Potential Impacts of Climate Change on Habitat and Conservation Priority Areas for *Lynx canadensis* (Canada Lynx)

**Patrick Gonzalez**, The Nature Conservancy, Global Climate Change Initiative  
**Ronald P. Neilson**, USDA Forest Service, Pacific Northwest Research Station  
**Kevin S. McKelvey**, USDA Forest Service, Rocky Mountain Research Station  
**James M. Lenihan**, USDA Forest Service, Pacific Northwest Research Station  
**Raymond J. Drapek**, USDA Forest Service, Pacific Northwest Research Station

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and:  
NatureServe, Arlington, VA

From:  
The Nature Conservancy, 4245 North Fairfax Drive, Arlington, VA  22203-1606  USA
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Impacts of climate change on potential habitat and conservation priority areas for *Lynx canadensis* (Canada Lynx)

Abstract

The dependence of *Lynx canadensis* (Canada Lynx) on winter snow and boreal forest renders it vulnerable to climate change. Our analyses of 496 lynx observations and snow cover in the period 1966-2005 indicate that the species requires at least four months of continuous winter snow coverage. Further analyses of potential snow cover under a range of Intergovernmental Panel on Climate Change (IPCC) future climate scenarios and modeling of vegetation using the MC1 dynamic global vegetation model indicates that potential habitat could decrease by up to two-thirds in the lower 48 United States and by up to one-fifth across the continental U.S. and Canada by 2100 A.D. A projected 3.9°C ± 0.7°C warming of annual average temperatures and changes in precipitation in the period 1990-2100 may decrease snow cover suitable for lynx by 10% to 20% across the continental U.S. and Canada, at an estimated confidence of 95%. Areas of nearly continuous snow cover and boreal forest may shift towards relatively cooler polar areas, shifting lynx habitat northward as much as 200 km. Canada and Alaska may lose lynx habitat in southern areas, while some new habitat may develop in polar areas that are now tundra. Potential conservation priority areas for lynx include areas in the Bridger-Teton National Forest (Wyoming) and Superior National Forest (Minnesota), which lie in potential refugia. Vulnerable areas that could lose potential lynx habitat in the long-term include the Bridger-Teton (Wyoming), Idaho Panhandle (Idaho), Kootenai (Montana), Okanogan (Washington), Wenatchee (Washington), and White Mountains (New Hampshire) National Forests, high-altitude areas in Colorado, and Yellowstone and Grand Teton National Parks (Wyoming). The conservation of these areas for lynx will require intensive natural resource management intervention.
Introduction

Habitat for the feline *Lynx canadensis* (Canada Lynx) has declined to the extent that the U.S. Fish and Wildlife Service has listed the species as threatened under the Endangered Species Act of 1973. Lynx requires a specific type of habitat that includes boreal conifer forest or subalpine forest dominated by *Abies spp.* (fir) and *Picea spp.* (spruce), winter snow, and sufficient populations of its main prey, *Lepus americanus* (snowshoe hare) (Murray and Boutin 1991, McKelvey et al. 2000, Stenseth et al. 2004, Hoving et al. 2005, Carroll 2007).

Greenhouse gas emissions from human activities have caused climate change (IPCC 2007a). Global surface temperatures increased 0.7°C in the 20th Century and may increase 1.4-5.8°C by the end of the 21st Century, if greenhouse gas emissions continue at current rates. Climate change is reducing snow pack in western North American mountains (Knowles et al. 2006) and shifting the distribution of boreal forest northward (IPCC 2007b, Sturm et al. 2001) and up mountain slopes (Danby and Hik 2007, IPCC 2007b). Consequently, climate change is altering the geographic location and extent of potential lynx habitat, threatening the long-term viability of lynx in the contiguous United States. This research quantifies the potential changes in lynx habitat under climate change.

Methods

We downloaded the Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent Version 3 from the National Snow and Ice Data Center <http://www.nsidc.org/data/nsidc-0046.html>. The data set includes monthly data of the presence or absence of snow from October 1966 to June 2005 at a spatial resolution of 25 km in the Lambert Azimuthal Equal-Area Projection, derived from field observations and AVHRR and other visible-band satellite data.

We acquired observed climate data, including monthly maximum, mean, and minimum temperature and total precipitation, for the continental U.S. from the Oregon State University Prism Group <http://prism.oregonstate.edu> and for Canada from the Canadian Forest Service (Price and Scott 2006). These data sets included observed climate for the period 1961-1990, downscaled from University of East Anglia global climate data (Mitchell and Jones 2005) using the PRISM method (Daly et al. 1994). We scaled all data to a spatial resolution of 5 geographic minutes.

