of I-70.

Despite these limitations, the predictive maps have a distinct strength in that they were constructed objectively from rigorous mathematical models based on empirical data collected from wild lynx. They are the first such maps for Colorado. Results from this effort confirmed some relationships that were already known (e.g., lynx are strongly associated with high-elevation spruce/fir and mixed spruce/fir forests but avoid lower-elevation montane forests and montane shrublands).

Site-scale descriptions of habitat use were obtained through snow-tracking of lynx (Shenk 2006). Habitat used by lynx for long beds, travel, and kill sites were found to have similar characteristics, typically occurring on gentle slopes (15.7°) with average elevation of 3,173 m (10,400 ft; Shenk 2009). Den sites were located at higher elevations (average of 3,354 m or 11,000 ft), on steeper slopes (average 30°) and on more northerly aspects than the other sites.

Fire has strongly influenced forest vegetation patterns in the southern Rockies. Natural fire regimes in subalpine fir-spruce forests of the southern Rocky Mountains are highly complex, reflecting great variation due to climate, topography, elevation, vegetation, and site productivity. Because of the high elevations and higher moisture gradients of the subalpine zone, stand replacement events occur infrequently on a given site, perhaps every 250–500 years. Such events occur with increasing frequency at lower elevations. Stand-replacing fires may occur every 100–150 years in the montane zone, while surface fires of low to moderate intensity occur relatively frequently (return intervals of 5–60 years). Insects, forest pathogens, avalanches and wind events are also important agents of disturbance.

The Southern Rockies Geographic Area is currently experiencing a major bark beetle epidemic in lodgepole pine and spruce-fir forests. Although bark beetles are native insects, and forests in the western United States have experienced regular insect infestations throughout their history, the current bark beetle epidemic is notable for its intensity and extensive geographic range. The causes of this epidemic include: relatively even-aged, dense, and homogenous forest conditions, which are highly susceptible to beetle attack, and which were created by large-scale logging in the late 1800s and subsequent fire suppression efforts; warmer winters due to climate change (cold winters typically reduce beetle populations); and a multi-year drought that occurred in the mid-1990s through early 2000s, stressing the trees and making them more susceptible to beetle attack (USDA Forest Service 2011).

In lodgepole pine forests, a mountain pine beetle (*Dendroctonus ponderosae*) epidemic typically kills the entire overstory and results in a stand-replacing disturbance event. In Colorado, more than 2,428,113 ha (6,000,000 ac), a portion of which overlaps with lynx habitat, has been affected by the current beetle epidemic (USDA Forest Service 2011). Even-aged mature and “dry” lodgepole pine stands characteristically have depauperate understory vegetation and are not capable of supporting dense populations of snowshoe hares. On moist sites, regeneration of beetle-killed lodgepole pine stands is expected to be rapid, and the new stands will be dominated by re-sprouting aspen or by a new cohort of lodgepole pine. If these newly-established stands grow tall and dense enough to provide horizontal cover above the snow layer, they may produce excellent habitat for snowshoe hares and lynx for several decades, until the crowns again lift above the reach of snowshoe hares.

A spruce beetle epidemic kills the larger-diameter trees and can also result in a stand-replacing disturbance event. Because of the importance of spruce-fir forests for production and survival of snowshoe hares (Ivan 2011*a*), widespread mortality of mature spruce/fir forests could impact lynx habitat for a long duration.

Connectivity of lynx populations and habitat

McKelvey et al. (2000*c*) stated that “fragmented forest cover types, high vagility of lynx, and linkages in population dynamics suggest that lynx in the contiguous United States are arranged as metapopulations." Colorado is separated from boreal forests in Wyoming by at least 100 km (62 mi; Halfpenny et al. 1979, McKelvey et al. 2000*a*) and likely functions as a metapopulation. A few of the lynx that were reintroduced into Colorado successfully travelled to the Northern Rockies Geographic Area, crossing through intervening desert and grassland habitats.

Connectivity of lynx habitat has been identified as an important consideration for the southern Rockies, because of the extreme topographic relief juxtaposed with human developments such as highways and residential communities. In the Remanded Rule (Federal Register Vol. 68, p. 400786), the FWS concluded that the population-level threat to lynx attributable to high traffic volume on roads that bisect suitable lynx habitat and associated suburban developments is low. However, the FWS recognized that a higher risk exists in Colorado than elsewhere in the range of the lynx.

In the Southern Rockies Lynx Amendment, 38 linkage areas were identified in Colorado and southern Wyoming. Management direction for these areas is to maintain connectivity of habitat and facilitate lynx movements. However, some of these linkage areas may be located in proximity to existing human developments or may not currently contain the conditions or structures needed to provide habitat connectivity.

Ski resort development, a growing and affluent population, and telecommuting capabilities have converged to spur rapid growth in some mountain valleys. Transportation corridors continue to be modified and expanded to handle increasing volumes of traffic and speeds, altering historical movement patterns of wide-ranging species and creating barriers to movement. These and other factors, both historical and current, have eliminated or degraded some landscape linkages, which increases the importance of remaining linkage areas.

Snowshoe hare population, distribution and habitat

Habitat that supports snowshoe hares is patchily distributed in the Southern Rocky Mountains Geographic Area, which limits their abundance. Zahratka and Shenk (2008) found densities of snowshoe hares to be greatest in mature Engelmann spruce-subalpine fir stands when compared to mature lodgepole pine stands in Taylor Park, Colorado. Their density estimates were 0.08±0.03 to 1.32±0.15 hares/ha (0.03–0.5 hares/ac) in Engelmann spruce-subalpine fir habitats, and 0.06±0.01 to 0.34±0.06 hares/ha (0.02–0.14 hares/ac) in lodgepole pine habitats (Zahratka and Shenk 2008).

Ivan (2011*a*) compared snowshoe hare density, survival, and recruitment in mature uneven-aged spruce/fir stands, small-diameter lodgepole pine (2.54–12.7 cm [1–5 in]) stands (20–25 years old), and medium-diameter (12.7–22.9 cm [5–9 in]) previously-thinned lodgepole pine stands (40–60 years old) in Colorado. During summer, Ivan (2011*a*) recorded densities of 0.2+0.01 to 0.66+0.07 hares/ha (0.08–0.27 hares/ac) in small lodgepole pine forest, 0.01+0.04 to 0.03+0.03 hares/ha (0.004–0.01 hares/ac) in medium lodgepole forest, and 0.01±0.002 to 0.26±0.08 hares/ha (0.004–0.1 hares/ac) in spruce/fir forest; densities were more similar across the 3 forest types during the winter months. He concluded that "hares reached their highest densities and recruited juveniles most consistently in stands of small lodgepole, followed closely by spruce/fir, but survival was highest in spruce/fir stands."

Dolbeer and Clark (1975) estimated a density of 0.73 hares/ha (0.3 hares/ac) within study sites of Utah and Colorado, with the highest densities of snowshoe hare in mature and late-successional spruce-fir forests. Beauvais (1997) reported that snowshoe hares in Wyoming have a strong affinity for the higher-elevation mature to late-successional spruce-fir forests. Also in Wyoming, Berg et al. (2012) documented the highest snowshoe hare densities in late-successional, dense multi-story spruce-fir forests and 30–70 year old densely-regenerating lodgepole pine forests.

In New Mexico, Malaney and Frey (2006) reported that snowshoe hares almost exclusively inhabit high-elevation, closed-canopy spruce-fir forests with dense horizontal cover.

Human activities and developments specific to the Southern Rockies

Climate change generally is expected to result in warmer winters, earlier spring snow melt, and a reduction in the extent of snow cover in the southern Rockies. McKelvey et al. (2011) used a variety of climate models to predict snow depth and the persistence of spring snow across the western United States. The models predicted an overall decline in persistent snow of 40%, but large areas of persistent snow would continue to be retained late in the 21st century, including the high elevations of Colorado.

Beginning in the 1860s through much of the latter half of the 19th century, large-scale alteration of the natural landscape resulted from the rush to extract the rich deposits of gold, silver, and other metals in portions of the southern Rockies. A huge demand for timbers, construction materials, and smelter and heating fuels resulted in extensive cutting of forests around mining centers. Human-induced and lightning-caused fires burned over large areas, and decades of phytotoxic smelter emissions killed or precluded the regeneration of forests around these centers. The effects of mining and large-scale logging are still evident today across much of the landscape. While many cut-over areas have recovered to varying degrees, some high-elevation forests still remain poorly timbered.

In 2008, all forest plans in the southern Rockies were amended to add objectives, standards, and guidelines to conserve the lynx while implementing a variety of resource management programs and activities (USDA Forest Service 2008).

As described previously, an extensive recent mountain pine beetle epidemic caused near-complete mortality of mature lodgepole pine forests in Colorado. Regeneration of beetle-killed stands is dominated primarily by lodgepole pine and aspen. Salvage harvesting of beetle-killed trees is occurring on a portion of the affected area.

Vehicular collisions are a potentially important cause of mortality for lynx in portions of the southern Rockies. Thirteen of the 102 mortalities documented for lynx translocated into Colorado were from vehicle collisions (Devineau et al. 2010). Brocke et al. (1990) suggested that translocated animals might be more vulnerable to highway mortality than resident lynx and this could have been a factor in Colorado. A number of highways with high speed and high traffic volume pass through lynx habitat, such as I-70, I-80, US 50, US 550 and US 160. These highways are not a barrier to lynx movement, as repeated successful crossings by radio-telemetered lynx have been documented on I-70 and Highways 9, 40, 50, 91, and 114 (Ivan 2011*b*, *c*, 2012; J. Squires, personal communication 2012).

As compared with other portions of the range of lynx, in Colorado more winter recreation and associated development overlaps with lynx habitat. Preliminary information from a study in Colorado indicates that some winter recreation uses may be compatible, but lynx may avoid some developed ski areas (J. Squires, personal communication 2012). It is possible that ski areas and 4-season resorts may reduce the amount and availability of lynx habitat within localized areas, in part by influencing the distribution or abundance of prey resources within the developed area. However, there is also considerable anecdotal evidence of lynx using ski areas.

Leg-hold trapping is currently prohibited under the state constitution of Colorado as a means of predator control or for commercial and recreational trapping. If a landowner can prove that all other non-lethal methods have been ineffective, a 30-day exemption may be granted for depredation cases. Incidental trapping mortality of lynx may be a minor risk during trapping seasons in southern Wyoming and surrounding states.

Predator control activities on federal lands, including coyote shooting or trapping, are common throughout most of this geographic area, mostly related to the grazing of domestic sheep. The majority of sheep grazing occurs on arid rangelands, but some grazing does occur during summer at the higher elevations, especially in south-central Colorado. Incidental capture of lynx is possible, but unlikely.

Northern Rocky Mountains Geographic Area

Geographic extent

The Northern Rocky Mountains Geographic Area encompasses western Montana on both sides of the Continental Divide, northeastern and southeastern Washington, northern, central, and southeastern Idaho, northeastern Oregon, northeastern Utah, and western Wyoming. Landforms, climate, and vegetation across this large area are complex and highly variable.

There are strong north-south and east-west gradients in climate across the Northern Rocky Mountains Geographic Area. The northwestern portions have a cool, temperate, maritime-influenced climate, while the eastern and southern portions have a cold continental climate (McNab and Avers 1994). As a result, vegetation varies from moist, dense conifer forests, to less productive forests with greater interspersion of grasslands and shrub lands.

The Northern Rocky Mountains Geographic Area intersects 3 ecological provinces (McNab and Avers 1994, Bailey 1998) and the following Sections within these provinces.

Northern Rocky Mountain Province

- Okanogan Highlands Section (M333A)
- Flathead Valley Section (M333B)
- Northern Rockies Section (M333C)
- Bitterroot Section (M333D)

Middle Rocky Mountain Province

- Idaho Batholith Section (M332A)
- Bitterroot Valley Section (M332B)
- Rocky Mountain Front Section (M332C)
- Belt Mountains Section (M332D)
- Beaverhead Mountains Section (M332E)
- Challis Volcanic Section (M332F)
- Blue Mountains Section (M332G)

Southern Rocky Mountain Province

- Yellowstone Highlands Section (M331A)
- Bighorn Mountains Section (M331B)
- Overthrust Mountain Section (M331D)
- Uinta Mountains Section (M331E)
- Wind River Mountains Section (M331J)

Lynx population status and distribution

Montana: Lynx are ranked by the Natural Heritage Program as S3 species of concern in Montana: "Potentially at risk because of limited and declining numbers, range, and habitat, even though its habitat may be abundant in some areas."

Historical and current lynx occurrence has been well documented in Montana. Museum records, historical information, and trapping data (McKelvey et al. 2000*b*) suggest persistence of lynx over time in portions of Montana. Squires et al. (2013) describe more specifically the distribution of lynx in Montana based on 81,523 telemetry points from resident lynx from 1998–2007. Lynx are primarily restricted to northwestern Montana from the Purcell Mountains east to Glacier National Park, then south through the Bob Marshall Wilderness Complex to Highway 200. The southern-most lynx population in Montana is currently in the Garnet Range, except for a few individuals in the Greater Yellowstone Area. From 1999–2006, reproduction was documented at 57 dens of 19 female lynx in Seeley Lake, the Garnet Range, and the Purcell Mountains in western Montana (Squires et al. 2008).

The National Lynx Survey detected lynx in the Lolo and Gallatin National Forests and in Glacier National Park, and additional snow-tracking surveys in conjunction with collection of DNA verified lynx presence on the Kootenai, Flathead, and Helena National Forests (K. McKelvey, unpublished data).

Wyoming: The lynx is considered a species of greatest conservation need by the state of Wyoming. Lynx presence has been documented historically and currently in western Wyoming, from the Wind River Range, Wyoming Range, and the Yellowstone area (McKelvey et al. 2000*b*). A single lynx specimen was collected from the Big Horn Mountains in 1919. Lynx were detected using the National Lynx Survey protocol on the Shoshone National Forest, but none were detected on the Bighorn National Forest (K. McKelvey, unpublished data). Additional snow-tracking surveys verified lynx presence on the Bridger-Teton National Forest. Recent reproduction was documented in the Wyoming Range through a radio-telemetry study (Squires and Laurion 2000, Squires and Oakleaf 2005). Several lynx that were translocated into Colorado were later found to have dispersed and established home ranges in the Wyoming Range (J. Squires, personal communication 2012).

Idaho: Canada lynx are classified as an S1 Idaho species of greatest conservation need. McKelvey et al. (2000*b*) reported 22 museum specimens of lynx dating from 1874–1917, all of which were collected north of the Snake River Plain in Idaho. Thirteen other verified records prior to 1960 were also from the north-central and northern regions of the state, with the exception of 2 from Caribou and Bonneville Counties, along the Wyoming border. Of the 35 verified records from 1960 to 1991, most coincided with lynx irruptions in the 1970s. Lynx harvest records are considered to be unreliable prior to the 1980s because of the ambiguous reporting category of "lynx cat."

Surveys conducted in Idaho using the National Lynx Survey protocol detected lynx only on the Boise National Forest (K. McKelvey, unpublished data). Snow-track surveys in 2007 on 721 km on the Nez Perce National Forest using the protocol developed by Squires et al. (2004) did not detect lynx (Ulizio et al. 2007).

The Idaho Department of Fish and Game (IDFG) established 28 snow track routes to monitor forest carnivores. No lynx were detected on any of the 20 routes that had adequate snow conditions when surveyed by Idaho Department of Fish and Game personnel from 2004–2006 (Patton 2006).

From 2010-2013, IDFG conducted forest carnivore surveys in the Selkirk, Purcell, and West Cabinet Mountains (M. Lucid, Idaho Department of Fish and Game, personal communication 2013). Photographs and genetic material were obtained from a male lynx in the Selkirk Mountains in 2010; this animal was not re-detected. Genetic material was obtained from a male lynx in the Idaho Purcell Mountains in 2011 and the same individual was again detected in 2012 near the Idaho-Montana state line.

Two lynx were recently captured in traps set for other furbearing animals in Idaho: 1 was released alive in 2012 on the Salmon-Challis National Forest (B. Waterbury, Idaho Department of Fish and Game, personal communication 2013) and 1 was reported to be misidentified as a bobcat and shot in northern Idaho in 2013 (M. Lucid, Idaho Department of Fish and Game, personal communication 2013).

<u>Northeastern Washington</u>: Lynx are considered a species of greatest conservation need in the state of Washington. Lynx occurrence, currently and historically, has been documented in the northeastern corner of the state (McKelvey et al. 2000*b*). Stinson (2001) stated that the highest lynx harvest in Washington was from Ferry County (Kettle/Wedge) at 35%. Lynx were present and reproducing in the Kettle Mountains through the 1970s (Stinson 2001), but subsequently were probably over-trapped. Currently, only occasional tracks are observed with no evidence of reproduction in northeastern Washington (Koehler et al. 2008).

<u>Northeastern Oregon and southeastern Washington</u>: Lynx are considered infrequent and casual visitors by the state of Oregon. Relatively few historical records of lynx occurrence were found in Oregon (McKelvey et al. 2000*b*). Only 3 recent (1964, 1974, and 1993) specimens are known from Oregon, and all were collected in anomalous habitats following population peaks in western Canada. The Snake River and Hells Canyon likely would impede lynx movements between Idaho and northeast Oregon/southeast Washington.

<u>Utah</u>: Lynx have been protected from harvest in Utah since 1974. The species is listed by the state as a Tier I species of greatest conservation need.

Relatively few historical records of lynx occurrence were found in Utah (McKelvey et al. 2000*b*). There are only 3 museum specimens of lynx from Utah from the early 1900s, and later records are all from northwestern Utah near the borders with Wyoming and Idaho (McKelvey et al. 2000*b*). It is unlikely that the La Sal or Abajo Mountains ever supported a resident lynx population, given the scarcity of records and the absence of snowshoe hares (memo from USDA Forest Service dated March 17, 1999). Prior to 2000, the last verified records of lynx from Utah were in 1977 from physical remains and in 1982 from tracks (McKelvey et al. 2000*b*). Since 2000, radio-collared lynx reintroduced into Colorado have dispersed into Utah in the northeastern, central, and southeastern portion of the state (Devineau et al. 2010).

<u>Nevada</u>: Lynx are not believed to have been resident in Nevada either historically or currently. Only 2 museum specimens exist from Nevada, both collected in 1916, a year of lynx irruption from their primary range in the northern boreal forest (McKelvey et al. 2000*b*).

<u>British Columbia</u>: Apps (2007) modeled probable lynx occurrence in southeastern British Columbia and suggested lynx occur in a discontinuous and highly variable pattern. This supports the notion that the population is patchily distributed as nodes of several animals persisting in localized core landscapes that anchor the larger regional population. Trapping and hunting are permitted in the Kootenay Region (southeastern British Columbia, immediately north of northwest Montana and Idaho). The hunting season is from 1–31 December with a bag limit of 1. Compulsory reporting of all captured and killed lynx is required in this region. Trapping occurs on approximately 50 registered traplines with a season from 15 November through 15 February (Ministry of Forests, Lands, and Natural Resource Operations 2012). Apps (2007) commented that no lynx had been trapped in his study area (in the Kootenay Region) in the past 15 years. Between 2000 and 2009, 74 lynx were

reported trapped from the registered traplines.

