Assessing and Reducing Threats to Mountain Birds on the Appalachian Trail through Monitoring, Modeling, and GIS Analysis

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Executive Summary

Mountain Birdwatch (MBW) is a long-term monitoring project for songbirds that breed in high-elevation forests of the northeastern United States and Canada. MBW's primary focus is Bicknell's Thrush, a montane-fir specialist that breeds only in the Northeastern U.S. and adjacent portions of Canada. Initiated in 2000, MBW trained citizen scientists to conduct annual surveys along point-count routes in Massachusetts, New York, Vermont, New Hampshire, and Maine. In 2010, MBW incorporated several protocol improvements, including a randomized selection of routes across the northeastern United States, a revised survey protocol to allow for more stringent statistical analyses, and an expansion into Canada to ensure consistent surveys across the entire breeding range of Bicknell's Thrush.

2011 yielded three notable accomplishments for the newly-launched program, Mountain Birdwatch 2.0 (MBW2): 1) a transition to volunteer-based surveys in the U.S.; 2) a completed launch of the full program in Canada, and 3) the establishment of a sub-sample of routes in NY and VT to more closely examine trends in the southernmost habitat of the Bicknell's Thrush breeding range. In the US, Bicknell's Thrush was detected at 32% of points, a detection rate that will allow us to achieve 80% power to detect a 3% annual change in Bicknell's Thrush abundance over 30 years at a significance level of 0.1. In Canada, detection rates were much lower (<10% of points with BITH detections), causing us to evaluate what potential program modifications will allow us to continue an international monitoring scheme while still achieving our goals. A single season occupancy analysis of United States data elucidates some of the variables related to Bicknell's Thrush expected occupancy in the southernmost reaches of the species' breeding habitat.

Background

The high-elevation forests of the northeastern United States provide habitat for a unique assemblage of breeding birds, several of which reach the southern limits of their distribution in these montane forests of spruce and fir. Most notably, mountain forests provide habitat for Bicknell's Thrush (*Catharus bicknelli*), the region's only endemic songbird. However, due to the inaccessibility of the high-elevation forests of the Northeast, several montane avian breeders are not included in any of the standardized state or federal bird monitoring schemes (e.g., the Breeding Bird Survey). As such, generating even rudimentary estimates of population trends or population size has proven difficult for species in this habitat, and the development of scientifically-defensible conservation strategies lagged accordingly. Mountain Birdwatch, a project of the Vermont Center for Ecostudies (VCE), was created to fill these information gaps.

Mountain Birdwatch began under the auspices of the VCE (at the time part of the Vermont Institute of Natural Science) Forest Bird Monitoring Program. Volunteers and staff 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, VCE biologists launched MBW as an independent project with fifty additional routes in Vermont and offered 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 survey region was expanded in 2001 to include over 100 new routes in New York, New Hampshire, Massachusetts, and Maine. The objectives of this original Mountain Birdwatch were to: 1) monitor the distribution and abundance of mountain-breeding birds in northern New England and New York; 2) describe the influence of landscape and habitat features on mountain bird distribution and abundance; and 3) guide stewardship of high-elevation forests.

Data collected under MBW have been put to a variety of uses: we have assessed the power of MBW 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); quantified short-term population trends (Lambert 2005); produced and validated a Bicknell's Thrush distribution model (Lambert et al. 2005); and projected effects of climate change on Bicknell's Thrush distribution (Lambert and McFarland 2004). We have also identified key management units and conservation opportunities for Bicknell's Thrush (Lambert 2003). More recently, we have conducted a ten-year trend analysis of MBW's five target species (Scarl 2011) and assessed the relative contribution of local and landscape variables to Bicknell's Thrush habitat occupancy in Vermont (Frey et al. 2011). We are currently using ten years of MBW data to construct an occupancy model assessing habitat requirements, colonization, and extinction trends for Bicknell's Thrush in the United States.

Mountain Birdwatch is also integral to the ongoing efforts of the International Bicknell's Thrush Conservation Group (www.bicknellsthrush.org) and serves as the main tool to evaluate progress towards the group's goals. In 2010, the International Bicknell's Thrush Conservation Group unveiled a Conservation Action Plan for Bicknell's Thrush; analyses of population trends and occupancy based on MBW data informed development of the Bicknell's Thrush Conservation Action Plan (IBTCG, 2010).

Despite the enormous potential of this monitoring project, the original MBW design exhibited several limitations. First, MBW investigated breeding birds in the high-elevation regions of New York, Vermont, New Hampshire, and Maine, yet birds are not constrained by state and country borders. High-elevation spruce-fir forests extend northward into Canada, as does the breeding range of Bicknell's Thrush (IBTCG, 2010). While Canadian-based Bicknell's Thrush distribution surveys and the High Elevation Landbird Program monitored this species in Quebec and the Canadian Maritimes, differences in survey protocols and timing made integration of results across regions difficult. Second, while initial route selection made an attempt at randomization across the available habitat, limitations in volunteer effort and the addition of new, non-random routes created a non-random MBW survey sample. This limits inferences that can be drawn across an entire population or habitat. Third, the original MBW allowed volunteers to select one of two survey protocols: volunteers could either focus on five species of high-elevation birds or note all species observed during a survey. Differences in observer attention or effort may have influenced results, even for detections of the five species that all volunteers surveyed. Finally, in recent years, scientists have recognized that detectability is an essential consideration in bird monitoring programs (MacKenzie et al. 2006); detectability is a measure of the probability of detecting a species if that species is in fact present. Analyses that account for detectability tend to more accurately represent population trends than those that do not consider this variable, especially for difficult-to-detect species (Rota et al. 2011). Although estimates of detectability are possible with MBW data, important variables that may influence detectability were not measured, and thus accuracy of detectability estimates may be poor.

Mountain Birdwatch 2.0

Mountain Birdwatch 2.0 (MBW2) was developed to address the shortcomings of the original MBW and provide a long-term, international monitoring program that surveyed high-elevation birds across the entire breeding range of the Bicknell's Thrush. MBW2 incorporates the following improvements:

1. MBW2 is a partnership between government, non-government, and academic institutions in the U.S. and Canada. Using a Bicknell's Thrush potential habitat model (Lambert et al 2005) to identify a survey frame, MBW2 routes were selected randomly across all potential Bicknell's Thrush habitat in both countries. A Generalized Random Tessellation Stratified (GRTS) sampling design ensured a spatially balanced but randomized selection of survey stations while also allowing for randomized subsampling in specific regions of interest. With randomly selected routes and systematic surveys conducted across the entire breeding range of the Bicknell's Thrush, MBW2 data will allow us to draw strong conclusions about abundance, occupancy, trends, and distribution across an entire habitat.
2. MBW2 incorporates a new survey protocol that focuses on a broader array of montane species while allowing for improved calculations of detectability. All MBW2 participants will collect data on 11 species (Table 1), leading to an expanded and consistent target list with one protocol for all participants. This expanded focus, which also incorporates surveys of the Red Squirrel, a common avian montane nest predator, will allow us to draw conclusions about the broader ecosystem and predator-prey cycles as well as standardize volunteer effort.

Table 1: Species surveyed by all MBW2 participants.

Common Name	Scientific Name	Species Code
Yellow-bellied Flycatcher	*Empidonax flaviventris*	YBFL
Black-capped Chickadee	*Poecile atricopilla*	BCCH
Boreal Chickadee	*Poecile hudsonica*	BOCH
Winter Wren	*Troglodytes troglodytes*	WIWR
Bicknell's Thrush	*Catharus bicknelli*	BITH
Swainson's Thrush	*Catharus ustulatus*	SWTH
Hermit Thrush	*Catharus guttatus*	HETH
Blackpoll Warbler	*Dendroica striata*	BLPW
Fox Sparrow	*Passerella iliaca*	FOSP
White-throated Sparrow	*Zonotrichia albicollis*	WTSP
Red Squirrel	*Tamiasciurus hudsonicus*	RESQ

Goals

Mountain Birdwatch 2.0 identifies the following monitoring and programmatic goals (reproduced from Hart and Lambert 2010):

<u>Monitoring</u>

Monitoring Goal 1: To measure the annual population status of target species in terms of distribution, abundance/density, and occupancy

Monitoring Goal 2: To measure changes in the population status of target species over time

Monitoring Goal 3: To relate population status and trend information to biotic and abiotic variables that may affect the target species

<u>Programmatic</u>

Programmatic Goal 1: To make observational data (date, location, count, etc.) and associated metadata publicly available for visualization and download through the Avian Knowledge Network (AKN), while recognizing legal, institutional, proprietary, and other constraints.

