Modelling the Critical Habitat of the Bicknell's Thrush in the Cape Breton Highlands

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Abstract

Bicknell's Thrush (*Catharus bicknelli*) is listed as a threatened species under SARA, and identification of critical habitat is a key priority in the species' recovery. LiDAR data was used to create a habitat suitability model for the critical breeding habitat of the Bicknell's Thrush (*C. bicknelli*) within Cape Breton Highlands National Park, where knowledge of the species distribution was limited to point-count survey records between 2002 and 2016, and songmeter records in 2017-18. The model identifies critical habitat as areas of dense, high elevation (>350 m) balsam fir dominated forest with a canopy height of ~four meters in height and stem density equal to or greater than 10,000 stems ha^{-1}. Three habitat suitability models were created, identifying percent canopy closure between 2-3 m, 2-4 m, and 2-5 m in canopy height at elevations greater than or equal to 350 m. When compared to ground truthing data, photo classification, and forest composition data, it was found that while the model accurately identified balsam fir and spruce dominated forests and general trends in stem density (stems ha^{-1}), it did not accurately identify areas of good/excellent *C. bicknelli* habitat as determined through photo classification. Presence/absence data collected through songmeter recordings found no presence of *C. bicknelli* populations within the study area. However, presence of *C. bicknelli* populations was confirmed in more remote areas of Cape Breton Highlands National Park. While this model was not proven to be an effective method of identifying *C. bicknelli* critical habitat, it provides a starting point for future research. Further study is required in order to fine-tune the parameters of the model using LiDAR data spanning over the entirety of the Cape Breton Highlands. A model identifying critical habitat within the Cape Breton Highlands will be an important tool in prioritizing areas for monitoring and conservation of *C. bicknelli* breeding habitat and directing forestry practices in Cape Breton, as well as providing a framework for modelling habitat suitability for *C. bicknelli* in other areas of its range.

Key Words

habitat modelling, habitat suitability modelling, habitat/range, breeding habitat, Bicknell's Thrush, *Catharus bicknelli*, Cape Breton Highlands National Park

Introduction

Biodiversity plays an important role in ecosystem functioning and the processes necessary for sustaining human life. The planet is currently facing a biodiversity crisis with the large-scale loss of wildlife, and avian species are no exception (Myers, 1996). A recent report has indicated a net loss of approximately three billion birds in North America over the past 48 years (Rosenberg et al., 2019). The Bicknell's Thrush (*Catharus bicknelli*) is a rare, migratory species found in Quebec, New Brunswick, Nova Scotia and the northeastern United States, as well as its wintering habitat in the Greater Antilles (ECCC, 2016). The protection and recovery of *C. bicknelli* is a transnational effort. *Catharus bicknelli* is listed as a threatened species in Canada under the Species at Risk Act (SARA) and a species of special concern in the United States (ECCC, 2016; COSEWIC, 2009).

Catharus bicknelli is a habitat specialist, restricted to inland forests reaching an elevation between 380-1,100 m and coastal lowland forests (ECCC, 2016). Emblematic of dense sub-alpine forests, the presence of *C. bicknelli* populations can indicate the health of this habitat and its avian populations (COSEWIC, 2009). Over the past few decades, the species' numbers have declined due to a number of threats, the greatest being habitat loss and degradation (COSEWIC, 2009). The main contributors to loss of habitat are deforestation and forestry practices in the species' breeding habitat, subsistence and slash-and-burn farming practices in the species' wintering habitat, the construction of wind farms, and the localized threat of hyperabundant moose populations in the Cape Breton Highlands (COSEWIC, 2009). In this study, a habitat suitability model utilizing LiDAR and Forest Inventory (NS DNR, 2016) data was developed in collaboration with Cape Breton Highlands National Park in order to identify the critical habitat of *C. bicknelli* in the northern highlands of Cape Breton Island.

The Cape Breton Highlands are characterized by high elevation boreal forest (above 330m), mixed Acadian forest in lower elevation coastal areas, and Taiga (Parks Canada, 2015). The boreal forest ecosystem within Cape Breton is made up of Balsam Fir (*Abies balsamea*), White Birch (*Betula papyrifera*) and Spruce (*Picea spp.*). This ecosystem has declined dramatically over the past three decades due to the spruce budworm (*Choristoneura fumiferana*) infestation in the 1970s (Parks Canada, 2015; Smith et al., 2010). Forest regeneration post-infestation has been negatively impacted by a hyperabundant population of moose (*Alces alces andersoni*) introduced to Cape Breton in 1947-1948 (Smith et al., 2010). The proliferation of *Betula papyrifera* and *Abies balsamea* saplings following the budworm infestation created ideal browsing conditions for the *A. a. andersoni* population, inhibiting the regeneration of the boreal ecosystem (Smith et al., 2010). The decline in forest health has led to the creation of Parks Canada's *Bring Back the Boreal* project, a four-year conservation and restoration project aimed at restoring forest health through a variety of management strategies (Parks Canada, 2015). Restoration methods include fenced enclosures, tree-planting, and a moose removal project in collaboration with Mi'kmaq partners (Parks Canada, 2015). The decline of the boreal forest has impacted the ecological integrity and health of the Cape Breton Highlands and has put strain on the species at risk found in the area, including *C. bicknelli*.

Critical habitat is defined in the Species at Risk Act (SARA) (2011) as "the habitat that is necessary for the survival or recovery of a listed wildlife species". While the characterization of critical habitat for *C. bicknelli* is incomplete, it currently includes high-elevation montane forests, high-elevation managed forests, and coastal lowland forests (COSEWIC, 2009). *Catharus bicknelli* is a habitat specialist, preferring undisturbed dense habitat or areas undergoing vigorous succession (ECCC, 2016). While defining the critical habitat for *C. bicknelli* is an ongoing process, these general characteristics provide a basis for further development of our understanding of this species' habitat.

The use of habitat modelling has been effective in the classification of habitat and distribution of avian species (Garabedian et al., 2014; Wilsey et al., 2012), including *C. bicknelli* (Aubry et al., 2016; Connolly, 2000; Hale, 2005; Lambert et al., 2005; McFarland et al., 2018). The distribution and range of *C. bicknelli* have been monitored and modelled within Southern Quebec, New Hampshire, Vermont, New York, and Maine, in addition to areas within the species' winter habitat (Aubry et al., 2016; Hale, 2006; Frey et al., 2011; Lambert et al., 2005; McFarland et al., 2018). These studies have discovered important information regarding *C. bicknelli*'s habitat requirements and distribution. However, there has yet to be any modelling of the species' habitat and distribution within the Cape Breton Highlands. While past studies have expanded our understanding of *C. bicknelli'*s critical habitat, there is a need to improve habitat suitability models through more specific habitat factors, such as tree height and presence of predators and competitors, and assessing the importance and abundance of low-density areas in comparison to high-density areas of *C. bicknelli* (Aubry et al., 2016; Hale, 2006; Lambert et al., 2005). In addition, it is not currently defined how habitat characteristics for *C. bicknelli* may vary across their breeding range due to specific landscapes and environmental factors. Addressing these knowledge gaps and monitoring areas within the breeding range that have yet to be studied will be important next steps in the monitoring and recovery of *C. bicknelli* populations and habitat.

The goal of this study is to identify areas of critical habitat for *C. bicknelli* in the Cape Breton Highlands by developing a habitat suitability model. The specific research question to be addressed is whether the critical habitat of the Bicknell's Thrush (*C. bicknelli*) within Cape Breton Highlands National Park can be identified through a habitat suitability model utilizing LiDAR data of forest characteristics (canopy height and closure, stem density, and forest species composition) and elevation, focusing primarily on a 500 m buffer on either side of the Cabot Trail. This project aims to provide a more concrete understanding of *C. bicknelli*'s presence and distribution in the Cape Breton Highlands, as well as to provide a framework for the conservation and management of the species' critical habitat.

We address the research question through the development and validation of a habitat suitability model combining LiDAR remote sensing data with provincial forest classification data and songmeter recordings of *C. bicknelli* within the study area of Cape Breton Highlands National Park. The accuracy of the model was validated through ground truth surveys conducted by Parks Canada staff over the summer of 2019. If successful, the model can be expanded for use over the entirety of the Cape Breton Highlands as remote sensing data become available. The model has the potential to be an effective tool for informing management and conservation decisions within the Cape Breton Highlands, in addition to contributing to the status reports and recovery strategy of *C. bicknelli*. This research will expand our understanding of *C. bicknelli*'s distribution and status, thereby improving habitat conservation and protection, as well as management and development decisions within Cape Breton Highlands National Park.

Literature Review

Introduction

This literature review introduces concepts inherent to conservation planning and recovery of species at risk, habitat modelling, and the background and habitat requirements of the Bicknell's thrush (*C. bicknelli*). Sources were found through bibliographic databases (Web of Science, Novanet), with the most frequently used journals being the Journal of Ecological Modelling and Remote Sensing of Environment. The main keywords and phrases used in this review include habitat modelling, habitat suitability modelling, habitat/range, breeding habitat, Bicknell's thrush, and Cape Breton Highlands National Park. The review identifies various GIS and remote sensing methods, looking specifically at examples where habitat suitability modelling has been used to assess critical habitat and distribution of avian species. A background on *C. bicknelli* is included with regard to behaviour, distribution, monitoring, and conservation/recovery efforts. Important knowledge gaps in habitat suitability modelling and the current efforts to protect and recover *C. bicknelli* populations are identified throughout this review.

