

MOUNTAIN BIRDWATCH 2003



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FINAL REPORT TO THE UNITED STATES FISH AND WILDLIFE SERVICE
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ABSTRACT

Mountain Birdwatch is a long-term monitoring program for songbirds that breed in high-elevation forests of the Northeast. Skilled volunteers conduct annual surveys along 1-km routes located on mountains in New York, Vermont, New Hampshire, and Maine. Primary emphasis is placed on Bicknell's Thrush, a montane fir specialist that breeds only in the northeastern U.S. and adjacent portions of Canada. Other focal species include Blackpoll Warbler, Swainson's Thrush, White-throated Sparrow, and Winter Wren. In 2003, Mountain Birdwatchers gathered observations from 139 locations, with point count surveys completed on 117 routes. As in previous years, Blackpoll Warblers and White-throated Sparrows were the most abundant and widespread of the focal species. Swainson's Thrush and Winter Wren occupied a second tier of abundance. Though still uncommon, Bicknell's Thrush maintained stable numbers and overall distribution in 2003. The combined count of focal species dropped for the second year in a row, falling below three individuals per point for the first time since monitoring began in 2001. In addition to monitoring population levels, we used two different modeling approaches to evaluate the potential effects of climate change on Bicknell's Thrush habitat. We present and discuss our findings in an addendum to this report.

BACKGROUND AND RATIONALE

Bicknell's Thrush (*Catharus bicknelli*), once considered a subspecies of Gray-cheeked Thrush (*C. minimus*), gained full species status in 1995. Since then, it has been recognized as one of the most at-risk passerines in eastern North America. Partners in Flight ranks Bicknell's Thrush as the top conservation priority among Neotropical migrants in the Northeast (Pashley et al. 2000), while the International Union for the Conservation of Nature classifies the songbird as "vulnerable" on its list of threatened species (BirdLife International 2000).

A number of factors contribute to the vulnerability of Bicknell's Thrush, including its limited breeding range. In the United States, Bicknell's Thrush breeds in montane fir forests of New York and northern New England (Atwood et al. 1996) and is often associated with recently disturbed areas characterized by vigorous regrowth (Wallace 1939, Rimmer et al. 2001). In southeastern Canada, it inhabits montane fir (Ouellet 1993), maritime spruce-fir (Erskine 1992), and regenerating mixed forest (Nixon et al. 2001). The species is similarly restricted in its wintering distribution, occurring primarily in wet, broadleaf forests of the Dominican Republic (Rimmer et al. 2001). These forests have been reduced to less than 10% of their historic extent in the last 30 years (Stattersfield et al. 1998).

Loss of the Northeast's montane fir habitat may also threaten Bicknell's Thrush. Expansion of recreation areas, cell tower construction, and wind power development have received the most regulatory attention, as each can result in highly visible forest loss. Effects of airborne pollutants on Bicknell's Thrush are unclear, but potential threats include forest decline from acid deposition (Johnson et al. 1992) and heavy metal toxicity (Gawel et al. 1996), mercury poisoning by uptake in the food chain, and egg-laying irregularities associated with calcium limitation, a possible consequence of acidified soils (Graveland et al. 1994). A study in the eastern United States suggests that acid deposition may have contributed to recent Wood Thrush declines by reducing the abundance and size of prey. The authors found that negative effects of acid rain on the predicted probability of breeding were greatest in high-elevation zones with low pH soils (Hames et al. 2002). Climate change represents yet another threat to the species. A warming climate is expected to cause incremental, but widespread changes in the composition and structure of mountain forests. Forest ecologists predict that balsam fir (*Abies balsamea*) will be

substantially diminished, if not lost from the Northeast if atmospheric concentrations of CO₂ double, as expected within the next century (Iverson and Prasad 2002).

Volunteers for the Vermont Institute of Natural Science's Forest Bird Monitoring Program surveyed 12 mountains from 1993 to 1999 in order to monitor changes in the status of Bicknell's Thrush and other high-elevation songbirds. In 2000, VINS piloted Mountain Birdwatch in Vermont on about fifty additional routes, offering observers the option to concentrate on five species: Bicknell's Thrush, Swainson's Thrush (*Catharus ustulatus*), Blackpoll Warbler (*Dendroica striata*), White-throated Sparrow (*Zonotrichia albicollis*), and Winter Wren (*Troglodytes troglodytes*). The following year, we expanded the survey region to include over one hundred routes in New York, New Hampshire, and Maine. Since 2000, we have assessed Mountain Birdwatch's power to detect population trends (Lambert et al. 2001); examined the influence of landscape structure on high-elevation bird communities (Lambert et al. 2002); measured habitat characteristics on 45 survey routes (Lambert 2003); and constructed a valid GIS model of Bicknell's Thrush habitat (Lambert et al. 2004). We have also identified key management units and conservation opportunities for Bicknell's Thrush (Lambert 2003).

During the 2003 breeding season, we monitored 117 routes and gathered observations of Bicknell's Thrush from 22 additional mountains. Over the winter, we used two different modeling approaches to project the effects of climate change on Bicknell's Thrush habitat. We present survey results in the body of this report and include our climate change analysis as an addendum.

METHODS

Volunteer engagement

We announced the opportunity to volunteer for Mountain Birdwatch on our web site (www.vinsweb.org/cbd/mtn_birdwatch.html) and in VINS publications. Cooperating conservation organizations publicized the project through electronic and print media. The Adirondack Mountain Club and the Wildlife Conservation Society sponsored a volunteer training session in Lake Placid that was attended by approximately 40 people. The Appalachian Mountain Club hosted a workshop for eight of its hut naturalists. In all, about 175 people participated in the survey in 2003, including companions of the primary route monitors. Mountain Birdwatchers received maps, survey instructions, an identification guide to high-elevation songbirds, and a training tape with an auditory identification quiz. A perfect score on the quiz was a prerequisite for participation. Repeat surveyors were encouraged to review the written and recorded material in order to maintain a high level of proficiency. The Mountain Birdwatch listserv (<http://groups.yahoo.com/group/MountainBirdwatch/>) and the Mountain Birdwatch newsletter ("Feathers and Fir"), help inform, coordinate, and engage volunteers.

Site selection, route placement and coverage

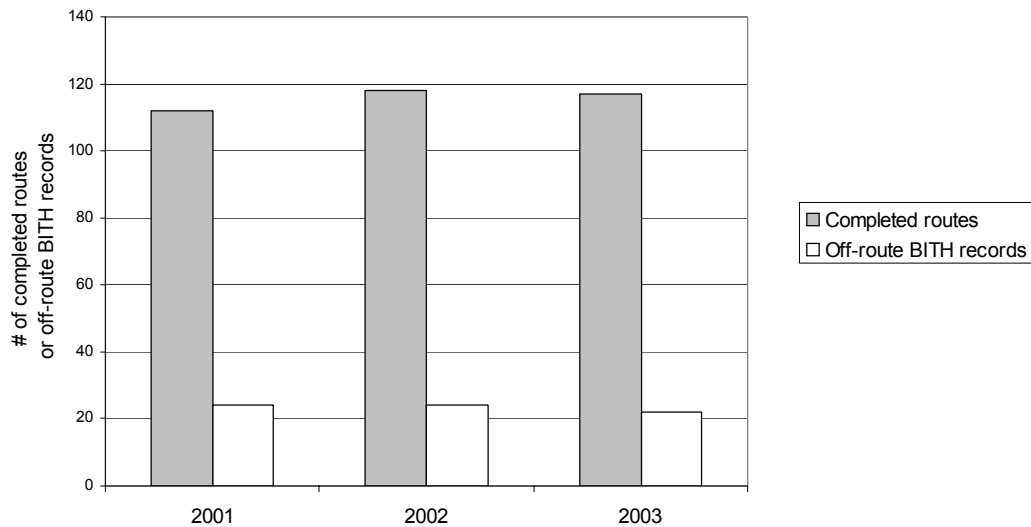
Site selection was based on a geographic information systems (GIS) model of potential Bicknell's Thrush habitat that incorporates elevation, latitude, and forest type (Lambert et al. 2004). Developed with recent Bicknell's location data, the model depicts conifer-dominated forests above an elevation threshold that drops 84.5 m for every one-degree increase in latitude (-84.5 m/1° latitude). The threshold's slope corresponds closely with the latitude-elevation relationship for treeline in the Appalachian Mountain chain, which is -83 m/1° latitude (Cogbill and White 1991). Six routes have been established on peaks lying below the elevation threshold. Over thirty routes cross the threshold, due to the limited length of trails and/or extent of modeled habitat at a given mountain. We made an attempt to randomize site selection by randomly

assigning priority ranks to discrete units of high-elevation habitat. However, the choice of sites was constrained by the availability of volunteers and the location of existing trails.

When placing routes, we favored distinct starting points (e.g. trail junction), extensive conifer stands, and upper elevations. Volunteers establishing a route for the first time placed five points at 325-step (200- to 250-m) intervals along a mapped course. Monitors submitted a detailed description of each station in order to facilitate its location in future years.

In 2003, Mountain Birdwatchers conducted 117 surveys in New York (40), Vermont (42), New Hampshire (19), and Maine (16). Forty-nine routes (41.8%) were surveyed for all species, while 68 routes (58.2%) were monitored for the five focal species only. We gathered Bicknell's Thrush observations from 22 additional mountains. Overall, survey effort was similar to previous years (fig. 1).

Figure 1. Mountain Birdwatch survey effort 2001-2003.



Survey Methods

Surveys were conducted under acceptable weather conditions between 4:00 a.m. and 8:00 a.m. on dates ranging from 1 to 21 June. Observers listened quietly for ten minutes at each of five stations.¹ They recorded the number of each focal species seen or heard during three time periods: 0-3 minutes, 3-5 minutes, and 5-10 minutes. If Bicknell's Thrush was not detected during or between point counts, surveyors returned to each point and broadcast a one-minute recording of the bird's vocalizations (formerly a three-minute recording), followed by a two-minute listening period. We used audioplaybacks to elicit responses from present, but silent birds. Audioplaybacks were discontinued upon detection of one or more individuals. If no Bicknell's Thrushes responded to the broadcasts, the status of the species was classified as unknown. Monitors who completed their surveys without encountering Bicknell's Thrush were asked to conduct follow-up, audioplayback surveys at dusk or dawn before 15 July (after

¹ In 2003, we increased the 5-species point count length from five to ten minutes in order to gather more information and to achieve methodological consistency with the all-species protocols and with Canada's High-Elevation Landbird Program.