Lynx habitat

Historical and current lynx records (McKelvey et al. 2000*b*) from this geographic area occur primarily in the spruce-fir forest potential vegetation types (Kuchler 1964, Pfister et al. 1977, Steele et al. 1981, Johnson and Simon 1987, Williams et al. 1995). Squires et al. (2010) determined lynx primarily foraged in subalpine fir forests with low topographic relief (Squires et al. 2013) during winter, in mid- to high-elevation (1,270–1,995 m [4,166–6,545 ft]) forests of mature, multi-story conifer with high horizontal cover. These environments supported higher-density snowshoe hare populations and provided dense horizontal cover from young trees and conifer boughs touching the snow.

Stand-replacing fire has been a dominant influence historically in the northern Rocky Mountains (Gruell 1983, Barrett et al. 1997). Surface fires, avalanches, insects, and forest pathogens have also been important agents of disturbance, creating more structural diversity at a smaller scale. Fire regimes in the northern Rocky Mountains are extremely complex, reflecting the great variation in climate, topography, vegetation, and productivity (Kilgore and Heinselman 1990). In general, the dominant regime in lynx habitat in pre-settlement times was long-interval (40–200 years), high-severity, stand-replacing fire in continuous forests of lodgepole pine, spruce, and subalpine fir, often with smaller acreages subjected to non-lethal, low-severity fires in the intervals between stand-replacing fires (Fischer and Bradley 1987, Losensky 1993, Smith and Fischer 1997).

Aspen forests occur as scattered inclusions throughout subalpine and montane forests in central and southeastern Idaho, southern Montana, Utah, and Wyoming. Though common and widely distributed, aspen forests occupy a small percentage of the total forested area. Berg et al. (2012) found that some of the highest snowshoe hare densities in Wyoming occur in multi-story mixed aspen/spruce-fir forests. Aspen/tall forb community types, especially those that include snowberry (*Symphoricarpos alba*), serviceberry (*Amelanchier alnifolia*), and chokecherry (*Prunus virginiana*) shrub understories, may be productive habitat for snowshoe hares, grouse, and other potential lynx prey.

Because the Northern Rocky Mountain Geographic Area encompasses such a large and diverse region, descriptions of vegetation and elevation conditions that provide lynx habitat are presented below by state.

Montana: Lynx research has been conducted in the Seeley-Swan Valley (Section M332B), Garnet Mountains (Section M332B), South Fork of the Flathead (Section M333C), and Cabinet and Purcell Mountains (Section M333D; Koehler et al. 1979, Smith 1984, Brainerd 1985, Squires and Laurion 2000, Squires and Ruggiero 2007, Squires et al. 2008, Squires et al. 2010).

The Seeley-Swan study area ranges in elevation from about 1,200–2,100 m (3,900–6,900 ft). Most lynx radiolocations were in the mid-elevation range of 1,300–1,800 m (4,260–5,900 ft), with a few locations up to 2,100 m (6,900 ft). Lynx generally occurred in moist subalpine fir potential vegetation types, above the dry ponderosa pine and Douglas-fir potential vegetation types, and below the alpine zone (Squires et al. 2010). Lynx did not appear to avoid forest roads or groomed snowmobile routes, and snow penetrability did not appear to be a factor in selecting travel routes or capturing prey (Squires et al. 2010). In winter, lynx primarily selected mature multi-story stands, primarily composed of mature Engelmann spruce and subalpine fir trees with lesser components of lodgepole pine, Douglas-fir and western larch. Lynx occupied similar areas year round; however, during the summer, lynx shifted toward more use of regenerating forests with abundant small diameter (2.5–8 cm dbh [1–3 in]) and pole-sized (8–18 cm [3–7 in] dbh) trees, dense shrubs, and high horizontal cover (Squires et al. 2010).

The Garnet Range is characterized by relatively moderate, rolling topography, with gentle to moderate slopes dissected by steep limestone canyons, mostly covered by coniferous forests. Habitat use by 5 radio collared lynx in the Garnet Range occurred in subalpine fir forest associations (Smith 1984). In the Cabinet Mountains, 2 lynx were studied in the west fork of Fishtrap Creek, which has moderate, rolling topography in the lower reaches and steep alpine ridges in the headwaters (Brainerd 1985).

Wyoming: Ehle and Keinath (2002) described the best contiguous lynx habitat in Wyoming as being in the northwestern and western portions of the state. The remainder is highly fragmented, widely dispersed and isolated by arid shrublands (Meaney and Beauvais 2004). In Wyoming, the primary vegetation that may contribute to lynx habitat includes subalpine fir, Engelmann spruce, and lodgepole pine forests at the higher elevations, generally 2,000–3,000 m (6,500–9,800 ft). In the Wyoming Range where 2 lynx were radiocollared, topography was steep to rolling, with about 20% of the area being non-forested, 20% spruce-fir forests (generally occurring on northerly aspects), 10% aspen, and about 10% riparian (Squires and Laurion 2000). The remainder of the area was primarily homogeneous stands of lodgepole pine on drier sites. Lynx habitat in Wyoming has a more open understory with fewer shrubs compared to lynx-use areas in northern Montana (Squires et al. 2003).

Idaho: In Idaho, subalpine fir potential vegetation types occur at upper elevations. Engelmann spruce potential vegetation types occur on very wet sites, on steep northerly aspects where snow accumulates, and along streams and valley bottoms (Steele et al. 1981). Large stands of fire-induced lodgepole pine commonly dominate much of the subalpine fir series in central Idaho (Steele et al. 1981). Undergrowth is variable in these stands, ranging from tall shrub layers of huckleberry (*Vaccinium* spp.) and menziesia (*Menziesia ferruginea*) to low, depauperate understories of grouse whortleberry (*Vaccinium scoparium*) or heartleaf arnica (*Arnica cordifolia*). Sites that are capable of producing dense, tall understory shrubs may be capable of supporting snowshoe hares and lynx.

Utah: In the Uinta Range, Engelmann spruce, white fir, subalpine fir, and lodgepole pine forests occur at the higher elevations, 2,250–3,250 m (7,300–10,500 ft). Quaking aspen dominates over much of the landscape on mountain slopes, but snowshoe hares use aspen stands much less than conifer stands in this area (Wolfe et al. 1982), probably because they lack dense understory cover (Hodges 2000*b*). Where intermixed with spruce-fir and lodgepole pine stands, aspen stands may contribute to lynx habitat.

Northeastern and southeastern Washington, northeastern Oregon: Subalpine fir potential vegetation types where lodgepole pine is a major seral species (Powell et al. 2007), generally between 1,250-2,000 m (4,100-6,600 ft), may contribute to lynx habitat.

Connectivity of lynx populations and habitat

Maintaining connectivity with Canada and between mountain ranges is an important consideration for this geographic area. Squires et al. (2013) combined resource selection, step selection, and least-cost path models to predict movement corridors for lynx in the northern Rocky Mountains. Connectivity between lynx habitat in Canada and that in the conterminous United States appears to be facilitated by only a few putative corridors that extend south from the international border.

In Wyoming, Squires and Oakleaf (2005) documented a male lynx crossing the 2-lane Highway 181/191 about 16 km (10 mi) east of Bondurant, Wyoming. This male lynx traveled over 500 km (310 mi) during the summers of 2000 and 2001 (Squires et al. 2003) and crossed the highway 4 times when moving between the Wyoming Range and the Wind River Range. The same lynx continued north on an exploratory movement and crossed Highway 26 on Togwotee Pass on a foray west of Yellowstone National Park.

The Kettle Mountains east of Highway 21 near Sherman Pass, Washington historically supported a population of lynx. However, the area was trapped heavily in the 1960s and 1970s and no reproduction has been documented since (Koehler et al. 2008). Recent surveys have only documented occasional single tracks, which suggest lynx have not re-established a population. The north end of the Kettle Crest is bisected by the low-elevation dry forest of the Kettle River valley and Highway 3 in British Columbia, potentially affecting the connectivity of habitat and potential movements from Canada. Maintaining connectivity on both sides of the border may be important to provide genetic exchange for lynx in northeastern Washington.

Snowshoe hare population distribution and habitat

Montana: Historically, western Montana has supported one of the most robust lynx populations in the lower 48 states, indicating there is sufficient prey base to maintain a self-sustaining lynx population. Snowshoe hares have been well documented throughout the Rocky Mountains of Montana from the Canadian border through the Yellowstone area. Adams (1959), Koehler et al. (1979), Malloy (2000), Griffin (2004), and Mills et al. (2005) estimated density and relative abundance of snowshoe hares throughout Montana. Hare densities generally were low, ranging between 0.1–0.6 hares/ha (0.04–0.24 hares/ac).

Hares occupy mixed-conifer forests, dominated by lodgepole pine, Engelmann spruce, Douglas-fir, western larch, and subalpine fir. Differences in hare abundance have been correlated with stand age within study sites in Montana (67 and 50–60 years old, respectively; Koehler et al. 1979, Zimmer 2004). Griffin and Mills (2004) reported strong differences in demographic rates among hare populations inhabiting patches with distinct habitat attributes (i.e., mature versus young, and closed versus open). In western Montana, Griffin and Mills (2004) found the highest snowshoe hare densities in regenerating forest stands with high sapling density and in uncut, mature multi-story stands with abundant saplings.

Zimmer (2004) documented the influence of deep snow on feeding patterns of hares. Lodgepole pine was the most heavily browsed conifer species by free-living hares, composing 59% of the overall diet in southern Montana.

Wyoming: Few data are available on historical distributions of snowshoe hare within Wyoming. Berg (2010) estimated an average density of 1.57 hares/ha (0.63 hares/ac) with a range of 0.07–4.82 hares/ha (0.03–1.95 hares/ac) in a study area in the southern portion of the Greater Yellowstone Area within the Bridger Teton National Forest, encompassing portions of the Absaroka, Gros Ventre, Wind River, Salt River, and Wyoming Ranges. The average density was higher than reported from several other areas of the contiguous United States, British Columbia, Labrador, and Quebec (Hodges 2000*b*, de Bellefeuille et al. 2001, McKelvey et al. 2002, Murray et al. 2002, Griffin 2004, Ausband and Baty 2005, Newbury and Simon 2005, Potvin et al. 2005, Homyack et al. 2006, Sullivan et al. 2006, Hodges and Mills 2008, McCann et al. 2008, Zahratka and Shenk 2008). Within 7 distinct potential vegetation types identified as suitable for supporting snowshoe hare, Berg (2010) and Berg et al. (2012) found snowshoe hare density to be greatest in multi-story thick spruce-fir forests, although hare densities were still high in dense young lodgepole pine stands (30–70-year-old regenerating lodgepole pine). Hare densities were lowest in young open lodgepole pine stands (Berg 2010). In comparison to the mature, multi-story patches where snowshoe hare density did not increase with increasing stem densities, Berg et al. (2012) found hares in the young, regenerating forests increased as stem densities increased. Overall, Berg concluded that snowshoe hares preferred dense, structurally diverse stands. These attributes were most consistently found on the Bridger-Teton National Forest within older multi-story forests with a spruce-fir component. Berg (2010) suggested that hares may demonstrate seasonal shifts in habitat use in western Wyoming due to the high degree of fragmentation between suitable habitat patches.

Young regeneration stands provide hare habitat over a relatively short period (Zimmer et al. 2008). Berg (2010) suggested that older multi-story stands would maintain higher hare densities over time than lodgepole pine stands 70+ years post-disturbance. Horizontal cover and tree canopy were the most significant predictors of hare density in western Wyoming.

Idaho: Wirsing et al. (2002) reported hare densities in the Clearwater National Forest that ranged from 0.01–0.10 hares/ha (0.004–0.04 hares/ac). Hare distribution throughout the study area was correlated positively with the availability of understory cover (Wirsing et al. 2002). Murray et al. (2002) established 615 transects on the Idaho Panhandle National Forest and estimated a density of 0.14 hares/ha with a range of 0.12–0.23 hares/ha (0.06 hares/ac, range 0.05–0.09 hares/ac). Hare abundance was greatest in habitats containing dense understories (Murray et al. 2002).

In northern Idaho, western red-cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*) and moist grand fir potential vegetation types support snowshoe hares (Murray et al. 2002), although these forest types do not appear to support lynx.

Utah: Estimated hare densities in a study area in northern Utah (Cache County) were about 0.46 hares/ha (0.19 hares/ac; Dolbeer and Clark 1975). The population studied did not appear to fluctuate, based on trapping records and capture rates during successive years. Snowshoe hares have been reported as absent from the La Sal and Abajo Mountains (memo from USDA Forest Service dated March 17, 1999), but there are documented populations in the Uinta and Wasatch Ranges (Dolbeer and Clark, 1975, Wolfe et al. 1982)

Dolbeer and Clark (1975) found snowshoe hares in Utah selected subalpine fir and lodgepole pine with dense understory cover over other habitats throughout the year, including aspen, which appeared to offer little understory cover for hares, especially in the winter. These findings were similar to Wolfe et al. (1982), who found strong correlations between snowshoe hare habitat use and horizontal cover density. Due to the snow depth and accumulation in northern Utah (commonly exceeding 1.0 m [3.3 ft]), it was suggested that a threshold density of horizontal cover must be available between 1.0–2.5 m (3.3–8.2 ft) above ground in the understory vegetation profile to support hares (Wolfe et al. 1982).

Northeastern Washington: Limited published information is available on snowshoe hares and habitat selection in northeastern Washington. Thomas et al. (1997) suggested that stand density and visual cover estimates were the best indicators of snowshoe hare habitat use in northeastern Washington. The 2 most important browse species were lodgepole pine and Douglas-fir. Low snow accumulation during the winters of 1995–1996 (0–61 cm [0–24 in]) may have accounted for snowshoe hares' use of shrubs that normally would be covered by snow in winter (Thomas et al. 1997).

Northeastern Oregon and southeastern Washington: Hare populations in northeastern Oregon and southeastern Washington are not well documented historically. However, snowshoe hares within this region have been shown to primarily use subalpine fir habitats where lodgepole pine is a major seral species. Moist grand fir and moist Douglas-fir habitats intermixed with subalpine fir habitats are used secondarily.

Human activities and developments specific to the Northern Rockies

McKelvey et al. (2011) used a variety of climate models to predict snow depth and the persistence of spring snow to infer effects of climate change on boreal species, specifically the wolverine. Snow depth and persistence are predicted to decline throughout the area during the 21st century. However, the models predicted that large areas of persistent snow would continue to be retained along the Montana-Idaho border and in the

Greater Yellowstone area. Idaho is predicted to lose proportionately more of its snow cover than either Montana or Wyoming, although there is a large degree of uncertainty associated with future snow conditions in Idaho.

Most climate change models generally predict a warmer and drier climate in this geographic area (Gayton 2008). With warming climate, fire seasons in the western United States will likely be extended and have higher severity, and the total area burned is likely to increase (McKenzie et al. 2004). This may reduce available lynx habitat, especially during the winter.

Precommercial thinning in Montana was shown to reduce snowshoe hare abundance in the short term (Griffin and Mills 2007). Forest plans were amended in 2008 to incorporate management direction that would conserve lynx, including direction that will minimize the impacts of thinning in lynx habitat.

Few highways intersect lynx habitat in this geographic area. State Highway 83 bisects the Swan Valley, but it does not appear to impede movement since radiocollared lynx have been documented to cross this highway (Squires and Laurion 2000).

Intense oil and gas development, such as is occurring in the Wyoming Range, may fragment habitat and may reduce or isolate already small populations of lynx.

The states regulate and administer hunting and trapping. Ten lynx have been reported captured in traps set for other species since 2000, resulting in at least 4 mortalities. Outreach and education efforts and trapping regulations are targeted to reduce the potential for incidental trapping and mortality of lynx. For example, in Montana, current furbearer trapping regulations (http://fwp.mt.gov/fwpDoc.html?id=56843) recommend that traps be checked every 48 hours (this is mandatory for wolf trapping http://fwp.mt.gov/fwpDoc.html?id=56685). In addition, an 8-pound pan tension requirement has been established in 2 trapping districts in western Montana. Idaho and Wyoming require that leghold and other live traps be visited at least every 72 hours. Washington does not allow body-gripping traps or pursuing animals with dogs. Utah requires trap checks at least every 48 hours.

Predator control activities on federal lands are commonly conducted throughout this geographic area, but the level of activity is currently lower than historical levels. Such efforts are aimed specifically at the offending animal or target species and usually take place outside of lynx habitats, in lower-elevation rangelands. As a result of the ban on poisons such as 1080 and adoption of wildlife conservation practices for lynx, predator control activities on federal lands conducted by USDA Wildlife Services probably have a low potential to impact lynx.

Cascade Mountain Geographic Area

Geographic extent

Vegetation and landforms in the Cascade Mountains of Washington have been described by Daubenmire and Daubenmire (1968), Franklin and Dyrness (1973), Demarchi (1994), McNab and Avers (1994), and Hann et al. (1997), among others. The Cascade Mountains Geographic Area is in the Cascade Mixed Forest-Coniferous Forest-Alpine Meadow Province (McNab and Avers 1994). Three sections are described within this province: Oregon and Washington Coast Ranges, Western Cascades, and Eastern Cascades. Current (Koehler et al. 2008, Maletzke et al. 2008) and historical (McKelvey et al. 2000*b*) records suggest that in the Cascade Mountains, lynx are found only on the east side of the range in Washington. Thus, the Eastern Cascades section is the only section in the Cascade Geographic Area that supports a reproductive lynx population. Lynx habitat is restricted to the subalpine fir potential vegetation type and adjacent habitats.

Volcanic peaks and glaciation have resulted in relatively steep eastern slopes. Many volcanic peaks are above the surrounding topography, some of which are still active. Volcanic ash originally covered the east slope. Elevations range from sea level to greater than 3,050 m (10,000 ft; McNab and Avers 1994).

Lynx population status and distribution

Museum records (McKelvey et al. 2000*b*) verify the presence of lynx in the Cascade Range of Oregon and Washington during historical times. However, the distribution of lynx was generally restricted to habitat occurring east of the Cascade Crest in northern Washington (Stinson 2001). Aubry et al. (2000), McKelvey et al. (2000*b*), and Mowat et al. (2000) reported lynx to be absent or uncommon in wet, coastal forests of western North America. Current and historical verified lynx records from the west side of the Cascade Crest in Washington or in the Cascade Range of Oregon are extremely rare: 12 from western Washington and 1 from Oregon. Ten of the 12 records from western Washington were of 1 individual from the Mt. Adams area (McKelvey et al. 2000*b*). Lynx still occur in the north-central Cascades of Washington; Brittell et al. (1989), Koehler (1990*a*), von Kienast (2003), Koehler et al. (2008), Maletzke et al. (2008), and unpublished data on file at the Methow Valley Ranger District documented continued occupancy of this area from 1980–2012.