Habitat Modelling

Habitat modelling is an important tool for species conservation as it expands our understanding of how environmental features and resources affect species distribution and behaviour. Introduced in the 1950s, habitat models are used to predict patterns or distributions of species diversity, as well as to make inferences on ecological processes and species attributes (Scott et al., 2002). The prediction of species occurrence, distribution and abundance can be modelled as a factor of habitat suitability, pattern recognition, and wildlife-habitat relations

(Scott et al., 2002). While optical remote sensing is more common in habitat models, LiDAR data have become increasingly popular as availability increases. LiDAR (light detection and ranging) data uses laser scanning and remote sensing to derive variables of vegetation structure, including canopy height, canopy closure, and other topographic information (Tattoni et al., 2012). When defining critical habitat and predicting species occurrence, predictions may focus on biological response, distribution, population fluctuations, or changes in community diversity (Drew et al., 2011). Based on the quality and relevance of the data included and predictions made, habitat suitability models can be very effective and accurate, and there are many examples of habitat suitability models being successful in monitoring and modelling avian species (Garabedian et al., 2014; Wilsey et al., 2012). While these models can be an important tool, it is important to understand their limitations.

Limitations and Verification

When working with models, it can be assumed that there will be elements of uncertainty and limitations in their operation. Sources of error associated with habitat models can include data deficiencies (lack of spatial data on habitat requirements), specifications of the model, or bias and error through the use of remote sensing technology (Barry & Elith, 2006; Gottschalk et al., 2011; Bradley et al., 2012; Scott et al., 2002). To limit sources of error and bias, it is necessary to verify habitat models with statistical tests or physical observations. Physical observations, such as observations in the field or multiple predictor characteristics (e.g. soil type) have been proven to provide a more accurate model (Garabedian et al., 2014; Wilsey et al., 2012). As models do not make precise predictions and often do not apply across different populations, locations, and time, it is necessary to test the accuracy of models through appropriate statistical assumptions and tests (e.g. Correlation coefficients) (Scott et al., 2002). The verification of habitat models is essential when applying models to real world situations.

Bicknell's Thrush (*Catharus bicknelli*)

Description and Status

The Bicknell's Thrush (*C. bicknelli*) is the smallest of the northern *Catharus* thrushes (body length 16-18 cm, body mass 25-30 g). The species was discovered in 1882. However, it was not recognized as a distinct species until 1995 (American Ornithologist's Union, 1995). Both males and females can be identified by warm brown feathers on the back, and grey underparts with dark spotting on the throat and breast (COSEWIC, 2009; ECCC, 2016) (Figure 1). *Catharus bicknelli* is very similar to the Gray-cheeked thrush, but they differ in size and birdsong (ECCC, 2016; COSEWIC, 2009; Rimmer & McFarland, 2013). *Catharus bicknelli* was listed as threatened under the Species at Risk Act (SARA) in 2012. Provincially, the species is listed as vulnerable in Quebec and Nova Scotia and threatened in New Brunswick (ECCC, 2016; COSEWIC, 2009). In the United States, *C. bicknelli* is listed as a species of concern in all states within its range. Globally, the species is considered "apparently secure" – indicating the potential for concern in the long-term due to population decline or risk factors (ECCC, 2016; COSEWIC, 2009). The major threats to *C. bicknelli* populations focus on land use change and fragmentation due to forestry practices and wind farms, as well as the localized threat of overgrazing by moose within their breeding range in Nova Scotia (ECCC, 2016; COSEWIC, 2009). These threats have led to the decline of *C. bicknelli* populations.

Figure 1 Adult Bicknell's Thrush (Catharus bicknelli). Photo from The Cornell Lab, 2019, Retrieved March 6, 2020, from https://www.allaboutbirds.org/guide/Bicknells_Thrush/id. Copyright 2016 by Simon Boivin.

Habitat and Distribution

Catharus bicknelli are habitat specialists, associated with dense coniferous forest or areas undergoing vigorous succession. They prefer forests dominated by Balsam Fir (*Abies balsamea*) with stem densities between 10,000-50,000 stems/ha. *C. bicknelli* also prefer elevations between 380-1000 m (ECCC, 2016; COSEWIC, 2009). The three main breeding habitat types of *C. bicknelli* are high-elevation montane forests, high-elevation managed forests, and coastal lowland forests (ECCC, 2016; COSEWIC, 2009; Lambert et al., 2005). High-elevation montane forests are defined as dense coniferous forests (between 10,000 and 50,000 stems ha^{-1}), at elevations greater than or equal to 390 m (J. Bridgland, personal communication, April 21, 2020). They are characterized primarily by *Abies balsamea*, although *Betula papyrifera, Picea spp.*, and *Sorbus Americana* may also occur. They are not typically managed for forest harvesting (COSEWIC, 2009). High-elevation managed forests are defined as dense conifer or mixed wood (50-75% conifers) stands, occurring at elevations greater than or equal to 380 m, that are managed for forest harvesting (COSEWIC, 2009). Coastal lowland forests are defined as dense maritime spruce-fir forests located in areas with high precipitation levels and sea breezes that recreate the characteristics of high-elevation forests (COSEWIC, 2009).

The breeding range of *C. bicknelli* lies within northeastern North America, with 95% of potential breeding habitat occurring within Canada (of which 95% occurs in Quebec, 2% in New Brunswick, and 3% in Nova Scotia) and the other 5% scattered throughout the US (Maine, New Hampshire, Vermont, and eastern New York State) (ECCC, 2016; COSEWIC, 2009) (Figure 2). *Catharus bicknelli* winters in the Greater Antilles, with the majority of the population inhabiting the Dominican Republic (ECCC, 2016; COSEWIC, 2009) (Figure 3). Conserving the preferred habitat of *C. bicknelli* within both its breeding and wintering habitat, including its migration routes, is essential for the survival and recovery of the species.

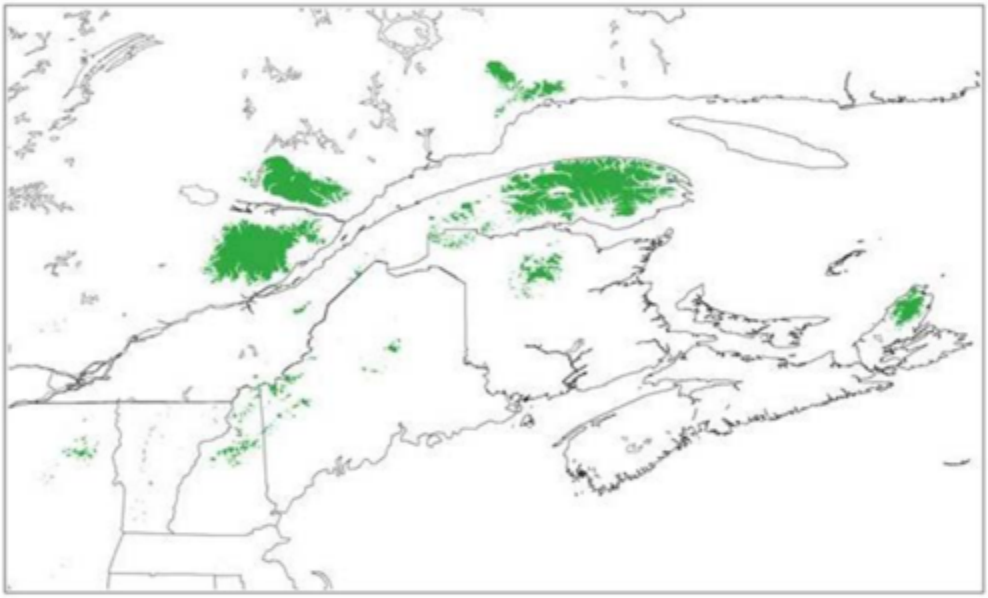

Figure 2 Bicknell's Thrush (Catharus bicknelli) breeding range in Canada and the United States, in green (adapted from Lambert et al. 2005; Hart et al. in prep; and unpublished data of Environment and Climate Change Canada's Canadian Wildlife Service) (ECCC, 2016).

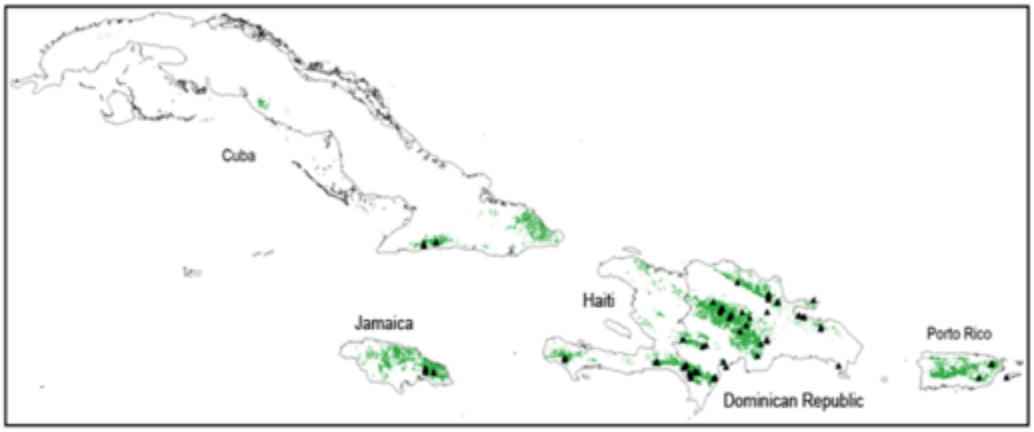

Figure 3 Potential wintering area of the Bicknell's Thrush (Catharus bicknelli) in the Greater Antilles, in green. The black triangles indicate the known observation sites of the species (adapted from McFarland et al., 2013) (ECCC, 2016).

Monitoring

Many studies have been completed within *C. bicknelli*'s breeding and wintering range in order to identify key habitat features and determine the status of populations to improve conservation efforts. These studies researched habitat within southern Quebec, New Hampshire, Vermont, New York, and Maine (Aubry et al., 2016; Hale, 2006; Frey et al., 2011; Lambert et al., 2005). All studies identified high elevation, amount of forest cover and forest density as important habitat characteristics of *C. bicknelli* (Aubry et al., 2016; Hale, 2006; Frey et al., 2011; Lambert et al., 2005; McFarland et al., 2018). Hale (2006) found that while the highest densities of *C. bicknelli* were predicted to be found at the uppermost elevations, areas along the outskirts of preferred habitat may support a significant fraction of *C. bicknelli* as habitat availability decreased with increasing elevation. The identification and conservation of critical habitat, as well as potential habitat, is essential to the recovery of the species' populations.