Atwood et al. 1996). In some cases, VINS staff substituted for volunteers who were unable to complete follow-up surveys. If no observations of Bicknell's Thrush were made during the second visit, the species was presumed to be absent from that site.

Data analysis: avian distribution and abundance

To include data from as many routes as possible, we subsampled records of the five focal species from the first five minutes of each ten-minute count. Where two point count series were conducted, we used results from the first survey only. We measured frequency of occurrence and relative abundance for each of the focal species. To calculate frequency of occurrence, we divided the number of routes on which a species was detected during point counts (first five minutes only) by the total number of routes surveyed. For Bicknell's Thrush, we also calculated the proportion of survey routes on which the species was detected by any means (10-minute point count, chance, playback, or follow-up).

For between-year comparisons, we calculated the average number of individuals per point on a route by route basis. This correction was necessary because close to 30% of the routes surveyed in 2001 contained fewer than five stations (mean = 2.87 stations). These routes were extended below the original elevation threshold in 2002 to meet the 5-point standard. For each focal species, we averaged per-point values across routes to produce an overall index of relative abundance for 2001 through 2003. Last year, we compared 2001 and 2002 data for all routes surveyed as well as for the 72 routes surveyed in both years. The two approaches yielded nearly identical results for both relative abundance and occurrence frequency (Lambert 2003). This year we present results from all routes surveyed, only. The data are best suited for quantifying changes in species occurrence and abundance over time. We advise caution in comparing frequency of occurrence and relative abundance measures among species, due to interspecific differences in detectability.

We used ArcView GIS (Environmental Systems Research Institute 1999) to produce a Bicknell's Thrush distribution map and a relative abundance map for each of the focal species (Appendix 3).

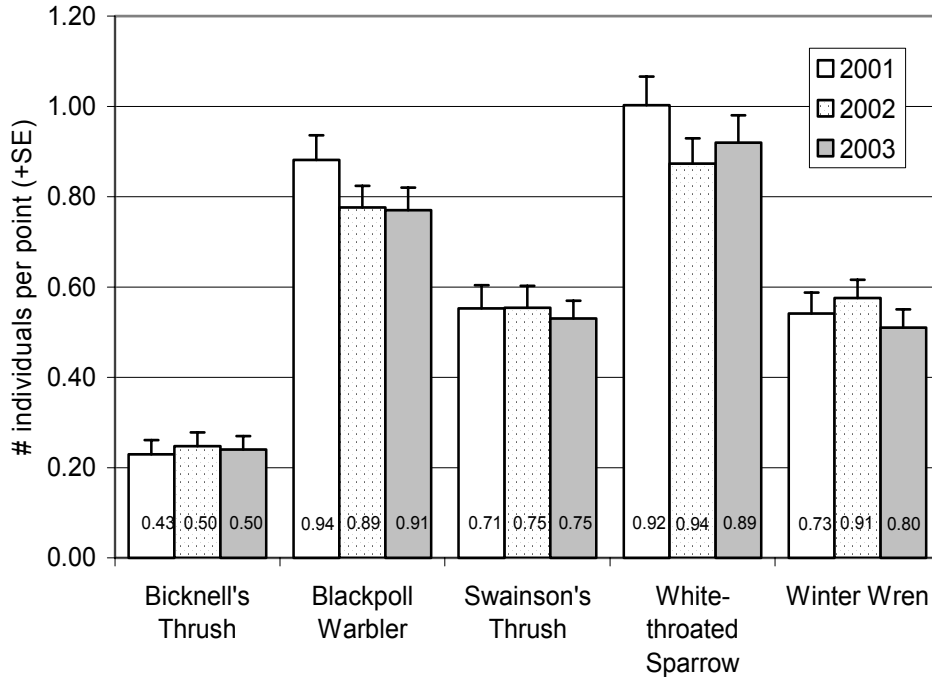
RESULTS AND DISCUSSION

Bird population levels change in response to a wide variety of natural and anthropogenic factors (Askins et al. 1990). Often, data gathered over brief time periods belie long-term trends (Holmes and Sherry 2001). These tenets of avian population monitoring confound efforts to evaluate short-term results. To reduce the likelihood of misinterpreting Mountain Birdwatch data, we will defer trend analyses until after the 2005 season. Until then, we will limit discussion to the most noteworthy results. In so doing, we recognize that many years of continuous effort may be required to reach meaningful conclusions with regard to population trends.

As in previous years, Blackpoll Warblers and White-throated Sparrows were the most abundant and widespread of the focal species (fig. 2). Swainson's Thrush and Winter Wren occupied a second tier of abundance. Though still uncommon, Bicknell's Thrush maintained stable numbers and overall distribution in 2003.

Winter Wren and White-throated Sparrow exhibited the most notable changes in distribution and abundance. Winter Wren numbers were down by 12% from 2002, averaging 0.51 individuals per point. The species was found on 11% fewer routes than in the previous breeding season. These changes mark a reversal of 2002 increases in abundance and occurrence frequency for this songbird. White-throated Sparrows rebounded from a 13% drop in 2002 with a 6% increase in abundance in 2003. Despite this increase, the species was counted on 5% fewer routes than in the previous year.

Figure 2. Relative abundance of five songbirds in 2001 (n = 112 survey routes), 2002 (n = 118), and 2003 (n = 117). Frequency of occurrence values appear as column numbers and refer to the proportion of routes on which a given species was detected during point counts.



The failure of Blackpoll Warbler numbers to recover from an 11% decrease in 2002 suggests that it is a species to watch. Reduced counts of Blackpoll Warbler, Winter Wren and White-throated Sparrow underlie a three-year pattern of focal species decline (fig. 3). Further monitoring will be required to assess the significance of this decline.

Figure 3. Combined count of focal species, 2001-2003.

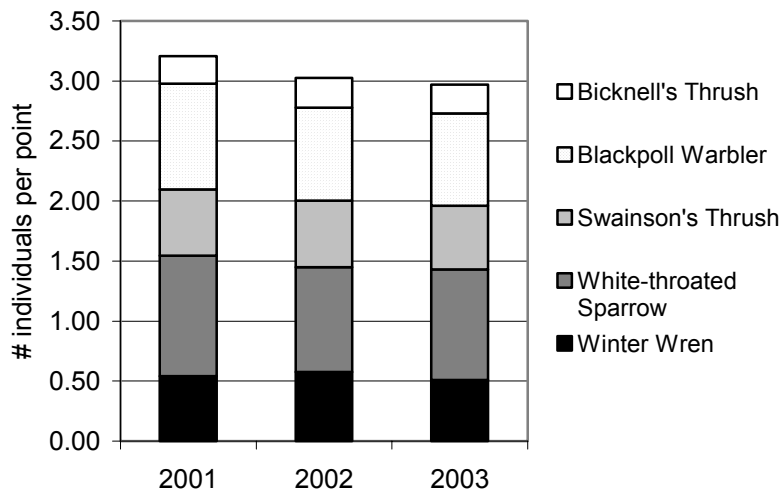
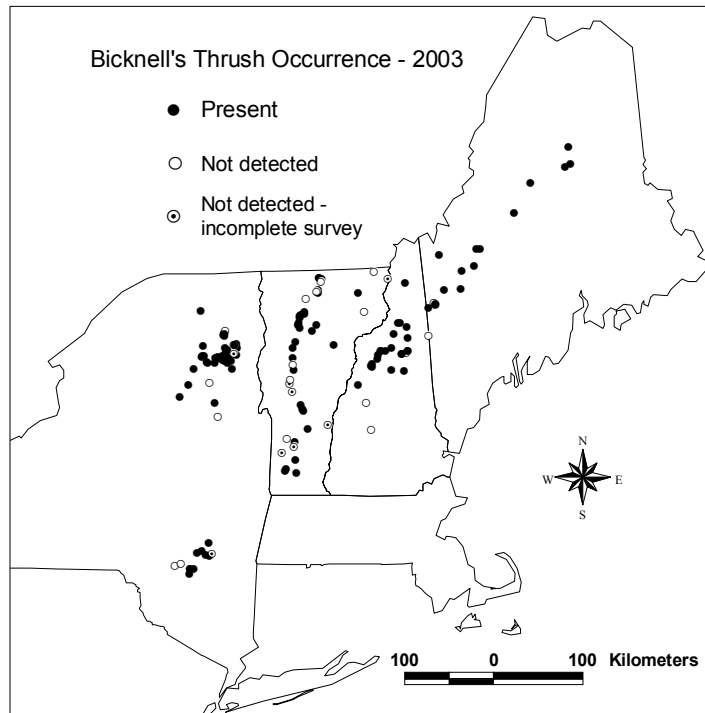


Figure 4. Bicknell's Thrush occurrence map; includes 22 off-route observations.



Bicknell's Thrush remained sparse, detected by point count just half of the time. Chance observations and use of audioplaybacks confirmed the species' presence on 84% of adequately surveyed routes (90 of 107; fig. 4), including four sites where the species went undetected in previous years: Crescent Ridge (NH), Debar Mountain (NY), Molly Stark Mountain (ME), and Spruce Mountain (VT). Observers did not encounter Bicknell's Thrush on seven mountains with records from previous years. Six of these were located in Vermont: Brousseau Mountain, Burke Mountain, Domey's Dome, Dorset Peak, Mount Grant, and Monadnock Mountain. The seventh, Big Crow Mountain, is a low Adirondack peak. Continued monitoring will reveal more about temporal patterns of site occupancy and allow us to detect upward or northward range shifts in mountain songbirds, should they occur as a result of climate change.