Programmatic Goal 2: To provide decision-makers with tools and analyses to conserve high-elevation birds in the Northern Appalachian and Laurentian Regions

Programmatic Goal 3: To increase public understanding of the ecology, status, and conservation requirements of high-elevation songbirds in the Northern Appalachian and Laurentian Regions.

For a detailed description of Mountain Birdwatch 2.0 protocols and history, please see Hart and Lambert 2010.

United States Initiative

Mountain Birdwatch 2.0 was launched in the United States in 2010. In June and July of 2010, nine technicians and Mountain Birdwatch director Judith Scarl established 96 routes with a total of 529 points across New York, Vermont, New Hampshire, and Maine. Technicians mapped and documented these routes using GPS points, written descriptions, and photographs. Since MBW2 aims to compare avian population trends with habitat characteristics, technicians measured habitat variables at up to three subplots around each survey station. Technicians conducted point counts at 410 of these stations in June and July of 2010. These efforts set the stage for decades of future surveys.

Re-Launching a Volunteer Program

Mountain Birdwatch has always been a citizen science program at its core, and in 2011 MBW2 welcomed volunteers onto its new routes. In May of 2011, Mountain Birdwatch director Judith Scarl held a volunteer training workshop in each of the four participating Mountain Birdwatch states (NY, VT, NH, and ME). 40 Mountain Birdwatch volunteers attended training sessions, with some volunteers traveling hundreds of miles to participate. At these sessions, volunteers learned about the history of the Mountain Birdwatch program, applications of the original MBW data, the benefits of the revised monitoring program, and identification characteristics of the target species. Volunteers also participated in a practice point count using recorded bird songs and calls.

In 2011, volunteers (for an example, see Figure 1) surveyed 64 routes across the northeastern United States. With the addition of new routes in 2011 and additional recruitment and training sessions in 2012, we expect the number of routes covered by volunteers to nearly double in 2012.

Figure 1: Volunteers Peg Ackerson and Pip Richens finish a dawn survey on Mt. Blue in June of 2011.

Mountain Birdwatch and the Appalachian National Scenic Trail

The Appalachian National Scenic Trail (AT) runs through the heart of much of the Bicknell's Thrush breeding habitat in the United States. Since MBW2 routes lie along roads or trails in potential Bicknell's Thrush habitat, many of this project's routes are on or within 1 km of the AT (Figure 2). In 2010, technicians set 22 routes that had at least one survey station within 1 km of the AT, and an additional 7 routes were added within these boundaries in 2011; these are considered AT routes.

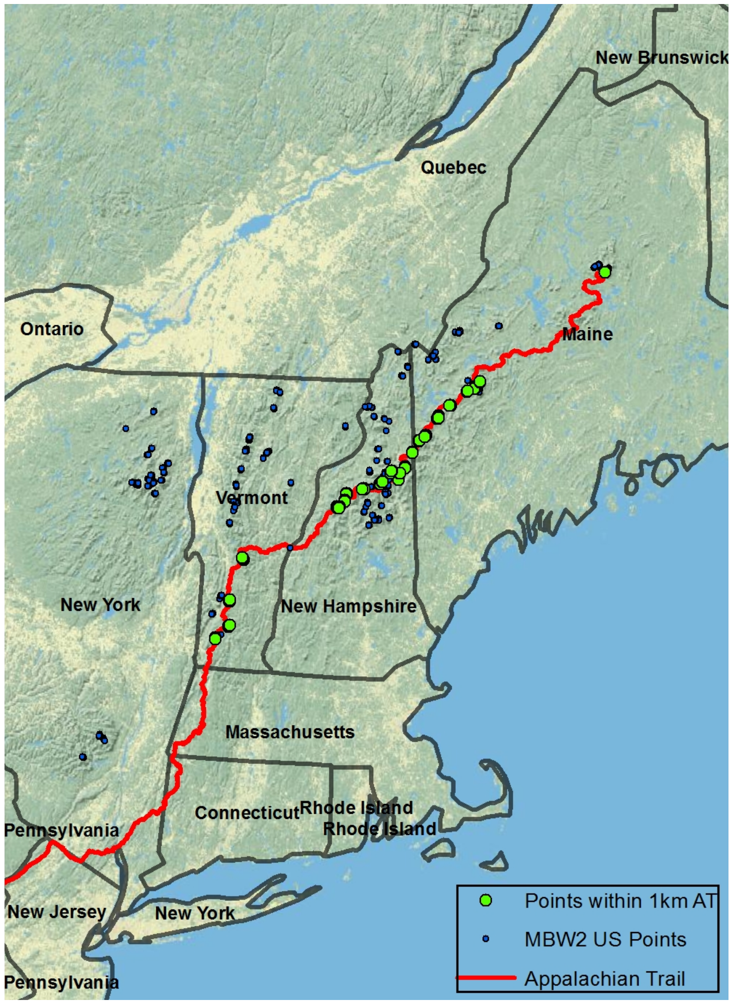

Figure 2: Mountain Birdwatch points near the Appalachian Trail.

Volunteers and technicians surveyed 151 points along 27 AT routes in 2011; this represents ~25% of all points successfully surveyed in the U.S. in 2011. Of these 27 AT routes, 5 are located in southern Vermont, 14 in the White Mountains of New Hampshire, and 8 fall in Maine.

New York and Vermont Subsample

Under the original MBW2 route selection criteria, Vermont and New York were assigned fewer routes than Maine and New Hampshire. In Vermont, high-elevation spruce-fir habitat is limited largely to the spine of the Green Mountains and to a few high peaks in the Northeast Kingdom, and thus the total area of spruce-fir forest is small compared to other regions. New York's Catskill Mountains have an even smaller area available for birds looking to nest in high-elevation spruce-fir forest. The Adirondacks of New York have a substantial percentage of the potential Bicknell's Thrush habitat in the United States; however, large portions of this habitat are difficult to reach due to lack of road or trail access or overly long hike durations.

Despite the small number of routes initially selected for New York and Vermont, the high-elevation regions of these two states merit closer attention. The Catskills and the southern Green Mountains of Vermont represent the southernmost extent of the high-elevation spruce-fir forest in which Bicknell's Thrush breeds. Climate-related changes in species' ranges often manifest as expansions or contractions at range edges (Parmesan 2006) and a regional increase of 1 degree Celsius may be enough to eliminate all Bicknell's Thrush breeding habitat from these regions (Rodenhouse et al 2008). Thus to detect early warning signs of global climate change, the southernmost limits of Bicknell's Thrush breeding habitat merit closer monitoring. Second, data from the original Mountain Birdwatch project indicate that unlike in other regions, Bicknell's Thrush detections have increased in the Adirondacks and Catskills over the past decade (Scarl 2011). More extensive monitoring will elucidate whether Bicknell's Thrush population size is increasing in New

York State or whether these trends are a short-term spike or an artifact of sampling effort. Third, the greatest numbers of Mountain Birdwatch volunteers have historically been active in New York and Vermont, demonstrating a potential for closer monitoring in those states.

In 2011, technicians established an additional 5 routes in the Catskills, 8 in the Adirondacks, and 12 in the Green Mountains of Vermont as part of a regional subsample; two of these routes were on or near the AT. In addition, in 2011 technicians set and surveyed an additional 17 routes for the national sample that were not established in 2010 or required revisions. Thus, 2011 marked the completion of the US launch of MBW2. Our randomized, statistically sound subsampling will allow us to draw conclusions about Bicknell's Thrush and other high-elevation breeding birds at international, national, and regional scales.