The National Lynx Survey (McKelvey et al. 1999) was initiated in 1999 to sample lynx habitat across the historical range to better understand lynx distribution in the contiguous United States; most survey grids were completed in 2002. There were 19 survey grids established in the Washington and Oregon Cascades, each monitored for at least 3 years. Two of the survey grids had lynx detections: 1 in the northern Okanogan National Forest north of Highway 20, and the second (Aubry et al. 2002) was along Highway 20 on the Okanogan-Wenatchee National Forest.

The Okanagan Region in British Columbia lies immediately north of the Cascade Geographic Area. Trapping occurs on approximately 25 registered traplines and the region has a compulsory reporting requirement for any lynx taken. Trapping and hunting seasons currently are from 15 November through 15 February (Ministry of Forests, Lands, and Natural Resource Operations 2012). The hunting bag limit is 1. Between 2000 and 2009, 82 lynx were trapped. The majority of those were from 5 registered traplines. The other traplines reported 0–4 lynx over the 10 year period.

Lynx habitat

In the Cascade Mountains Geographic Area, subalpine fir potential vegetation types provide lynx habitat (McCord and Cardoza 1982, Koehler 1990*a*, Apps 2000, Aubry et al. 2000, McKelvey et al. 2000*b*, Koehler et al. 2008). Fire, insect outbreaks, and root rot are common disturbance agents in the subalpine zone (McNab and Avers 1994). The natural frequency, intensity, and extent of fire are highly variable in the Eastern Cascades section.

Maletzke et al. (2008) described lynx habitat in the Black Pine Basin area of north-central Washington as Engelmann spruce and subalpine fir on slopes <30° at elevations between 1,525–1,828 m (5,000–6,000 ft), and moderate canopy closure (11–39%). Lodgepole pine is frequently present as a seral species in subalpine fir potential vegetation types. The elevations of lynx habitats vary, depending on moisture patterns and temperatures. Subalpine fir potential vegetation types are generally present above 1,220 m (4,000 ft) on the east side of the Cascade Mountains (Williams and Lillybridge 1983, Lillybridge et al. 1995). These potential vegetation types generally occur in areas with heavy winter snowfalls. Cool, moist Douglas-fir, grand fir, Pacific silver fir, or western larch forests, where they are interspersed with subalpine fir forests, may also contribute to lynx habitat.

During winter, lynx selected mature multi-story Engelmann spruce and subalpine fir habitats in Washington (Koehler et al. 2008, Maletzke et al. 2008). These stands generally had a component of young trees in the understory and lower limbs touching the snow (von Kienast 2003, Koehler et al. 2008, Maletzke et al. 2008). Von Kienast (2003) reported that lynx generally avoided young (<15 years old) conifer regeneration (primarily lodgepole pine) resulting from timber harvest and wildfires that was not protruding through the snow during winter. Lynx movements and hunting behavior were associated with mature Engelmann spruce and subalpine fir stands, dense understory cover, and high densities (>1 hare/ha [>0.4 hares/ac]) of snowshoe hares (Maletzke et al. 2008). Lynx used edges of recently burned areas, recent clear cuts, and forest openings, but rarely crossed openings greater than 150 m (500 ft; von Kienast 2003, Maletzke et al. 2008). Forest openings and stands dominated by Douglas-fir or ponderosa pine were generally avoided (Koehler et al. 2008, Maletzke et al. 2008).

Koehler and Aubry (1994) and Maletzke et al. (2008) described lynx habitat as generally occurring in areas of low topographic relief. Apps (2000) found selection for slope was significant among 3 of 6 radio-collared lynx in the southern Canadian Rocky Mountains. Of those 3 animals, 2 selected and 1 avoided <20 percent slopes during the summer, and >40 percent slopes were avoided by all of the lynx during winter. In north-central Washington, lynx preferred <30° slopes during winter (Koehler et al. 2008, Maletzke et al. 2008).

Connectivity of lynx populations and habitat

Connectivity to larger lynx populations in Canada is important to ensure the long-term persistence of lynx populations in the United States (U.S. Fish and Wildlife Service 2005). There are no known barriers to movement between the Cascades in the United States and British Columbia.

Lynx are highly mobile and able to disperse long distances. It is nevertheless important to maintain connectivity between blocks of habitat to support populations and promote genetic exchange. Forest disturbances such as large wildfires and timber harvest have affected the current distribution and movement patterns of lynx in Washington (Koehler et al. 2008). The juxtaposition of forest disturbance in relation to topographic features and the current amount and arrangement of forest vegetation can directly affect habitat connectivity for lynx.

The North Cascades Highway, Highway 20, bisects lynx habitat in the Cascades Geographic Area, but it is closed during the winter (typically late November through mid-April) because of deep snowpack and avalanches. Much of the lynx habitat is north of the highway, but habitat and lynx are present south of the highway. Surveys in 2000 and 2001 along Highway 20 were designed to determine if lynx crossed the highway during summer months when it was open (Aubry et al. 2002). Lynx were detected on both sides of the highway, but the DNA samples were not sufficient to determine whether these were the same or different individuals. Apps (2007) reported that lynx in the southern Canadian Rocky Mountains do cross highways, but highways can affect movements depending on the highway type and use.

As it is throughout the range of lynx in the contiguous U.S., maintaining connectivity with Canada is important to lynx populations in northern Washington and the Cascade Mountains. Singleton et al. (2002) evaluated landscape permeability for large carnivores in Washington. They reported broad landscape permeability for lynx between the Thompson River watershed in British Columbia and the United States portion of the northern Cascades. Currently, connectivity appears functional, as lynx dispersal from Washington into Canada was recently documented. A male lynx radiocollared in 2008 in the Loomis State Forest remained there until late winter in 2009, when it dispersed north into Canada toward Hope, British Columbia, and then headed northeast toward Kamloops where it appeared to establish a home range just southeast of Kamloops. This individual was later trapped and killed in British Columbia, highlighting the need for cooperation and shared management goals across political boundaries.

Snowshoe hare population distribution and habitat

Snowshoe hares in the Cascade Mountains Geographic Area are found primarily in boreal forests of sub-alpine fir and Engelmann spruce, but can also be found in stands that are occasionally interspersed with Douglas-fir, lodgepole pine, western larch, and whitebark pine (Walker 2005). Based on pellet counts in north-central Washington, Koehler (1990*a*) reported that snowshoe hare densities were highest in 20-year old lodgepole pine stands with 16,320 stems/ha (2,559 stems/ac), in both winter and summer.

Snowshoe hare pellet densities in Washington were correlated with understory (horizontal) cover, sapling density, and medium-size tree density (Walker 2005). Hares were plentiful in both young regenerating forests and older multi-story Engelmann spruce and sub-alpine fir forests with dense understories. Structural density and the amount of contiguous habitat were important considerations when managing for hares. The landscape mosaic within which snowshoe hare habitat was embedded had the potential to influence snowshoe hare densities by affecting movement characteristics and resource availability.

Lewis et al. (2011) sampled 76 stands that were about 20 ha (49 ac) in size across a study area in northcentral Washington. They reported an average density of 0.82 hares/ha (0.33 hares/ac), ranging from 0.03-2.38 hares/ha (0.01–0.96 hares/ac). This compares favorably with the estimate by Ruggiero et al. (2000*b*) that a density of at least 0.5 hares/ha (0.2 hares/ac) is required to support a lynx population.

Human activities and developments specific to the Cascades

McKelvey et al. (2011) used a variety of climate models to predict snow depth and the persistence of spring snow during the 21st century to infer effects of climate change on boreal species. The models predicted that despite an overall decrease in persistent snow, large areas of spring snow cover will continue to persist in northern Washington. The Pacific Northwest is characterized by large amounts of winter precipitation at temperatures near freezing. Modest increases in temperature due to climate change would cause precipitation to fall as rain rather than snow, making its snowpack highly vulnerable to loss. However, perhaps because historical snowpack is so deep and extensive in the Pacific Northwest, estimated spring snow cover is not expected to be impacted as much by climate change as some other areas such as Idaho.

Some vegetation management practices, especially thinning in young dense regeneration and reducing overstory canopy in mature multi-story spruce-fir forests, have likely had detrimental effects to snowshoe hares and lynx in the past. On national forest system lands in the Cascades, the priority for vegetation management is in the dry and mesic forests, with minimal treatments in the subalpine fir forests. On state managed forests (Loomis State Forest) precommercial thinning in lynx habitat has been conducted.

Koehler et al. (2008) reported that more than 50% of the lynx habitat in the Chelan and Okanogan Counties has burned in the past 2 decades (1990–2010). Increases in the length of the fire season and in the annual area burned as a result of climate change (McKenzie et al. 2004) could further reduce available lynx habitat.

Climate change has increased forest insect infestations within the Cascade Mountains (Carroll et al. 2003, Taylor and Carroll 2004). Climate change may cause further changes to natural disturbance regimes.

Lynx habitat in the western portion of the Cascade Mountains Geographic Area is naturally fragmented (Koehler et al. 2008). Lewis et al. (2011) reported that landscapes with contiguous snowshoe hare habitat, or where patches of hare habitat are surrounded by patches of similar habitat quality, support more snowshoe hares than more fragmented landscapes or where surrounding patches are of poorer quality habitat. Lynx in the Black Pine Basin area of northcentral Washington avoided openings, burned areas, and other areas with <10% overstory cover (Koehler et al. 2008). While a landscape mosaic is desirable, vegetation management projects that create large openings can reduce the quality of snowshoe hare habitat, requiring lynx to travel farther and increase energy expenditures when foraging, leading to an increased risk of starvation.

State Highways 2 and 20 are the only paved highways through lynx habitat in the Cascades Geographic Area. Highway 20 is closed because of avalanche hazard during the winter (generally from mid-November through March) and is a low-volume highway in the summer. Highway 2 is the southern boundary of known lynx occupancy. Highway 20 bisects lynx habitat in the United States and Highway 3 in British Columbia bisects habitat to the north. There were no known lynx mortalities along either highway in the past 15 years.

Incidental trapping and illegal shooting of lynx are low risks in the Cascades. Body-gripping traps are not legal in Washington (except by permit for "animal problems"), which reduces the risk of mortality if a lynx were to be incidentally trapped. The trap check requirement in Washington is 24 hours for non-killing restraint traps. One accidental lynx shooting occurred in October 1999 in the Washington Cascades. A lynx was shot by a licensed hunter, who mistook it for a bobcat (H. Allen, Washington Dept. of Fish and Wildlife, personal communication 1999). Since that incident, no illegal or accidental lynx shootings have been reported in this geographic area.

Chapter 4 - ANTHROPOGENIC INFLUENCES ON LYNX AND LYNX HABITAT

The Lynx Biology Team identified “risk factors” in the 2000 LCAS that were a suite of programs, practices, and activities with the potential to negatively influence lynx or lynx habitat. The list of risk factors was meant to be inclusive; and to help ensure that no possible impacts would be overlooked, it was not prioritized.

Since then, substantial new scientific literature on lynx and their habitat has been published. This new information has improved the understanding of the ecology of lynx across the southern edge of their range, and their responses to various forms of resource management and other human activities (now referred to as anthropogenic influences). Based on new scientific information, the 2003 listing (Remanded Rule), and professional judgment gained from experience in managing lynx habitat, we developed a list of anthropogenic influences that may affect lynx and lynx habitat. By consensus, we grouped these into 2 tiers: those that have the potential to negatively effect lynx populations and habitat, and those that may affect individual lynx but are not likely to have a substantial effect on lynx populations and lynx habitat.

Not every possible human activity that could occur in lynx habitat has been examined. Rather, in this chapter we identify those anthropogenic influences most likely to occur in lynx habitat and for which we have information indicating how they may affect lynx and lynx habitat. The concepts and approach used here also could be applied to other activities that are not specifically addressed in this document.

As described in Chapter 2, lynx are highly specialized predators of snowshoe hares, are vulnerable to certain types of human-induced mortality, and occur at low densities and in small populations throughout their range in the contiguous United States. These natural history characteristics increase their susceptibility to local extirpation. These attributes are important drivers of lynx population dynamics, and were considered as we evaluated the potential impact of the various anthropogenic influences.

The first tier of anthropogenic influences includes climate change, vegetation management, wildland fire and fragmentation of habitat. Each of these can directly effect both snowshoe hare and lynx population dynamics. There is some uncertainty about the rate and magnitude of impacts from climate change, and federal agencies may be limited in actions that can be taken to ameliorate those impacts. Nevertheless, those impacts will interact with and perhaps magnify the effects of vegetation management, wildland fire, and fragmentation of habitat.

The second tier of anthropogenic influences include several activities that were previously identified as “risk factors” in the 2000 LCAS. Subsequent research or management experience have shown that these are not likely to have substantial effects on lynx or their habitat. The discussion of the anthropogenic influences in the second tier provides updated information about these relationships.

Some risk factors, including habitat degradation by non-native invasive plant species, development of reservoirs, conversion to agriculture, and lynx movement and dispersal across shrub-steppe habitats, have been dropped entirely from the revised LCAS. This is because they are now thought to have few or no impacts on lynx or lynx habitat.

In this chapter, we describe how specific anthropogenic influences could impact lynx via the primary drivers of their population dynamics: snowshoe hare prey base, direct mortality, and small population effects. This provided the foundation for development of the conservation measures, which are actions within the authority and jurisdiction of the federal agencies that can be taken to conserve the lynx.

Federal agencies have amended or revised land management plans across much of the range of the lynx to provide direction to conserve lynx and lynx habitat. Thus the impacts of anthropogenic influences have been substantially reduced. Maintaining consistent and appropriate management direction is important to minimize the impacts, particularly for the 4 anthropogenic influences included in the first tier.

First tier of anthropogenic influences

In the first tier are 4 anthropogenic influences that are of greatest concern to the conservation of the lynx. Some regulations or policy may be in place to minimize impacts on lynx or lynx habitat, but we address them fully here because by their nature, these anthropogenic influences can directly impact lynx and their snowshoe hare prey. Chapter 5 contains conservation measures that address vegetation management, wildland fire management, and fragmentation of habitat. No conservation measures are identified for climate change due to the limited ability of the federal land management agencies to alter the current trajectory.

Climate change

Physical and biological systems on all continents and in most oceans are being affected by climate change, especially by regional temperature increases (Rosenzweig et al. 2007). Climate change is strongly affecting some species and altering many aspects of systems that are related to snow, ice, and frozen ground (Hannah and Lovejoy 2003, Root et al. 2003, Harris et al. 2006, Parmesan 2006, Rosenzweig et al. 2007). Inkley et al. (2004) and Rosenzweig et al. (2007) predicted that the ranges of wildlife and native plants in North America will generally move northward or to higher elevations as temperatures increase.

Several possible effects of climate change on lynx can reasonably be anticipated. These include: 1) potential upward shifts in elevation or latitudinal distribution of lynx and their prey; 2) changes in the periodicity or loss of snowshoe hare cycles in the north; 3) reductions in the amount of lynx habitat and associated lynx population size due to changes in precipitation, particularly snow suitability and persistence, and changes in the frequency and pattern of disturbance events (e.g., fire, hurricanes, insect outbreaks); 4) changes in demographic rates, such as survival and reproduction; and 5) changes in predator-prey relationships. In addition, it is possible that interactions between these variables may intensify their effects.

<u>Shifts in distribution</u>. Arctic and alpine ecosystems are expected to be among the most sensitive to climate warming (Diaz and Millar 2004). Less snowfall, reduced extent of snow cover, accelerated retreat of most mountain glaciers, and earlier spring snowmelt have already been observed across much of the northern latitudes (Gitay et al. 2002). Results from climate change modeling suggest that snow cover in the contiguous United States will be substantially reduced in extent and distribution (McKelvey et al. 2011). From this can be inferred a contraction of the range of lynx. In Maine, for example, it is predicted that once annual snowfall declines below a key threshold of 270 cm/yr (106 in/yr; Hoving et al. 2005), lynx may be displaced by bobcats (Jacobson et al. 2009).

<u>Changes in periodicity of the snowshoe hare cycle</u>. The 10-year cycle that occurs in northern Canada and Alaska involves an interaction between lynx, hares, and the hares' plant resources (Krebs et al. 1995, 2001*a*). The periodicity of lynx abundance may be triggered by North Atlantic Oscillation (NAO) climate effects (Stenseth et al. 1999), with the strength of the trophic interactions varying with region-specific vegetation (e.g., forest–tundra, boreal conifer–deciduous mixed woods) and winter conditions. NAO-determined winter snow levels may mediate lynx hunting efficiency, the effects of which then cascade down through snowshoe hares to the plants (Stenseth et al. 1999, Krebs et al. 2001*b*).

In Europe, there are indications that the population cycles of voles, grouse, and insects now are breaking down, with several lines of evidence implicating climate change as the underlying cause (Ims et al. 2008). The geographical borders between cyclic and noncyclic populations are shifting, and the spatial extent of regions that have cycles are shrinking. The collapse of cycles in herbivores with high-amplitude population cycles also would imply collapses of important ecosystem functions such as pulsed flows of resources and disturbances (Schmitz et al. 2003, Ims et al. 2008). A common denominator of cycles that exhibit spatial gradients, such as the more pronounced cycle of snowshoe hares in its northern range of North America, is that the cycles appear to fade as winters become shorter (Ims et al. 2008). The loss of the hare cycle would likely translate into a reduced potential for lynx to expand into new or unoccupied habitat in Canada or the adjoining United States.

<u>Reduction in lynx habitat and population size</u>. Climate change may reduce the extent of deep snow habitats selected by lynx. Based on a general circulation model, Kerr and Packer (1998) predicted that lynx would be

among the 25 mammal species in Canada likely to undergo significant losses of habitat, with accompanying decreases in population size. McKelvey et al. (2011) estimated that contiguous areas of spring snow cover would become smaller and more isolated throughout the Columbia, Upper Missouri, and Upper Colorado Basins, with greatest losses at the southern periphery, which likely is an indicator of the trajectory of lynx habitat. According to Carroll (2007), climate change could result in dwindling of potential lynx habitat in the northern Appalachians to small areas in the Canadian Maritime Provinces.

Forests in the northeast are predicted to significantly change in the next 100 years under every emissions scenario (Prasad et al. 2007). The extent of oak and pine forest types is projected to increase and expand into central and possibly northern Maine (Iverson et al. 2008). Maine and the northeast forest region are predicted to lose much of their spruce-fir and mixed-conifer forest, including upland spruce-fir forest and lowland spruce flats (Prasad et al. 2007, Ollinger et al. 2008, Tang and Beckage 2010). Warming climate and selective logging for conifers has already resulted in an increase of the deciduous forest in northern Maine (Seymour 1992), which is contributing to fragmentation of lynx habitat (Simons 2009).

Galatowitsch et al. (2009) estimated that by 2069, average annual temperatures in Minnesota will increase 3° C (5.4° F) with a slight increase (6%) in precipitation. Minnesota forests will experience warmer summers with more frequent and longer droughts. Most simulations for the Great Lakes-St. Lawrence Basin predict reduced precipitation and lower lake levels (Inkley et al. 2004). Similarly, most climate models predict that the northern Rockies and the Greater Yellowstone ecosystem will be warmer and drier, with increased risk of bark beetle epidemics and forest fires in susceptible age classes. The recent mountain pine beetle outbreak in British Columbia, for example, was associated with warmer winters, longer growing season, and fire suppression (Gayton 2008).