ACKNOWLEDGMENTS

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APPENDIX 1. *Off-route Bicknell's Thrush observations reported in 2003.*

State	Mountain	# of BITH
ME	Baldpate Mountain - East Peak	1
ME	Little Baldpate Mountain	1
NH	Mount Osceola	3
NH	Mount Resolution	2
NH	Mount Waumbek	2
NH	South Twin Mountain	3
NY	Big Crow Mountain	1
NY	Blake Peak	1
NY	Dial Mountain	1
NY	Donaldson Mountain	1
NY	Haystack Mountain	1
NY	Little Marcy	1
NY	Lookout Mountain	2
NY	Nippletop	2
NY	Panther Peak	2
NY	Sawteeth	1
NY	Seward Mountain	4
NY	Seymour Mountain	2
NY	Slide Mountain	1
NY	Table Mountain	1
VT	Mount Worcester	1
VT	Pico Peak	2

APPENDIX 2. 2003 Mountain Birdwatch results summarized by route.

State	Mountain	BITH status*	# of BITH	# of BLPW	# of WIWR	# of WTSP	# of SWTH
ME	Avery Peak	2	0	9	5	2	5
ME	Baldpate Mountain	1	2	6	3	7	2
ME	Big Spencer Mountain	2	0	5	3	7	3
ME	Big Squaw Mountain	2	0	4	4	2	7
ME	East Royce Mountain	5	0	0	0	10	4
ME	Little Bigelow Mountain	1	3	5	0	1	0
ME	Little Jackson Mountain	1	4	0	0	12	4
ME	Mount Abraham	1	1	5	6	7	0
ME	Mount Katahdin	2	0	7	4	7	4
ME	North Traveler Mountain	1	2	2	0	10	2
ME	Old Blue Mountain	1	3	8	5	6	5
ME	Old Speck Mountain	1	4	10	2	1	6
ME	Saddleback Mountain	1	3	4	1	16	1
ME	South Turner	2	0	4	0	9	8
ME	Surplus Mountain	5	0	2	3	2	4
ME	West Kennebago Mountain	1	2	7	4	7	9
NH	Cannon Mountain (5-min. count)	1	6	11	5	12	4
NH	Crescent Ridge	2	0	3	4	10	0
NH	Dixville Peak	1	5	9	5	4	7
NH	Kinsman Mountain (N. Peak)	1	4	9	3	9	6
NH	Mount Blue	1	3	5	1	4	5
NH	Mount Cardigan	5	0	5	0	11	0
NH	Mount Clay	1	6	4	5	2	3
NH	Mount Crawford (5-min. count)	4	0	3	2	6	5
NH	Mount Kearsarge	5	0	0	1	7	2
NH	Mount Lafayette	1	3	3	0	10	1
NH	Mount Martha	2	0	3	4	3	0
NH	Mount Moosilauke	1	1	3	4	4	1
NH	Mount Nancy	1	4	5	2	11	3
NH	Mount Passaconaway	1	3	2	4	3	4
NH	Mount Starr King	2	0	4	5	5	6
NH	Mount Tecumseh	1	5	0	2	2	2
NH	Mount Wolf	1	1	4	3	3	6
NH	Smarts Mountain	1	1	4	3	5	3
NH	Stairs Mountain	1	1	4	4	6	5
NY	Ampersand Mountain	1	1	5	4	3	2
NY	Balsam Lake Mountain	5	0	6	0	4	0
NY	Big Crow Mountain	5	0	0	0	4	6
NY	Big Slide Mountain	1	2	4	4	6	4
NY	Blue Mountain	1	4	2	2	1	2
NY	Crane Mountain	5	0	6	0	0	3
NY	Debar Mountain	2	0	4	1	3	1
NY	Eagle Mountain	5	0	4	0	0	2
NY	Esther Mountain	1	5	7	5	11	3

State	Mountain	BITH status	# of BITH	# of BLPW	# of WIWR	# of WTSP	# of SWTH
NY	Giant Mountain	1	1	2	3	3	3
NY	Gore Mountain	1	1	7	1	6	0
NY	Gothics	1	2	3	2	7	1
NY	High Peak	3	0	4	2	0	1
NY	Hopkins Mountain	4	0	0	4	4	6
NY	Hunter Mountain	1	2	9	2	3	5
NY	Hurricane Mountain	1	5	4	5	9	8
NY	Kempshall Mountain	2	0	2	7	3	4
NY	Little Whiteface Mountain	2	0	3	3	6	4
NY	Morgan Mountain	5	0	3	5	5	5
NY	Mount Adams	2	0	0	4	2	1
NY	Mount Colden	1	2	3	0	2	0
NY	Mount Marcy	1	6	6	1	12	6
NY	Mount Marshall	1	1	2	4	7	2
NY	Noonmark Mountain	2	0	2	0	2	1
NY	Phelps Mountain	1	1	6	1	3	3
NY	Pitchoff Mountain	2	0	4	1	9	6
NY	Plateau Mountain	1	10	8	3	1	2
NY	Porter Mountain	1	3	7	4	20	13
NY	Santanoni Peak	2	0	5	6	1	1
NY	Slide Mountain	1	3	3	2	9	6
NY	Soda Range	1	3	4	6	1	7
NY	Sunrise Mountain	1	2	6	3	9	3
NY	Thomas Cole Mountain	1	2	10	3	0	0
NY	Twin Mountain	1	3	6	6	5	0
NY	Vanderwhacker Mountain	5	0	0	3	1	0
NY	Wakely Mountain	1	2	3	0	5	0
NY	West Kill Mountain	2	0	4	2	0	2
NY	Whiteface Mountain	1	3	2	6	10	1
NY	Wittenberg Mountain	1	1	6	7	1	3
NY	Wright Peak	1	4	5	6	5	5
VT	Bald Mountain	2	0	5	4	10	4
VT	Bear Head	1	4	6	4	15	1
VT	Belvidere Mountain	2	0	5	3	9	1
VT	Big Jay	1	2	6	1	6	4
VT	Bloodroot Mountain	4	0	10	3	5	7
VT	Bolton Mountain	1	5	10	7	11	6
VT	Bromley Mountain	4	0	2	0	5	4
VT	Brousseau Mountain	5	0	3	5	6	6
VT	Burke Mountain	5	0	2	2	1	0
VT	Domey's Dome	5	0	6	3	8	2
VT	Dorset Peak	5	0	1	0	1	0
VT	Gillespie Peak	3	0	5	8	4	7
VT	Gilpin Mountain	2	0	2	1	0	2
VT	Glastenbury Mountain	1	2	7	1	5	3
VT	Jay Peak	1	3	3	8	9	0

State	Mountain	BITH status	# of BITH	# of BLPW	# of WIWR	# of WTSP	# of SWTH
VT	Killington Peak	1	7	10	5	6	2
VT	Laraway Mountain	5	0	6	4	3	0
VT	Ludlow Mountain	1	2	2	1	9	0
VT	Madonna Peak	1	6	11	9	11	9
VT	Molly Stark Mountain	2	0	5	3	10	3
VT	Monadnock Mountain	4	0	3	8	6	6
VT	Morse Mountain	2	0	8	3	8	2
VT	Mount Abraham	1	2	6	0	9	2
VT	Mount Ascutney	4	0	2	3	2	0
VT	Mount Equinox	3	0	5	2	5	4
VT	Mount Grant	5	0	8	3	7	5
VT	Mount Hunger	1	4	4	3	16	3
VT	Mount Ira Allen	1	4	5	5	15	4
VT	Mount Mansfield (Adam's Apple)	1	3	3	3	13	0
VT	Mount Mansfield (Forehead)	1	1	8	9	10	7
VT	Mount Mayo	2	0	5	0	3	0
VT	Mount Snow	1	3	11	1	13	9
VT	Mount Wilson	1	2	3	6	6	3
VT	North Glastenbury	1	1	3	1	0	7
VT	Ricker Mountain	1	3	8	5	6	7
VT	Shrewsbury Peak	1	4	5	0	5	6
VT	Spruce Mountain	2	0	1	4	4	1
VT	Stratton Mountain	2	0	2	0	5	3
VT	Styles Peak	1	1	5	6	4	0
VT	Tillotson Peak	2	0	8	6	5	4
VT	Worth Mountain	5	0	5	1	7	1
VT	Unnamed between Tillotson & Belvidere (5-min. count)	5	0	4	3	4	2

* Key to BITH status

1 = present, detected by point count

2 = present, detected by chance, playbacks, or on follow-up survey

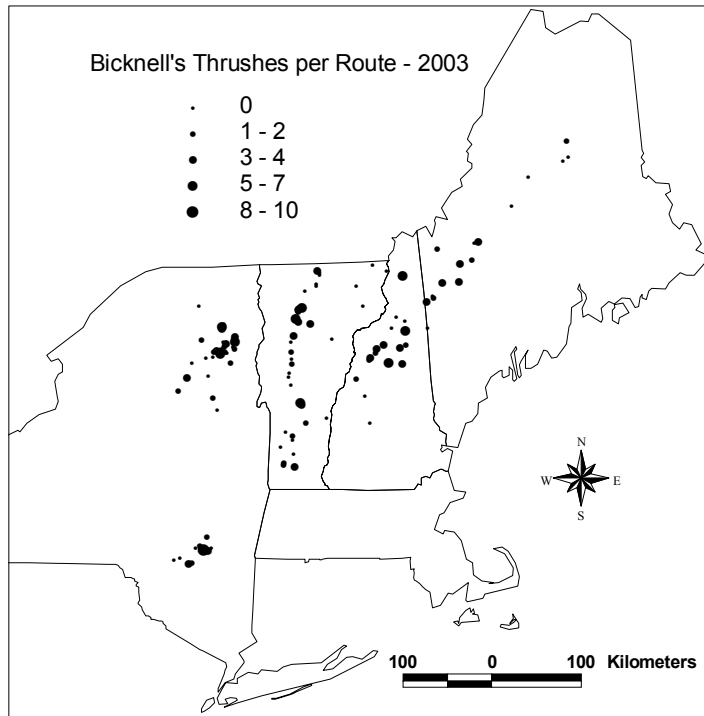
3 = not detected during point counts, no playbacks or follow-up