2011 U.S. Overview

Volunteers and technicians surveyed 636 points along 118 routes in the United States in 2011 (see Figures 3 and 4); data from 23 points were excluded from analysis due to improper collection (survey methods not followed, data collected at wrong location, survey station not within Bicknell's Thrush habitat model). Bicknell's Thrush was detected on 59% of routes and at 31.9% of points (Table 2). Vermont had the lowest percentage of points with Bicknell's Thrush detections; BITH was observed at only 23% of points in this state. The Catskills had the highest detection rates of any region; 18 out of 31 points (58.1%) had Bicknell's Thrush detections. While these data are uncorrected for detectability, observer skill, or field conditions, they do suggest that the New York mountains provide important habitat for this vulnerable species.

Table 2: U.S. sampling effort in 2011.

Region	Routes Surveyed	Points Surveyed	Routes with BITH detections	Points with BITH detections
Catskills (NY)	6	31	6 (100%)	18 (58.1%)
Adirondacks (NY)	16	84	9 (56.3%)	33 (39.3%)
New York Total	22	115	15 (68.2%)	51 (44.3%)
Vermont	23	120	11 (47.8%)	28 (23%)
New Hampshire	46	236	31 (67.4%)	79 (33.5%)
Maine	27	142	13 (48.1%)	38 (26.7%)
Overall (U.S.)	**118**	**613**	**70 (59.3%)**	**196 (31.9%)**

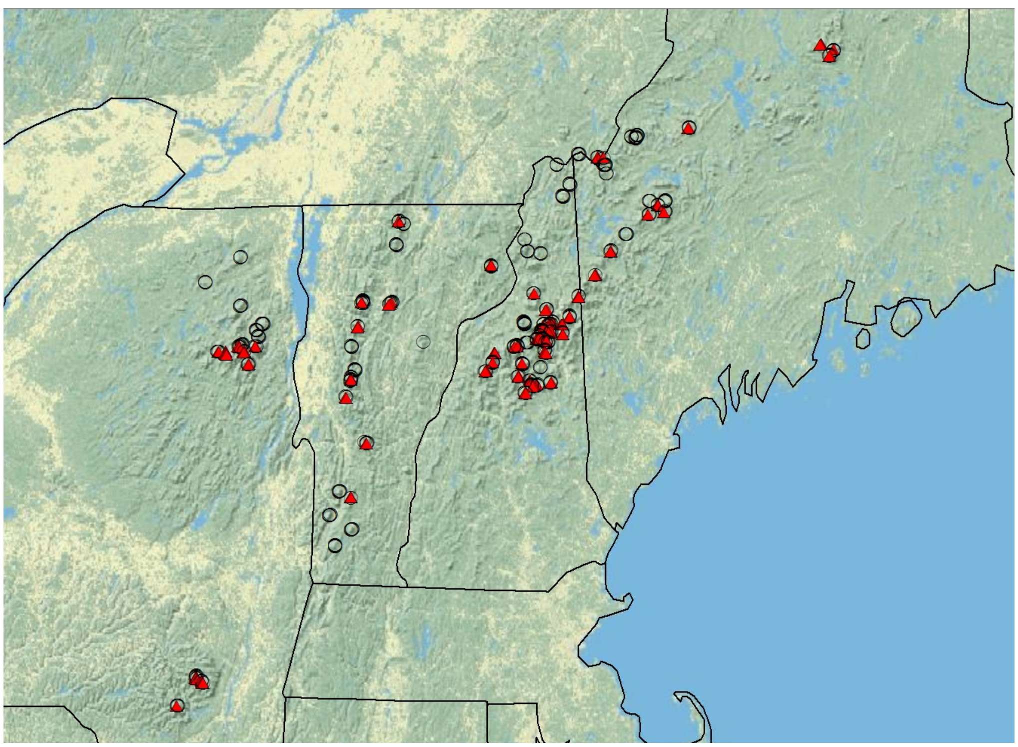

Figure 3: MBW2 points surveyed in the U.S. in 2011. Red triangles represent points with BITH detections; open circles represent points where no BITH were detected. Some data from Maine have been excluded from this map due to confidentiality agreements with landowners.

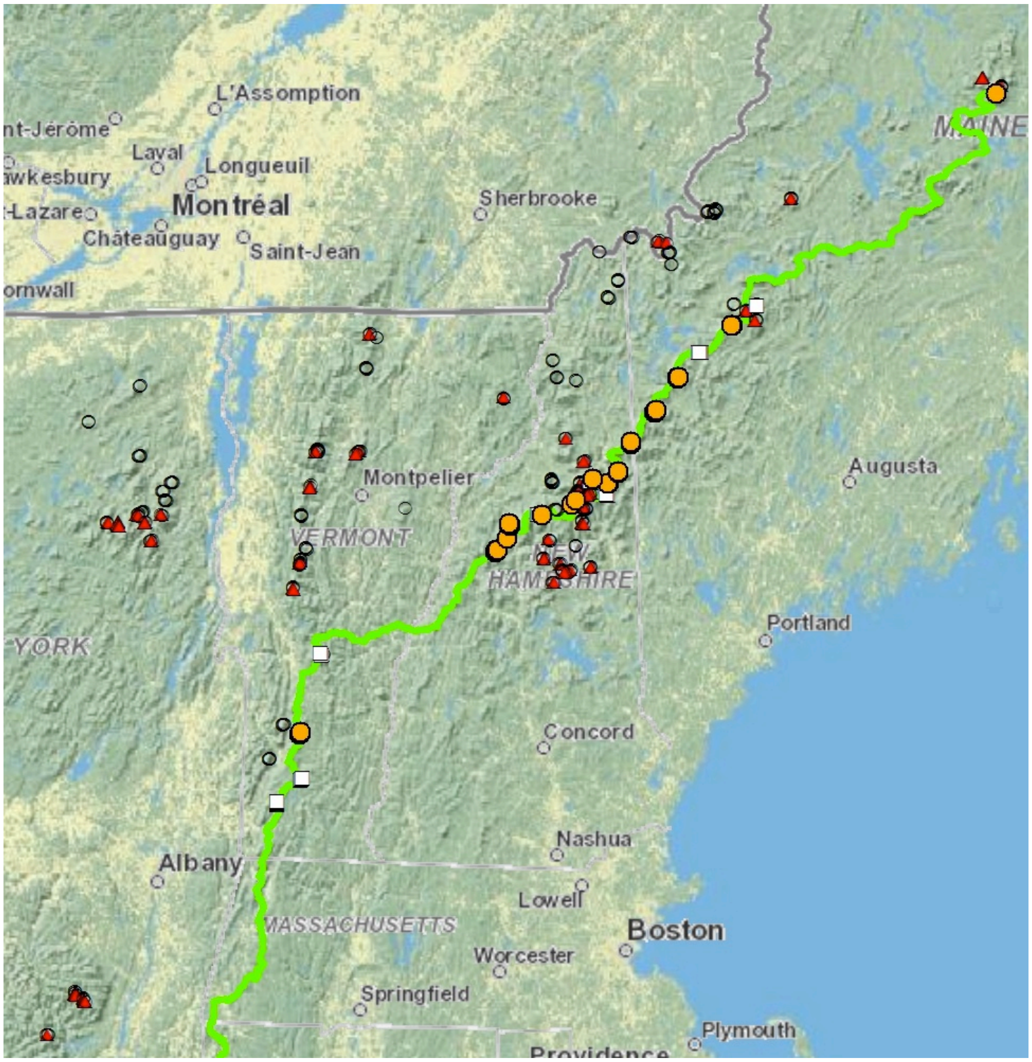

Figure 4: BITH detections along AT-associated points in 2011. Orange circles represent points where BITH was detected; white squares represent surveyed points where BITH was not detected in 2011. BITH detections are evenly distributed across the high-elevation areas of the northeastern AT.

"Across the Breeding Range"- International Mountain Birdwatch

Launch and Surveys

2011 marked the international launch of MBW2. A total of 1063 points were surveyed internationally as part of Mountain Birdwatch 2.0 (Figure 5); approximately 475 of these points were part of the original international sample, while the remaining points represented U.S. and statewide subsamples. As noted above, 636 points along 118 routes were surveyed in the United States, and Bicknell's Thrush was detected at 196 points (32%) along 70 routes in the U.S. alone. In Québec, 338 points along 58 routes were surveyed in 2011, with BITH detected at only 3% of these points. In the Maritimes, 88 points were surveyed along 15 routes, and Bicknell's Thrush was detected at 7 (8%) of these points. All of the BITH detections in the Maritimes occurred in New Brunswick; no BITH were detected in Nova Scotia. Overall, BITH was detected at 6% of international survey stations (see Table 3).