Knowledge Gaps

The literature indicates that while there have been strides in modelling and monitoring *C. bicknelli* populations across its range, there is still much to learn about the species and its habitat distribution, and more research is necessary to better understand the dynamics between populations and their habitat, as well as other environmental factors. Specifically, there is a need for improved habitat suitability models that include more specific habitat and environmental factors (tree height, abundance of predators/good predator habitat, etc.) (Aubry et al., 2016). It is also necessary to understand the importance and abundance of areas at the limits of the habitat range in comparison to areas of preferred habitat, especially in the context of climate change (Hale, 2006; Lambert et al., 2005). While there have been many studies researching the presence and quality of *C. bicknelli's* breeding and winter habitat, there has yet to be any modelling completed for the range of breeding habitat within the Cape Breton Highlands, which make up 3% of the species breeding habitat in Canada in an isolated region. Therefore, the specific environmental variables of this region, such as the effects of introduced moose populations, are largely unknown. Through this study I aim to address the knowledge gaps by increasing the body of knowledge available for *C. bicknelli* within the Cape Breton Highlands, while including more specific habitat factors and greater ranges of habitat requirements in order to improve the habitat suitability model and our understanding of the importance of areas at the limits of the habitat requirements.

Conclusion

This literature review has explored habitat modelling techniques and their use and effectiveness in *C. bicknelli* research and monitoring. The benefits and limitations of habitat suitability models have been highlighted throughout the review, specifically through previous research on *C. bicknelli*, which have used varying habitat modelling techniques to better understand the species distribution and trends in population density. This literature review has identified the need for further research on *C. bicknelli* behaviour and population dynamics, in addition to their relationships to other habitat and environmental characteristics in order to improve current models. Through my research I aim to address some of the outlined knowledge gaps, including region-specific environmental variables and threats, as well as the importance of areas on the outskirts of critical habitat, by incorporating more local and specific habitat characteristics in a habitat suitability model of *C. bicknelli* within Cape Breton Highlands National Park.

Methods

Overview

This study investigated the area of critical *C. bicknelli* habitat within the Cape Breton Highlands, Nova Scotia. Critical habitat within this region was identified through the development of a habitat suitability model indicating specific habitat requirements of elevation, stem density, canopy height, and forest species composition using a geographic information system (GIS; ESRI ArcMap 10.5) and an open-source LiDAR analysis software (Fusion; US Forest Service). The model was validated using the results from ground truthing surveys conducted by Parks Canada staff between June-August 2019. In addition to the ground truthing data, photo classification of designated habitat sites and the placement of songmeters in select sites were used as further indicators of model accuracy and presence of *C. bicknelli*.

Study Area

The study area of this research falls within Cape Breton Highlands National Park, specifically focusing on the area within 500 m on either side of the Cabot Trail (Figure 4). This study area was chosen based on available LiDAR data for the area (NS DNR, 2015). However, the area covers enough representative boreal forest habitat in order to determine the effectiveness and accuracy of the habitat suitability model. If successful, this model could be used for the entirety of the Cape Breton Highlands once the LiDAR data become available.

Figure 4 The study area, spanning 500 m on either side of the Cabot Trail within Cape Breton Highlands National Park, Nova Scotia, Canada.

The Cape Breton Highlands were chosen for the study area of this research as the area has been identified as *C. bicknelli* breeding habitat, making up ~3% of the breeding habitat found within Canada (COSEWIC, 2009). As a national park, the identification of critical habitat within Cape Breton Highlands National Park is a necessary contribution to the recovery strategy under SARA. As this range of habitat has yet to be researched, the assessment of critical habitat within the Cape Breton Highlands will provide important insights for species recovery and conservation.

Habitat Suitability Model

The main component of this study was the creation of a habitat suitability model for *C. bicknelli* within Cape Breton Highlands National Park. The model used LiDAR data covering 500 m on either side of the Cabot Trail licensed to Public Works and Government Services Canada by Leading Edge Geomatics of Fredericton, New Brunswick, as well as open-source NS DNR forest inventory data (NS DNR, 2016), in order to extract features of *C. bicknelli* habitat requirements (canopy closure, canopy height, elevation). The model was developed using Fusion (version 3.8, United States Department of Agriculture Forest Service, Seattle, Washington), an open-source LiDAR analysis software developed by the US Forest Service, as well as ESRI ArcPro (version 2.3, Earth Systems Research Institute, Redlands, California). Habitat requirements of canopy height and percent canopy closure were extracted from the LiDAR data using Fusion to create a raster layer (Appendix A). The model was isolated to areas with elevations greater than or equal to 350 m. Canopy closures of 60% or greater were determined to be preferred habitat. Raster layers were created for canopy heights of 2-5 m, 2-4 m, and 2-3 m. These variables were chosen based on literature that has identified *C. bicknelli*'s habitat preference of medium height to stunted forests (~4 m in height) (Connolly, 2000; COSEWIC, 2009; ECCC, 2016; Hale, 2006; Noon, 1981; Rimmer et al., 2005). The average nest tree height of *C. bicknelli* is 3.2 m (SD = 1.55), with populations documented at a mean canopy height of 4.8 m in the mountains of New Hampshire (Rimmer et al., 2005). The minimum height was set at 2 m to avoid lower land cover types (rocks, grasses, shrubs, etc.) that may be picked up by the

LiDAR data. These three height variables were compared and analyzed in terms of their accuracy when compared to ground truthing data, and whether they represent appropriate *C. bicknelli* habitat. The raster layers were exported to ArcPro and clipped to areas with elevations greater than 350 m. Forest inventory data from NS DNR and historic ecological land classification data from 1973 (EER, 1978) were used to incorporate historic and present contexts of forest composition. The forest inventory data were isolated to patches where Balsam Fir (*Abies balsamea*) or Black Spruce (*Picea mariana*) were identified as the dominant species for use in the model. The historic ecological land classification data (EER, 1978) were filtered to locations where one of three vegetation groups were found. These vegetation groups consisted of Balsam Fir (*Abies balsamea*), Balsam Fir (*Abies balsamea*) - Black Spruce (*Picea mariana*), or dwarf Black Spruce (*Picea mariana f. semiprostrata*). The data were also specified to locations with *Abies balsamea* as the dominant species, at a canopy height of 5 m or less, crown closure of 61-100%, and a condition of regeneration following disturbance, young, normal growth, or young to mature retarded growth due to poor site conditions.

Ground Truthing

Throughout the months of June to August, 2019, Parks Canada staff conducted ground truthing surveys of 125 sites within the study area. Sites were selected based on areas that the preliminary pilot model defined as strong habitat for *C. bicknelli*. The purpose of the ground truthing surveys was to validate the accuracy of the habitat suitability model in its ability to determine areas of critical *C. bicknelli* breeding habitat. The model identified five stands within the study area that appeared to represent the critical habitat of *C. bicknelli* (P1 – Canadian Brook, P2 – French Mountain, P3 – Fishing Cove River, P4 – Old Fishing Cove Trailhead, P5 –

Mackenzie Mountain) (Figure 5). Within these stands, a number of sampling points were chosen for ground truthing (P1 = 26, P2 = 31, P3 = 19, P4 = 24, P5 = 25) (Figure 6).

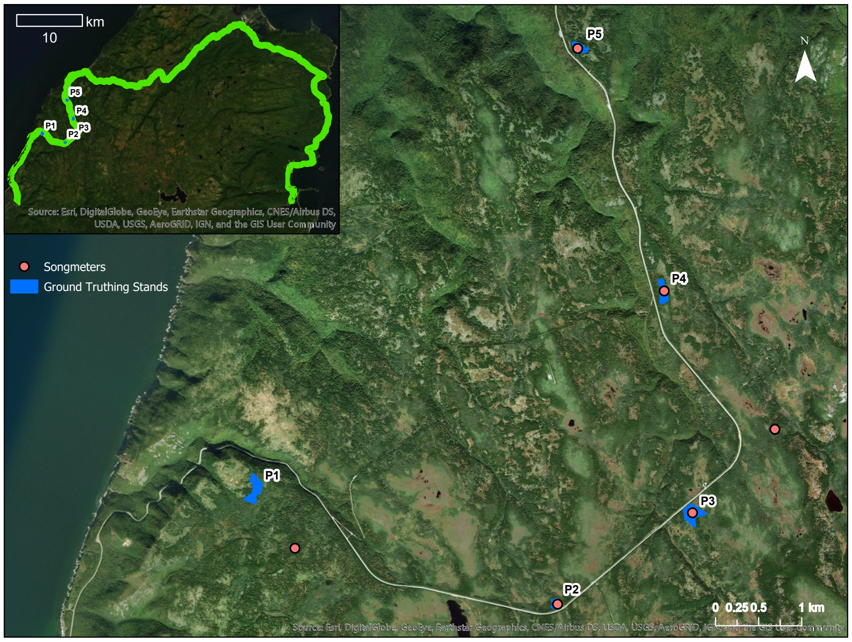

Figure 5 Location of ground truthing stands and songmeters within the study area.