4 = not detected during point counts or playbacks, no follow-up

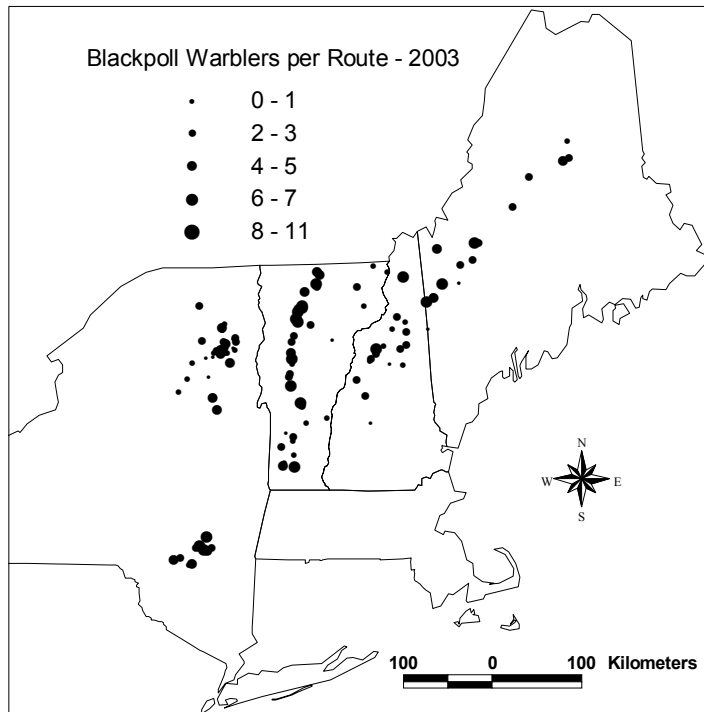
5 = presumed absent, not detected by point count, playback, or follow-up

APPENDIX 3. *2003 Mountain Birdwatch relative abundance maps.*
Symbols represent the number of individuals detected per route by 10-minute count.

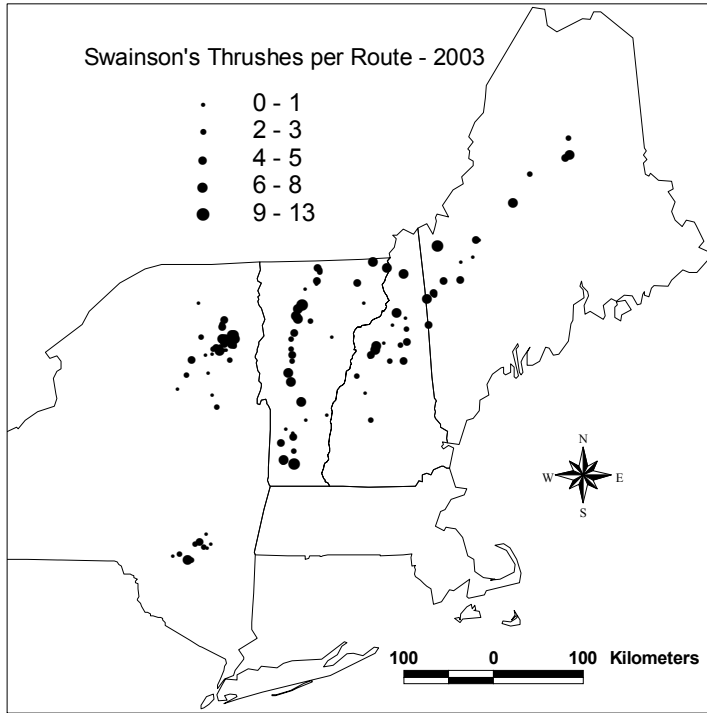
Bicknell's Thrush



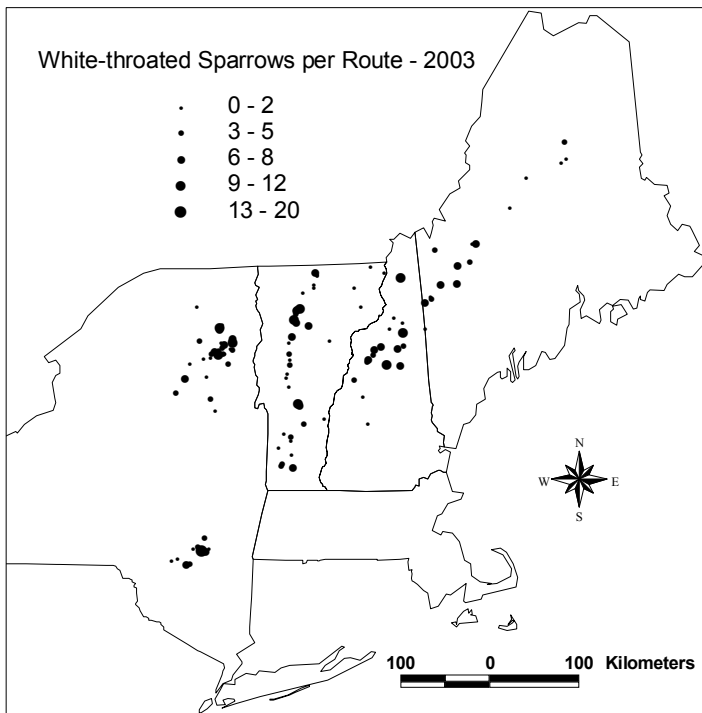
Blackpoll Warbler



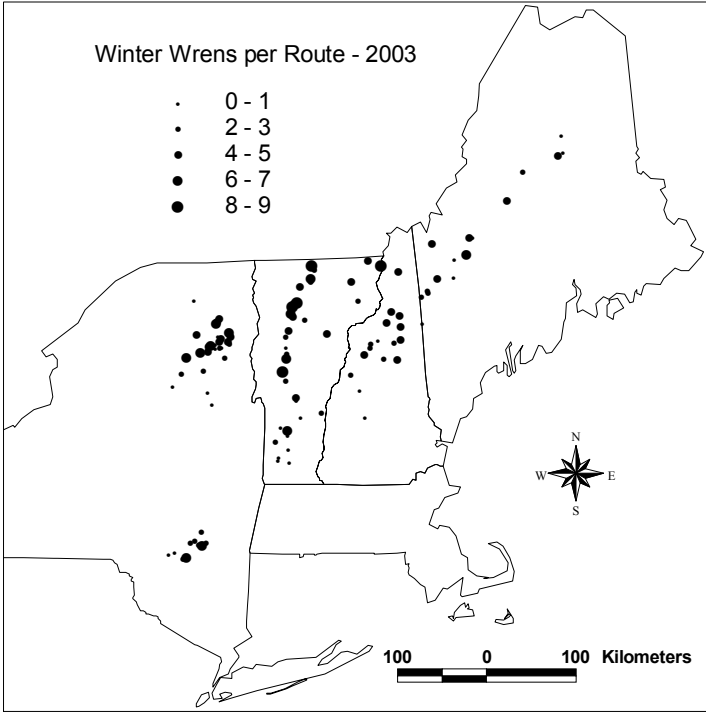
Swainson's Thrush



White-throated Sparrow



Winter Wren



PROJECTING EFFECTS OF CLIMATE CHANGE
ON BICKNELL'S THRUSH HABITAT IN THE NORTHEASTERN UNITED STATES
ADDENDUM TO MOUNTAIN BIRDWATCH 2003: FINAL REPORT TO THE U.S. FISH AND WILDLIFE SERVICE

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ABSTRACT. - Bicknell's Thrush (*Catharus bicknelli*) is a rare habitat specialist that breeds in montane fir-spruce forests of the northeastern United States and adjacent Canada. A warming climate may reduce availability of this forest type by allowing upslope encroachment of mixed and hardwood forests. We used two GIS modeling approaches to assess how elevated temperatures could affect Bicknell's Thrush habitat in the U.S. Both methods rely on known relationships between forest type, temperature, and elevation. We measured the possible effects of 1° C to 8° C temperature increases on habitat area, number of habitat patches, and mean patch size. Results indicate that a 3° C increase in mean July temperature could result in an 88% to 98% loss of U.S. habitat and extirpations of Bicknell's Thrush from the Catskill Mountains, the southern Adirondacks, the Green Mountains, and the mountains of western Maine. The same increase could eliminate breeding habitat from up to 144 mountains in New Hampshire. The Adirondack High Peaks, the Presidential Range, and Mount Katahdin are most likely to maintain forest characteristics suitable for Bicknell's Thrush. The recent disappearance of Bicknell's Thrush from coastal locations in Canada and from small mountains in the U.S. may signal early effects of climate change. The actual pace and pattern of habitat loss will depend on the rate of temperature change, the influence of site factors (slope, aspect, substrate), and the effect of climate on reproductive rates, resource competition, and natural disturbance.

BICKNELL'S THRUSH (*Catharus bicknelli*) is a rare, migratory songbird that is range-restricted on both its wintering and breeding grounds. It winters primarily in moist broadleaf forests on the island of Hispaniola (Rimmer et al. 2001b) and breeds in high-elevation balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*) forests of New York and northern New England (Atwood et al. 1996). Habitat patches also occur in adjacent portions of Québec, New Brunswick, and Nova Scotia (Ouellet 1993), although these areas are thought to contain a small percentage of the world's breeding population (Nixon 1999).

Evidence of regional declines (Rompré et al. 1999, Rimmer et al. 2001a) and local extirpations (Christie 1993, Atwood et al. 1996, Nixon 1999) have caused concern for the status of Bicknell's Thrush throughout its breeding range (Pashley et al. 2000, BirdLife International 2000). In the last century, the species has disappeared from coastal locations in Canada (Erskine 1992, Christie 1993, Ouellet 1996) and from several low mountains in the U.S., most notably along the southern perimeter of its range (Atwood et al. 1996, Lambert et al. 2001). Such upward and poleward shifts in animal distribution can result from global warming (McCarty 2001, Parmesan and Yohe 2003) and may occur in response to changes in vegetation patterns (Davis and Zabinski 1992).