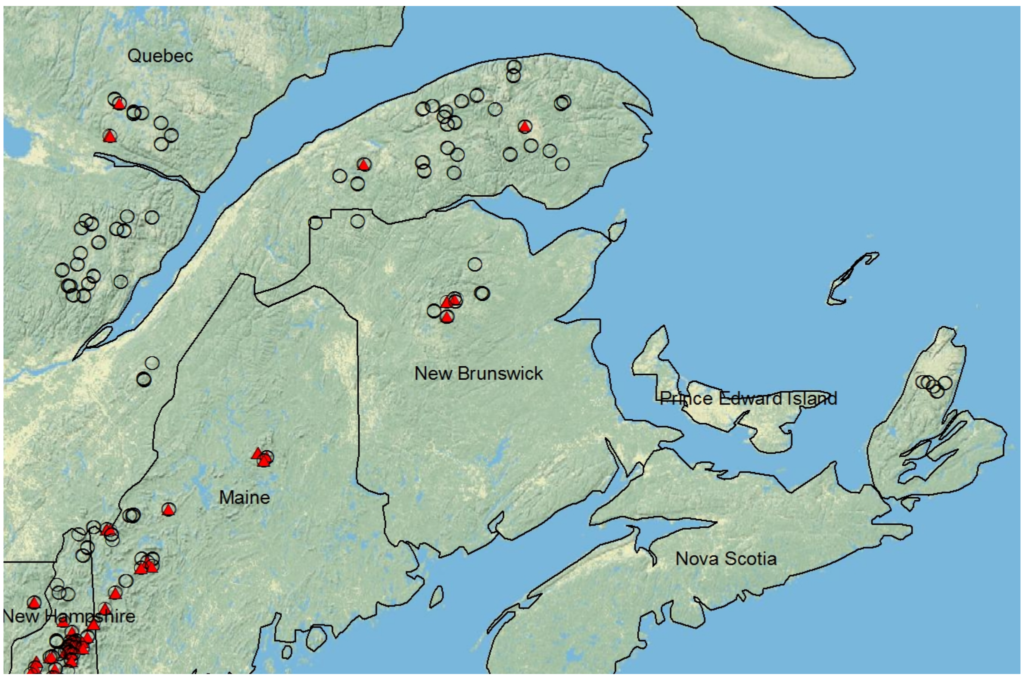

Figure 5: MBW2 points surveyed in Canada in 2011. Red triangles represent points with BITH detections; open circles represent points where no BITH was detected.

Table 3: International MBW2 sampling effort in 2011. Data from the U.S. represent points surveyed as part of the international sample only.

Region	Routes Surveyed	Points Surveyed	Points with BITH detections
Québec	58	338	11 (3%)
Maritimes	15	88	7 (8%)
U.S. (Int'l Sample)	8	46	10 (21.7%)
TOTAL	**81**	**472**	**28 (5.9%)**

International Survey: Meeting our Goals?

As part of MBW2's objectives, detailed in Hart and Lambert 2010, this project aimed to:

- Achieve 80% power to detect a 3% annual change in Bicknell's Thrush abundance over 30 years at a significance level of 0.1
- Maintain a coefficient of variation less than or equal to 0.4 for BITH population trend estimates over 30 years.

Prior to the launch of MBW2, Frank Rivera of the U.S. Fish and Wildlife Service analyzed MBW2 pilot data from 2008 and concluded that 400-700 stations would allow a coefficient of variation of 0.2 on an annual estimate of Bicknell's Thrush density (Hart and Lambert 2010). However, Rivera's calculations of sample size were based on pilot data from the U.S., where Bicknell's Thrush densities may be much higher than in Canada (COSEWIC 1999); 30% of pilot survey stations yielded BITH detections. With Bicknell's Thrush detected at fewer than 6% of international points in 2011, MBW2 partners are concerned that Mountain Birdwatch will not achieve its original objectives. In addition, participants are concerned about the difficulty of financially sustaining the international program; Canadian funders may hesitate to support a program that fails to detect Bicknell's Thrush across such a large percentage of Canadian routes.

At an IBTCG meeting in Québec in November 2011, regional managers discussed whether to modify MBW2 protocols to obtain higher rates of BITH detections in Canada. With much of the potential BITH habitat in Canada falling within industrial forest, many MBW2 stations may exist within recently harvested parcels, with no appropriate habitat remaining. Alternatively, elevation thresholds of the BITH habitat model may include areas that are generally too low to support high-quality Bicknell's Thrush habitat, except in extreme conditions. Limiting route selection to higher-quality habitat would limit the program's conclusions to birds only in that habitat, but the benefits of detecting BITH more frequently may outweigh the downsides of further limiting route selection. As of April 2012, international MBW2 managers are exploring the possibility of developing separate sampling schemes for protected/unmanaged land and industrial forests to further elucidate the impact forestry practices have on Bicknell's Thrush while concentrating sampling effort on current high-quality potential Bicknell's Thrush habitat. We will continue to use the existing MBW2 protocol to survey routes established in 2010 and 2011 in the United States.

2011 US Occupancy Analysis

While the primary MBW2 objectives involve detecting long-term trends and changes in order to inform conservation strategies, each year of data collection offers a "snapshot" of the status of high-elevation breeding birds during a given season. These early years of MBW2 will provide a baseline against which we can evaluate future changes and can provide information about species' current distribution patterns and habitat requirements.

One issue with conventional analyses of abundance and distribution is that few statistical analyses take detectability into account. Detectability is the probability that if a species is present (available to be detected), the observer will detect it. With variations in frequency and intensity of animal signals, along with environmental factors that impede the ability to detect species in the field, raw counts of individuals detected or sites at which individuals are detected may dramatically underestimate the number of individuals or occupied sites.

Analyses that account for detectability, such as occupancy analyses (Mackenzie et al 2006) are becoming more popular for analyzing data collected during research and monitoring. Single-season occupancy modeling allows researchers to analyze presence-presumed absence data in relation to environmental variables (Mackenzie et al 2006) while modeling and accounting for detectability.

Mountain Birdwatch survey protocols were optimized to provide data suitable for several types of analyses, including occupancy analysis. Using 2011 MBW2 data collected in the U.S., we constructed a single-season, single-species occupancy model to evaluate how Bicknell's Thrush occupancy of sites in the United States relates to environmental and habitat variables.

Survey Methods

Routes were selected randomly across all potential Bicknell's Thrush habitat (Lambert et al 2005) using a Generalized Random Tessellation Stratified Design, which allows for spatially balanced randomized sampling. Routes were established only along trails or roads, further limiting the selection process. Each route contained up to 6 points set at 250-meter intervals within potential habitat along the road or trail.

Trained technicians established routes in 2010 or 2011, using GPS to document point locations along trails. Technicians further documented each point through digital photographs and verbal descriptions to ensure that observers could find the exact survey station in subsequent years. Technicians also conducted habitat surveys at up to three 10-

meter radius plots located 25 meters E, S, N, or W of the survey station. Habitat surveys measured average tree height, canopy and subcanopy composition, slope and aspect of plot, basal area of vegetation, and amount of canopy, shrub, and ground cover within each plot.

Volunteers and technicians conducted 20-minute point counts at each survey station along routes in June and July of 2011. Point counts were divided into four 5-minute simple count intervals; individual birds were counted once within each 5-minute interval, and the count started over every five minutes. Each individual Bicknell's Thrush was tracked every minute for the first ten minutes; for the last ten minutes Bicknell's Thrush was counted in five-minute simple counts like the other species. Observers recorded temperature, wind speed, and cloud cover at the start of each point count. For a more detailed description of Mountain Birdwatch 2.0 methods, see Hart and Lambert 2010.