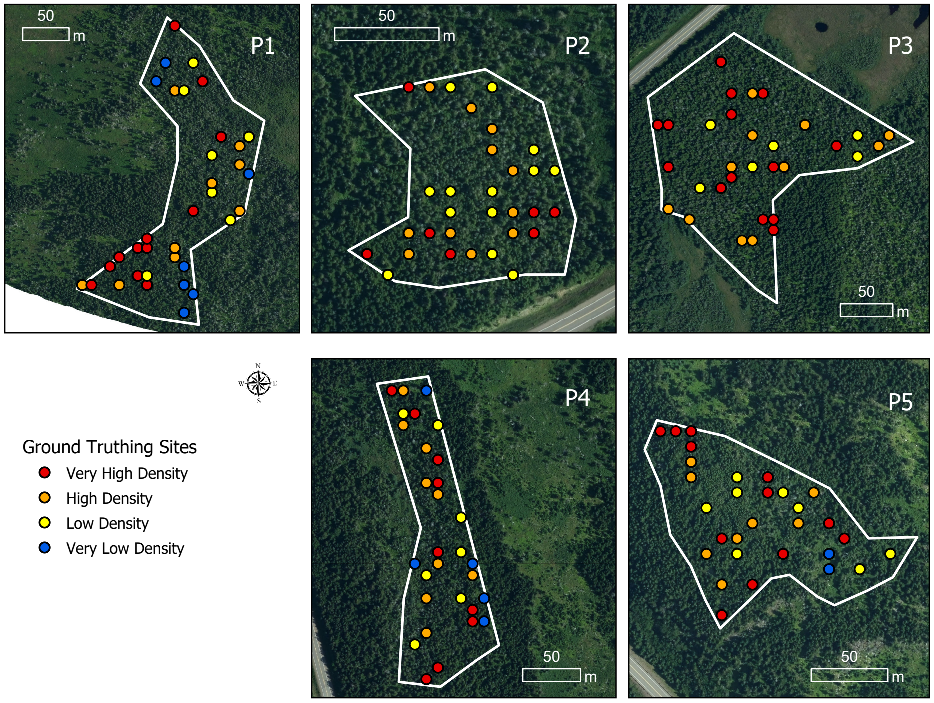

Figure 6 125 study sites within the five ground truthing stands, symbolized by canopy closure density values.

Sites were located using a GPS. Upon arrival, a tripod was placed in a central location at breast height, and a compass was used to note the cardinal directions. At each site, six pictures were taken from the tripod of each of the cardinal directions, as well as a zenith (sky) and ground photo. These photos were used for photo classification. The four closest trees to the tripod, one in each quadrant of the site (NE, NW, SW, SE), were flagged using flagging tape. The distances between the tripod and the base of each of the four trees were recorded, as well as tree diameter at breast height (DBH), and tree species. An approximate canopy height for the site was recorded. This ground truth data was used to calculate stem density using the point quarter method (stems/ha = 10,000/mean distance) (Mitchell, 2015).

Songmeters

Songmeters were deployed by the Canadian Wildlife Service and Birds Canada at select sampling points in order to record bird song over the breeding season. A total of ten songmeters were placed within Cape Breton Highlands National Park, one within each of the five ground truthing stands (Figure 5). In addition, five songmeters were placed outside of the study area in locations where *C. bicknelli* have been found in the past. Following the breeding season, the songmeters were collected and delivered to Bird Studies Canada to determine if *C. bicknelli* were heard within the sites. The songmeter recordings were analyzed using a high-resolution call recognizer for *C. bicknelli* call types, with positive hits reassessed for false positives. Any sites where the call types were picked up on the recording were flagged as having *C. bicknelli* populations present. The data were then added into the habitat suitability model.

Photo Classification

The photo classification component of this study utilized the site photos taken during ground truthing to expand the analysis of habitat suitability. The collection of six photos per site (north, east, south, west, zenith (sky), and ground) were ranked on a scale of 1-3, where 1 = poor habitat, 2 = mediocre habitat, and 3 = good/excellent habitat (Figures 7 & 8). Photos were scored according to a set of guidelines (see Appendix B) that were developed based on feedback from experts on *C. bicknelli*, including representatives from Environment and Climate Change Canada (ECCC), Bird Studies Canada, and several academic institutions (including Dalhousie University and University of New Brunswick). Photo classification was completed personally in order to standardize the scoring process. The completed photo scores were added to the ground truthing data in order to test the accuracy of the habitat suitability model.

Figure 7 An example of good/excellent Bicknell's Thrush habitat based on photo classification guidelines. Photo shows high density, young Balsam Fir stand with dense foliage and some snags and taller trees for song posts.

Figure 8 Example of poor Bicknell's Thrush habitat based on photo classification guidelines. Photo shows high density stand of mature, self-thinning trees with canopy height extending out of the range of the photo.

Critical Habitat Analysis

In order to test the accuracy of the habitat suitability model in its identification of representative *C. bicknelli* habitat, a variety of methods were used to determine the relationship between data extracted from the model and ground truthing/photo classification data. Firstly, the values for canopy closure (in percentage) derived from the LiDAR model were sorted according to stem density (in descending order) into three equal groups (high, medium, and low) for each of the 125 sites. A single factor ANOVA test was run for these three groups (high, medium, and low) of LiDAR canopy closure values, followed by a Two-Sample t-Test assuming equal variances in order to determine whether there was a significant difference in canopy closure percentages between the three groups when sorted by calculated stem density. A similar process was repeated for three groups sorted by photo classification scores (3 – good/excellent habitat, 2 – mediocre habitat, 1 – poor habitat). Secondly, the habitat suitability models (2-5 m, 2-4 m, and 2-3 m) and the ground truthing stem density data were clustered into three groups using a K-means algorithm. The model was analyzed spatially using both Global and Local Moran's I tests, as well as Hot Spot Analysis (Getis Ord Gi*) for the results of the K-means analyses and the photo classification scores in order to assess whether or not there was a spatial relationship between the different sites.

Limitations and Delimitations

The main limitation of this study was the use of GPS in dense forest in order to locate sites. This is likely to have caused some issues of accuracy in the location of sites during the ground truthing surveys, which may affect the calculated accuracy of the model. Sites were made to be 10 m by 10 m cells (the same resolution or cell size of the habitat suitability model) in order to account for any inaccuracy associated with the use of GPS.

The major delimitations of this study were the study area and the lack of known *C. bicknelli* breeding sites or populations in the area. The study area of 500 m on either side of the Cabot Trail is relatively small and may have unexpected adverse effects on *C. bicknelli*, through factors such as proximity to roads and populated recreation areas. The lack of known *C. bicknelli* breeding sites or populations limits our ability to verify the model's accuracy. However, the placement of songmeters within our study area could rather provide an indication of whether or not *C. bicknelli* populations are present in the area.

Results

Habitat Suitability Model

The habitat suitability models show the range in percent canopy cover within 2-5 m, 2-4 m, and 2-3 m of canopy height at elevations greater than or equal to 350 m (Figure 9). By isolating the model to areas greater than or equal to 350 m, the study area was focused to two main segments in the northwest corner of Cape Breton Highlands National Park, covering an area of 17.2 km^2. Only one of these segments showed areas of significant canopy closure (>60%). Areas with canopy closure representative of *C. bicknelli*'s preferred habitat are symbolized in red. The 2-5 m threshold showed the greatest area of representative canopy closure density, with the areas of canopy closure percentages between 60-100% covering an area of 5.2 km^2 (30.4% of study area). The areas of canopy closure percentages between 60-100% decreased steadily between the 2-4 m threshold (3.45 km^2 or 20.09% of study area) and the 2-3 m threshold (0.87 km^2 or 5.07% of study area).

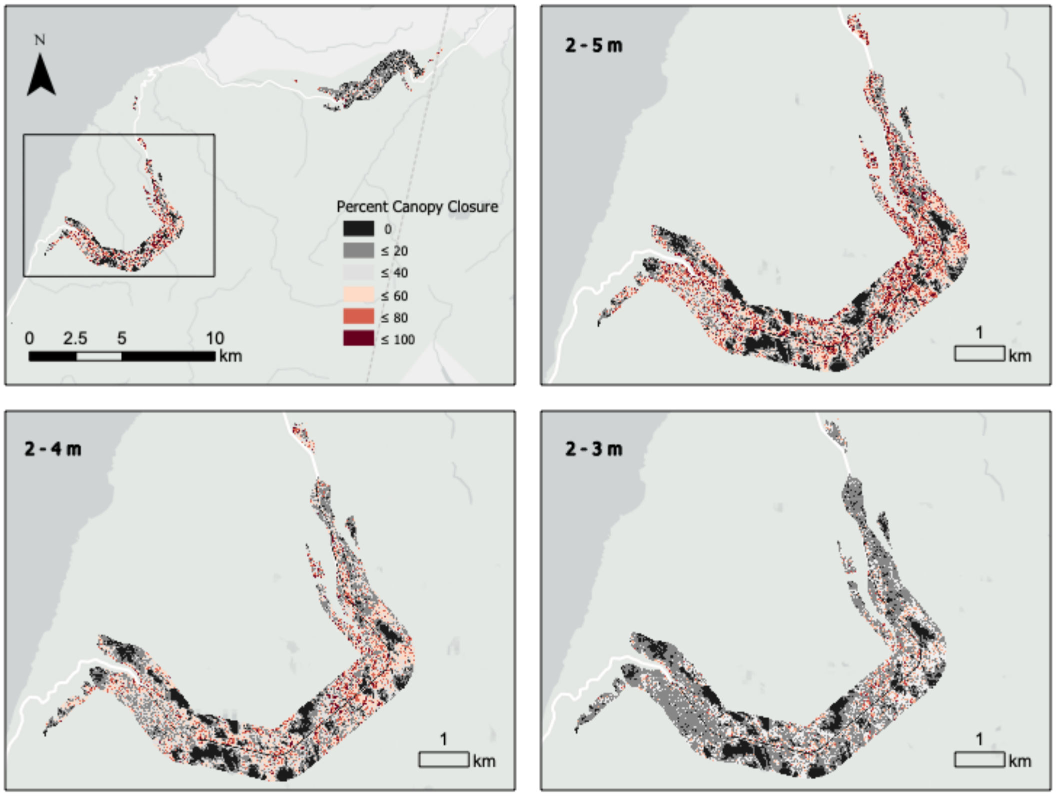

Figure 9 Habitat suitability model for the Bicknell's Thrush (*C. bicknelli*) showing percent canopy closure between 2-5 m, 2-4 m, and 2-3 m at an elevation of 350 m or greater.