Altitudinal limits of plant zones on northeastern mountains are correlated with mean July temperature, with average readings of 12.9 °C at treeline and 17.1 C° at the spruce-fir/deciduous forest boundary (Cogbill and White 1991). Rising summer temperatures could cause an upslope shift in mountain ecotones and threaten high-elevation plant communities, such as montane fir-spruce forest. Two studies, in particular, underscore the vulnerability of this forest type. Iverson and Prasad (2002) demonstrated that warming temperatures could severely restrict or eliminate suitable habitat for balsam fir in the eastern U.S., while creating favorable conditions for temperature-limited hardwoods. Hamburg and Cogbill (1988) identified climatic warming as a driving force behind the historical decline of red spruce in the region.

Warming temperatures have been implicated in upward shifts of alpine plants in central Europe (Grabherr et al. 1994) and of treeline in the western United States (Peterson et al. 1994, Taylor 1995), Europe (Meshinev et al. 2000, Kullman 2001), and New Zealand (Wardle and Coleman 1992). A similar shift in the coniferous/deciduous boundary may be underway on eastern mountains (Hamburg and Cogbill 1988), as rising temperatures favor the growth of beech (*Fraxinus americana*), sugar maple (*Acer saccharum*), and yellow birch (*Betula alleghaniensis*) over balsam fir and red spruce (Botkin and Nisbet 1992).

Meteorological records from Hanover, NH indicate a 2.2° C increase in mean summer temperature between 1870 and 1983 (Hamburg and Cogbill 1988). Statewide increases in summer temperature for the period of 1895 to 1999 have been estimated at 0.3° C in New York and 0.6° C in New Hampshire and Vermont, with no change detected in Maine (Keim and Rock 2001). The Canadian General Circulation Model and the Hadley Climate Model project substantial increases in the region's average annual temperature in both the near- and long-term. Both models predict a 1.3° C rise by 2030. By the year 2100, the average annual temperature could be 2.6° C to 5.2° C higher than at the turn of the millennium (Hadley and Canadian models, respectively; Hurtt and Hale 2001).

We used two GIS modeling approaches to determine how elevated temperatures might affect Bicknell's Thrush habitat in the United States. Both methods rely on known relationships between temperature, elevation, and forest type. Model results project climate change impacts on habitat area, number of habitat patches, and mean patch size. We do not attempt to predict the rate of habitat loss or describe patterns of forest change at a fine scale. Rather, we aim to estimate critical warming thresholds for Bicknell's Thrush habitat and identify areas facing the

greatest risk of extirpation. We present data for the Northeast, as a whole (New York, Vermont, New Hampshire, and Maine), and include separate results for New Hampshire because it contains the most habitat in the region and is at the center of the species' U.S. range.

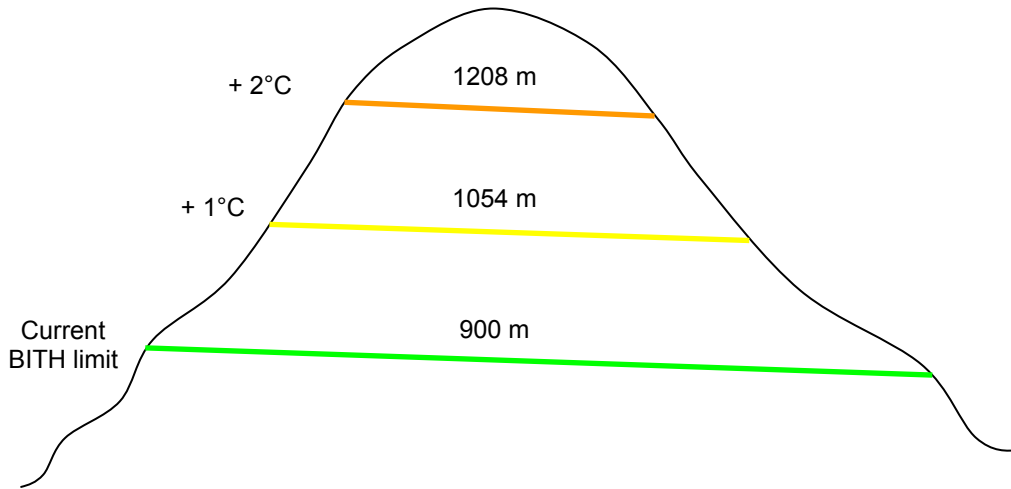
METHODS

Using temperature lapse rate to project changes in current distribution – the TLR method

We used two complementary approaches to assess potential effects of climate change on Bicknell's Thrush habitat. The first was based on a validated GIS model that depicts conifer-dominated forest as 30-m cells above an elevation mask representing Bicknell's Thrush's lower distributional limit. This boundary occurs at 1,100 m in the southern Catskills and drops -84.5 m for every one-degree gain in latitude. Its slope reflects the influence of latitude on climate and the corresponding effect of climate on forest composition and structure (Lambert et al. 2004).

Elevation affects climate in a manner similar to latitude. Temperatures in New York and New England decrease by 1° C for every 154 m increase in elevation (Ollinger et al. 1995). We hypothesize that the lower limit of Bicknell's Thrush habitat will respond to warming conditions in accordance with this temperature lapse rate. In other words, a 1° C increase in July temperature will eventually result in a 154-m upslope shift in the current threshold. To simulate the effect of 1° C to 6° C temperature increases on Bicknell's habitat, we raised the original model's elevation mask by six successive increments of 154 m (154 m, 308 m, . . . 924 m; Fig. 1). We used the nearest-neighbor resampling method to produce a 100-m grid for each warming scenario. The change in resolution from 30 m to 100 m was made to better approximate the scale at which temperatures change on northeastern mountains. This first approach, conducted in ArcView 3.2 (Environmental Systems Research Institute 1999), assumes that land cover will remain constant above the rising threshold. Such an assumption could be problematic for mountains capped with large alpine zones, unless the damaging effects of wind and ice hold treeline at or near its current position.

Figure 1. Projected shifts in the lower limit of Bicknell’s Thrush habitat on a hypothetical mountain. Cross-sectional view is to the west, with thresholds sloping down to the north.



Projecting distributional limits using July temperature – the JulT method

We based our second modeling approach on the correlation of mountain ecotones with mean July temperature (Cogbill and White 1991). Although site factors such as moisture and wind exposure also influence forest zonation (Spear 1989, Lloyd 1997), boundaries generally occur where temperature limits the growth of individual species or plant associations (Cogbill and White 1991, Woodward 1992).

We modeled mean July temperature throughout the study region to identify temperature limits that correspond with the upper and lower boundaries of current Bicknell’s Thrush habitat. We considered climatic conditions within these isotherms favorable to Bicknell’s Thrush and projected effects of warming on this zone. We began the analysis in ArcGIS (Environmental Systems Research Institute 2002) by resampling the U.S. Geological Survey’s 30-m digital elevation model of the Northeast (U.S. Geological Survey 1999) to produce a grid of 100-m cells. We used nearest-neighbor resampling methods to make the conversion. We then applied an existing model of mean July temperature, based on the following equations:

$$\text{JulyMax} = 42.57 - (0.497 * \text{lat}) + (0.099 * \text{lon}) - (0.00623 * \text{elev});$$

$$\text{JulyMin} = 38.61 - (0.757 * \text{lat}) + (0.136 * \text{lon}) - (0.00789 * \text{elev}); \text{ and}$$

$$\text{JulyMean} = (\text{JulyMax} + \text{JulyMin} / 2). \text{ (Ollinger et al. 1995)}$$

The result was a grid of 100-m cells stretching from the Catskill Mountains to northern Maine, each with a value representing mean July temperature.

Next, we observed that the upper and lower limits of our Bicknell's Thrush habitat model (Lambert et al. 2004) corresponded well with mean July isotherms of 13 °C and 19 °C, respectively. The area within these limits contains 96% of the forest identified as potential Bicknell's Thrush habitat. Finally, we simulated effects of warming by adding 1 °C to each cell and quantifying changes to the 13 °C to 19 °C zone. We repeated this step seven times until all temperatures in the model exceeded 19 °C.

Unlike the first method, which narrowly projects future habitat based on current vegetation cover, the second method broadly classifies all areas within the designated temperature limits as potentially suitable. Both modeling approaches involve simplifying assumptions that limit their ability to predict the occurrence of Bicknell's Thrush at a given location. However, the combination of approaches is adequate for assessing the overall vulnerability of the bird's habitat.

Calculating patch metrics

After applying both methods to model effects of incremental warming, we measured a series of patch metrics with the ArcView extension Patch Analyst for Grids (Carr et al. 1999). We used diagonal clumping to generate habitat patch themes, from which number of patches, mean patch size, and total area could be calculated. We measured these three variables for each state and for the Northeast as a whole under a range of warming scenarios. Isolated, 1-ha patches were excluded from this analysis, since home ranges average 4.5 ha for males and 2.3 ha for females (Rimmer et al. 2001b).

We conducted a separate patch analysis for ecoregions of New Hampshire. New Hampshire was chosen as a special focus area because it contains approximately 45% of the Northeast's potential Bicknell's Thrush habitat and because it lies at the heart of the species' U.S. range (Lambert et al. 2004). In addition to calculating patch metrics, we assessed the risk of extirpation at 161 New Hampshire mountains that are known or possible Bicknell's Thrush sites.

RESULTS

The dual simulation approach indicates that a temperature increase of 1 °C could reduce Bicknell's Thrush habitat by 48% to 66% in the Northeast (Fig. 2, Tables 1 and 2). At this level of warming, the TLR method projects the disappearance of suitable sites from the Catskills, as well as significant losses from the Green Mountains, the southern Adirondacks, northern New

Hampshire, and western Maine (Fig. 3). Vermont and Maine stand to experience the sharpest reductions from short-term warming, estimated at 83% and 75%, respectively (Fig. 4).