Of the 613 points at which survey data was accurately collected in 2011, 581 points were analyzed in the occupancy model. The remaining 32 points were missing environmental measurements; in the majority of these cases, the observer did not measure temperature or technicians did not measure tree height, canopy composition, or balsam basal area.

Model Selection

In collaboration with Dr. John Lloyd of Ecostudies Institute, we constructed a single-season, single-species occupancy model for Bicknell's Thrush observations in the United States in 2011. Bicknell's Thrush detections were collapsed into five-minute periods for the first ten minutes of each count, yielding four five-minute periods across each 20-minute survey. Each period was coded for whether the species was detected (presence) or not detected (presumed absence) during each of the four periods, yielding a temporally replicated survey design at each point. Each survey station ("site") was treated as an independent sample, even though multiple survey stations fell along each route. Site-level habitat variables measured at up to three subplots near each survey station were averaged to yield one value for each site.

Seven variables were used to model detectability (p): wind speed, cloud cover (including rain), temperature, date, time, observer experience, and patch size (Table 4). Weather variables such as wind speed (Simons et al 2007), cloud cover, and temperature (Gottlander 1987) commonly affect breeding bird detectability, both because birds' signal characteristics or signaling frequency may be changed by those conditions (Lengagne and Slater, 2002) and also because variations in environmental conditions affect an observer's ability to hear or see (Simons et al 2007). Detectability can also be influenced by date and time during the breeding season (Mattsson & Marshall 2009; Slagsvold, 1976) as patterns of behavior change during the day and across the season. Observer characteristics, such as experience and training, can impact how an observer "performs" during a point count (Sauer and Link, 2011). Species abundance can also impact detection; with more individuals at a given location, detection of the species may be more likely. Although we do not have a priori knowledge of species abundance at our survey stations, habitat patch size may serve as a proxy for abundance, with larger patches able to support more individuals on average. Frey, Strong, and McFarland (2011) found patch size to be a strong predictor of detection probability in research on Bicknell's Thrush in Vermont.

Table 4: Detectability variables.

Variable	Description
Date	Survey Date
Time	Time of day- start of survey
Training	Categorical; staff, volunteer attended training session, volunteer did not attend training session
Wind	Categorical; wind speed (see Hart and Lambert 2010)
Cloud	Categorical; weather (see Hart and Lambert 2010)
Temperature	Temperature (Fahrenheit)
PatchSize	Area of suitable habitat within a 2 km radius of survey station

Variables used to model species occupancy (psi; Table 5) were based on the species' natural history (Rimmer et al 2001) and previous occupancy analyses of Bicknell's Thrush in its breeding habitat in Vermont (Frey et al 2011). Although elevation and latitude are limited by the model used to select sites (Lambert and McFarland 2005), the model does not differentiate habitat by quality, and a visual inspection of the data suggested that Bicknell's Thrush was not detected at the lowest-elevation sites surveyed. We predicted that expected occupancy would increase with increasing elevation. Bicknell's Thrush nests in dense, short or stunted patches of balsam fir (Rimmer et al 2001) and thus we included basal area of balsam fir, average tree height, and percent of the canopy that is balsam fir in our model. We predicted that expected occupancy would decrease with increasing tree height and increase with increasing balsam fir basal area and canopy composition. Average patch size, representing the amount of coniferous habitat within the model envelope within 2 km of each point, was found to be a good predictor of Bicknell's Thrush occupancy in Vermont by Frey et al (2011) when combined with local habitat factors, and we included this variable in our model as well.

Table 5: Occupancy variables.

Variable	Description
Elevation	Elevation of survey station
Latitude	Latitude of survey station
PatchSize	Area of suitable habitat within a 2 km radius of survey station
BalsamBasal	Basal area of balsam fir averaged across up to three subplots
BalsamCanopy	Percentage of balsam fir in the canopy, averaged across up to three subplots
TreeHeight	Height of average canopy tree, averaged across up to three subplots

We used a two-stage process for modeling detectability and occupancy using R statistical software (R Development Core Team, 2012) with the package "Unmarked" (Fiske & Chandler 2011). We began by considering all detectability models (Figure 6) while holding occupancy constant. We then selected the best detectability models based on Akaike Information Criterion (AIC) weights; all models within 3 AIC units of the top model were included with all of the occupancy models (Figure 7). This was to reduce the number of model runs; instead of running all detectability models with all occupancy models, we included only the detectability models that had a reasonable likelihood of being the best model in the set.

Detectability
Global Model: Date+Time+Wind+Cloud+Temperature+PatchSize+Training
Model1: Date+Time+Wind+Cloud+Temperature+PatchSize
Model2: Date+Time+Wind+Cloud+Temperature+Training
Model3: Date+Time+Wind+Cloud+PatchSize+Training
Model4: Date+Time+Wind+Cloud+Temperature
Model5: Date+Time+Wind+Cloud+Training
Model6: Date+Time+Wind+Cloud+PatchSize
Model7: Date+Time+Wind+Cloud
Model8: (.)

Figure 6: All potential detectability models

Occupancy
Global Model: Elevation+Latitude+PatchSize+BalsamBasal+BalsamCanopy + TreeHeight
Model1: Elevation+Latitude+PatchSize+BalsamBasal+BalsamCanopy
Model2: Elevation+Latitude+PatchSize+BalsamBasal+TreeHeight
Model3: Elevation+Latitude+PatchSize+BalsamCanopy+TreeHeight
Model4: Elevation+Latitude+PatchSize+BalsamBasal
Model5: Elevation+Latitude+PatchSize+BalsamCanopy
Model6: Elevation+Latitude+PatchSize+TreeHeight
Model7: Elevation+Latitude+PatchSize
Model8: Elevation+Latitude
Model9: PatchSize
Model10: (.)

Figure 7: All potential occupancy models

Model Results

Only three detectability models had AIC values within three points of the top model (Table 6), and we used each of these top three models in our occupancy analysis.

Table 6: Detectability models with AIC values and weights. The top three detectability models were retained for analysis with occupancy models.

Detectability Model	Variables	AIC value	Delta AIC	AIC Weight
p(date+time+wind+cloud+patchsize)	14	1648.17	0	0.44
p(date+time+wind+cloud+temperature+patchsize)	15	1648.53	0.35	0.37
p(date+time+wind+cloud+patchsize+training)	16	1650.91	2.74	0.11
p(Global)	17	1651.61	3.43	0.079
p(date+time+wind+cloud+temperature)	14	1662.75	14.58	0.0003
p(date+time+wind+cloud)	13	1663.78	15.61	<0.0001
p(date+time+wind+cloud+temperature+training)	16	1665.08	16.91	<0.0001
p(date+time+wind+cloud+training)	15	1665.66	17.48	<0.0001
p(.)	2	1675.68	27.51	<0.0001

Several of our occupancy models received support (Table 7), creating substantial uncertainty about which occupancy model most closely aligns with our data. Since the goal in conducting occupancy analysis was to generate a better understanding of how occupancy varied as a function of habitat covariates, we used model-averaged predictions to allow us to examine the nature of the relationship between each covariate and occupancy.

Table 7: Occupancy models with AIC values and weights. Only models with an AIC weight >0.01 are shown here. Elev=elevation; lat=latitude; area=patch size; height= tree height; %balsam= percent canopy balsam; basal= balsam basal area.