Forest Composition

The Forest Inventory data (NS DNR, 2016) indicated that areas in which Balsam Fir (*Abies balsamea*) or Black Spruce (*Picea mariana*) were the dominant species overlapped with the study area, as well as the majority of the surrounding area (Figure 10).

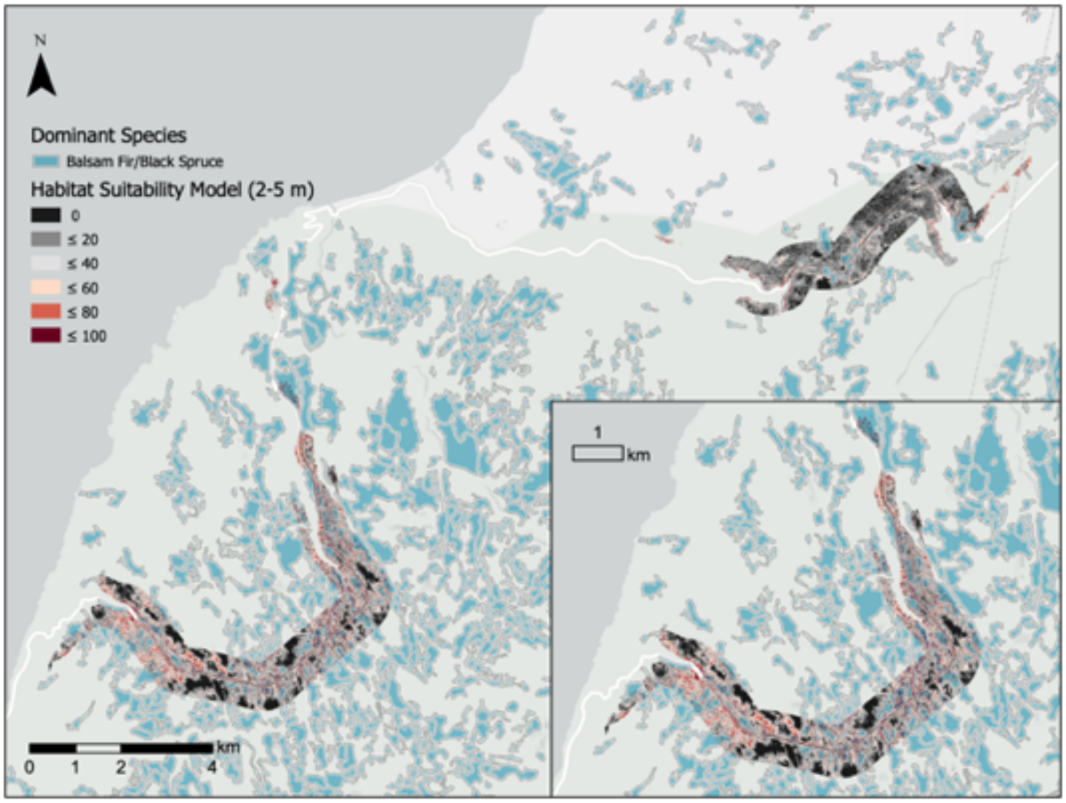

Figure 10 Nova Scotia Department of Natural Resources forest inventory data (2016), isolated to areas in which Balsam Fir (Abies balsamea) or Black Spruce (Picea mariana) were the dominant species (SP1), overlapping the study area.

The historic ecological land classification data from 1973 (prior to the Spruce Budworm outbreak in the 1970s-80s) identified multiple patches representative of preferred *C. bicknelli* habitat (EER, 1978) (Figure 11). These patches were mainly outside of the study area, further south/south-east of the Cabot Trail.

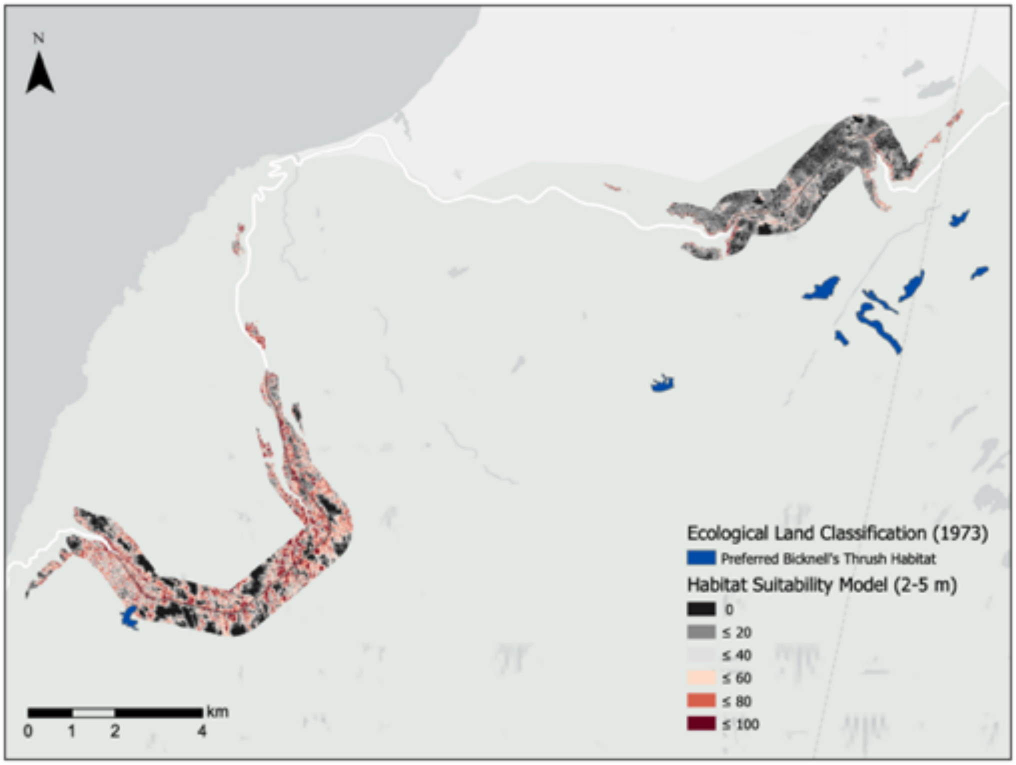

Figure 11 Preferred Bicknell's Thrush (Catharus bicknelli) habitat (including factors of tree species composition, density, canopy height, and condition of vegetation) derived from ecological land classification data (1973) compared to the study area.

K-means Analysis

A K-means cluster analysis was calculated for the canopy closure percentages derived from the habitat suitability models (2-5 m, 2-4 m, and 2-3 m) (Figures 12, 13, & 14). The values were clustered into three groups; 3 = High, 2 = Medium, and 1 = Low.

For the 2-5 m model, the High category (M = 75.82%, SD = 7.33) included 54 sites. This group had a mean stem density of 7,395 stems ha^{-1} ± 2,816 SD. The Medium category (M = 48.53%, SD = 6.38) included 51 sites, with a mean stem density of 6,616 stems ha^{-1} ± 2,077 SD.

The Low category (M = 23.80%, SD = 6.04) included 20 sites, with a mean canopy stem density of 6,566 stems ha^{-1} ± 4,287 SD.

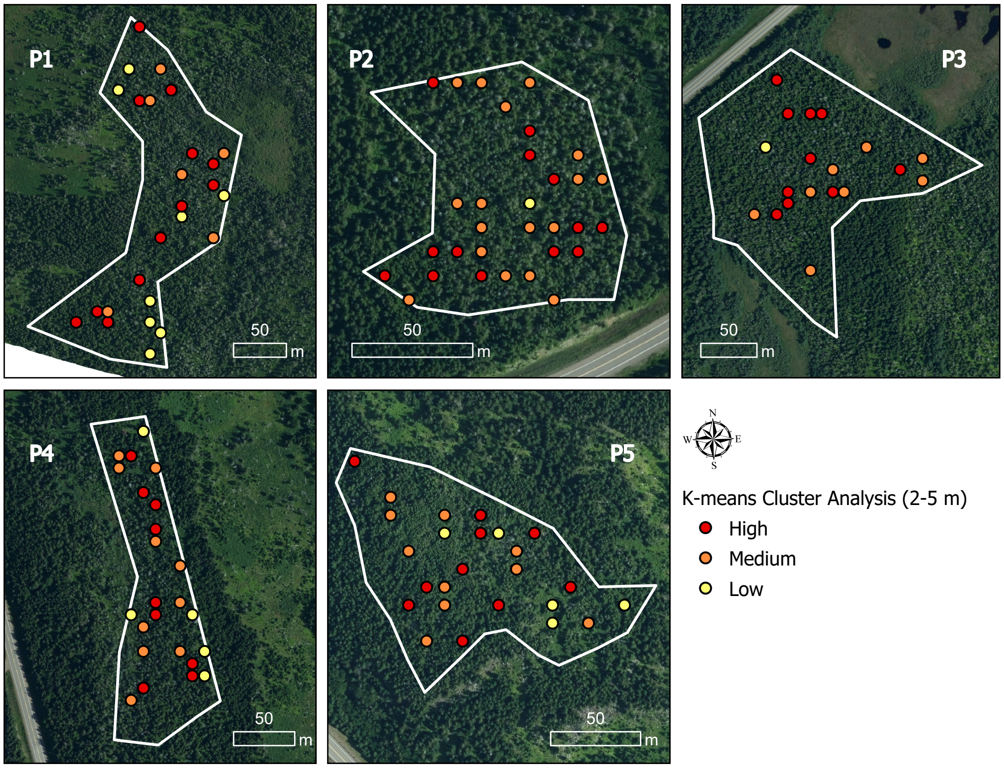

Figure 12 Spatial distribution of K-mean analysis clusters (High – red, Medium – orange, Low – yellow) for the canopy closure percentages between 2-5 m for each study site within each of the five ground truthing stands.