Because the JulT method maps whole temperature zones as favorable to Bicknell’s Thrush, it projects higher patch sizes and greater patch persistence than the TLR method, which is based on current land cover. Nonetheless, both modeling approaches exhibit sensitivity to moderate increases in temperature (Tables 1 and 2). Measures of area, number of patches and mean patch size decrease through three degrees of warming, as suitable sites are progressively restricted to the highest Adirondack Peaks (NY), Mount Washington (NH), and Mount Katahdin (ME). In the TLR model, a temperature rise of 3 °C eliminates 98% of current Bicknell’s Thrush habitat. In the JulT simulation, the same level of warming reduces by 88% the amount of area within the 13 °C to 19 °C isotherms. Habitat patches disappear at temperature increases of 6 °C (TLR) and 8 °C (JulT).

In both analyses, the most persistent patches occur in the White Mountains, where vast stands of montane fir-spruce cover long ridgelines and broad slopes. Mount Moosilauke and the high mountains of Franconia Ridge, the Twin/Bond Ridge, the Presidential Range, and the Carter Range emerge as strongholds for Bicknell’s Thrush, while lower peaks in the same ecoregion appear to be vulnerable to small increases in temperature (Fig. 5). A 1 °C rise in temperature may be enough to eliminate Bicknell’s Thrush habitat from 63 New Hampshire mountains, including all confirmed and possible sites in the Mahoosuc-Rangely Lakes, Connecticut Lakes, and New Hampshire Uplands ecoregions (Table 3, Fig. 6). The mountains at greatest risk of climate-related extirpation include: Mount Chocorua, Loon Mountain, Percy Peaks, and Smarts Mountain. Two additional degrees of warming could result in the disappearance of Bicknell’s Thrush habitat from another 81 New Hampshire mountains.

Table 1. Projected effects of 1 °C to 6 °C warming on area and configuration of Bicknell’s Thrush habitat in the Northeast, based on TLR modeling method.

Temperature	Area (ha)	No. patches	Mean patch size (ha)	SE
current	110000	1357	81.06	12.99
plus 1° C	37900	459	82.57	18.10
plus 2° C	10134	135	75.07	26.80
plus 3° C	2358	61	38.49	8.99
plus 4° C	259	29	8.93	2.24
plus 5° C	24	6	4.00	1.27
plus 6° C	0	0	0.00	0.00

Table 2. Projected effects of 1 °C to 8 °C warming on area and configuration of Bicknell’s Thrush habitat in the Northeast, based on JulT modeling method.

Temperature	Area (ha)	No. patches	Mean patch size (ha)	SE
current	209098	589	355.00	48.00
plus 1° C	107804	380	283.69	47.64
plus 2° C	52976	247	214.48	45.01
plus 3° C	24302	144	168.76	47.40
plus 4° C	11581	69	167.84	66.93
plus 5° C	5956	33	180.48	96.66
plus 6° C	3300	11	300.00	200.51
plus 7° C	1929	8	241.13	101.91
plus 8° C	0	0	0.00	0.00

Figure 2. Projected effects of rising temperatures on Bicknell’s Thrush habitat (TLR method) and on climate zone suited to Bicknell’s Thrush habitat (JulT method).

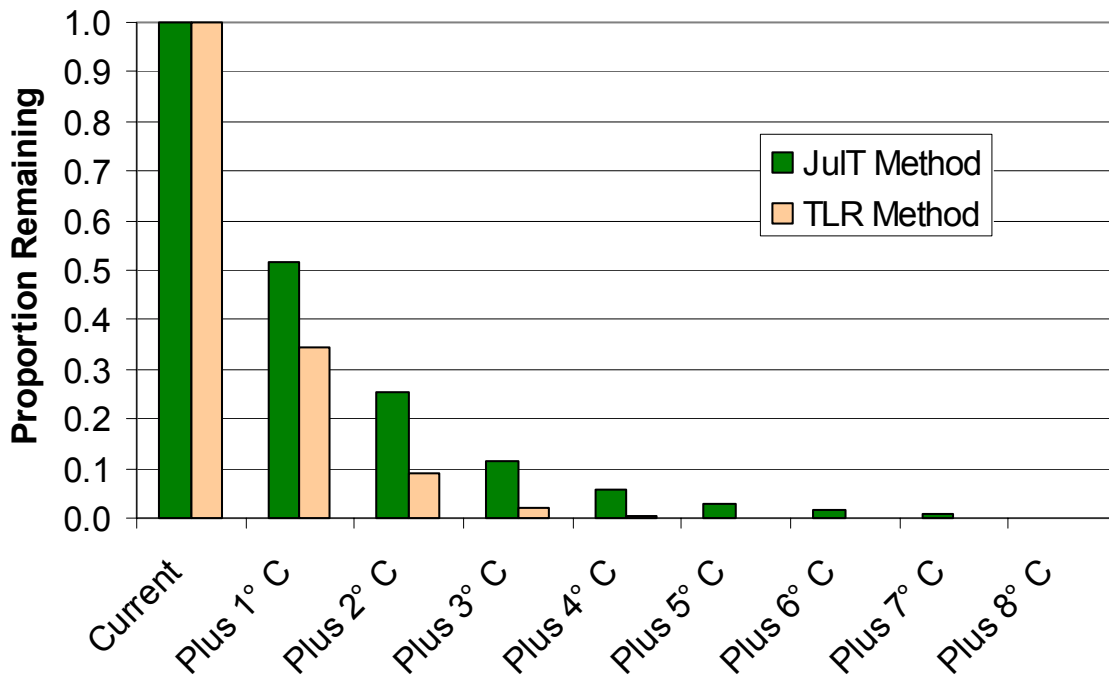


Figure 3. Pattern of projected habitat loss based on TLR modeling method for temperature increases of 1 °C to 3 °C.

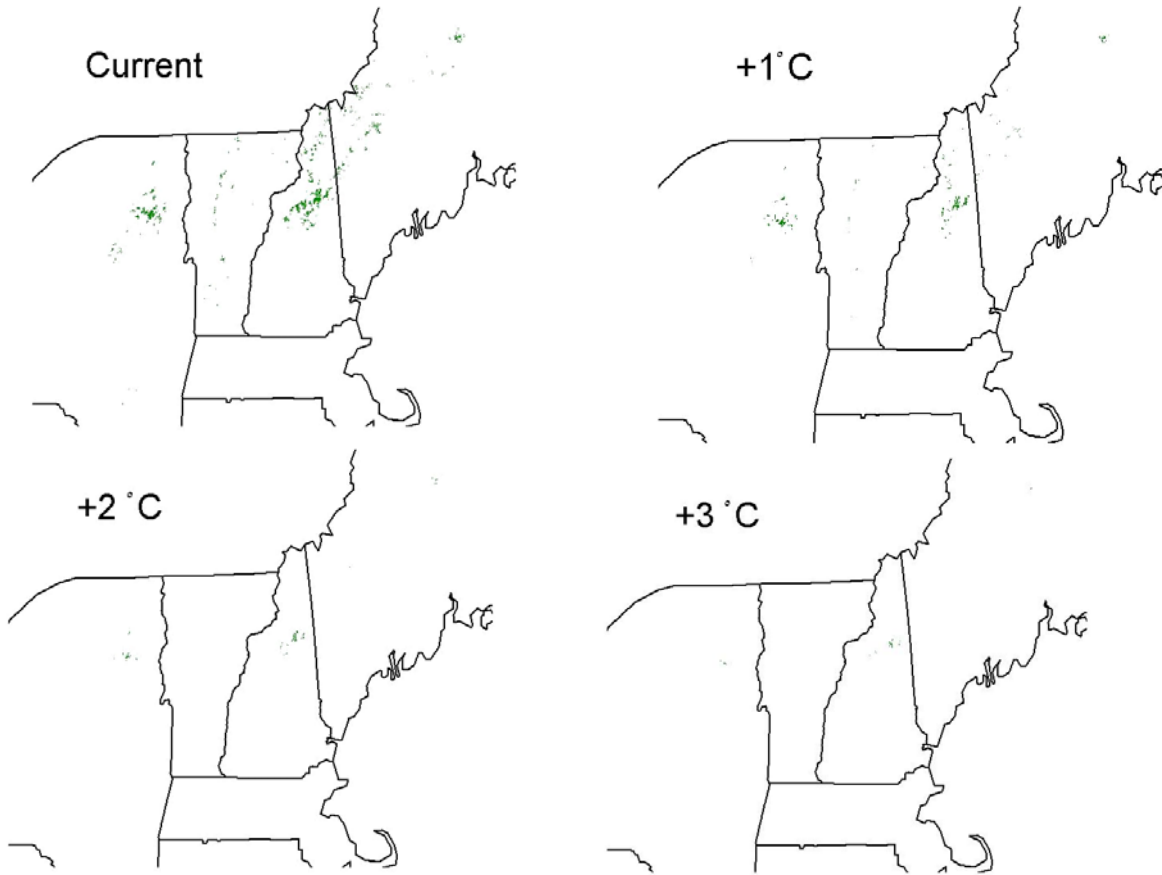


Figure 4. Projected effects of rising temperatures on extent of Bicknell's Thrush habitat, by state (TLR method).

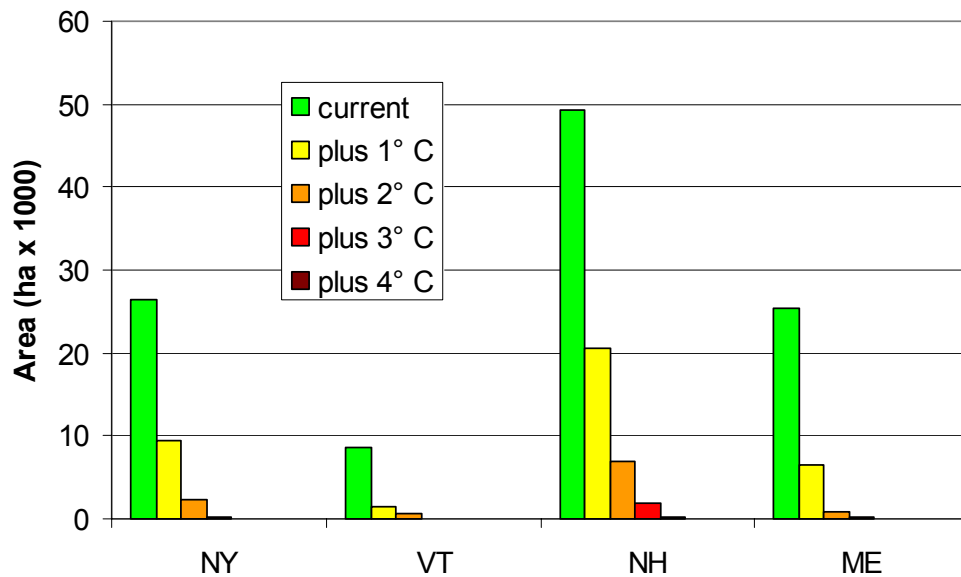


Figure 5. Projected effects of rising temperatures on extent of Bicknell's Thrush habitat in New Hampshire (TLR method). Habitat projections for each temperature increment include areas designated by warmer colors.