We downloaded climate change projections of maximum, mean, and minimum temperature, total precipitation, and vapor pressure from the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Center (Livermore, CA). These projections are output of IPCC Fourth Assessment Report (AR4) (IPCC 2007a) runs of general circulation models (GCMs) on IPCC Special Report on Emissions Scenarios (SRES) (IPCC 2000) scenarios.

An ensemble of three GCMs represents low, medium, and high temperature sensitivity, respectively, relative to the IPCC AR4 ensemble of 21 GCMs: CSIRO Mk3 (Gordon et al. 2002), HadCM3 (Johns et al. 2003), and MIROC 3.2
medres (Hasumi and Emori 2004). As in IPCC AR4, SRES B1, A1B, and A2 scenarios represent, respectively, low, medium, and high greenhouse gas emissions. Together, the three GCMs and three emissions scenarios define nine GCM-emission scenario combinations that bracket the range of temperature projections of the IPCC AR4 combinations. As the central scenario, results from the IPCC SRES A1B indicate representative future conditions.

In order to downscale the 2.5º latitude by 3.75º longitude GCM output to the 5 geographic minute spatial resolution of the observed climate data, we calculated the difference (temperature) or ratio (precipitation, vapor pressure) of future projected values and observed 1961-1990 monthly means, then used bi-linear interpolation to calculate climate anomalies at the finer scale. For all of the spatial analyses, we projected climate and vegetation data to the Lambert Azimuthal Equal Area projection at a spatial resolution of 8 km.

Comparison of the 496 highest precision lynx occurrences in the United States from 1966 to 1998 (McKelvey et al. 2000) with snow cover at those locations produced probability distributions of snow versus the probability of finding lynx for each month from November to April. The distributions for 5%, 50%, 90%, and 95% probability of finding lynx defined snow cover thresholds for each month. We identified those areas that met the four thresholds for January and derived the observed temperature distribution of the pixels in those four areas. These distributions indicated the maximum and minimum temperatures for each of the four thresholds.

Using those temperature thresholds for the 5%, 50%, 90%, and 95% lynx probability areas, we identified the geographic areas meeting the thresholds for the 1961-1990 climatology period and for the 2071-2100 periods under the three climate change scenarios. We identified the areas of loss, no change, and gain in snow area between the two time periods.

We ran the MC1 dynamic global vegetation model (Daly et al. 2000) to model potential vegetation. MC1 reads five climate variables (mean, maximum, and minimum temperature; precipitation; vapor pressure) at a monthly time step and five soil variables (soil depth; bulk density; clay, sand, and rock fractions) to run interacting modules of biogeography, biogeochemistry, and wildfire. MC1 models 15 potential vegetation types, wildfire occurrence and extent, and biomass. We combined the vegetation types into 10 biomes. The biome that MC1 most often modeled for each pixel for each of two periods (1961-1990, 2071-2100) represents the vegetation for each period.

To address uncertainty of projections, we identified locations where all nine GCM-emissions scenario combinations agreed on the same type of biome change. The fraction of GCM-emission scenario combinations that project the same type of biome change for a pixel is an indicator of confidence in the projection of biome conversion. Areas where all nine GCM-emissions scenario combinations agreed on the same type of biome change are most
vulnerable. Conversely, areas where all nine combinations agreed that the biome would not change comprise potential refugia. We identified areas of loss, no change, and gain in potential boreal forest area between the two time periods. For the climate change scenarios, we identified areas where all nine GCM-emissions scenario combinations agreed on the location of boreal forest.

We identified potential lynx habitat as areas with suitable snow conditions at 95% lynx probability and areas of boreal forest under all nine GCM-emission scenario combinations. These areas only indicate potential, not realized, habitat. Realized habitat is likely more restricted in extent due to factors other than snow and vegetation cover. We identified the areas of loss, no change, and gain in potential lynx habitat between the 1961-1990 and 2071-2100 time periods.

Results

Lynx requires nearly continuous snow cover for four months (December through March) and at least a 75% probability of snow in January for a 5% probability of finding lynx (graph, page 11) and a 100% probability of snow in January for a 95% probability of finding lynx. The January temperature thresholds for suitable snow are -8.5°C (95% lynx probability), -3.8°C (90%), 1.4°C (50%), and 3.1°C (5%).

Suitable snow reaches south along the Rocky Mountains into Colorado under current conditions (map, page 12), but retreats north under the future scenarios (map, page 13). Loss of suitable snow area in the lower 48 states (map, page 14) ranges from 46% to 84% (table, page 10).