For the 2-4 m model, the High category (M = 68.98%, SD = 7.45) included 49 sites. This group had a mean stem density of 7,629 stems ha^{-1} ± 2,844 SD. The Medium category (M = 43.00%, SD = 6.17) included 56 sites, with a mean stem density of 6,958 stems ha^{-1} ± 2,805 SD. The Low category (M = 18.95%, SD = 6.21) included 19 sites, with a mean canopy stem density of 5,881 stems ha^{-1} ± 2,952 SD.

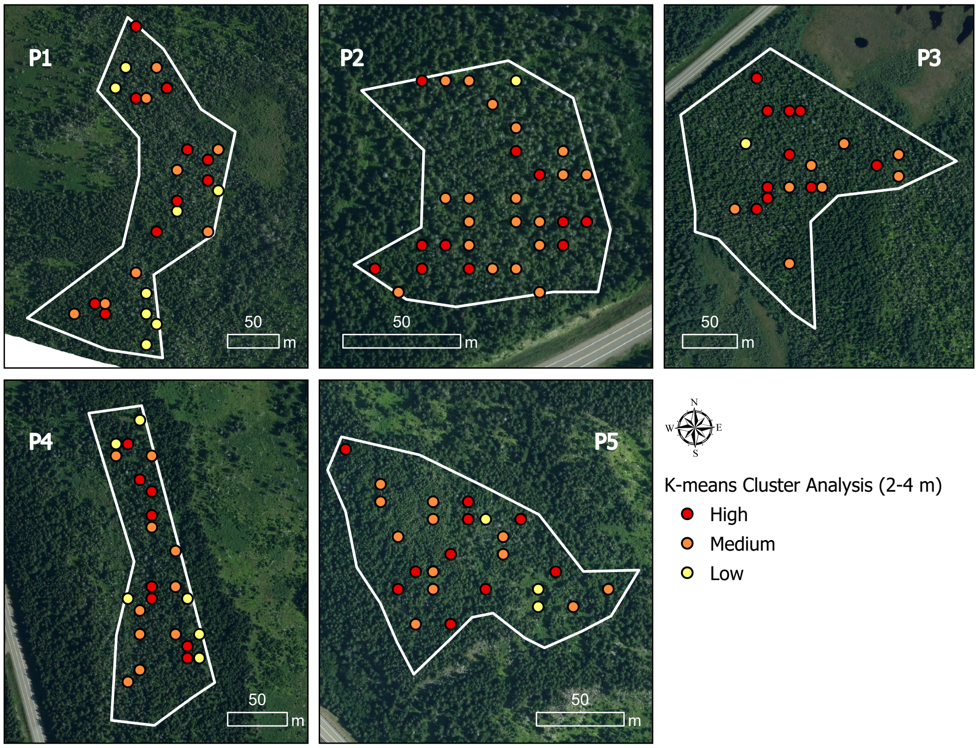

Figure 13 Spatial distribution of K-mean analysis clusters (High – red, Medium – orange, Low – yellow) for the canopy closure percentages between 2-4 m for each study site within each of the five ground truthing stands.

For the 2-3 m model, the High category (M = 47.66%, SD = 7.70) included 44 sites. This group had a mean stem density of 6,903 stems ha^{-1} ± 3136 SD. The Medium category (M = 26.77%, SD = 4.92) included 61 sites, with a mean stem density of 6,882 stems ha^{-1} ± 2,593 SD. The Low category (M = 9.34%, SD = 4.60) included 20 sites, with a mean canopy stem density of 7,229 stems ha^{-1} ± 3,045 SD.

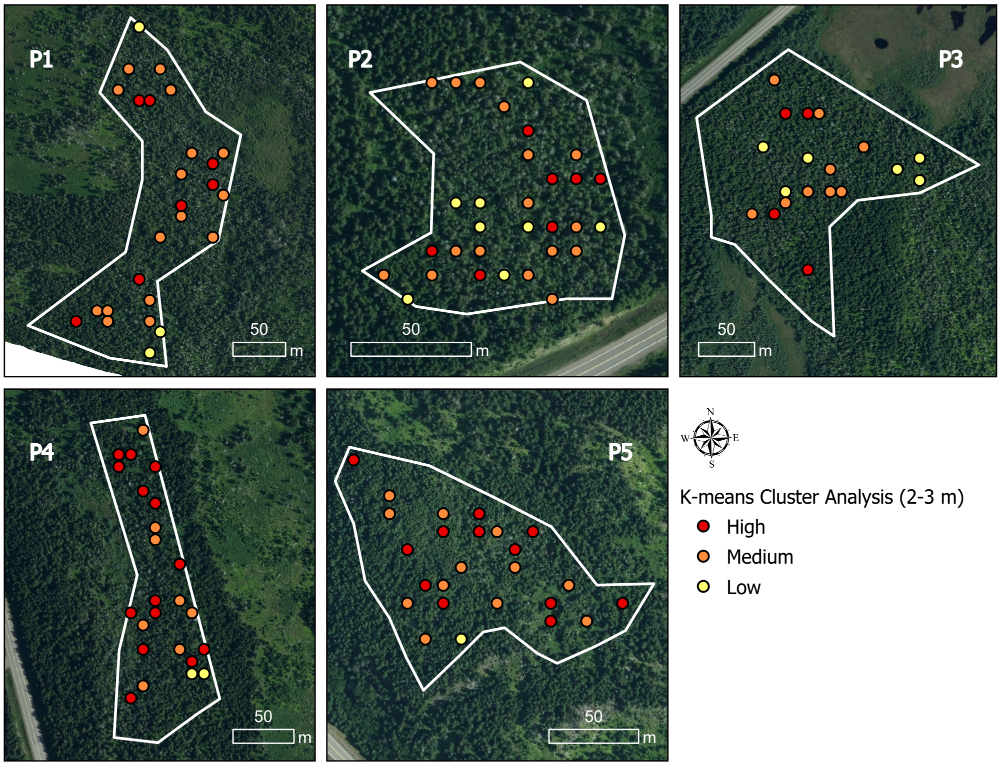

Figure 14 Spatial distribution of K-mean analysis clusters (High – red, Medium – orange, Low – yellow) for the canopy closure percentages between 2-3 m for each study site within each of the five ground truthing stands.

Ground Truthing

Tree Species Composition

In total, 125 sites were surveyed during the ground truthing component of this study. Of the tree species recorded, 47% were Balsam Fir (*Abies balsamea*) and 47.2% were Black Spruce (*Picea mariana*) (Table 1). Canopy heights recorded during ground truthing ranged from 2-8 m.

Table 1 Composition of tree species recorded during ground truthing surveys across 125 sites.

Tree Species	Observations
Balsam Fir	235
Black Spruce	236
Red Spruce	20
White Spruce	7
Tamarack/Eastern Larch	1
Mountain Ash	1
Total	500

Stem Density vs. Canopy Closure

Stem density was calculated using the point quarter method (Mitchell, 2015) in order to determine if a relationship existed between stem density and canopy closure. As we are using canopy closure as an indication of forest density, we hypothesized that stem density and canopy closure would have a positive relationship. If the relationship is found to be negative, canopy closure is likely not an appropriate measure of forest density for this study. Stem density data were sorted from highest to lowest density, with a range of 20,000-1,887 stems ha^{-1}. The stem density data sorted into three equal groups – high (42 observations, M = 10,107 stems ha^{-1} ± 2,433 SD, medium (42 observations, M = 6,339 stems ha^{-1}, SD = 535.17), and low (41 observations, M = 4,326 stems ha^{-1}, SD = 914.00). The canopy closure percentages extracted from the LiDAR data were sorted into these same groupings based on site number. A Single Factor ANOVA test was calculated for the three groups of canopy closure percentages (Table 2). The analysis was significant at the 2-3 m threshold and the 2-4 m threshold where $p < 0.05$. However, the analysis was not significant for the 2-5 m threshold where $p < 0.05$.

Table 2 Results of a Single Factor ANOVA test for the three groupings of canopy closure values.

	High (Mean)	Medium (Mean)	Low (Mean)	Degrees of Freedom	F-value	P-value	Significant/ Non-Significant
2-3 m	37.2% ± 15.7 SD	30.6% ± 12.3 SD	26.1% ± 14.3 SD	2, 122	6.39	0.0023	**Significant**
2-4 m	55.4% ± 20.1 SD	48.0% ± 17.0 SD	44.8% ± 18.4 SD	2, 122	3.64	0.029	**Significant**
2-5 m	61.9% ± 21.2 SD	54.8% ± 18.6 SD	52.3% ± 19.9 SD	2, 122	2.62	0.077	Non-Significant

The height thresholds that tested significant in the Single Factor ANOVA test were further tested with a two-sample t-Test assuming equal variances in order to determine which of the means of the High, Medium, and Low groups were significantly different than the others (Table 3).

Table 3 Results of a two-sample t-Test assuming equal variances for the three groupings of canopy closure values.

	Group Comparison	**Degrees of Freedom**	**T-value**	**P-value**	**Significant/Non-Significant**
2-3 m	High-Medium	82	2.14	0.035	**Significant**
	Medium-Low	81	1.52	0.132	Non-Significant
	High-Low	81	3.35	0.001	**Significant**
2-4 m	High-Medium	82	1.84	0.069	Non-Significant
	Medium-Low	81	0.83	0.407	Non-Significant
	High-Low	81	2.53	0.013	**Significant**
2-5 m	High-Medium	82	1.65	0.103	Non-Significant
	Medium-Low	81	0.58	0.565	Non-Significant
	High-Low	81	2.13	0.036	**Significant**

K-means Analysis

A K-means cluster analysis was calculated for the stem density values collected during ground truthing. This analysis groups sites into natural clusters of stem density values, allowing us to compare variables based on their clustered values. The values were clustered into three groups; 3 = High, 2 = Medium, and 1 = Low (Figure 15). The High category (M = 11,904.67 stems ha^{-1}, SD = 2,247.94) included 22 sites. This group had a mean canopy height of 4.95 m (SD = 1.40), and a mean canopy closure of 54.42% (SD = 19.23) between 2-4 m in height. The Medium category (M = 7,175.11 stems ha^{-1}, SD = 1,006.45) included 56 sites, with a mean canopy height of 4.83 m (SD = 1.22) and a mean canopy closure of 50.46% (SD = 18.42) between 2-4 m in height. The Low category (M = 4,506.08 stems ha^{-1}, SD = 952.55) included 48 sites, with a mean canopy height of 4.96 m ± 1.53 SD and a mean canopy closure of 46.06% ± 19.10 SD between 2-4 m in height.