An increasing occurrence and persistence of drought, along with associated insect outbreaks and wildfires, could rapidly and dramatically affect the distribution, amount, and composition of lynx habitat. Cohen and Miller (2001) suggested climate change could alter both the nature and extent of wildfire and beetle outbreaks. With warming climate, fire seasons in the western United States will likely be extended and the total area burned may increase (McKenzie et al. 2004). Westerling et al. (2006) predicted that warmer springs could increase the frequency and duration of wildfires, which in turn could reduce the resistance of surviving trees to bark beetle attack. Raffa et al. (2008) suggested that increasing temperatures and forest homogeneity likely will result in bark beetle outbreaks that exceed natural disturbance thresholds; this may set the landscape for additional outbreaks since there will be even-aged forests over a larger area.

Westerling et al. (2006) compiled information on large wildfires in the western United States from 1970–2004; large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases occurred in mesic, middle- and high-elevation forest types (such as lodgepole pine and spruce-fir) in the northern Rocky Mountains. Fire exclusion has had little impact on natural fire regimes of these higher-elevation forest types in this area; rather, climate appears to be the primary driver of forest wildfire risk. Large wildfires were strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.

<u>Changes in demographic rates</u>. Incremental changes in climate would affect lynx directly or indirectly through effects on prey abundance. Annual weather patterns are known to affect survival and reproduction of snowshoe hares, which in turn would influence lynx productivity and survival. Reductions in lynx population size and the amount of available habitat possibly could decrease the likelihood of persistence of smaller subpopulations and successful genetic interchange between subpopulations (Gonzalez et al. 2007).

<u>Changes in predator-prey relationships</u>. Climate change is likely to negatively affect lynx habitat and its ability to support lynx and snowshoe hares, although the rates of change and magnitude of effects are difficult to predict. It seems likely that snowshoe hares, which have shorter generation times than lynx, would respond to habitat changes more quickly than would the lynx themselves.

A characteristic of the snowshoe hare is its seasonal pelage coloration, turning white during the winter from a brown coat in the other seasons. This pelage change appears to be triggered by day length (Severaid 1945). A shift in the duration of snow cover could result in a mismatch of the pelage of snowshoe hares with the background color of its environment, increasing its vulnerability to predation. Over time, natural selection pressure could be expected to correct the mismatch.

Reduced snow depth, condition, and persistence may diminish the competitive advantage of lynx relative to bobcats and coyotes. This could also increase the likelihood of habitat overlap with wolves and mountain lions, increasing predation risk to lynx and competition for snowshoe hare prey.

Federal land management agencies have limited ability to alter the trajectory or to ameliorate the effects of climate change. Assessments should be conducted to consider possible ways to assist with adaptation to climate change. Chapter 6 of this document identifies research needs, which include the need for additional work to more accurately predict specific effects of climate change on lynx.

Vegetation management

Stand structure, composition, and arrangement are important elements of habitat for snowshoe hares and lynx. Vegetation management practices can have beneficial, neutral, or adverse effects on lynx and snowshoe hare habitat and populations, and the duration of effects varies. Effects of vegetation management on snowshoe hare habitats have been studied across the range of the species (Conroy et al. 1979, Sullivan and Sullivan 1988, Koehler 1990*b*, Thomas et al. 1997, Homyack et al. 2005, Robinson 2006, Griffin and Mills 2007, Berg 2010, Ivan 2011*a*, Lewis et al. 2011, and McCann and Moen 2011). Effects on lynx have been investigated by Koehler (1990a), Koehler and Brittell (1990), Fuller et al. (2007), Homyack et al. (2007), Moen et al. (2008), Vashon et al. (2008*b*) and Squires et al. (2010).

Vegetation management occurs across the range of the lynx and can directly affect important habitats and prey. Management activities uninformed by consideration of negative impacts to the species were identified as being of greatest potential concern to lynx conservation (Federal Register, July 3, 2003, vol. 68, no. 28, pp. 40076-40101).

Historically, the dominant natural disturbance processes that created early-successional stages within the range of the lynx were wind events, fire, and insect and disease outbreaks (Kilgore and Heinselman 1990, Heinselman 1996, Veblen et al. 1998, Agee 2000, Seymour et al. 2002, Lorimer and White 2003). In forests of the Northeast Geographic Area, wind, fire, insects, and diseases were predominant natural disturbance agents, while fire, insects, and diseases were predominant in the Great Lakes Geographic Area and across the western United States.

After disturbances, forests generally develop through several stages described by Oliver (1980) as "stand initiation," "stem exclusion," "understory reinitiation," and "old growth." Stand dynamics, particularly within-stand competition for light, nutrients, and space, determine how forests grow and respond to intentional manipulations and natural disturbances (Oliver and Larson 1996). The frequency and severity of disturbances influence which species will dominate in a stand after the disturbance event. The stand initiation stage, once the trees have established and grown tall enough to protrude above the snow, may provide snowshoe hare and lynx habitat. During the stem exclusion stage, the tree crowns lift and lower branches self-prune, thus growing above the reach of snowshoe hares. As the stand moves into understory reinitiation and old-growth structural stages, food and cover may again become available to support snowshoe hares.

Commercial timber management of conifer forests traditionally has been designed to: reduce tree density and promote tree growth (e.g., precommercial thinning), especially in young regenerating forests; improve growth and vigor of mature trees (e.g., commercial thinning, thinning from below); reduce the vulnerability of commercially-valuable trees to insects and disease (e.g., commercial thinning, group selection); and harvest forest products (e.g., regeneration harvest). Timber management practices may mimic natural disturbance processes but often are not an exact ecological substitute. Some practices, such as use of herbicides to suppress hardwood regeneration, do not have an historical analogue. Timber harvest may differ from natural disturbances by:

- Removing most standing biomass from the site, especially larger size classes of trees, and down logs, which alters microsite conditions and nutrient cycling;

- Creating smaller, more dispersed patches and concentrating harvest at lower elevations in mountainous regions and on more nutrient rich soils, resulting in habitat fragmentation;
- Causing soil disturbance and compaction by heavy equipment, which may result in increased water runoff and slower tree growth at the site; or
- Giving a competitive advantage to commercially-valuable tree species and reducing the structural complexity of the forest through the application of harvest, planting, thinning, and herbicide treatments.

Stem density and snowshoe hare density are directly and positively correlated (Conroy et al. 1979, Sullivan and Sullivan 1988, Koehler 1990*b*, Koehler and Brittell 1990, Thomas et al. 1997, Hodges 2000*a*, Mowat et al. 2000, Homyack et al. 2006). Vegetation management that promotes high stem density and dense horizontal cover can increase snowshoe hare densities (Keith and Surrendi 1971; Fox 1978; Conroy et al. 1979; Wolff 1980; Parker et al. 1983; Livaitis et al. 1985; Bailey et al. 1986; Monthey 1986; Koehler 1990*a*, *b*; Robinson 2006; Fuller et al. 2007; Homyack et al. 2007; Scott 2009; McCann and Moen 2011).

Where the objective is to provide snowshoe hare habitat by creating additional early-successional forest conditions, management considerations include selecting areas that are capable of, but not currently providing, dense horizontal cover (e.g., stem exclusion structural stage), designing the appropriate size and shape of treatment units, retaining coarse woody debris, and maintaining high stem densities in regenerated forests (Koehler and Brittell 1990, Homyack et al. 2004, Bull et al. 2005, Fuller and Harrison 2005, Ivan 2011*a*).

Precommercial thinning of young, dense regenerating conifers is generally designed to increase the growth of selected trees by removing competing trees of the same species or shrubs and trees of other species (Plate 4.1; Daniel et al. 1979; Homyack et al. 2005, 2007). Reducing the density of sapling-sized conifers in young re-

Plate 4.1. Precommercial thinning, as seen in the stands on the left of the photo, reduces dense horizontal cover and results in lower snowshoe hare density.

generating forests to increase the growth of certain selected trees promotes more homogeneous patches and reduces the amount and density of horizontal cover, which is needed to sustain snowshoe hares (Sullivan and Sullivan 1988, Hodges 2000*b*, Griffin and Mills 2004, Ausband and Baty 2005, Griffin and Mills 2007, Homyack et al. 2007, Ellsworth 2009). Precommercial thinning has been shown to reduce hare numbers by as much as 2- and 3-fold (Griffin and Mills 2004, 2007; Homyack et al. 2007) due to reduced densities of sapling and shrub stems and decreased availability of browse. Griffin and Mills (2007) reported that, if their results were representative, the practice of precommercial thinning could significantly reduce snowshoe hares across the range of lynx.

There are anecdotal examples of precommercially thinned stands that subsequently "filled in" with understory trees. Some have suggested this could be a technique to extend the time that understory trees and low limbs provide the dense horizontal cover that constitutes snowshoe hare habitat. The duration between time of thinning and regrowth to a height providing winter snowshoe hare habitat would likely vary by tree species, each having different regenerative capacities that could be influenced by a variety of local factors (e.g., topographic relief, moisture, and mineral and organic content of the soil; Baumgartner et al. 1984, Koch 1996). Bull et al. (2005) reported that the slash and coarse woody debris remaining after precommercial thinning provided both forage and cover for snowshoe hares up to a year following treatment. However, Homyack et al. (2007) found that snowshoe hare densities were reduced following precommercial thinning for 1–11 years post-thinning. They further suggested that after precommercial thinning, the stands did not regain the structural complexity in the understory that would be needed to support snowshoe hare densities to the level that were present pre-treatment. At this time, no other data are available to quantify the re-establishment of snowshoe hare habitat and over what time period, or the response by snowshoe hares, as compared with sites that were not precommercially thinned, so this remains an unproven management technique. As an alternative to standard precommercial thinning (i.e., complete thinning resulting in a homogeneous patch), Griffin and Mills (2007) suggested retaining at least 20% of the patch in untreated clumps of about ¼ ha (½ ac), which would maintain hare habitat in the short term. However, Lewis et al. (2011) found that landscapes with patches of high-quality habitat surrounded by similar vegetation supported more hares than did more fragmented landscapes composed of high-quality patches in a matrix of poorer-quality habitat. Further long-term studies of modified thinning methods are needed.

Uneven-aged management (single tree and small group selection) practices can be employed in stands where there is a poorly developed understory, but have the potential to produce dense horizontal cover for snowshoe hares. Removal of select large trees can create openings in the canopy that mimic gap dynamics and help to maintain and encourage multi-story attributes within the stand.

If removal of large trees opens the canopy to the extent that the patch functions as an opening, this may discourage use by lynx (Plate 4.2; Koehler 1990*a*, von Kienast 2003, Maletzke 2004, Squires et al. 2010). Removal of larger trees from mature multi-story forest stands to reduce competition and increase tree growth or resistance to forest insects may reduce the horizontal cover (e.g., boughs on snow), thus degrading the quality of winter habitat for lynx (Robinson 2006, Koehler et al. 2008, Squires et al. 2010). Similarly, removing understory trees from mature multi-story forest stands reduces the dense horizontal cover selected by snowshoe hares, and thus reduces winter habitat

Plate 4.2. Wildfires and vegetation management techniques such as clearcutting create openings in the forest canopy. Large openings may be avoided by lynx, especially during the winter.

for lynx (Koehler et al. 2008, Squires et al. 2010).

Current favorable habitat conditions for snowshoe hare and lynx in Maine resulted from large-scale salvage cutting following a spruce budworm outbreak in the 1970s and 1980s (Hoving et al. 2004). After salvage harvest of the affected trees, a portion of the area was sprayed with herbicide to reduce deciduous competition (Scott 2009). This created favorable habitat conditions for snowshoe hares and lynx. After the passage of the Maine Forest Practices Act of 1989, various forms of partial harvesting have since replaced clearcutting as the predominant form of forest management in northern Maine. Partial harvested stands result in a wide range of residual stand conditions, but many have lower conifer stem densities and higher hardwood density than regenerating clearcuts (Robinson 2006). On average, partial harvested stands supported about 50% of the hare densities observed in regenerating clearcuts (Robinson 2006).

Fuels treatments commonly are designed to remove understory biomass and reduce stem density in forests that are outside their historical range of variability, and to clear fuels adjacent to human developments for safety or to protect investments (Plate 4.3). These types of projects are becoming more common. In the western United States, projects designed to restore forests to a condition more representative of the historical range of variability are generally targeted to drier, lower-elevation forests affected by fire suppression (Hessburg et al. 2005), which are not lynx habitat. Lynx habitats in higher-elevation spruce-fir forests have been less affected by past fire suppression and are mostly within the historical range of variability (Agee 2000). Fuels treatments may be needed to protect human communities and capital improvements by reducing the intensity and rate of spread of a fire, affording control actions with a higher probability of success and providing safer conditions for fire fighters. By removing or reducing the understory and ladder fuels to meet those objectives, dense horizontal cover important to snowshoe hares is reduced and habitat value is diminished for hares and lynx.

Plate 4.3. Fuels management projects reduce ladder fuels in mature multi-story forests, reduce horizontal cover, and can degrade winter lynx habitat, as shown in these comparison photographs.

Prescribed burning is a technique used to reduce tree stem density and reduce fuels. In the Great Lakes Geographic Area, prescribed burning is used in lynx habitat primarily as a tool to reduce fuels (including from blowdown) and mimic a more natural fire regime in pine forest types (Plate 4.4). In these instances there is a short-term (10–30 years) impact on snowshoe hare habitat. In the western United States, prescribed fire for ecosystem restoration is most applicable to the dry ponderosa pine and Douglas-fir forests that are not lynx habitat. Because spruce-fir forests are generally composed of thinner-barked trees that are easily killed even with light fire, this technique is not used frequently in most lynx habitat.

Biomass removal for energy production targets the removal of dead trees, logging slash, and small-diameter trees and shrubs. Biomass removal is similar to fuels treatments in reducing cover and habitat for snowshoe hares.

Plate 4.4. Prescribed fire treatments are designed to decrease fuels, but also have the effect of reducing snowshoe hare habitat in the short term (10–30 years in Minnesota), as shown in these comparison photographs.

Wildland fire management

Fire and other natural disturbance processes historically played an important role in maintaining a mosaic of forest successional stages that provides habitat for both snowshoe hare and lynx (Fox 1978, Bailey et al. 1986, Quinn and Thompson 1987, Koehler and Brittell 1990, Poole et al. 1996, Slough and Mowat 1996). The response of snowshoe hare and lynx in their use of habitat after fires follows a somewhat predictable pattern. For the first few years after a burn, there appears to be a negative correlation between lynx use and the amount of area burned (Fox 1978). This short-term effect is likely a response to a reduction of snowshoe hare populations, reduced cover, and possibly also to increased competition from coyotes in the now-open habitat (Stephenson 1984, Koehler and Brittell 1990). The mid-term (10–40 years post-fire) effect on vegetation in a burned area is development of small tree and shrub cover sufficient for hare populations to reoccupy the area. The length of time varies depending on tree species, potential vegetation, fire severity, and the presence of re-sprouting broadleaf species. Where broadleaf species are denser, hare re-occupancy occurs more quickly (within 3–12 years). Hare population density again decreases as the conifer tree canopy develops and shades out the understory. Forest gap processes, such as tree blowdown, insect infestations, and outbreaks of disease, follow a similar pattern (Agee 2000).

Across the range of lynx, vegetation dynamics differ somewhat as a result of the natural fire frequency and intensity. For example, lynx habitat in the northeastern boreal forests had very long fire-return intervals of up to 500 years (Agee 2000). The Great Lakes boreal forests tended to have shorter fire-return intervals of 50 –150 years (Heinselman 1996). In much of the Rocky Mountains, the fire regime was more variable in lynx habitat, with both frequent (35–100 years) stand-replacing or mixed-severity fires, and infrequent (200+ years) stand-replacement fires (Hardy et al. 1998). The Cascade Mountains were dominated historically by infrequent (70–150 years) stand-replacing fire regimes (Agee 2000). Disturbance interval and fire severity vary by cover type, with xeric pine types such as lodgepole or jack pine typically experiencing more frequent and more severe fires than mixed-conifer types and spruce/fir.

In the Cascades Geographic Area wildfire has been a significant disturbance influence in lynx habitat. Fires burned more than 50% of suitable lynx habitat in Okanogan County since 1994 (Koehler et al. 2008). In 2006, the Tripod Fire in the Meadows burned 600 km^2 (20 mi^2) of the most contiguous lynx habitat in Washington.

Gayton (2008) reported that recent mountain pine beetle epidemics in British Columbia were the result of a changing climate that contributed to warmer winters and longer growing seasons. Cohen and Miller (2001) and McKenzie et al. (2004) have suggested climate change could affect the extent of bark beetle outbreaks and extent and fire seasons and total area burned in the west.

Land management agencies began effective fire suppression with the advent of aircraft support approximately 70 years ago. Over time, continued fire suppression altered vegetation mosaics and species composition. In jack pine forests of the Great Lakes region, fire suppression changed stand composition and successional pathways (Agee 2000). In the western United States, a shift to uncharacteristically severe and intense wildfires has occurred recently in lower-elevation forests (Quigley et al. 1996, Morgan et al. 1998). However, fire suppression in areas with a history of infrequent fires, as is typical of cool moist forest types such as spruce-fir forests, has probably not had much impact (Habeck 1985, Agee 1993, Schoennagel et al. 2004, Whitlock 2004). This is true across much of the boreal forest in the western United States.

The current goals for vegetation management on federal lands in the United States are to restore ecosystem health, ecological processes, and forest structure, composition, and function appropriate to the site (e.g., USDA Forest Service 2010). Westerling et al. (2006) suggested fuel management and ecological restoration practices will likely not reverse current wildfire trends; large increases in wildfires in the western United States since 1970 resulted from increased temperatures and earlier spring snowmelt. Particularly in the western United States, ecosystem restoration is primarily focused in the dry and mesic forest types at lower elevations, rather than in lynx habitat, and includes reestablishing frequent, low-intensity fire in those systems. Applying ecosystem restoration across a landscape may reduce the risk of uncharacteristic large, stand-replacing fires occurring in the lower-elevation forest types, and thereby prevent their spread into adjacent lynx habitat.

After large dead trees fall to the ground, they provide cover and may enhance lynx foraging habitat in the short term and potential denning habitat in the longer term, depending on post-disturbance stand conditions. Standing snags also may provide sufficient vertical structure and cover to allow lynx to traverse long distances (>1 km [>0.6 mi]) across burned habitat (Maletzke 2004).

Similar to vegetation management, wildland fire management may either diminish, enhance, or sustain the density and distribution of snowshoe hare prey resources and lynx habitat, depending on the design and implementation of programs and actions.

Fragmentation of habitat

We use the term "fragmentation" to describe human-caused alterations of natural landscape patterns that reduce the total area of habitat, increase the isolation of habitat patches, and impair the ability of wildlife to effectively move between those patches of habitat. Fragmentation may be permanent, for example by converting forest habitat to residential or agricultural purposes, or temporary, for example by creating an opening but allowing trees and shrubs to regrow. Fragmentation of habitat accentuates the viability risk inherent in a small population and increases its vulnerability to local extirpation. The combination of human-caused and natural disturbances may exacerbate fragmentation effects.