Modeled vegetation under current conditions (map, page 15) broadly corresponds to observed patterns, with boreal forest stretching across Canada and reaching into the Rocky Mountain states and northern New England. MC1 inaccurately models as potential boreal forest a region from North Dakota to southern Alberta and Manitoba that is actually grassland. The area comprises less than one-tenth of potential lynx habitat.

The A1B scenario projects a warming of North America land temperatures of 3.9 ± 0.7° C century⁻¹ and a precipitation increase of 8% ± 16% per century between the climatology periods of 1961-1990 and 2071-2100.

Unanimity of future projections indicates that vegetation may shift latitudinally (north) and altitudinally (upslope) (map, page 16). The most vulnerable areas cover over a tenth of the area of the continental U.S. and Canada (map, page 17). Consequently, boreal forest could shift northward (map, page 18), with half of the area in the lower 48 converting to drier temperate conifer and mixed forest. Extensive areas of existing boreal forest in the western U.S. and New England may be lost.
Potential lynx habitat could decrease from one-half to two-thirds in the lower 48 and by up to one-fifth across the continental U.S. and Canada (map, page 19). Canada and Alaska may lose lynx habitat in southern areas, while some new habitat may develop in polar areas that are now tundra. Consistent with previous analyses of potential impacts of climate change on lynx in the northern Appalachians (Carroll 2007), potential lynx habitat may dwindle to small areas in the Canadian maritime provinces.

Potential conservation priority areas for lynx include certain areas of the Teton-Bridger National Forest (Wyoming) and Superior National Forest (Minnesota), which lie in potential refugia. Vulnerable areas that could lose potential lynx habitat in the long-term include parts of the Bridger-Teton (Wyoming), Idaho Panhandle (Idaho), Kootenai (Montana), Okanogan (Washington), Wenatchee (Washington), and White Mountains (New Hampshire) National Forests, high-altitude areas in Colorado, and Yellowstone and Grand Teton National Parks (Wyoming).

**Continuing Research**

We will continue to refine the definition of lynx requirements for snow. We also plan to fix some line scan anomalies in the MC1 vegetation output. We also plan to quantitatively validate the snow, vegetation, and lynx results against field data. In order to further examine the vulnerability of ecosystems to changes in climate already experienced in the 20th Century, we are conducting statistical analyses of the 100-year climate record.

**Conclusion**

Spatial analyses of climate, snow, and vegetation indicate that climate change may decrease potential lynx habitat across wide parts of the continental United States and Canada. The conservation of vulnerable areas for lynx will require intensive natural resource management intervention. On the other hand, potential refugia in Wyoming, Minnesota, and across western Canada offer priority areas for lynx conservation.

More broadly, the 8 km scale of this analysis identifies areas of vulnerability at a landscape scale appropriate for regional planning. The data offer the USDA Forest Service and The Nature Conservancy tools for setting natural resource management and conservation priorities in a changing climate.

**References**


Hasumi, H. and S. Emori (eds.) 2004. K-1 coupled model (MIROC) description. Center for Climate System Research, University of Tokyo, Tokyo, Japan.


Potential Changes in Snow, Boreal Forest Extent, and Lynx Habitat (%) Between 1990 and 2100 Under Three IPCC Scenarios of Climate Change

P. Gonzalez, R.P. Neilson, K.S. McKelvey, J.M. Lenihan, and R.J. Drapek

Gain as a fraction of area of no change and area of gain
Loss as a fraction of area of no change and area of loss

<table>
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<th></th>
<th>US (Lower 48)</th>
<th>US (Alaska)</th>
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| **Boreal Forest Changes** |               |             |        |       |
| *All Scenarios Combined* |               |             |        |       |
| gain                     | 0             | 20          | 9      | 11    |
| no change                | 50            | 94          | 93     | 90    |
| loss                     | 50            | 6           | 7      | 10    |

| **Lynx Habitat Changes** |               |             |        |       |
| *Scenario B1 (warm)*    |               |             |        |       |
| gain                    | 0             | 22          | 9      | 11    |
| no change               | 53            | 86          | 91     | 88    |
| loss                    | 47            | 14          | 9      | 12    |
| *Scenario A1B (central projection)* |           |             |        |       |
| gain                    | 0             | 24          | 10     | 12    |
| no change               | 42            | 75          | 88     | 83    |
| loss                    | 58            | 25          | 12     | 17    |
| *Scenario A2 (hot)*     |               |             |        |       |
| gain                    | 0             | 23          | 10     | 12    |
| no change               | 31            | 77          | 85     | 81    |
| loss                    | 69            | 23          | 15     | 19    |
SNOW REQUIREMENTS FOR LYNX