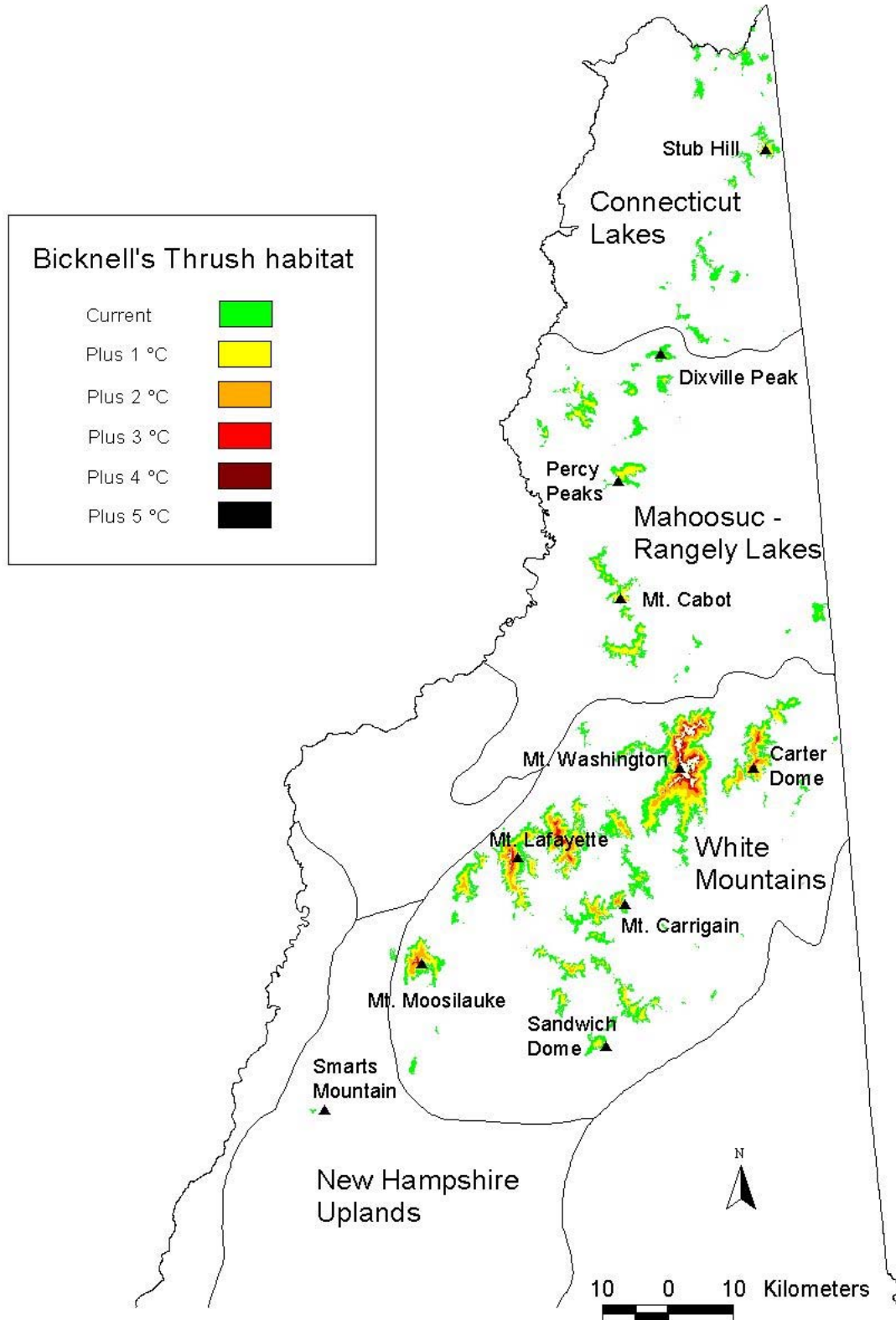


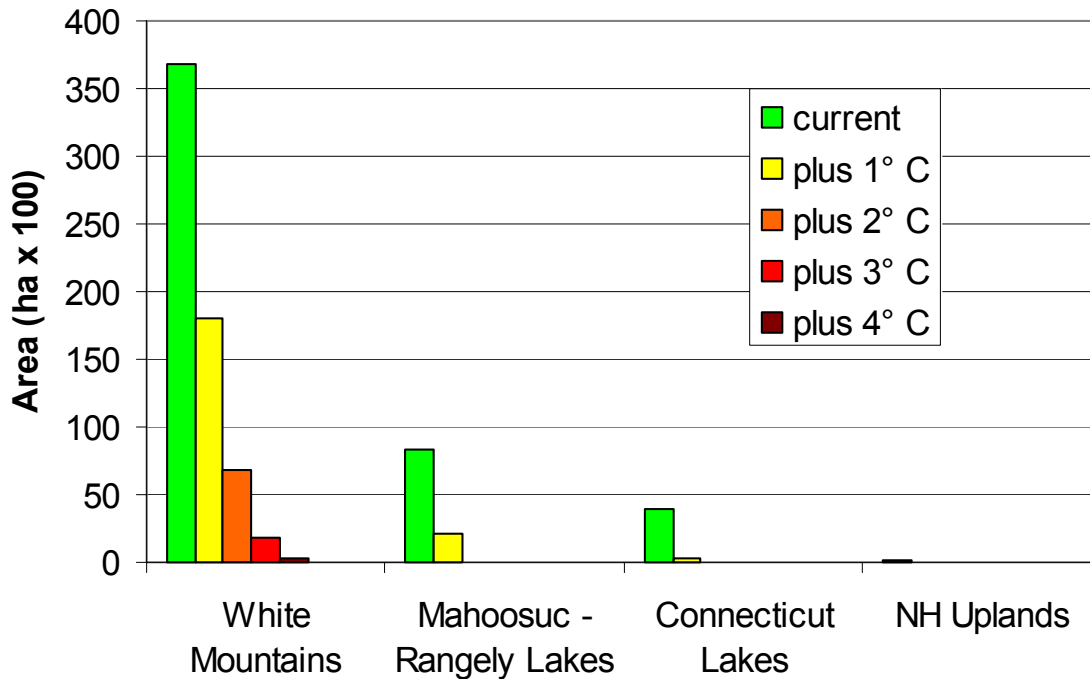
Table 4. Vulnerability of New Hampshire mountains to risk of local extirpation. Listed mountains lose Bicknell’s Thrush habitat in response to given level of warming, according to the TLR model.

Plus 1 °C	Plus 2 °C	Plus 3 °C	Plus 4 °C	Plus 5 °C	Plus 6 °C
Bald Cap	Anderson, Mount	Blue, Mount	Bond, Mount	Adams, Mount	Washington, Mount
Bear Mountain	Baldhead Mountain	Bulge, The	Carrigain, Mount	Clay, Mount	
Big Bickford Mountain	Bemis, Mount	Cabot, Mount	Carter Dome	Lafayette, Mount	
Big Coolidge Mountain	Blue Mountain	Cannon, Mount	Gulf Peak	Madison, Mount	
Black Crescent Mountain	Cannon Balls, The	Cliffs, The	Guyot, Mount		
Black Mountain	Castle Mountain	Field, Mount	Lincoln, Mount		
Blue Ridge (W of Crystal Mtn.)	Dartmouth, Mount	Flume, Mount	Little Haystack		
Bowman, Mount	Davis, Mount	Galehead Mountain	Middle Carter Mountain		
Carr Mountain	Deception, Mount	Garfield, Mount	Moosilauke, Mount		
Cave Mountain	Diamond Ridge	Hale, Mount	Mount Hight		
Chandler Mountain	Dixville Peak	Hancock, Mount	North Carter Mountain		
Chocorua, Mount	Eisenhower, Mount	Jackson, Mount	South Twin Mountain		
Clough, Mount	Fitch Mountain	Jim, Mount			
Crawford, Mount	Goback Mountain	Kinsman Mountain			
Crescent, Mount	Gore Mountain	Liberty, Mount			
Crystal Mountain	Hitchcock, Mount	Moriah, Mount			
Cushman, Mount	Horn, The	Osceola, Mount			
Deer Mountain	Huntington, Mount	Passaconaway, Mount			
Duck Pond Mountain	Imp Mountain	Pierce, Mount			
D'Urban, Mount	Isolation, Mount	South Carter Mountain			
Dustan, Mount	Kancamagus, Mount	Tom, Mount			
Fool Killer, The	Long Mountain	Tripyramid, Mount			
Green Mountain	Lowell, Mount	unnamed ridge N of Owls Head			
Jennings Peak	Magalloway, Mount	Waumbek, Mount			
Kearsarge North	Martha, Mount	Wildcat Mountain			
Kelsey, Mount	Middle Moriah Mountain	Willey, Mount			
Kent, Mount	Nancy, Mount				
Kineo, Mount	North Baldface				
Loon Mountain (North Peak)	Notch Mountain				
Millen Hill	Pilot Range				
Mitten, Mount	Pliny Mountain				
North Doublehead	Rice Mountain				
North Moat Mountain	Rumpm Mountain				
Owlhead Mountain	Salmon Mountain				
Owls Head	Sandwich Dome				
Owlshead	Savage Mountain				
Percy Peaks	Scar Ridge				
Pleasant, Mount	Shelburne Mountain				

Table 4. (cont.) Vulnerability of New Hampshire mountains to risk of local extirpation

Plus 1 °C	Plus 2 °C	Plus 3 °C	Plus 4 °C	Plus 5 °C	Plus 6 °C
Prospect Hill	Sleepers, The				
Randolph, Mount	South Baldface				
Resolution, Mount	Starr King, Mount				
Sable Mountain	Stub Hill				
Sanguinary Mountain	Success, Mount				
Scaur Peak	Sugarloaf				
Smarts Mountain	Teapot Mountain				
South Sugarloaf	Tecumseh, Mount				
Spruce Mountain	Terrace Mountain				
Stairs Mountain	unnamed NNE of Salmon Mountain				
Sugar Hill	unnamed W of Mount Kelsey				
Tremont, Mount	unnamed W of Salmon Mtn.				
Tucker, Mount	Watnomee, Mount				
Tumble Dick Mountain	Webster, Mount				
unnamed E of Rice Mountain	Weeks, Mount				
unnamed N of Cleveland Notch	Whitcomb Mountain				
unnamed S of Deer Mountain	Whiteface, Mount				
unnamed S of Prospect Hill					
unnamed S of Salmon Mountain					
unnamed SW of Rump Mountain					
unnamed ridge W of Scott Bog					
West Royce Mountain					
Whaleback Mountain					
Whitewall Mountain					
Wolf, Mount					

Figure 6. Projected effects of rising temperatures on extent of New Hampshire Bicknell's Thrush habitat, by ecoregion (TLR method).