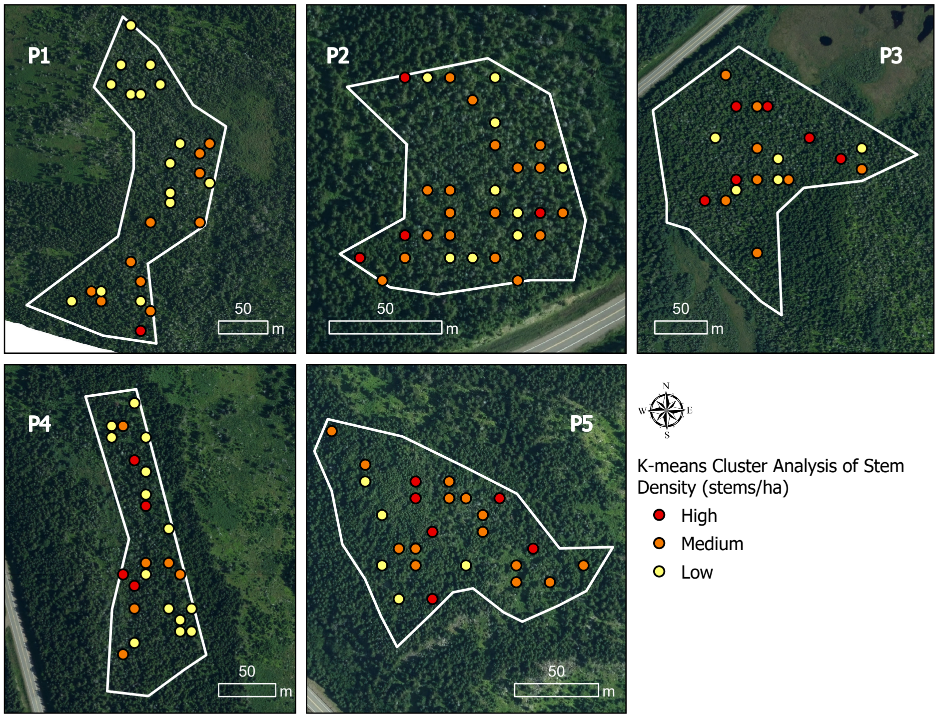

Figure 15 Spatial distribution of K-mean analysis clusters (High – red, Medium – orange, Low – yellow) for the stem density (stems ha-1) values for each study site within each of the five ground truthing stands.

Photo Classification

Photo Classification vs. Canopy Closure

The canopy closure values for each of the 125 study sites were sorted and grouped based on their assigned score (3 = good/excellent habitat, 2 = mediocre habitat, 1 = poor habitat). 38 sites were labeled as good/excellent habitat (3), 34 sites were labeled as mediocre habitat (2), and 53 sites were labeled as poor habitat (1). A Single Factor ANOVA test was calculated for the three groups. The analysis was very significant at the 2-3 m threshold (F(2, 122) = 9.28, p = 0.00018), the 2-4 m threshold (F(2, 122) = 14.54, p = 2.16E-06), and 2-5 m threshold (F(2, 122) = 16.22, p = 5.68E-07) where $p < 0.001$. For the 2-3 m threshold, the canopy closure for each of the three photo classification scores were High (M = 28.93%, SD = 12.00), Medium (M = 24.74%, SD = 13.65) and Low (M = 37.29%, SD = 15.21). The difference in means between the Medium and Low groups was very significant by a two-sample t-Test assuming equal variances ($t = -3.91$, df = 85, $p < 0.001$) and significant between the High and Low groups ($t = -2.81$, df = 89, $p < 0.05$). For the 2-4 m threshold, the canopy closure for each of the three groups were High (M = 42.68%, SD = 15.55), Medium (M = 41.98%, SD = 18.60), and Low (M = 59.06%, SD = 17.22). The difference in means was very significant between the Medium and Low groups ($t = -4.38$, df = 85, $p < 0.001$) and the High and Low groups ($t = -4.66$, df = 89, $p < 0.001$). For the 2-5 m threshold, the canopy closure for each of the three groups were High (M = 47.80%, SD = 16.73), Medium (M = 49.25%, SD = 19.92), and Low (M = 67.06%, SD = 17.72). The difference in means was very significant between the Medium and Low groups ($t = -4.36$, df = 85, $p < 0.001$) and the High and Low groups ($t = -5.23$, df = 89, $p < 0.001$).

Songmeters

Songmeter recordings were analyzed by Laura Achenbach, on contract to Environment and Climate Change Canada, using a high-resolution call recognizer for the call types of *Catharus bicknelli*. As of March 27, 2020, the songmeter analysis is still in progress. However, results have been confirmed for ground truthing sites P1, P2, P3, and P4, in addition to four sites outside of the study area. Due to technical failure, no results were recorded from P4. Stands P1-P3 were determined as having no presence of *C. bicknelli.* However, *C. bicknelli* was confirmed at two of the sites outside of the study area of this research. These sites were centrally located within Cape Breton Highlands National Park. This confirms that *C. bicknelli* populations are present and active within the Cape Breton Highlands.

Spatial Analyses

Global Moran's I

The output clusters of the K-means cluster analysis for the three habitat suitability models (2-5 m, 2-4 m, and 2-3 m) and the ground truthing stem density data, as well as the scores derived from the photo classification were tested for spatial autocorrelation using a Global Moran's I test (Table 4). Based on Tobler's First Law of Geography, if the variables test positive for spatial autocorrelation there is statistical evidence that like values are grouped together in space. If the variables test negative for spatial autocorrelation the values are dispersed throughout space. For this study, a positive spatial autocorrelation would indicate certain clusters of areas with similar values, allowing us to determine whether sites are similar in their habitat or not. The distance threshold was set at 58.32 m in order to assess each of the five ground truthing stands separately.

Table 4 Summary of Global Moran's I test results. Variables determined significant tested positive for spatial autocorrelation. Variables determined not significant tested negatively for spatial autocorrelation, indicating random distribution.

Variable	**Moran's Index Score**	**Probability (p-value) at 0.05**	**Standard Deviation (z-score)**	**Significant vs. Not Significant**
K-means groupings for 2-5 m model	-0.0016	0.87	0.16	Not Significant
K-means groupings for 2-4 m model	0.0041	0.76	0.30	Not Significant
K-means groupings for 2-3 m model	0.12	0.0011	3.25	**Significant**
Photo classification scores	0.11	0.0028	2.98	**Significant**
K-means groupings for stem density (stems ha^{-1})	0.069	0.055	1.92	**Significant**

Local Moran's I

The variables that showed positive spatial autocorrelation were further tested using a Local Moran's I test for cluster and outlier analysis. This test considers the relationship between each point or study site and its neighbours to identify clusters. Areas where high values are found around other high values are labeled as high-high, and areas where low values are found around low values are labeled as low-low. Outliers are also identified, where a high value is found surrounded by lower values or vice versa. The 2-3 m model showed varied results between the five ground truthing stands (Figure 16). P1 was mainly insignificant except for one low-low cluster study site in the south-east corner of the stand. P2 showed more low-low clustering in the south-west corner, with a couple of sites determined as high-low outliers. P3 showed multiple low-low clustered sites in the eastern to central portion of the stand. P4 showed high-high clusters in its northern region, with a few low-high outliers throughout the northern to central region of the stand. P5 showed low-high outliers throughout the stand, with a couple of high-high cluster points in the north-central region.

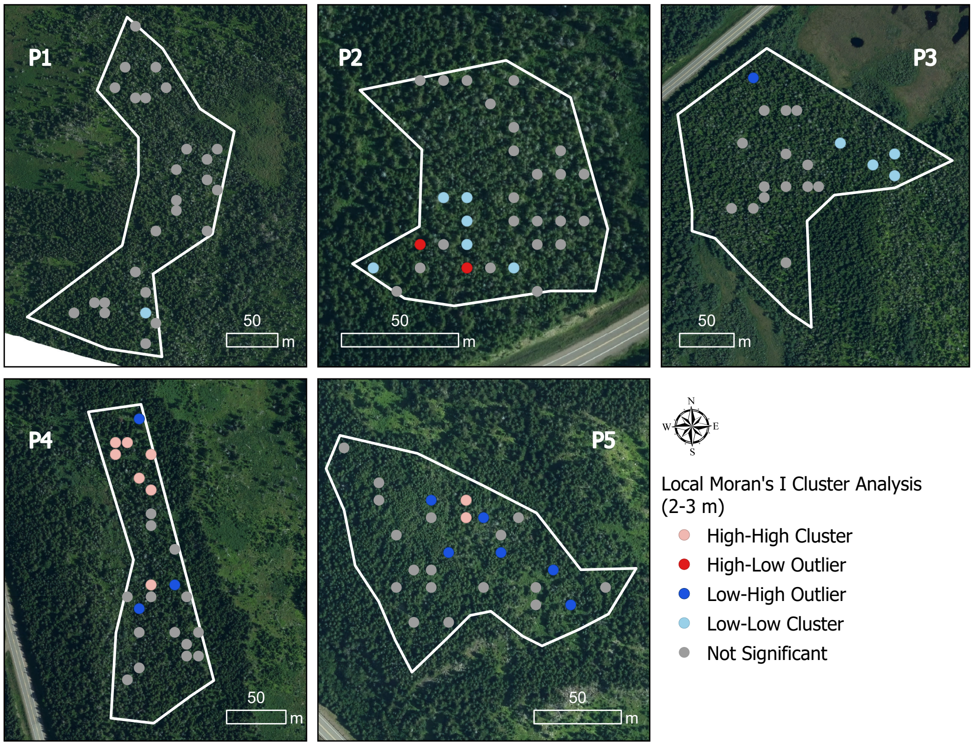

Figure 16 Output of a Local Moran's I test for cluster and outlier analysis of the K-means analysis output of 2-3 m habitat suitability model for each ground truthing stand.