Lynx habitat in the contiguous United States is inherently patchier than in the northern boreal forest with its extensive forests, gentle topography, and relatively consistent winter snow conditions (Aubry et al. 2000). The pronounced topographic relief in the mountains of the western United States restricts lynx habitat to a relatively narrow elevational band.

A variety of anthropogenic activities can result in increased habitat fragmentation at the home range or broader scale. For example, permanent or temporary removal of forest cover, development of highways and associated infrastructure, and intensive minerals or energy development can fragment lynx habitat.

Within their home ranges, lynx strongly select for habitat patches that enhance their foraging opportunities (Moen et al. 2008, Vashon et al. 2008*a*, Fuller and Harrison 2010, Squires et al. 2010). Analysis of winter movements of lynx in Maine indicated that lynx responded to habitat heterogeneity at a coarse scale within their home ranges, by maximizing their access to snowshoe hare prey (Fuller and Harrison 2010). In Montana, lynx selected homogeneous spruce-fir patches that supported snowshoe hares and avoided recent clearcuts or other open patches (Squires et al. 2010). Similarly, in Washington, Lewis et al. (2011) reported that landscapes in which hare habitat was more contiguous, or surrounded by a mosaic of similar habitat quality, supported more hares than did more fragmented landscapes.

Both lynx and hares are influenced by the spatial arrangement of preferred habitat. In Maine and northern Washington, landscapes where habitat was more contiguous supported more snowshoe hares than landscapes that were more fragmented (Simons 2009, Lewis et al. 2011). Several studies (Koehler 1990*a*, Mowat et al. 2000, von Kienast 2003, Maletzke 2004, Squires and Ruggiero 2007, Squires et al. 2010) have reported that lynx avoid large openings, especially during winter. Mowat et al. (2000) suggested that relatively few snowshoe hares use large openings, and consequently lynx spend little time hunting in these areas. Koehler (1990*a*) speculated that vegetation management prescriptions that result in distance to cover >100 m (328 ft) may change lynx movement and use patterns until such time as sufficient reestablishment of forest vegetation occurs. Opening size can also influence seedling regeneration and stocking densities (Kreyling et al. 2008).

Fragmentation of the naturally patchy pattern of lynx habitat in the contiguous United States can affect lynx by reducing their prey base and increasing the energetic costs of using habitat within their home ranges. Buskirk et al. (2000*a*) identified direct effects of fragmentation on lynx to include creation of openings that potentially increase access by competing carnivores, increasing the edge between early-successional habitat and other habitats, and changes in the structural complexities and amounts of seral forests within the landscape. At some point, landscape-scale fragmentation can make patches of foraging habitat too small and too distant from each other to be effectively accessed by lynx as part of their home range. Maintaining preferred habitat patches for lynx and hares within a mosaic of young to old stands in patterns that are representative of natural ecological processes and disturbance regimes would be conducive to long-term conservation.

Highways typically follow natural features such as rivers, valleys, and mountain passes that may have high value for lynx in providing habitat or connectivity. Various studies have documented lynx crossings of highways. A male lynx in western Wyoming was documented to have successfully crossed several 2-lane highways during exploratory movements (Squires and Oakleaf 2005). In Colorado, lynx successfully and repeatedly crossed major highways, including I-70 (J.Squires, personal communication 2012; Ivan 2011*b*, *c*, 2012). However, in Alberta, Canada, high road densities, human activity, and associated developments appeared to reduce the habitat quality based on decreased occupancy by lynx (Bayne et al. 2008). Apps et al. (2007) found lynx were 13 times less likely to cross the Trans-Canada Highway relative to random expectation, but only 2.2 and 3.1 times less likely to cross Highway 93 and Highway 1A, respectively, compared to random expectation.

Highways pose a risk of direct mortality to lynx and may inhibit lynx movement between previously connected habitats. If lynx avoid crossing highways, this could lead to a loss of effective habitat within a home range and reduced interaction within a local population (Apps et al. 2007). Lynx and other carnivores may avoid using habitat adjacent to highways, or become intimidated by highway traffic when attempting to cross (Gibeau and Heuer 1996, Forman and Alexander 1998). As the standard of road increases from gravel to 2-lane or 4-lane highways, traffic volumes and the degree of impact are expected to increase. Four-lane highways, such as the interstate highway system, commonly have fences on both sides, service roads, parallel railroads or power lines, and impediments like "Jersey barriers" that make successful crossing more difficult, or impossible, for

Plate 4.5. Jersey barriers in the medians or along the shoulders of highways and fenced areas adjacent to highways may impede movement of lynx between habitat patches.

wildlife (Plate 4.5). Alexander et al. (2005) suggested traffic volumes between 3,000 and 5,000 vehicles per day may be the threshold above which successful crossings by carnivores are impeded.

Between 2000 and 2011, 27 lynx were reported to have been killed on roads (both paved and unpaved) in Maine (Vashon et al. 2012), 4 in Minnesota (U. S. Fish and Wildlife Service 2012), 1 in Idaho and 1 in Montana (K. Broderdorp, U.S. Fish and Wildlife Service, personal communication 2012). Between 1995 and 2011, 15 lynx were reported killed on British Columbia highways (British Columbia Wildlife Accident Reporting System 2012).

Translocated animals may be more vulnerable to highway mortality than resident lynx (Brocke et al. 1990), because they often move extensively after their release and are unfamiliar with their surroundings. In the Adirondack Mountains of New York, an attempt to reintroduce lynx failed and 18 of 37 mortalities of translocated animals were attributed to road kills (Brocke et al. 1990). Over a 7-year period in Colorado, 13 of 102 translocated lynx were killed on highways (Devineau et al. 2010). Traffic volumes on Colorado highways where the 13 lynx mortalities occurred were estimated to range from about 2,300 to >25,000 vehicles per day (K. Broderdorp, personal communication 2012).

Coordination of management across international, federal, state, county, and private land boundaries is essential to minimize fragmentation. Connectivity to source populations in Canada is considered critical to persistence of populations in most parts of the range in the United States (Federal Register Vol. 68 pp. 40076–40101, Squires et al. 2013).

Second tier of anthropogenic influences

The following 6 anthropogenic influences are placed in the lower tier, indicating that they are judged to have less impact on lynx and lynx habitat or are the responsibility of agencies other than the federal land management agencies. Regulations that are already in place may have reduced the impacts on lynx, or the nature of the activity confers a lesser impact.

Incidental trapping

Like most felids, lynx are very vulnerable to trapping and snaring and can be easily overexploited (Mech 1980, Carbyn and Patriquin 1983, Parker et al. 1983, Ward and Krebs 1985, Bailey et al. 1986, Quinn and Thompson 1987, Slough and Mowat 1996). In Canada during a snowshoe hare decline, rates of trapping mortality of lynx were positively related to average pelt value, and appeared to be additive to nontrapping mortality (Brand and Keith 1979).

State wildlife management agencies regulate the trapping of furbearers. Trapping and snaring of lynx is currently prohibited across the contiguous United States. Incidental trapping or snaring of lynx can occur in areas where regulated trapping for other species, such as wolverine, coyote, fox, fisher, marten, bobcat and wolf, overlaps with lynx habitats (Plate 4.6; Mech 1973, Carbyn and Patriquin 1983, Squires and Laurion 2000, U.S. Fish and Wildlife Service unpublished data 2011, U. S. Fish and Wildlife Service 2012, Vashon et al. 2012).

Lynx that were captured in the United States for research projects have subsequently been killed in traps or snares in Canada (Moen 2009, Vashon et al. 2012). In Maine from 2000-2012, 59 lynx were reported captured in traps set for other furbearers (snares were not legal), of which at least 6 were mortalities (Vashon et al. 2012). In Minnesota during the same time period, 22 lynx were reported captured in traps and snares, of which at least 12 were killed (U.S. Fish and Wildlife Service 2012). In Montana, 10 lynx were reported trapped, of which at least 4 died. Two lynx were trapped in Idaho, 1 in 2012 (B. Waterbury, Idaho Department of Fish and Game, personal communication 2013) and 1 in 2013 (M. Lucid, Idaho Department of Fish and Game, personal communication 2013), 1 of which died. Lynx were also incidentally trapped and snared in New Brunswick and Nova Scotia where they are a protected species. These figures reflect the reported captures only.

Plate 4.6. Trapping for lynx is not legal in the contiguous United States. However, traps set in lynx habitat that target other furbearing species, such as fishers, coyotes, wolverine, and bobcats, can result in an incidental capture of lynx.

The total number of mortalities due to incidental trapping is unknown. Moen (2009) investigated the proportion of radiocollared animals that were represented in the total number reported to FWS in Minnesota. In comparison to incidental shooting and vehicle collisions, proportionately fewer mortalities of non-collared lynx were reported due to incidental trapping, suggesting that trap-related mortalities may be underreported (Moen 2009).

Although many incidentally trapped lynx were reported to have been released, the physical condition of the released animals and the effect on animal fitness are unknown. Depending on environmental conditions and the types of traps used, a substantial portion of lynx caught in foothold traps may experience injuries and foot freezing (Mowat et al. 1994, Nybakk et al. 1996, Kolbe et al. 2003). Some trap-related injuries (e.g., dislocations, fractures, mild freezing) are difficult to detect in lynx in the field (Mowat et al. 1994). Injuries and mortality rates are greatest to lynx incidentally caught in snares and Conibear traps.

Injuries and mortalities related to incidental trapping can be minimized through various techniques. Avoiding areas where lynx are present, avoiding use of suspended flags or sight-attractants near traps, avoiding drag sets and anchoring traps with short chains (Mowat et al. 1994) and multiple swivels, using padded foothold traps or traps with offset jaws (Olsen et al. 1988, Houben et al. 1993, Association of Fish and Wildlife Agencies 2011), employing boxes or other devices to exclude lynx from Conibear traps (U.S. Fish and Wildlife Service 2011), and trapping when temperatures are above -8° C (18° F; Mowat et al. 1994) are recommended. Daily checking of traps can minimize freezing injuries and starvation. Several states including Maine, Minnesota, and Montana have implemented special regulations to reduce the likelihood of incidental capture of lynx in traps set for other furbearers.

State wildlife agencies have effectively used trapper outreach such as training, DVDs, and mailings, as a tool to avoid or minimize incidental take of lynx. Some states also have protocols to quickly respond to lynx in traps (e.g., 24-hour hotline) and have trained personnel ready to evaluate trapped lynx and assist with release or rehabilitation.

No conservation measures to address incidental trapping are included in this document because trapping is regulated by the states.

Recession

Trends in recreation. Cordell et al. (2009) compared the results of national recreation surveys conducted during 1982–1983, 1994–1995, 1999–2001, and 2005–2009. In terms of both the number of people and percentage of population, participation in outdoor recreation has continued to grow in the United States. Over the years, walking outdoors has been the most popular activity, with 194 million participants currently. Activities gaining more than 50 million participants between 1982–83 and 2005–09 were viewing or photographing wild birds (an increase of 287%), attending outdoor sports events (an increase of 74%), and day hiking (an increase of 210%). Downhill skiing increased by 4.4% to 14.8 million participants, and snowmobiling increased by 3.5% to 8.7 million participants. Cross-country skiing declined by about 5.8% over the same period. Social trends may have cycles that are influenced by economic conditions, technology changes, population growth, cultural evolution, and other factors, making it difficult to project future trends.

Mechanisms of effects. Our understanding of the effects of outdoor recreation on lynx and their habitat is incomplete. The effects, if any, may depend on the type of activity and the context within which it occurs. Mechanisms through which recreational activities could impact lynx may include loss of habitat, reductions in habitat availability due to disturbance, or changes in competition for snowshoe hare prey.

Habitat loss. Construction or expansion of developed areas such as large ski areas and 4-season resorts, as well as smaller recreational sites like nordic ski huts or campgrounds, may directly remove forest cover. Such removal in lynx habitat could decrease prey availability, affect lynx movement within home ranges, or result in a more fragmented landscape.

Disturbance. Few studies have examined how lynx react to human presence. Some anecdotal information suggests that lynx are quite tolerant of humans, although given differences in individuals and contexts, a variety of behavioral responses to human presence may be expected (Staples 1995, Mowat et al. 2000). Preliminary information from winter recreation studies in Colorado indicates that some recreation uses are compatible, but lynx may avoid some developed ski areas (J. Squires, personal communication 2012).

Some wildlife species have been found to be more sensitive to disturbance when bearing and rearing young than in other times of the year. Olson et al. (2011) reported they approached 8 dens of females; half of the females moved their dens within 4 days, while the other half did not move dens for at least 20 days following disturbance. Olson et al. (2011) noted that lynx dens were located in more remote areas and unlikely to be disturbed by humans. Frequent movement of kittens from natal dens to 1 or more maternal dens is normal behavior exhibited by lynx even in the absence of human disturbance (J. Squires, personal communication 2012).

Changes in competition for snowshoe hare prey. Packed trails created by snowmobiles, cross-country skiers, snowshoe hares, and other predators might serve as travel routes for potential competitors and predators of lynx, especially coyotes (Plate 4.7; Bider 1962, Ozoga and Harger 1966, Murray and Boutin 1991, Koehler and Aubry 1994, Murray et al. 1995, and Buskirk et al. 2000*a*). Unique morphological differences between coyotes and lynx would appear to spatially segregate these species by snow conditions (Murray and Boutin 1991, Litvaitis 1992), with coyotes at a disadvantage in deep, soft snow due to their high foot-load (the ratio of body mass to foot area; Murray et al. 1994). Buskirk et al. (2000*a*) hypothesized that the natural spatial segregation of lynx and coyotes in winter could break down where human modifications to the environment allow coyotes to access deep snow areas.

Plate 4.7. Snow may be compacted by recreational activities. Continually compacted trails as a result of grooming may provide access into areas with deep snow for other predators such as coyotes.

The strength of this hypothesis rests on 2 primary assumptions: a) that the presence of compacted snow resulting from certain recreational activities leads to increased coyote use of or access to lynx habitat; and b) that such increased use or access reduces prey availability to lynx or increases interference interactions. Some studies suggest that coyotes select for snow conditions that are shallower, more supportive, and characterized by low sinking depth (Murray and Boutin 1991, Thibault and Ouellet 2005). Coyote use of more supportive snow may reduce the relatively high energetic cost of travel in and avoidance of deep snow conditions (Crete and Lariviere 2003).

Studies of coyote use of compacted snowmobile trails have yielded variable results. In Montana, Kolbe et al. (2007) snow-tracked coyotes and found that although they did use snowmobile trails, they did not travel closer to these trails than randomly expected. Rather, coyotes adapted to deep snow conditions by selectively using habitats with shallower and more supportive snow (Bunnell et al. 2006, Kolbe et al. 2007), corroborating observations made by others (Murray and Boutin 1991, Crete and Lariviere 2003, Thibault and Ouellet 2005, Burghardt-Dowd 2010). Further, coyotes in the Kolbe et al. (2007) study did not use compacted roads any more than uncompacted roads, suggesting that coyotes may have used roads because they provide a "cleared travel corridor" whether they are compacted or not.

In contrast, the distribution of coyotes in Utah and Wyoming appeared to be influenced by proximity to compacted snowmobile trails in deep, powdery snow areas (Bunnell et al. 2006, Burghardt-Dowd 2010). Bunnell et al. (2006) observed more coyote activity along trails compacted by snowmobiles than those that were not. Burghardt-Dowd (2010) applied methods used by Kolbe et al. (2007) in western Wyoming and similarly found that coyotes selected shallower snow when off compacted trails than randomly expected. However, coyotes in her study area also traveled closer to compacted snowmobile trails than would be expected. The seemingly contradictory results from Kolbe et al. (2007) and Burghardt-Dowd (2010) might be attributable to differences in snow penetrability between the 2 geographic areas. Average snow penetrability measured using the same method was higher in northwestern Wyoming (Burghardt-Dowd 2010) than in Montana (Kolbe et al. 2007), making coyote movement in the absence of artificially compacted snow potentially more energetically costly in Wyoming. Based on these studies, it appears that snow column density and the number of freeze/thaw events in different regions may influence coyote movements and habitat selection (Burghardt-Dowd 2010). That is, snow penetrability in the region may determine whether or not snowmobile trails influence coyote movement patterns in lynx habitats (Bunnell et al. 2006, Kolbe et al. 2007, Burghardt-Dowd 2010).

Regarding the second assumption, if snow compaction assists coyote movement during winter, does this result in reduced prey for lynx? Coyotes are found throughout the majority of the boreal forest ecosystem (Bekoff and Gese 2003) including areas inhabited by lynx (O'Donoghue et al. 2001, Kolbe et al. 2007, Burghardt-Dowd 2010). Unlike lynx, coyotes demonstrate strong prey- and habitat-switching abilities (Buskirk 2000). In the Yukon, coyote and lynx winter diets overlapped most during a peak in hare densities and least during periods of low hare densities (O'Donoghue et al. 2001).

In Maine, hares represented 37% of the winter diet of coyotes in a study on the Maine eastern coast (Major and Sherburne 1987), outside of lynx habitat. Litvaitis and Harrison (1989) reported that snowshoe hares composed 39% of the winter diet of coyotes in a western Maine study in lynx habitat. However, there is no indication that lynx were present in this study area at the time of the study, making it difficult to infer whether or not competition between coyotes and lynx might have occurred.

In Montana, coyotes primarily scavenged ungulate carrion, and killed snowshoe hares at only 3 of 88 documented feeding sites (Kolbe et al. 2007). Dowd and Gese (2012) analyzed 470 coyote scats and 24 lynx scats (from 5 individual lynx) in northwestern Wyoming and reported that coyotes scavenged primarily on mule deer or elk (*Cervus elaphus*) carrion in winter; only 3.5% of scats contained remains of snowshoe hares during winter. As expected, lynx preyed mostly on snowshoe hares in winter, with 85% of prey items consisting of snowshoe hares. Thus in both Montana and Wyoming, there was not a significant dietary overlap during winter between these species. In Wyoming, the potential for competition between lynx and coyotes would be most likely to occur during the fall when coyotes appear to increase predation on snowshoe hares (Burghardt-Dowd 2010).

Existing information suggests that some low level of competition for prey could occur naturally between lynx and coyotes. However, this is apt to vary spatially or temporally depending on overall prey availability and composition. Research that could conclusively demonstrate and quantify the effects of competition would be challenging due to numerous confounding factors.

Likely effects of specific winter recreational activities on lynx.

Ski areas and 4-season resorts. More than 50 ski areas exist throughout the range of the lynx in the contiguous United States. Most ski areas are located on north-facing slopes, where ample snow conditions provide for extended ski/snowboard recreational seasons. In the western states, many of these landscapes feature spruce-fir forests. While ski resorts occupy a small proportion of the landscape, spruce-fir forests provide important stable habitat for snowshoe hares and lynx at the southern extent of their range. In winter, alpine and Nordic skiing and snowboarding are the primary uses. Most of these resorts offer year-round recreation, with summer activities typically including hiking and mountain biking.