DISCUSSION

Our findings indicate that a slight increase in temperature has the potential to considerably diminish Bicknell's Thrush habitat in the Northeast. The greatest reduction in area may occur in response to a warming of just 1 °C. Barring dramatic cutbacks in greenhouse gas emissions, a warming of this magnitude is expected to occur before 2030 (Hurtt and Hale 2001). The projected loss of habitat from lower summits and slopes could eliminate Bicknell's Thrush from significant portions of its range, such as the Catskill Mountains and most of the Green Mountains. However, the impact on overall population size is likely to be muted since the most vulnerable areas are also the most sparsely inhabited by Bicknell's Thrush (Lambert et al. 2004, Hale 2001).

Temperature increases of 2 °C and 3 °C, which are predicted to occur before 2100 (Hurtt and Hal 2001), are of greater concern because they could affect areas with relatively high numbers of Bicknell's Thrush (VINS, unpubl. data). Climate change of this magnitude has caused forest zones to shift in the past. When temperatures rose by an estimated 2° C during the early Holocene, white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*) advanced upslope

by 350 m (Davis et al. 1980). During the cooling period that followed, red spruce spread from high-elevation sites into lower (<1,100 m), hardwood forests (Davis et al. 1980). Their subsequent decline in these areas has coincided with a warming trend that began in the early 1800s (Hamburg and Cogbill 1988). Dramatic warming (4° C to 6° C) around 10,000 years ago enabled invasion of alpine tundra by red spruce and balsam fir. Smaller fluctuations since that time have had little effect on treeline elevation (Spear 1989).

Simulated responses of tree species to a 100-year doubling of greenhouse gas emissions corroborate the sensitivity of northeastern forest types to a moderate increase in temperature. In the most conservative of five warming scenarios, the Hadley Climate Model, a 2.4 °C rise in temperature caused a 72% reduction in the range of balsam fir (Iverson and Prasad 2002). A 5.0 °C increase, predicted by the Canadian General Circulation Model, resulted in a 100% loss of suitable balsam fir habitat from the northeastern U.S. Our own simulations indicate that the higher level of warming could restrict suitable Bicknell's habitat to Mount Washington (TLR) and possibly the highest summits of New York and Maine (JulT). It is uncertain whether the remaining population of Bicknell's Thrush would be large or vagile enough to persist under such conditions. However, a population clinging to few remnant patches would be vulnerable to extreme meteorological events (MacArthur and Wilson 1967), which appear to be increasing along with temperature in the Northeast (Keim and Rock 2001).

Shifts in the position of mountain ecotones will not progress in an orderly fashion because the influence of temperature on vegetation patterns can be modified by human land use (Hamburg and Cogbill 1988), competitive processes (Woodward 1992), natural disturbance, and site factors such as soil and topography (Cogbill and White 1991). Treeline is strongly affected by wind exposure, snow depth, and ice-loading (Spear 1989, Kimball and Weihrauch 2000). The current boundary's considerable breadth and patchiness underscore the influence of mechanical damage (Kimball and Wehrauch 2000) and supports the idea of steep gradients in vulnerability to temperature change at treeline (Lloyd 1997).

If rising temperatures are accompanied by an increase in precipitation, as the Hadley model predicts (Hurtt and Hale 2001), treeline movement might be restrained by increased ice damage along this boundary. However, an increase in winter damage can not be reliably predicted, since three out of five climate models project little change in precipitation in the eastern United States (Iverson and Prasad 2002). Furthermore, an ongoing rise in the eastern cloud base of 6 m per

year (Richardson et al. 2003) may curb accumulation of rime ice. Whether or not precipitation patterns change, winds are likely to remain near current levels as they are largely generated orographically (Davis 1984).

Recent observations of rising treeline in the Sierra Nevada (Taylor 1995), the Olympic Mountains (Peterson et al. 1994), New Zealand (Wardle and Coleman 1992), and Sweden (Kullman 2001) support the possibility of treeline advance in the Northeast. However, movement of this ecotone beyond its current limit may require dramatic warming (Spear 1989). Whatever the temperature threshold, lag times will be longer on exposed ridges than in areas sheltered from the wind (Kimball and Weihrauch 2000, Kullman 2001). Our dual modeling approach describes the range of possibilities, from a static treeline (TLR method) to one that shifts in direct response to temperature (JulT method). Effects of temperature on the hardwood/spruce-fir boundary are thought to be modified by soil characteristics and/or competition among canopy trees, rather than by chronic disturbance (Hamburg and Cogbill 1988). Still, changes in this boundary could lag behind an abrupt temperature change by 100-200 years (Davis and Botkin 1985, Woodward 1992).

Rapid reorganization of ecosystems may occur in response to habitat alterations from climate change. The conversion of grassland to desert shrubland in southeastern Arizona, attributed to an increase in winter precipitation, caused substantial changes to the animal assemblage (Brown et al. 1997). During the period of transition (1977-1994), several common rodents and ant species declined or crashed while numbers of shrubland animals increased. Historic extirpations of Bicknell's Thrush from coastal locations in Canada (Erskine 1992, Christie 1993, Ouellet 1996) and from low mountains in the Northeast (Atwood et al. 1996, Lambert et al. 2001) may have resulted from habitat alterations caused by climatic warming. Establishing a link between climate change and local extirpations would require a detailed forest history and improved understanding of the species' habitat requirements.

Can Bicknell's Thrush adapt to a change in forest type? Extensive surveys (Atwood et al. 1996) and intensive radio-tracking studies (VINS, unpubl. data) in the northeastern U.S. indicate a nearly exclusive association with high-elevation conifer. However, the species may be less discriminating than evidence from the northeastern U.S. would suggest. Bicknell's Thrush occurs in mixed forest at upper elevations in Québec (Ouelett 1993) and in dense, hardwood

regeneration following clearcutting in highlands of New Brunswick (Nixon et al. 2001). The value of these habitats for breeding remains unknown.

The effort to predict future distributional limits for Bicknell's Thrush is further confounded by the complex relationship between climate and bird populations. Climate patterns can influence the breeding and migratory phenology of birds (Forchhammer et al. 1998, Lane and Pearman 2003), limit access to food (Saether et al. 2000), regulate prey abundance (Jones et al. 2003), and alter avian community structure with potential consequences for resource competition (Lemoine and Böhning-Gaese 2003). Demographic effects have been observed by computer simulation (Rodenhouse 1992) and field study (Rodenhouse and Holmes 1992, Winkel and Hudde 1997, Saether et al. 2000, Sillett et al. 2000). A combination of these investigative methods may one day reveal the most important factors for Bicknell's Thrush.

Future research should specifically assess the threat of competition from Swainson's Thrush (*Catharus ustulatus*) and the possibility of habitat loss from an infestation of balsam woolly adelgid (*Adelges piceae*). Interactions between Bicknell's Thrush and Swainson's Thrush are agonistic where the two species overlap along the lower reaches of Bicknell's habitat (Able and Noon 1976, JDL and KPM pers. obs.). Cold spring nights at high altitude appear to restrict Swainson's Thrush, which has a low cold tolerance compared to its congeneric (Holmes and Sawyer 1975). Low temperatures in winter are all that shield northeastern fir forests from the balsam woolly adelgid, an exotic pest that has laid waste to fir stands in the southern Appalachians (Iverson et al. 1999).

Ultimately, the pace, pattern and magnitude of climate change impacts on high-elevation bird communities will depend on the rate of warming and the relative importance of various biotic and abiotic factors. Studies in the French Alps (Archaux 2004) and Costa Rican cloud forests (Pounds et al. 1999), conducted over a span of 27 and 16 years, respectively, failed to detect upward shifts in birds occupying the highest elevations. However, the number of lower-slope species at a high-elevation (1,540 m) site in Costa Rica increased four-fold in ten years, with concurrent increases in abundance (Pounds et al. 1999). Similar altitudinal shifts have been observed in butterflies (Parmesan 1996) and amphibians (Pounds et al. 1999), while northward range expansions have been documented in both European (Thomas and Lennon 1999) and North American birds (Johnson 1994).

Despite lingering uncertainties as to how climate change will affect Bicknell's Thrush, a negative response seems likely. Greenhouse warming is expected to accelerate over the next 50-100 years (Intergovernmental Panel on Climate Change 1996) and continue for many centuries (Karl and Trenberth 2003). In a warming world, projecting availability of future habitat is an essential element of biodiversity conservation (Peters and Darling 1985, Hunter et al. 1988). It enables the design of nature reserves, informs political debate on emissions standards, and prepares land managers to develop mitigation strategies. Given the vulnerability of current Bicknell's Thrush habitat, we propose that experimental manipulations of high-elevation forests are warranted in order to identify management options for counteracting or delaying effects of climate change.

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