Data: snow (NOAA), lynx (McKelvey et al. 1999); Analysis: P. Gonzalez (The Nature Conservancy)

- 5% probability of lynx occurrence
- Mean (± s.d.) of 496 occurrences
- 50%, 90%, and 95% probability levels
Snow Suitable for Lynx
1961-1990 [Draft]

Climate Data: National Snow and Ice Data Center, Natural Resources Canada, University of East Anglia, University of Oregon
Lynx Data: K.S. McKelvey (USDA Forest Service)
Analyses: P. Gonzalez (The Nature Conservancy), R.P. Neilson (USDA FS), J.M. Lenihan (USDA FS), R.J. Drapek (USDA FS)
Snow Suitable for Lynx Under Climate Change
2071-2100 [Draft]
IPCC SRES A1B Scenario, CSIRO Mk3, HadCM3, Miroc 3.2 GCMs

Climate Data: Intergovernmental Panel on Climate Change, National Snow and Ice Data Center, Natural Resources Canada, University of East Anglia, University of Oregon
Lynx Data: K.S. McKelvey (USDA Forest Service)
Analyses: P. Gonzalez (The Nature Conservancy), R.P. Neilson (USDA FS), J.M. Lenihan (USDA FS), R.J. Drapek (USDA FS)
Potential Loss of Snow for Lynx Under Climate Change 1990-2100 [Draft]
IPCC SRES A1B Scenario, CSIRO Mk3, HadCM3, Miroc 3.2 GCMs

Climate Data: Intergovernmental Panel on Climate Change, National Snow and Ice Data Center, Natural Resources Canada,
University of East Anglia, University of Oregon
Lynx Data: K.S. McKelvey (USDA Forest Service)
Analyses: P. Gonzalez (The Nature Conservancy), R.P. Neilson (USDA FS), J.M. Lenihan (USDA FS), R.J. Drapek (USDA FS)
Biomes
- Ice and Barren Land
- Tundra and Alpine
- Boreal Conifer Forest
- Temperate Conifer Forest
- Temperate Broadleaf Forest
- Temperate Mixed Forest
- Temperate Shrubland
- Temperate Grassland
- Desert
- Tropical Broadleaf Forest

Potential Vegetation 1961-1990 [Draft]
MC1 Dynamic Global Vegetation Model

Climate Data: Natural Resources Canada, University of East Anglia, University of Oregon
Analyses: P. Gonzalez (The Nature Conservancy), R.P. Neilson (USDA FS), J.M. Lenihan (USDA FS), R.J. Drapek (USDA FS)
Potential Vegetation Under Climate Change 2071-2100 [Draft]

IPCC SRES Scenarios B1, A1B, A2; CSIRO Mk3, HadCM3, MIROC 3.2.4, HADley Dynamic Global Vegetation Model

Climate Data: Intergovernmental Panel on Climate Change, Natural Resources Canada, University of East Anglia, University of Oregon
Analyses: P. Gonzalez (The Nature Conservancy), R.P. Neilson (USDA FS), J.M. Lenihan (USDA FS), R.J. Drapek (USDA FS)
Potential Vegetation Shifts Under Climate Change 1990-2100 [Draft]

IPCC SRES Scenarios B1, A1B, A2; CSIRO Mk3, HadCM3, MIROC4.2 GCMs; MC Dynamic Global Vegetation Model

Climate Data: Intergovernmental Panel on Climate Change, Natural Resources Canada, University of East Anglia, University of Oregon Analyses: P. Gonzalez (The Nature Conservancy), R.P. Neilson (USDA FS), J.M. Lenihan (USDA FS), R.J. Drapek (USDA FS)
**Potential Shift of Boreal Forest Under Climate Change 1990-2100 [Draft]**

IPCC SRES Scenarios B1, A1B, A2; CSIRO Mk3, HadCM3, Miroc 3.2 GCMs, MC1 Dynamic Global Vegetation Model

Climate Data: Intergovernmental Panel on Climate Change, Natural Resources Canada, University of East Anglia, University of Oregon
Analyses: P. Gonzalez (The Nature Conservancy), R.P. Neilson (USDA FS), J.M. Lenihan (USDA FS), R.J. Drapek (USDA FS)
Potential Shift of Lynx Habitat Under Climate Change
1990-2100 [Draft]
IPCC SRES A1B Scenario, CSIRO Mk3, HadCM3, Miroc 3.2 GCMs, MC1 Dynamic Global Vegetation Model

Climate Data: Intergovernmental Panel on Climate Change, National Snow and Ice Data Center, Natural Resources Canada, University of East Anglia, University of Oregon
Lynx Data: K.S. McKelvey (USDA Forest Service)
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