Plate 4.8. Ski resorts and associated human developments may fragment forest landscapes by removing cover, reducing snowshoe hare abundance, and impeding lynx movement.

Ski resort development may fragment the forested landscape (Plate 4.8). One ski run is often separated from the next only by small inter-trail forest is-lands. Ski runs often are intermixed with other open areas such as open or gladed bowls, rock outcrops, or barren tundra ridges. Ski resorts that are built or expanded in lynx habitat may impact lynx by removing forest cover, reducing the snowshoe hare prey base, and creating or increasing human disturbance in or near linkage areas.

There is limited information on lynx behavior and habitat use in and around ski areas. Lynx have been known to incorporate smaller ski resorts within their home ranges, but may not utilize the large resorts. Preliminary information from an ongoing study in Colorado suggests that some recreation use may be compatible, but lynx may avoid some areas with concentrated recreation use. In some areas, lynx habitat may be limited and concentrated in the ski area development footprint (J. Squires, personal communication 2012).

Snowmobile warming huts and Nordic ski huts. Most backcountry ski hut sites are primitive in nature. Some facilities may have utilities, summer road access, and on-site storage for grooming equipment and fuel. Use by snowmobile clubs and the general public is often focused or concentrated around these sites. Many have developed trail systems that loop around the site or provide access to other remote areas.

These facilities are generally located along designated cross-country ski and snowmobile routes. Users compact the snow along the route to and from the huts and in the immediate vicinity. Off-trail travel has the potential to create larger areas of compacted snow. However, as indicated above, this local snow compaction is short term and not likely to change the competitive interactions between lynx and coyotes.

Developed campgrounds. Typically these are single-season summer facilities that might provide limited winter use, and generally supply such amenities as water and holding tanks for sewage disposal. Access could be further facilitated through the plowing of roads. When located in lynx habitat, the effects might be similar to those described for Nordic ski huts and snowmobile huts.

Minerals and energy exploration and development

Leasable minerals. Activities associated with exploration and development of leasable minerals could affect lynx habitat by changing or eliminating the native vegetation and contributing to habitat fragmentation. Development of a high density of wells, as is typical of coal-bed methane development (e.g., 1 well per 2–4 ha [5–10 ac]), could affect lynx by directly removing habitat. The development of associated roads, powerlines, and pipelines to facilitate exploration and development could also result in a loss of lynx habitat and contribute to fragmentation of habitat. In some areas, for example in the Wyoming Range, extensive oil and gas development is occurring within lynx habitat.

Locatable minerals. Only a fraction of the historical number of mines is operating today; those that continue to operate do so with more stringent environmental protection measures. However, in some parts of the United States, minerals exploration and new development appear to be on the rise. Activities associated with exploration and development of locatable minerals could affect lynx habitat by changing or eliminating the native vegetation, and by contributing to habitat fragmentation. Amount of impact can be variable depending on the size of the associated mining operation or development. Locatable minerals are extracted through both open pit and sub-surface mines with potential habitat alteration ranging from tens to thousands of hectares. In some instances, such as larger mining operations, land exchanges are conducted to consolidate private ownership of the surface above a deposit prior to mine development. Depending on lands exchanged this could retain lynx habitat in public ownership, but could still result in a net loss of habitat. Development of road and railroad access to facilitate exploration and development could also directly impact lynx habitat, contribute to fragmentation, facilitate increased competition as a result of snow-compacted routes, and result in direct mortality. Despite these potential impacts, mining exploration and development is generally anticipated to affect only a small portion of lynx habitat in the contiguous United States.

Salable minerals. In general, salable minerals are found close to the surface. During exploration activities, equipment is moved to the site and a number of test pits are dug or holes drilled to determine the quality of material. If desired minerals are found in suitable quantity, then vegetation is removed and materials are excavated.

Areas developed for salable minerals can vary in size from a single truck load to tens of acres. Impacts to lynx could include the potential alteration or removal of lynx habitat, increased fragmentation, and the potential for human-caused mortality from road development.

Wind energy. Wind energy development and associated transmission lines in lynx habitat is increasing across the nation. Facilities are located on ridge tops or other areas exposed to consistent wind. The construction of wind facilities including access roads may result in loss of lynx habitat and increased fragmentation from permanent forest clearings. Noise and human activity associated with operation of wind facilities would likely continue through the life of the project, which may exceed 20 years.

Utility corridors. Utility corridors contain developments such as overhead or buried powerlines and gas pipelines, and often are located within or adjacent to existing road rights-of-way. Utility corridors potentially could have short- or long-term impacts to lynx habitats, depending on location, type, vegetation clearing standards, and frequency of maintenance. Those that are extensively cleared of vegetation and maintained in a low structure condition, likely equate to a permanent habitat loss. When associated with highways and railroads, utility corridors may further widen the right-of-way. Utility corridors may facilitate human access into previously remote areas.

Illegal shooting

Lynx can be mistakenly shot by legal hunters or illegally killed by poachers. The actual magnitude of shooting mortality is unknown. In Canada, incidents were reported by Saunders (1963*b*), Parker et al. (1983), and Slough and Mowat (1996). In Maine, 5 lynx were reported shot (Vashon et al. 2012). In Minnesota, 1 of 17 radiocollared lynx that are known to have died was shot (Moen 2009); a total of 6 lynx were reported shot over about a 10-year period in that state (U.S. Fish and Wildlife Service 2012). Two lynx were reported poached by lion hunters in Montana, and 1 lynx was reported shot in Washington (U.S. Fish and Wildlife Service 2001). In the first 10 years of the reintroduction project in Colorado, Devineau et al. (2010) reported that 14 of 102 (14%) of lynx mortalities were attributable to illegal shooting, with another 5 that were probably shot.

No conservation measures were developed to address illegal shooting. Misidentification errors can be reduced by disseminating information about where lynx occur and providing education to hunters about the characteristics that can be used to distinguish lynx from bobcats. This is being done by state wildlife agencies.

Forest/backcountry roads and trails

This section addresses transportation and distribution systems on public lands. Forest and backcountry roads are typically low-speed (<56kph [<35 mph]), single- or double-lane gravel or paved roads. Extensive (>600 km) backtracking studies found that lynx did not avoid gravel forest roads (Squires et al. 2010). Trails are typically narrow routes with a native surface; there is no information to suggest that trails have negative impacts on lynx.

Construction of roads results in a small reduction of lynx habitat by removing forest cover. In some instances, vegetation along less-traveled roads provides good snowshoe hare habitat, and lynx may use the roadbed for travel and foraging (Koehler and Brittell 1990). Similar to McKelvey et al. (2000*d*), Squires et al. (2010) concluded that forest roads with low vehicular or snowmobile traffic had little effect on lynx seasonal resource-selection patterns in Montana. In Maine, Fuller et al. (2007) documented lynx traveling on roads (unplowed during winter), but determined that roads and their associated edges were selected against within home ranges. Lynx may have exhibited negative selection for road edges because these areas were associated with the lowest density of conifer saplings and hare abundance compared to all other stand types.

Squires et al. (2008) reported that lynx denned farther from all roads compared to random expectation. Lynx occupy dens in early May when many forest roads are still impassable by wheeled vehicles due to persistent snowdrifts and wet, muddy roads; snowmobiles no longer used the roads because of intermittent and unpredictable availability of sufficient snow (Squires et al. 2008). They concluded that lynx did not avoid the subset of roads that were open to wheeled vehicle travel. Rather, the observed avoidance of roads was more a function of the correlation of roads and landscape pattern; fewer roads were located in denning habitat and higher road density occurred along forest edges and in managed stands, which lynx avoided (Squires et al. 2010).

In Minnesota, Moen et al. (2010*b*) found that lynx selected for roads during long-distance movements. Roads may not have been essential to these movements, but lynx appeared to benefit energetically from the use of these linear features.

There have been no documented mortalities on low-use forest roads in Washington; however, several have occurred in Maine and Minnesota. The private forest roads in Maine have a higher traffic volume and faster speeds than many national forest road systems in lynx habitat. Twelve of 27 lynx mortalities on roads in Maine between 2000 and 2011 occurred on forest roads (Vashon et al. 2012). In Minnesota, between 2000 and 2011, 2 lynx were killed on backcountry railroads, and 2 on unpaved forest roads (U.S. Fish and Wildlife Service 2012). Backcountry roads also provide human access into lynx habitat where incidental trapping or illegal shooting can occur.

Grazing by domestic livestock

Grazing by domestic sheep, goats and cattle is common in the western United States. There is little scientific information available about dietary overlap with, or competition between, livestock and snowshoe hares, or the response of snowshoe hares to livestock grazing. If there were significant forage competition, this could have an indirect impact on lynx by reducing its prey base.

As discussed in Chapter 2, the summer diet of snowshoe hares is dominated by herbaceous food including forbs, grasses, and leaves of shrubs. The winter diet is restricted to woody browse, including smaller-diameter twigs, branches, small stems and evergreen needles of shrubs and trees (Adams 1959, Wolff 1978, Koehler 1990a, Hodges 2000*a*). The habitats used by snowshoe hare that are most likely to be affected by livestock grazing are riparian willow and aspen communities.

High-elevation riparian areas dominated by willows have been shown to provide important summer and fall habitat for lynx in Colorado (Shenk 2008). In Wyoming, Berg and Gese (2012) found hare use during the summer of small patches of forest surrounded by non-forest vegetation containing willow. Overbrowsing by domestic livestock or wild ungulates that altered the structure or composition of the native plant community, particularly by impacting willows, could negatively affect snowshoe hare habitat.

Overall, grazing or browsing by domestic livestock on federal lands is unlikely to reduce the snowshoe hare prey base or have a substantial effect on lynx. Grazing/browsing could have some localized effects on high-elevation willow communities or aspen stands if not managed appropriately.

Chapter 5– CONSERVATION STRATEGY

Approach to development of conservation measures

The following conservation measures are intended to apply to lynx habitat on federal lands. The assessment contained in the previous chapters addressed all aspects of lynx ecology and comprehensively considered potential lynx responses to various anthropogenic influences, in order to provide a full context for federal management actions. The conservation measures in this chapter are focused on those programs and activities under the jurisdiction of the federal agencies.

In all geographic areas, some lynx habitat falls within state and private lands. In the Northeast Geographic Area, lynx habitat in Maine occurs almost entirely on privately-owned industrial forest lands. Guidelines have been developed for use by private landowners who may wish to manage their lands in a manner that benefits lynx. Various examples are available; the Maine guidelines are available at: http://www.fws.gov/mainefieldoffice/PDFs/Canada%20lynx%20habitat%20management%20guidelines%20for%20Maine%209.13.07.pdf.

We used current knowledge about lynx, their primary prey (snowshoe hares) and basic principles for maintaining or restoring native ecological processes and patterns to develop the conservation measures. The information and the standards and guidelines contained in the 2000 edition of the LCAS were reviewed in light of new information on lynx and snowshoe hares, with emphasis on peer-reviewed published information. An important change from the 2000 edition of the LCAS is that separate objectives and conservation measures were developed for core areas and secondary/peripheral areas (as identified in the recovery outline, U.S. Fish and Wildlife Service 2005), rather than applying the same guidance throughout mapped lynx habitat. The intent is to assist managers in prioritizing conservation efforts.

We identified conservation measures that address those anthropogenic influences identified and described in Chapter 4 that are within the authority and jurisdiction of federal agencies. This set of conservation recommendations may not cover all possible actions, in all locations across the broad range of the lynx. The measures may not be applicable in all settings. The unique circumstances of individual projects or settings will be considered during project analysis and design. If a particular project would result in different effects on lynx than would be expected in a more typical setting, then the measures can and should be adjusted as needed to achieve the desired objectives for lynx conservation.

Lynx Analysis Units

Lynx Analysis Units (LAUs) are intended to facilitate analysis and monitoring of the effects of management actions on lynx habitat. LAU boundaries are not to be adjusted for individual projects, but must remain constant to be effective for their intended purposes of planning and monitoring.

LAUs are a tool to guide management that will support a reproductive population of lynx in core areas. It is not necessary to delineate LAUs in secondary/peripheral areas.

LAUs do not depict actual lynx home ranges, but should approximate the size of a female's home range and contain year-round habitat components. Females have smaller home ranges than males and are more restricted in their movements during the period of kitten dependency. Maintaining good quality and distribution of denning and foraging resources within a LAU will help to assure survival and reproduction by adult females, which is critical to sustain the overall lynx population.

Certain conservation measures are applied across a LAU to encourage well-distributed lynx habitat throughout the landscape. In some cases, project impacts will need to be assessed across 2 or more LAUs to fully address direct, indirect, and cumulative impacts of particular actions. Naturally-occurring events such as lightning-ignited stand-replacing wildfires may create change across many adjoining LAUs.

Lynx habitat mapping and the delineation of LAUs should be completed using criteria specific to each geographic area. Primary vegetation will include those forest types necessary to support lynx survival and reproduction. Because lynx are highly mobile, it is recognized that other vegetation types when intermixed with the primary vegetation may also be used by lynx. However, these are only considered to contribute to lynx habitat where they are associated with the primary vegetation in that geographic area.

As stated above, the size of the LAU reflects female lynx home range size in the geographic unit. A sufficient amount of lynx habitat must be present within the LAU to support a female lynx. For example, in the western United States, it appears that at least 26 km^2 (10 mi^2) of primary vegetation (e.g., spruce/fir) must be present.

The arrangement of habitat within the LAU should take into consideration the daily movement distances of resident females. When delineating LAUs, small patches of primary vegetation located beyond daily movement distances could be discarded or incorporated into a neighboring LAU. Since the LAU represents a hypothetical female home range, and is the basis for analysis, it can be larger and contain more lynx habitat than an actual home range.

Lynx habitat was identified using criteria described in the 2000 LCAS. In some areas, better information on identifying lynx habitat is currently available. Where new vegetation databases will improve identification of lynx habitat, we encourage updating maps. Where information in new maps suggests LAUs need adjusting, coordinate changes with FWS.

Core areas and secondary/peripheral areas

The recovery outline (U.S. Fish and Wildlife Service 2005) stratified lynx habitat into 3 categories: core, secondary, and peripheral areas (Fig. 3.1). The Southern Rockies was identified as a "provisional" core area because of the uncertain status of the reintroduced population. Here we have treated core and provisional core areas the same, and use only the term core area.

Core areas are places where long-term persistence of lynx and recent evidence of reproduction have been documented. Based on historical lynx occurrence information (McKelvey et al. 2000*b*), recent research (e.g., Hoving 2001, Squires et al. 2003, von Kienast 2003, Maletzke 2004, Fuller et al. 2007, Burdett 2008, Koehler et al. 2008, Vashon et al. 2008*a*, Devineau et al. 2010, and Squires et al. 2010), results from the National Lynx Survey (K. McKelvey, unpublished data), and snow tracking surveys (Plate 5.1), evidence of persistence and reproduction of lynx in the core areas has been confirmed. Delineation of core areas may be refined in the future if supported by new information.

The contribution of lynx occurring outside of core areas to population dynamics and persistence within core areas is unclear. It has been suggested that secondary and peripheral areas might contribute to lynx persistence by sup-

Plate 5.1. Lynx tracks in the snow are readily detected when lynx are present in an area. Putative bobcat and lynx tracks on the left photo show how lynx can more easily travel across soft snow. Back-tracking can be used to locate hair or scat samples for DNA analysis.

porting successful dispersal or exploratory movements. Lynx habitat in secondary/peripheral areas appears to be inherently more patchy and less productive than in core areas.

Historical information suggests that lynx were much less likely to occupy these areas over time, and many records appear to have a time lag following cyclic irruptions of lynx populations in Canada. We do not anticipate that secondary/peripheral areas will support home ranges and reproduction over time. We speculate that the amount and quality of habitat required to support an independent adult or subadult disperser is less than is necessary to support reproduction and sustain a local population. During an incursion of lynx from the north, it is possible that some individuals could survive in secondary/peripheral areas for a time and later colonize vacant habitat in a core area. In this way, these areas could be important in maintaining or enhancing genetic diversity.

Conservation measures for core areas and for secondary/peripheral areas are presented separately below.

Relationship of the LCAS to land management plans

Management direction to conserve lynx and lynx habitat has been adopted into land management plans by federal agencies across most of the range of lynx in the contiguous United States. This direction was developed in accordance with the National Forest Management Act (NFMA) of 1976 and the Federal Land Policy and Management Act (FLPMA) of 1976, which require public review and comment as part of the decision-making process.

In accordance with the NFMA, projects must be consistent with the management direction contained in the forest plan. The NFMA regulations (36 CFR 219.22) require the responsible official to consider the best available science in plans.

The conservation measures in the LCAS provide updated information that will complement and be useful in implementing land management plans, and may serve to inform future updates or refinements of existing plans.

Relationship to designated critical habitat

In the Remanded Rule, the FWS described lynx habitat as boreal forest where there are cold winters with deep snow (Federal Register Vol. 68 pp. 40076–40101). Lynx habitat has been further characterized in Chapter 2 as boreal forest with gentle rolling topography, dense horizontal cover, deep snow, and moderate to high (>0.5 hares/ha [0.2 hares/ac]) snowshoe hare densities.

In 2009, the FWS designated critical habitat for lynx (Federal Register Vol. 74 No. 36 pp. 8616–8701). In the 2009 rule, the primary constituent element of lynx habitat was defined as boreal forest landscapes supporting a mosaic of differing successional forest stages and containing:

- Presence of snowshoe hares and their preferred habitat conditions, which include dense understories of young trees, shrubs or overhanging boughs that protrude above the snow, and mature multi-story stands with conifer boughs touching the snow surface;
- Winter snow conditions that are generally deep and fluffy for extended periods of time;
- Sites for denning that have abundant coarse woody debris, such as downed trees and root wads; and
- Matrix habitat (e.g., hardwood forest, dry forest, non-forest) that occurs between patches of boreal forest in close juxtaposition (at the scale of a lynx home range) such that lynx are likely to travel through such habitat while accessing patches of boreal forest within a home range.

LAUs contain a mix of lynx habitat as well as the matrix as defined in the 2009 rule designating lynx critical habitat. Since the matrix provides limited snowshoe hare resources or other life requisites for lynx, no conservation measures were developed that specifically address management of matrix, except as related to maintaining connectivity.

Core areas: conservation measures

Refer to the recovery outline (Fig. 3.1; U.S. Fish and Wildlife Service 2005) for the locations of identified core areas. We note that core areas may be refined in the future to reflect more recent information on lynx distribution and habitat use. As core area delineations and lynx habitat maps continue to be refined, we expect that the areas to which conservation measures are applied will change accordingly.

Conservation measure applicable to core areas:

- Delineate LAUs within the core areas. Using the best available mapping tools, assess the abundance and juxtaposition of lynx habitat, and ensure that adequate amounts of lynx habitat are present within each LAU. If not, redelineate the LAU in coordination with FWS to encompass additional lynx habitat, eliminate the LAU, or combine LAUs as appropriate.