Models	Var	AIC	deltaAIC	AIC weight
p(time+date+cloud+wind+temp+area),Psi(elev+lat+area+height)	19	1597.56	0	0.22
p(time+date+cloud+wind+area),Psi(elev+lat+area+height)	18	1597.92	0.36	0.18
p(time+date+cloud+wind+temp+area),Psi(elev+lat+area+%balsam+height)	20	1599.03	1.47	0.10
p(time+date+cloud+wind+temp+area),Psi(elev+lat+area+basal+height)	20	1599.3	1.74	0.09
p(time+date+cloud+wind+area),Psi(elev+lat+area+%balsam+height)	19	1599.46	1.9	0.084
p(time,date,cloud,wind,area),Psi(elev+lat+area+basal+height)	19	1599.62	2.06	0.077
p(time+date+cloud+wind+exp+area),Psi(elev+lat+area+height)	20	1600	2.44	0.064
p(time+date+cloud+wind+temp+area),Psi(elev+lat+area+basal+%balsam+height)	21	1600.18	2.62	0.059
p(time+date+cloud+wind+area),Psi(elev+lat+area+basal+%balsam+height)	20	1600.58	3.02	0.048
p(time+date+cloud+wind+exp+area),Psi(elev+lat+area+%balsam+height)	21	1601.56	4	0.029
p(time+date+cloud+wind+exp+area),Psi(elev+lat+area+basal+height)	21	1601.76	4.2	0.027

Using model-averaged predictions to create graphs of habitat-occupancy relationships, three variables emerge that are closely related with variation in occupancy: elevation, patch, size, and tree height. Although the habitat model used for site selection was limited to elevations and latitudes that could potentially contain Bicknell's Thrush habitat, elevation emerged as a strong predictor of expected occupancy. Holding all other variables constant at their mean values, expected occupancy doubled as elevation increased by ~450 meters (Figure 8).

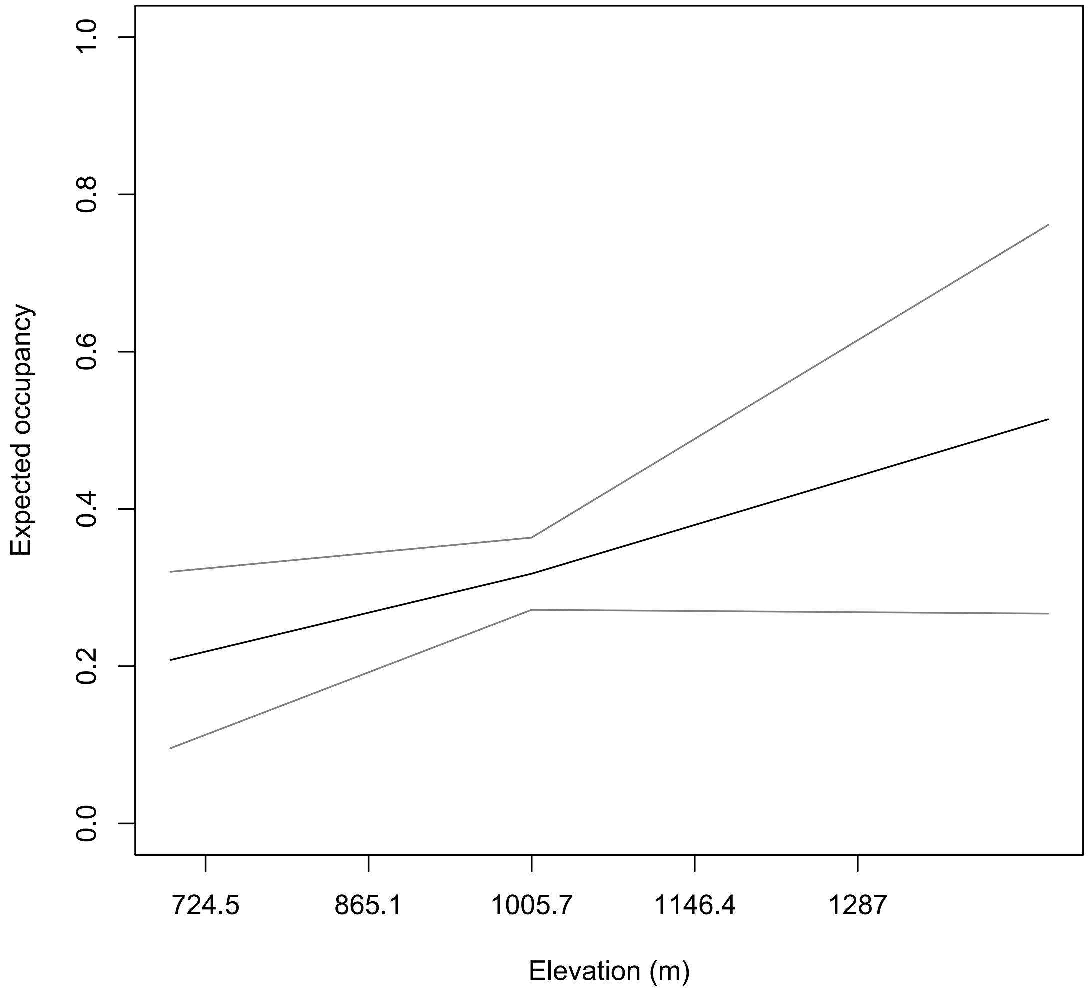

Figure 8: Relationship between elevation and expected occupancy. Note that only three values, centered around the mean, were used to create this and subsequent graphs.

The amount of habitat within 2 km of each survey station was also related to the expected occupancy of a site; expected occupancy approximately doubles as patch size quadruples (Figure 9), holding other variables at their mean values.

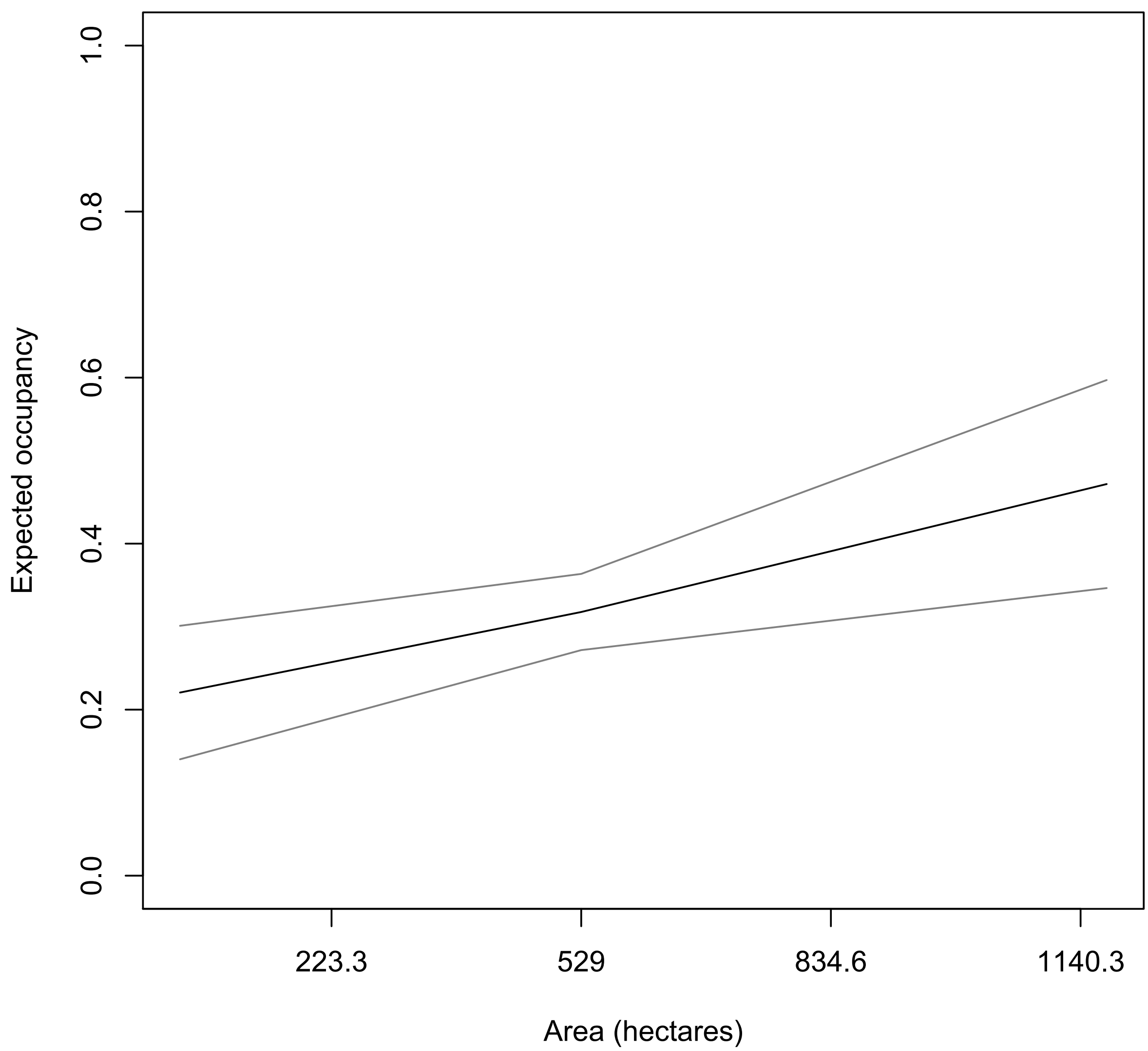

Figure 9: Expected occupancy approximately doubles as amount of habitat within a 2-kilometer radius quadruples.