First tier of anthropogenic influences in core areas

Vegetation management

Winter is the most constraining season for lynx and snowshoe hares. Dense horizontal cover of conifers above the snow level is critical to support snowshoe hares in winter. Vegetation management should be designed to provide for winter snowshoe hare habitat as forest stands develop successionally over time.

Fires, insect epidemics, and some types of timber harvest cause the boreal forest to revert to early stand initiation structural stage, which is a temporary condition that does not provide dense cover and food for snowshoe hares, nor does it provide foraging habitat for lynx. Over time, (20–30 years or so depending upon the site) trees will grow tall enough and dense enough to once again provide food and cover for snowshoe hares in winter.

In some areas in the southern part of their range, lynx populations appear to be limited by the availability of snowshoe hares, as suggested by large home range sizes, high kitten mortality, and greater reliance on alternate prey, further highlighting the importance of the following conservation measures. Ruggiero et al. (2000*b*) recommended maintaining some minimum density of snowshoe hares across a broad landscape, e.g., >0.5 hare/ha (>0.2 hares/ac), to support a self-sustaining population of lynx.

Conservation measures for vegetation management (cont. on next page):

- Provide a mosaic that includes dense early-successional coniferous and mixed-coniferous-deciduous stands, along with a component of mature multi-story coniferous stands to produce the desired snowshoe hare density within each LAU (Plate 5.2).

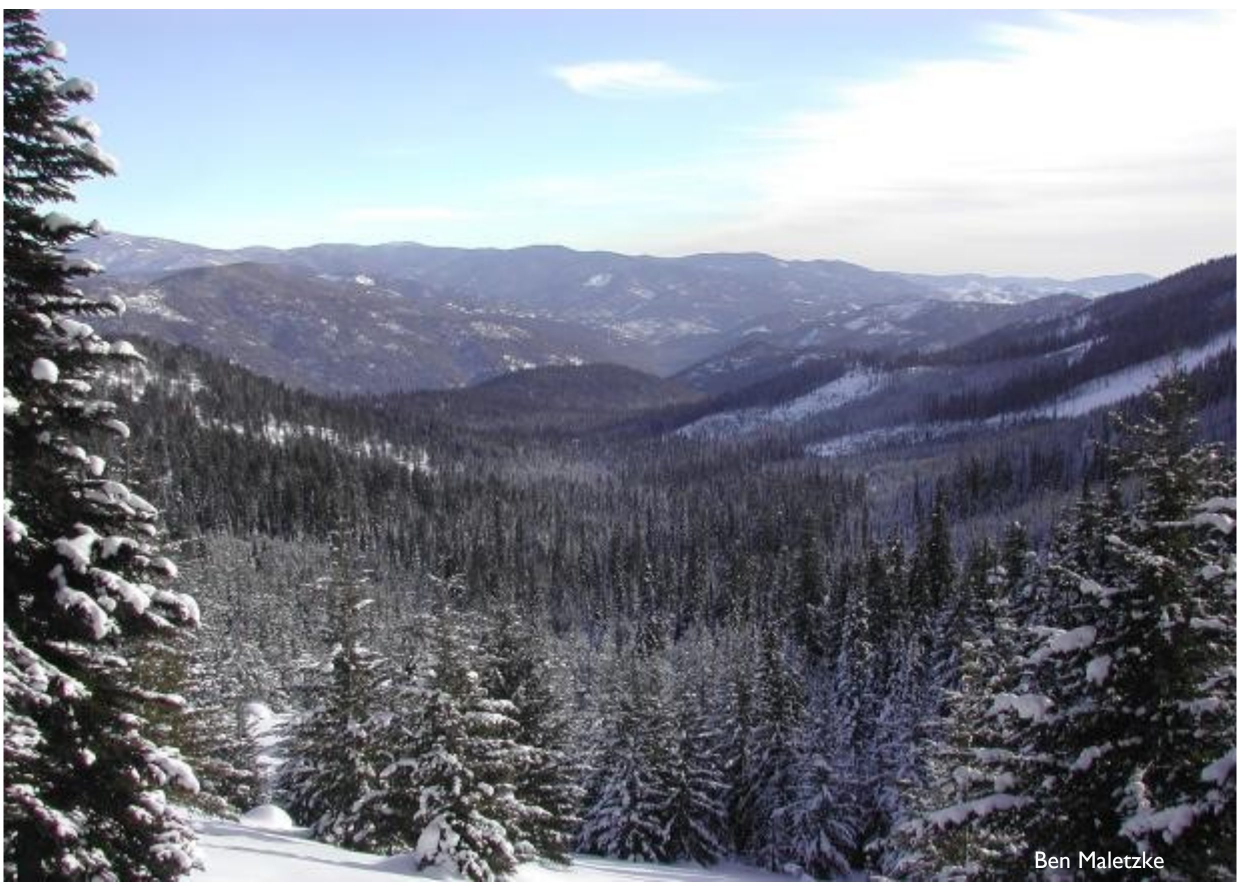

Plate 5.2. Lynx habitat in a landscape providing a variety of forest structures, including mature forests and mid- and early-successional forests, interspersed with openings.

Conservation measures for vegetation management (cont.):

- Use fire and mechanical vegetation treatments as tools to maintain a mosaic of lynx habitat, in varying successional stages, distributed across the LAU in a landscape pattern that is consistent with historical disturbance processes.
- Design vegetation management to develop and retain dense horizontal cover. Focus treatments in areas that have the potential to improve snowshoe hare habitat by developing dense horizontal cover in areas where it is presently lacking. In areas of young, dense conifers resulting from fire, timber harvest or other disturbance, do not reduce stem density through thinning until the stand no longer provides low, live limbs within the reach of hares during winter (e.g., self-pruning processes in the stem exclusion structural stage have eliminated snowshoe hare cover and forage availability during winter conditions with average snowpack). If studies are completed that demonstrate that thinning can be used to extend the duration of time that snowshoe hare habitat is available (e.g., by maintaining low limbs), then earlier thinning could be considered.
- Retain mature multi-story conifer stands that have the capability to provide dense horizontal cover (Plate 5.3). If portions of these stands currently lack dense horizontal cover, focus vegetation management practices (such as group selection harvest) in those areas to increase understory density and improve snowshoe hare habitat.
- To maintain the amount and distribution of lynx foraging habitat over time, manage so that no more than 30% of the lynx habitat in an LAU is in an early stand initiation structural stage or has been silviculturally treated to remove horizontal cover (i.e., does not provide winter snowshoe hare habitat). Emphasize sustaining snowshoe hare habitat in an LAU. If more than 30% of the lynx habitat in an LAU is in early stand initiation structural stage or has been silviculturally treated to remove horizontal cover (e.g., clearcuts, seed tree harvest, precommercial thinning, or understory removal), no further increase as a result of vegetation management projects should occur on federal lands.
- Recognizing that natural disturbances and forest management of private lands also will occur, management-induced change of lynx habitat on federal lands that creates the early stand initiation structural stage or silviculturally treated to remove horizontal cover should not exceed 15% of lynx habitat on federal lands within a LAU over a 10-year period.
- Conduct a landscape evaluation to identify needs or opportunities for adaptation to climate change. Consider potential changes in forest vegetation that could occur as a result of climate change (e.g., Gärtner et al. 2008). Identify reference conditions relative to the landscape's ecological setting and the range of future climate scenarios. For example, the historical range of variability could be derived from landscape reconstructions (e.g., Hessburg et al. 1999, Blackwell et al. 2003, Gray and Daniels 2006).
- Design harvest units to mimic the pattern and scale of natural disturbances and retain natural connectivity across the landscape.
- In aspen stands, maintain native plant species diversity including conifers.
- Recruit a high density of stems, generally greater than 4,600/ha (1,862/ac), of conifers, hardwoods, and shrubs, including species that are preferred by hares.
- Provide for continuing availability of lynx foraging habitat in proximity to denning habitat.
- When designing fuels reduction projects, where possible retain patches of untreated areas of dense horizontal cover within treated areas.

Plate 5.3. In the western United States, mature multi-story stands provide dense horizontal cover producing stable snowshoe hare densities, especially during winter.

Wildland fire management

Vegetation disturbances have historically and currently been important in maintaining habitat for snowshoe hares and lynx. For several years (10 to 40 depending on site productivity) following stand-replacing disturbances, snowshoe hare and lynx habitat is lost.

Historically, natural processes played a dominant role in maintaining a mosaic of forest successional stages in lynx habitat. Boreal forests historically experienced large (thousands of acres), infrequent (100 to 300 years), stand-replacing fires. Current forest conditions generally fall within the historical range of variation. In areas with a mixed-severity fire regime, moderate- to low-intensity fires also occurred in the intervals between stand-replacing events. Refer to the geographic area descriptions for more detailed information regarding historical fire regimes, the resulting landscape patterns, and the interaction of fire with other agents of natural disturbance.

In drier forests adjacent to boreal forest, fire suppression may have resulted in unnaturally dense fuels. Restoration of these communities may be desirable to reduce the risk of spreading uncharacteristically frequent or severe fires into lynx habitat.

Conservation measures for wildland fire management:

- Maintain fire as an ecological process in lynx habitat, where small populations are not at risk of extirpation due to habitat loss. Evaluate whether fire suppression, forest type conversions, and other management practices have altered fire regimes and the functioning of ecosystems.
- Consider the use of mechanical pre-treatment and management ignitions if needed to restore fire as an ecological process or to maintain specific lynx and/or prey species habitat components.
- As federal fire management plans are developed or revised, integrate lynx habitat management objectives into the plans. Prepare plans for areas that are large enough to encompass large historical fire events. Collaborate across management boundaries to develop approaches that are complementary and that simulate natural disturbance patterns where possible.
- Design burn prescriptions to promote response by shrub and tree species that are favored by snowshoe hare.

Fragmentation of habitat

Within core areas, the amount and arrangement of lynx habitat must be sufficient so that lynx can easily access all parts of their home range and travel between home ranges to find mates. Human-caused alterations of natural landscape patterns that would result in an uncharacteristic reduction of lynx habitat and impaired ability of lynx to effectively utilize those patches of habitat is what is meant by habitat fragmentation. Habitat fragmentation increases the resistance to movement between habitat patches, either within home ranges or during dispersal (Squires et al. 2013).

A mosaic of forest vegetation is desirable. Human developments in lynx habitat, such as highways, utility corridors, residences, and recreation developments, may impede lynx movements but are not likely to be barriers to movement.

It is critical to maintain connectivity of habitat with Canada for those core areas that are adjacent to the international border.

Conservation measures to minimize habitat fragmentation:

- Emphasize land uses that promote or retain conservation of contiguous blocks of lynx habitat.
- Maintain a mosaic of vegetation and features such as riparian areas, forest stringers, unburned inclusions or forested ridges to provide habitat connectivity within and between LAUs.
- Identify linkage areas where needed to maintain connectivity of lynx populations and habitat. Factors such as topographic and vegetation features and local knowledge of lynx movement patterns should be considered. Retain lynx habitat and linkage areas in public ownership and acquire land to secure linkage areas where needed and possible. On private lands in proximity to federal lands, agencies should strive to work with landowners to develop conservation easements, explore potential for land exchanges or acquisitions, or identify other opportunities to maintain or facilitate lynx movement.
- Minimize large-scale developments that would substantially increase habitat fragmentation, reduce snowshoe hare populations, or introduce new sources of mortality.
- Give special attention to the design of highway improvements such as new road alignments, adding traffic lanes, installing Jersey or Texas barriers, or other modifications that increase highway capacity or speed. Upgrading unpaved roads should be avoided in lynx habitat, if the result would be increased traffic speeds and volumes or a substantial increase in associated human activity or development. Crossing structures or other techniques could be used to minimize or offset impacts (Plate 5.4).

First tier of anthropogenic influences in core areas

Plate 5.4. Highway development and upgrades to increase vehicle speeds can be planned to allow for movement of wildlife, including lynx.

Second tier of anthropogenic influences in core areas

Recreation management

There is little empirical information regarding the responses by lynx to recreational activities. Ongoing studies in Colorado are investigating the effects of snowmobiling, backcountry skiing, downhill skiing, and other winter recreation on lynx. Preliminary information suggests that some recreation use may be compatible, but lynx may avoid some areas that have concentrated recreation use (J. Squires personal communication 2012).

Three studies investigated whether compacted snow trails may increase competition for food resources (Bunnell et al. 2006, Kolbe et al. 2007, Burghardt-Dowd 2010). Studies of coyote use of roads having a compacted vs. uncompacted snow surface showed no difference in Montana; however, in Wyoming, coyotes used roads with compacted snow more than random expectation. Whether roads that have a compacted snow surface might facilitate use by coyotes appears to vary depending on snow conditions. The degree of dietary overlap between these 2 species also varies across geographic areas, but appears to be limited within lynx habitat.

Conservation measures for recreation management:

- Manage winter recreation activities within LAUs such that lynx habitat connectivity is maintained or improved where needed.
- To minimize habitat loss, concentrate recreational activities within existing developed and high winter-use areas, rather than developing new sites and facilities in lynx habitat. On federal lands in areas with low levels of recreation currently, consider limiting the future development or expansion of developed winter recreation sites or concentrated winter use areas.
- Direct recreational activities and facilities away from identified linkage areas.
- Consider not expanding designated over-the-snow routes or designated play areas in lynx habitat, unless the designation serves to consolidate use.

Second tier of anthropogenic influences in core areas

Minerals and energy exploration and development

Manage human activities related to mineral and energy exploration and development, including transmission corridors, to minimize the loss and fragmentation of lynx habitat.

Conservation measures for minerals and energy development:

- To minimize loss of lynx habitat resulting from minerals and energy development, locate facilities and roads outside of lynx habitat and linkage areas where possible. Minimize the footprint of developments within lynx habitat.
- Use existing roads and utility corridors to the fullest extent possible for all activities involving exploration and development.
- If upgrading existing access roads, design the roads to the minimum standard needed.
- To the extent possible, restrict public access on roads that were built or used for mineral and energy exploration and development in lynx habitat.
- Encourage remote monitoring to reduce need for and frequency of site visits in lynx habitat.
- Develop reclamation plans for abandoned mine lands to fully rehabilitate and restore as nearly as possible to original contours and native vegetation as habitat for lynx.

Forest/backcountry roads and trails

Forest and backcountry roads and trails are typically low-speed (<72 kph [<45 mph]) single or 2-lane gravel or paved roads that occur on public lands. As described in Chapter 4, lynx in Maine selected against roads and their associated edges within lynx home ranges. In Minnesota, lynx selected for roads during long-distance movements. In Montana, forest roads with low vehicular or snowmobile traffic had little effect on lynx resource selection patterns. McKelvey et al. (2000*d*) reanalyzed information from the lynx studies in Okanogan County (Koehler and Brittell 1990, Koehler 1990*a*) and concluded that road density within lynx home ranges did not affect habitat selection.

There have been no documented mortalities of lynx due to vehicular collisions on forest roads in Washington or Montana, but several have been reported in Maine and Minnesota. Forest roads in Maine and Minnesota often have higher traffic volume and speed limits than are typical in the western United States. Site-specific conditions will need to be assessed to determine the potential for impacts.

Conservation measure for forest/backcountry roads and trails:

- Avoid forest/backcountry road reconstruction or upgrades that substantially increase traffic volume and speed. If traffic volume and speed are of concern, incorporate appropriate mitigation such as traffic calming measures in the project design.

Livestock grazing

High-elevation riparian areas dominated by willows provide important summer and fall habitat for lynx (Shenk 2006, 2008). There is potential for overlap with areas that are also utilized by domestic livestock. Manage livestock grazing in a manner that makes competitive interactions unlikely.

Conservation measure for livestock grazing:

- Manage livestock grazing within riparian areas and willow carrs in lynx habitat to maintain conditions that support snowshoe hares by maintaining a preponderance of mid or late-seral stages.

Secondary/peripheral areas: conservation measures

It is not necessary to delineate LAUs in secondary/peripheral areas. The conservation measures are intended to provide a greater degree of flexibility for management activities in secondary/peripheral areas as compared with the core areas. The focus of management is on providing a mosaic of forest structure to support snowshoe hare prey resources for individual lynx that infrequently may move through or reside temporarily in the area. Landscape connectivity should be maintained to allow for lynx movement and dispersal.

Vegetation management

Conservation measures for vegetation management:

- Provide a mosaic of forest structure that includes dense early-successional coniferous and mixed-coniferous-deciduous stands, along with a component of mature multi-story conifer stands. Flexibility in the amounts and arrangement of various successional stages is acceptable, provided that a mosaic can be sustained. Vegetation treatments should be designed with consideration of historical landscape patterns and disturbance processes.
- Design timber harvest, planting, and thinning to include some representation of young densely-stocked regenerating stands in the mosaic for snowshoe hare production areas.

Chapter 6–INVENTORY, MONITORING, AND RESEARCH

Ruggiero et al. (2000*a*) identified many areas of uncertainty and information gaps relevant to the conservation of lynx. Since 2000, a substantial number of studies on lynx and snowshoe hares and their habitats have been conducted in Maine, Minnesota, Montana, Washington, Wyoming, and Colorado. There are numerous peer-reviewed published papers reporting results from those studies. Nevertheless there are still gaps in our information on lynx, snowshoe hares, and their habitats. The following section identifies the topics to be of the most importance for future inventory, monitoring, and research efforts.

Inventory

The National Lynx Survey was conducted in 1999–2003. The survey protocol sampled lynx habitat using lynx rub pads to collect hair for DNA to be analyzed to confirm species identification (McKelvey et al. 1999, Kendall and McKelvey 2008). Squires et al. (2004) developed a snow tracking protocol for follow-up or additional surveying of areas of potential lynx occupancy. McKelvey et al. (2006) described methods to backtrack putative tracks to collect samples (hair, feces) for DNA analysis and positive species identification. Squires et al. (2012) further refined snow tracking survey methods to determine the presence or absence of lynx in an area of interest. Long et al. (2007) used scat detection dogs to search for rare or low density forest carnivore species and found dogs can be an effective method to locate scats of target species, while ignoring non-target species.

Through the National Lynx Survey, positive identification of lynx occurrence was made in Idaho, Maine, Minnesota, Colorado, Wyoming, Montana, and Washington. Some follow-up snow tracking surveys were also completed to better understand lynx distribution. Following completion of the National Lynx Survey, many additional surveys have been conducted in identified lynx habitat in various locations across the contiguous United States.

Beginning in 2000, lynx habitat was identified using criteria identified in the LCAS. Some of these early efforts misclassified areas, either mapping areas that do not provide habitat for lynx as lynx habitat, or failing to identify areas that actually provide habitat for lynx. Significant efforts have been made throughout the range of lynx in the contiguous United States to field verify and update lynx habitat maps. Validation of lynx habitat within core areas will continue to be a priority to assure that conservation measures are applied effectively.

Surveys for detection of lynx in secondary/peripheral areas are a low priority. Compared to core areas, secondary/peripheral areas are defined as having fewer and more sporadic records of lynx occurrence and the quality and quantity of habitat to support populations of snowshoe hare and lynx is questionable (U.S. Fish and Wildlife Service 2005), making surveys a low priority. The exception would be in secondary/peripheral areas where lynx are reported to be present, such in New Hampshire and Vermont; verifying occurrence and determining the status of lynx in such locations would be a high priority.