Only one locally-measured habitat variable included in the model played a role in predicting expected occupancy. At the mean of all other variables, tree height demonstrated a strong negative relationship with expected occupancy (Figure 10), with expected occupancy halving as tree height triples.

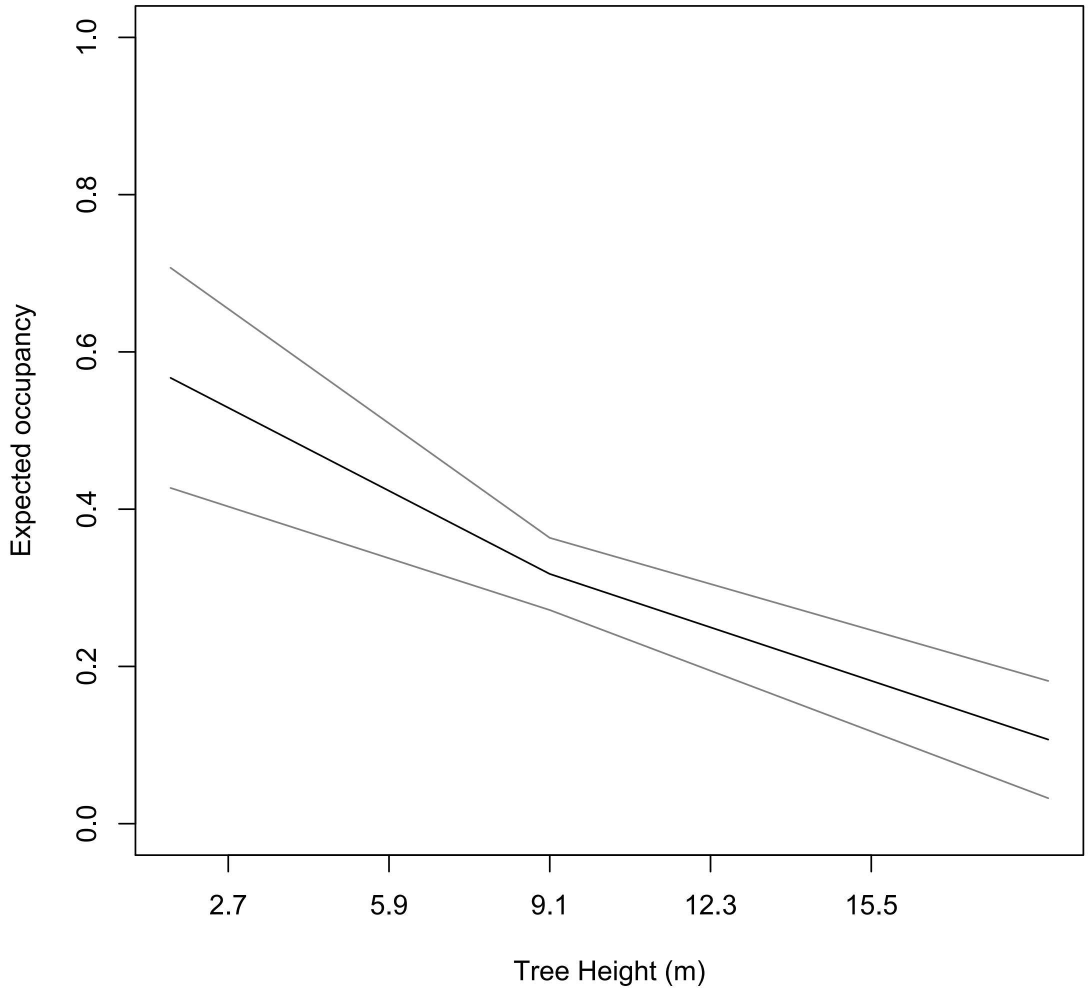

Figure 10: Expected occupancy is halved as tree height triples.

Neither balsam basal area (Figure 11) nor percent of the canopy composed of balsam fir had a strong relationship with expected occupancy (Figure 12). These analyses indicated a strong negative relationship between latitude and occupancy, but this may be confounded by land use practices (more industrial forest at northern latitudes in the U.S.) and thus we do not include a discussion of this effect.

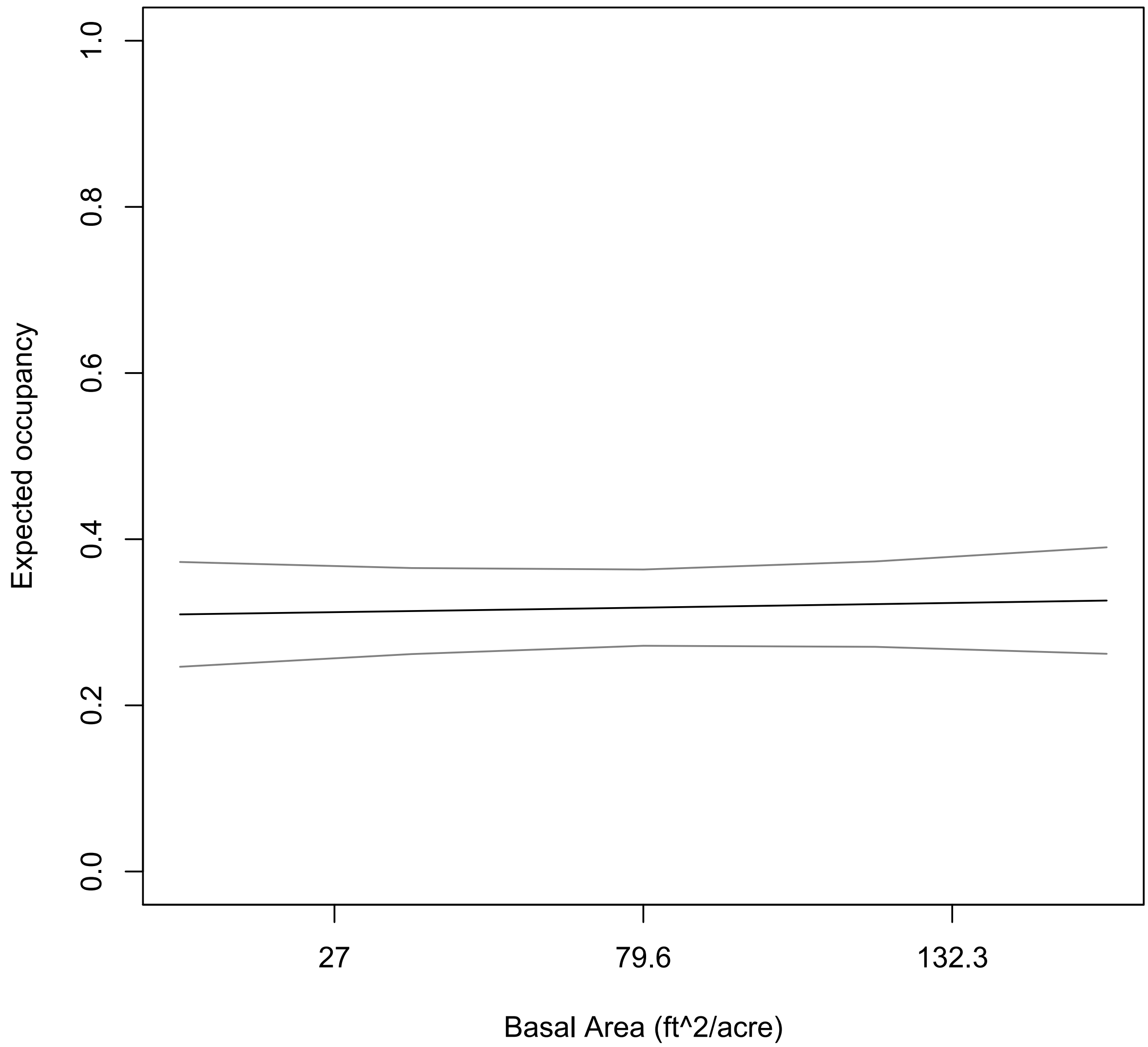

Figure 11: Relationship between expected occupancy and basal area of balsam fir.

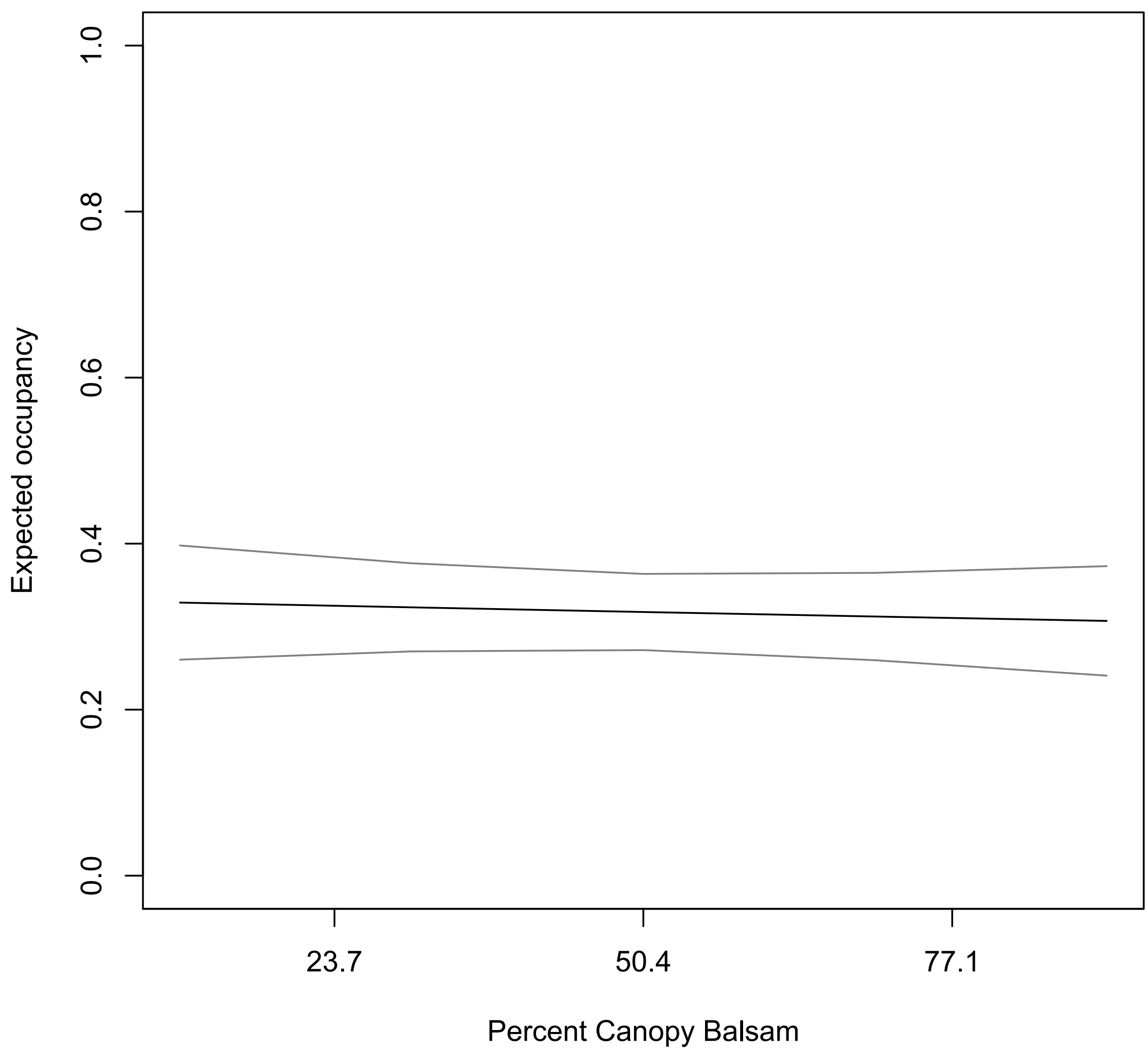

Figure 12: Relationship between expected occupancy and the percent of canopy composed of balsam fir.

Occupancy Model: Discussion

While no one model emerged as the obvious best fit for explaining the pattern of occupancy data, examining each weighted variable demonstrated which environmental variables were most closely related to occupancy: elevation, patch size, and tree height. While the Bicknell's Thrush model used to select potential survey sites was limited by elevation

(Lambert and McFarland 2005), this habitat model reflects *potential* Bicknell's Thrush habitat, rather than habitat that is currently suitable for this species. That is, the model indicates the envelope within which Bicknell's Thrush habitat could exist given the right environmental conditions; many sites surveyed as part of MBW2 would require major disturbances in order to support Bicknell's Thrush habitat. In addition, this model does not address the quality or potential quality of the potential habitat. The lowest elevations within this habitat envelope may represent habitat that would be suitable for Bicknell's Thrush only in rare situations. Our model results that expected occupancy increases with elevation also mirror the subjective experiences of several volunteers and technicians, who indicated that some of the survey sites were "too low"; that is, they were dominated largely by hardwoods, which are prevalent on mountains in the northeastern U.S. below the spruce-fir ecotone. These results suggest that the lowest elevations within the Bicknell's Thrush model may have less potential to serve as high-quality Bicknell's Thrush habitat than higher areas.

Patch size also had a strong relationship with expected occupancy. Frey et al (2011) found that patch size could be a strong predictor of expected occupancy in Vermont when local variables were also considered; the current model suggests that patch size on its own may be an important factor in Bicknell's Thrush occupancy across the northeastern U.S. Tree height shows an even stronger relationship with expected occupancy. Bicknell's Thrush prefers to nest in areas of short, stunted, dense balsam fir and red spruce (Rimmer et al 2001), and these results help to quantify the ideal canopy height for Bicknell's Thrush.

Although Bicknell's Thrush tend to like dense stands of trees, basal area of balsam fir was not closely related to expected occupancy. A measurement of basal area may not be addressing the characteristics of a tree stand that are relevant to this species. Basal area measures the cross-sectional area of all stems of a species. Several small trees may have a similar area to one large tree. Thus tree density may be more important to Bicknell's Thrush than basal area of balsam fir.

The percent of canopy represented by balsam fir also was not strongly related to estimated occupancy when all other factors were held constant. This variable may be most important when trees are small; if canopy is 100% balsam but the canopy is 10 meters high, Bicknell's Thrush will not find the short, stunted habitat it prefers. Exploring the relationship between canopy composition and Bicknell's Thrush occupancy at different tree heights may yield different results.

Even though no single model emerged as the strongest representative of the relationship between occupancy and habitat variables, these analyses clarified the role that three environmental variables play in expected occupancy of Bicknell's Thrush in the northeastern United States. As we collect more occupancy data into the future, we will be able to explore longer-term trends in Bicknell's Thrush habitat use and distribution.

Conclusions

The past two years have marked an important transition for the Mountain Birdwatch program; we concluded a decade of data collection across the mountains of NY, VT, NH, and

ME, and we launched an international collaboration to monitor high-elevation birds throughout the spruce-fir forests of the northeastern U.S. and Canada. With a dual focus on high-elevation conservation and citizen science, Mountain Birdwatch engages and trains more than 100 volunteers who collect extensive data that are critical for conservation. The launch of Mountain Birdwatch 2.0 expands an already-successful conservation initiative across state and country borders, a powerful initiative that will allow us to draw conclusions across the entire breeding range of Bicknell's Thrush. Although the international protocols require modification to account for low densities of Bicknell's Thrush and high levels of forestry in Canada, this first full year of Mountain Birdwatch represents an essential first step towards understanding habitat use and distribution of Bicknell's Thrush across its entire breeding range.

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