Monitoring

The objectives of a long-term monitoring program ideally would include:

1. Detecting changes in lynx population distribution, adult female survival, mortality factors, and population productivity;
2. Snowshoe hare abundance and population trend, including changes in hare abundance in response to different types of vegetation management and landscape patterns in boreal forests; and

3. The effects of climate change on lynx and their habitat, addressing important aspects of lynx habitat such as the depth, density, and duration (annual) of snow cover, and changes in snowshoe hare population density and distribution.

National monitoring design and sampling protocols that are adaptable to regional differences should be established that will enable a cost-effective program to be implemented and coordinated with multiple agencies and partners.

Research needs

Considerable knowledge about lynx has been gained since the original LCAS was completed in 2000. Nevertheless, many unanswered questions remain regarding conservation of lynx and the effects of management actions, thresholds of human activity (including recreation and access) on lynx use of habitat, and effects of climate change on lynx and lynx habitat in the contiguous United States. We have listed what are considered the highest priority topics for research. These are not listed in priority order.

1. The effects of climate change on lynx, lynx habitat, snowshoe hares, and boreal forests in the contiguous United States are unclear. How will the depth, density, and duration (annual) of snow cover vary? Will changes in snow depth and density change influence predator, prey, and competitor relationships for lynx? If climate change results in changes in snow duration, how will pelage changes for snowshoe hare affect their survival? How will climate change affect forest composition, especially the expected decline of spruce and fir in the Northeast? Will fires become more frequent, larger? How will insect outbreaks be altered by climate change and how will this affect fire size and frequency?
2. Current techniques to document presence and distribution of lynx (snow tracking, hair snaring, scat detection dogs) have been developed and tested, but are not proven to estimate population size or trend, or may not work consistently throughout the lynx range.
3. What are the effects of vegetation management activities on lynx population distribution and density? What are the desired amounts and arrangement of habitat within an adult female home range to support reproductive success and recruitment of kittens into the population? How does fragmentation of habitat affect female lynx productivity and home range size? Were key assumptions in the original LCAS (e.g., no more than 30% of a female home range can be in an unsuitable condition) reasonable?
4. What if anything limits the dispersal of lynx? To what extent are lynx moving between Canada and the United States on a yearly basis? What management actions are needed to maintain connectivity across the international border?
5. Expand research to investigate the effects of silvicultural practices on snowshoe hare. Can current partial harvesting practices (such as in Maine) be modified to promote the high stem densities of sapling conifers required to support high snowshoe hare densities?
6. Evaluate the extent to which winter recreational activities and developments, such as skiing and snowmobiling, influence lynx behavior and habitat use. Are there thresholds of human activity in lynx habitat that result in displacement of lynx, loss of prey resources, or increased competition from other carnivores?
7. What role, if any, do secondary and peripheral areas as identified in the recovery outline play in the long-term persistence of lynx and in maintaining occupancy of core areas?

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Glossary

Boreal forest – Homogeneous arboreal stands, dominated by conifers during later stages of succession, and by arboreal members of the birch and willow families in early succession (Agee 2000). The arctic tundra defines the northern border of boreal forest, but the southern border is less clear. Here we use the term boreal forest to include the transition into subalpine forests in the western part of the continent, mixed-coniferous-deciduous forests in the mid-continent, and mixed-coniferous and deciduous temperate forests of the Acadian forest region in the northeastern part of the continent.

Canopy cover (canopy closure) – The percentage of ground surface that is shaded by the live foliage of plants as seen from above. This measurement or estimate is used to describe how open or dense a stand of trees is.

Carr – Deciduous woodland or shrubland occurring on permanently wet, organic soil.

Clearcut – A regeneration tree harvest method that cuts and removes all merchantable trees in a single step, except for certain trees or snags retained for wildlife use.

Coarse woody debris – Any piece(s) of dead woody material, e.g., dead boles, limbs, and large root masses on the ground or in streams.

Competition – An interaction that occurs when 2 or more individuals make demands of the same resources that are in short supply. Exploitation competition occurs when 1 species uses common resources in a manner that reduces the fitness of the other species, for example by causing starvation or reduced reproductive success. Interference competition occurs when 1 species, almost invariably the species with larger body size, acts aggressively toward another, denying it access to a resource.

Composition (of forest vegetation) – The proportion of each tree species in a stand, expressed as a percentage of the total number, basal area, or volume of all tree species in the stand.

Conservation measures – Recommendations to alleviate or reduce the adverse effects of anthropogenic influences on lynx or lynx habitat.

Core area – Areas with the strongest long-term evidence of the persistence of lynx populations over time within the contiguous United States, as identified in the Canada Lynx Recovery Outline.

Cover type – The present vegetation composition of an area, described by the dominant plant species.

Crepuscular – Active during the twilight hours of early morning or early evening.

Critical habitat – Specific areas legally designated by the Secretary of the Interior within the area occupied by Canada lynx at the time they were listed under the Endangered Species Act that contain the physical or biological features that are essential to the conservation of the species and may require special management considerations or protection.

Cumulative effects – Effects on lynx or lynx habitat that result from the incremental impact of the proposed action when added to other past, present, and/or reasonably foreseeable future actions. Cumulative effects can be significant even when direct and indirect effects are minor.

Denning habitat – The environment lynx use when giving birth and rearing kittens until they are mobile. The most common component is large amounts of coarse woody debris to provide escape and thermal cover for kittens. Denning habitat may occur within mature and old growth forests, young regenerating forests, or areas where down trees are jack-strawed. Denning habitat must be located within daily travel distance of an adult female lynx (typical distance is 5-10 km [3-6 mi]) to snowshoe hare habitat.

Depauperate – Lacking in numbers, biomass or diversity of species.

Designated over-the-snow routes and designated snowmobile play areas – Areas managed under permit or agreement or by the agency, where use is encouraged, either by on-the-ground marking or by publication in brochures, recreation opportunity guides or maps (other than travel maps), or in electronic media produced or approved by the agency. The routes identified in outfitter and guide permits are designated by definition; groomed routes also are designated by definition. This definition does not apply to permitted ski areas.

Developed recreation – Recreational activities requiring facilities that result in concentrated use. For example, skiing requires lifts, parking lots, buildings, and roads; campgrounds require roads, picnic tables, and toilet facilities.

Dispersal – Movement of an individual away from its parent or an existing population to establish a home range.

Disturbance – Events that alter the structure, composition, or function of terrestrial or aquatic habitats. Natural disturbances include drought, floods, wind, fires, wildlife grazing, and insects and pathogens. Human-caused disturbances include actions such as timber harvest, livestock grazing, road construction, and the introduction of exotic species.

Ecological processes – The flow and cycling of energy, materials, and organisms through an ecosystem.

Ecological restoration – Management practices to reestablish sustainable and resilient vegetation communities.

Endangered Species Act – A law passed in 1973, and subsequently amended, for the purposes of conserving the ecosystems upon which endangered species and threatened species depend, and providing a program for the conservation of such species.

Facultative predator – Capable of exploiting more than one type of prey by changing its behavior.

Fire suppression – Any act taken to slow, stop, or extinguish a fire.

Fire regime – A characterization of the combination of fire frequency and fire severity under which plant communities evolved and were maintained.

Foraging habitat (for lynx) – Habitat that supports the primary prey (snowshoe hare) of lynx and has the vegetation structure suitable for lynx to capture prey. These conditions may occur in early successional stands following some type of disturbance, or in older forests with a substantial understory of shrubs and young conifer trees. Coarse woody debris, especially in early successional stages (created by harvest regeneration units and large fires), provides important cover for snowshoe hares and other prey.

Forb – A broad-leaved, herbaceous plant other than grasses, sedges, and rushes.

Forest and backcountry roads – Roads that are generally not paved with vehicle speeds typically less than 35 miles per hour. The surface can be gravel or natural materials.

Forest cover type – A description of the composition and structure of an area, focusing primarily on the dominant overstory tree species.

Four-season resort – Recreational facility on national forest land, permitted to operate during more than one season of the year. Resorts with either a winter or summer emphasis may be authorized to allow facilities to remain open to allow additional recreation use during other seasons.

Fragmentation (of habitat) – Human-caused alterations of natural landscape patterns that result in a reduction of the total area of habitat, increased isolation of habitat patches, and impaired ability of wildlife to effectively move between those patches of habitat. Depending on the cause, fragmentation of habitat may be temporary or permanent.

Fuels treatment – A type of vegetation management that reduces the threat of ignition, fire intensity, or rate of spread, and is used to restore fire-adapted ecosystems.

Geographic Area (for lynx) – A broad area that contains ecological conditions that may support lynx and snowshoe hares. The geographic areas identified for lynx are the Northeast, Great Lakes, Northern Rocky Mountains, Southern Rocky Mountains, and Cascade Mountains, which have uniquely different forest ecosystems, management histories, and current lynx population status.

Habitat – The complete suite of biotic and abiotic components of the environment where an animal lives.

Habitat connectivity (for lynx) – Vegetation cover in sufficient quantity and arrangement to facilitate lynx movements. Connectivity may be affected by human developments.

Highway – All roads that are part of the National Highway System (23 CFR 470.107(b)).

Historical range of variability – The condition of vegetation at some reference point in the past.

Home range – The area used by an individual, either during the entire calendar year or seasonally, in its normal activities of foraging, mating, and rearing of young. Female home ranges typically do not overlap, but female offspring may establish a home range in part of her mother's.

Horizontal cover – The visual obscurity provided by vegetation that extends to the ground or snow surface, primarily provided by tree stems and tree boughs, but may also be provided by shrubs, herbaceous vegetation, and landscape topography.

Incidental trapping or snaring – Capture of non-target species. Lynx are susceptible to being captured in traps or snares intended for other species such as wolverine, coyote, fox, fisher, American marten, bobcat, and wolf.

Infrastructure – Facilities, utilities, and transportation systems required to meet public and administrative needs.

Irruption – A drastic and rapid increase in the density of a population.

Landscape – A specific geographic area with characteristic traits, patterns, and structure, including its biological composition, its physical environment, and its anthropogenic or social patterns.

Linkage areas – Areas that facilitate movements of lynx beyond their home range, such as dispersal, breeding season movements or exploratory movements. Linkage areas may incorporate topographic features that tend to funnel animal movements and may encompass areas of non-lynx habitat.

Long bed – A site where a lynx lays in the snow for an extended period, characterized by having an iced surface. May also be referred to as a long-duration bed.

Lynx Analysis Unit (LAU) – Landscape units that approximate the size of a female lynx annual home range (appropriate to the Geographic Area) and encompass all seasonal habitats. These may also contain areas of non-lynx habitat, such as open meadows, especially in mountainous regions. An LAU is a unit for which the effects of a project would be analyzed; its boundaries should remain constant.

Lynx habitat – Boreal forest with gentle rolling topography, dense horizontal cover, deep snow, and moderate to high (>0.5 hares/ha [0.2 hares/ac]) snowshoe hare densities. In the northeastern United States, lynx habitat includes coniferous and mixed-coniferous/deciduous forests dominated by white, black, and red spruce, balsam fir, pine, northern white cedar, hemlock, sugar maple, aspen, and paper birch. In Minnesota, lynx habitat includes coniferous and mixed-coniferous/deciduous vegetation types dominated by pine, balsam fir, black and white spruce, northern white cedar, tamarack, aspen, and paper birch. In the western United States, forest cover types dominated by Engelmann spruce, subalpine fir and lodgepole pine provide habitat for lynx.

Lynx habitat in suitable condition – Areas within the boreal forest providing lynx habitat in all seasons. Forest stands may be in various ages or structural stages (i.e., young saplings in stand initiation structural stage, pole-size stands in stem exclusion structural stage, mature multi-story forest) provided that, following a stand-replacing disturbance or treatment that reduced the dense horizontal cover required by snowshoe hares, trees have grown tall enough and dense enough to protrude above the snow and provide food and cover for snowshoe hares and lynx in winter.

Lynx habitat currently in unsuitable condition – Areas within the boreal forest that are in the early stand initiation stage (typically less 30 years old) or have been silviculturally treated to remove cover, in which the vegetation has not developed sufficiently to support snowshoe hare populations during all seasons. Stand-replacing fire, insect epidemics or wind events can create stand initiation structural stage. Vegetation management projects that may create unsuitable conditions for a period of time include clearcuts, seed tree harvest, precommercial thinning, or understory removal.

Matrix – Matrix (e.g., hardwood forest, dry forest, non-forest) occurs between patches of boreal forest in close juxtaposition (at the scale of a lynx home range) such that lynx are likely to travel through matrix while accessing patches of boreal forest within a home range.

Mature multi-story forest – A structural stage characterized by understory reinitiation, resulting in several age classes and vegetation layers. Fallen trees may be present, creating gaps in the overstory canopy. In lynx habitat, these stands typically have high horizontal cover from young understory trees and lower limbs of mature trees that reach the ground or snow level.

Mid-seral stage – A successional stage in a plant community that is the midpoint in the progression from bare ground to climax. In riparian areas, willows or other shrubs have become established and have grown to protrude above the snow.

Monitoring – Systematic sampling, testing or collection of information on a regular or ongoing basis.

Mosaic – A dynamic, heterogeneous pattern of vegetation and other habitat elements within a given area, such as a LAU.

Patch – An area of uniform vegetation that differs from what surrounds it in structure and composition.

Peripheral areas – Areas where the majority of historical lynx records are sporadic and generally correspond to periods following cyclic lynx population highs in Canada. There is no evidence of long-term presence or reproduction that might indicate colonization or sustained use of these areas by lynx.

Plant succession – A relatively predictable process by which a series of different plant communities, and their associated animals and microbes, successively occupy and replace each other over time in a particular ecosystem or landscape location following a disturbance event.

Potential vegetation type – The community of plants that would become established if all successional sequences were completed, without interference by humans, under existing environmental conditions at the site including soils, topography, and climate. Potential vegetation types are typically named by using one or more species from the dominant (overstory) vegetation layer and one or more indicator plants from the subordinate (undergrowth) layer (e.g., subalpine fir/grouse huckleberry or ABLA/VASC).

Precommercial thinning – A management technique that does not yield trees of commercial value, usually designed to reduce stem density to promote the growth of the more desirable trees.

Recovery outline – An interim strategy to guide recovery efforts and inform the critical habitat designation process until a draft recovery plan has been completed. Recovery outlines are intended primarily for internal FWS use.

Red squirrel habitat – Coniferous forests of seed and cone-producing age that usually contain snags and downed woody debris, generally mature or older forests.

Regeneration harvest – The cutting of trees and creating an entire new age class; an even-age harvest. The major methods are clearcutting, seed tree, shelterwood, and group selection cuts.

Riparian area – Area with distinctive soil and vegetation between a stream or other body of water and the adjacent upland; includes wetlands and those portions of floodplains and valley bottoms that support riparian vegetation.

Salvage harvest – Removal of dead trees or trees being damaged or dying due to injurious agents other than competition, in order to recover value that would otherwise be lost. Collecting firewood for personal use is not considered salvage harvest.

Secondary areas – Areas with historical records of lynx presence but with no record of reproduction; or areas with historical records and no recent surveys to document the presence of lynx or reproduction.

Self-sustaining population – A population that remains viable without human intervention.

Sinuosity – A statistical measurement of movement paths that are curved or crooked.

Ski area – A site and attendant facilities expressly developed to accommodate alpine or Nordic skiing. Operation of Nordic and alpine ski areas for up to 40 years and encompassing such acreage as the Forest Officer determines sufficient and appropriate is authorized by the National Ski Area Permit Act of 1986.

Skid trail – A linear feature in a forest environment resulting from removing cut trees/logs from the site of cutting to a gathering site.

Snow compaction – Human activities, such as travel on designated snowmobile routes, that compress the snow and reduce its penetrability.

Snow cover – The area of land that is covered by snow at any given time.

Snow pack – The thickness of snow that accumulates on the ground.

Snow penetrability – A measure of the resistance of the snow column to compression.

Snowshoe hare habitat – Boreal and upper montane forests in North America with cold, moderately deep winter snowpack and dense horizontal cover in the understory. During the winter, hares are restricted to areas where young trees or shrubs grow densely (thousands of woody stems per ha) and are tall enough to protrude above the snow during winter, or where numerous overhanging boughs of mature conifer trees touch the snow surface provide cover and browse. Winter snowshoe hare habitat develops primarily in the later phase (15 to 40 years post-disturbance) of stand initiation structural stage and in multi-story mature and old stands.

Specialist – A species that can only thrive in a narrow range of environmental conditions or has a limited diet. The lynx is a specialist predator of snowshoe hare.

Stand – A group of trees or other vegetation occupying a specific area and sufficiently uniform in composition, age, spatial arrangement, and conditions as to be distinguishable from the vegetation on adjoining lands.

Stand initiation structural stage – Following a stand-replacing disturbance or regeneration timber harvest, a new single-story layer of shrubs, tree seedlings, and saplings establish and develop, reoccupying the site. Trees that need full sun are likely to dominate these even-aged stands. [In the years immediately following the disturbance, tree seedlings are too small to provide food and cover for snowshoe hares and lynx, particularly during the winter (see also the definition for *lynx habitat currently in unsuitable condition*). As time progresses, the trees grow tall and dense enough to provide food and cover for snowshoe hares and lynx during all seasons (see also the definition for *lynx habitat in suitable condition*).]

Stand-replacing fire – A fire that kills aboveground parts of the dominant vegetation. Approximately 80 percent or more of the aboveground dominant vegetation is either consumed or dies as a result of fire.

Stem exclusion structural stage – A phase of forest development following the typically rapid establishment of an initial cohort of trees, during which new establishment is precluded and competition occurs within the existing cohort for light, nutrients and space.

Structure (of forest vegetation) – The horizontal and vertical distribution of plants in a stand, including height, diameter, crown layers, and stems of trees, shrubs, herbaceous understory, snags, and coarse woody debris.

Structural stage – A recognizable condition in forest stand development describing the physical size and arrangement (both vertical and horizontal) of trees occupying the site.

Subnivean habitat – Habitat that is under the snow surface.

Topographic relief – The difference in elevation in a landscape from the lowest point to the highest point. Lynx habitat typically has low topographic relief, described by Squires et al. (2013) as low surface roughness and by Maletzke et al. (2008) as <30° slopes.

Understory re–initiation structural stage – Establishment of a new age class of trees after overstory trees begin to die, are removed, or no longer fully occupy their growing space. The stand of trees begins to stratify into vertical layers, with some small shade-tolerant trees in the understory.

Wildland urban interface (WUI) – Defined in the Healthy Forests Restoration Act. Basically, the wildland urban interface is the area adjacent to an at-risk community that is identified in the community wildfire protection plan. If there is no community wildfire protection plan in place, the WUI is the area 0.5 mile from the boundary of an at-risk community; or within 1.5 miles of the boundary of an at-risk community if the terrain is steep, or there is a nearby road or ridgetop that could be incorporated into a fuel break, or the land is in condition class 3, or the area contains an emergency exit route needed for safe evacuations. (Condensed from HFRA. For full text see HFRA § 101.)