The photo classification scores were found to be insignificant for stands P4 and P5, with some clusters and outliers identified in stands P1-P3 (Figure 17). P1 was mainly insignificant with a few high-low outliers spread throughout the stand. P2 showed significant high-high clustering throughout the stand, with a few low-high outliers. P3 showed a lesser amount of high-high clustering with a few low-high outliers throughout the stand.

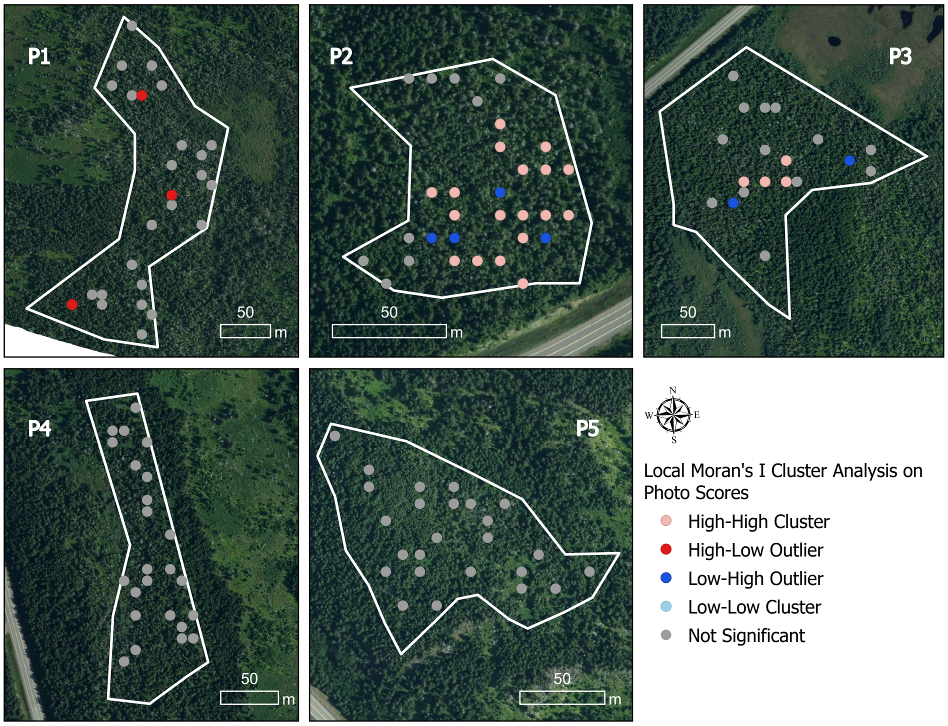

Figure 17 Output of a Local Moran's I test for cluster and outlier analysis of the photo classification scores for each ground truthing stand.

The stem density (stems ha^{-1}) values showed varied results between the five stands (Figure 18). P1 showed a low-low cluster in its northern region, with a single high-low outlier. P2 was found to be insignificant. P3 showed a couple of high-high cluster points in the northern region of the stand with an equal amount of low-high outlier points. A cluster of low-low points was identified in P4 along with a few high-low outliers. P5 showed a large cluster of high-high points, with a single low-high outlier.

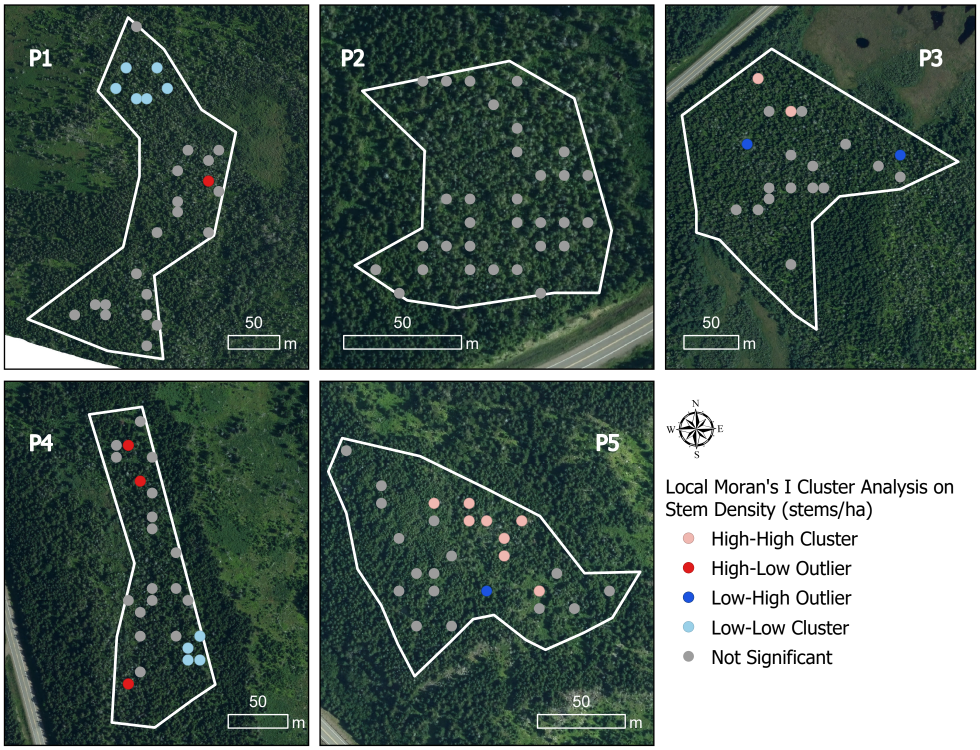

Figure 18 Output of a Local Moran's I test for cluster and outlier analysis of the K-means analysis output of stem density (stems ha-1) values for each ground truthing stand.

Hot Spot Analysis (Getis Ord Gi)*

The 2-3 m model, photo classification scores, and ground truthing stem density were further tested using the Hot Spot Analysis (Getis Ord Gi*) test. This test considers the relationship between each point or study site and its study area, in this case the associated ground truthing stand. Clusters of high value sites within the stand are represented by hot spots (orange to red) at varying levels of statistical significance. Clusters of low value sites within the stand are represented by cold spots (grey-blue) at varying levels of statistical significance. The 2-3 m model showed relatively insignificant results for P1, P3, and P5 (Figure 19). However, multiple cold spots were identified within P2, ranging in significance from 90-99% confidence. In addition, P4 showed multiple hot spots ranging in significance from 95-99% confidence.

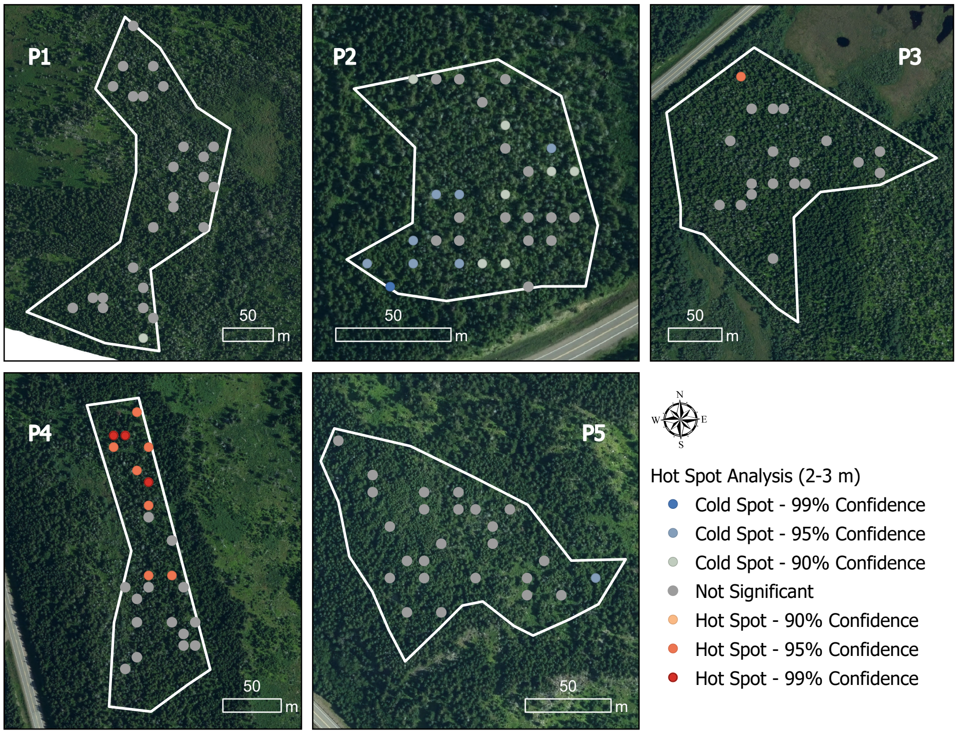

Figure 19 Output of hot spot analysis (Getis Ord Gi*) for the K-means analysis output for the canopy closure percentages between 2-3 m in height for each ground truthing stand.

The photo classification scores showed little significance in P1, P4, and P5 (Figure 20). However, P2 and P3 showed larger clusters of hot spots throughout their stands. P2, in particular, showed a significantly sized patch of hot spots at the 99% confidence level spanning the majority of the stand.

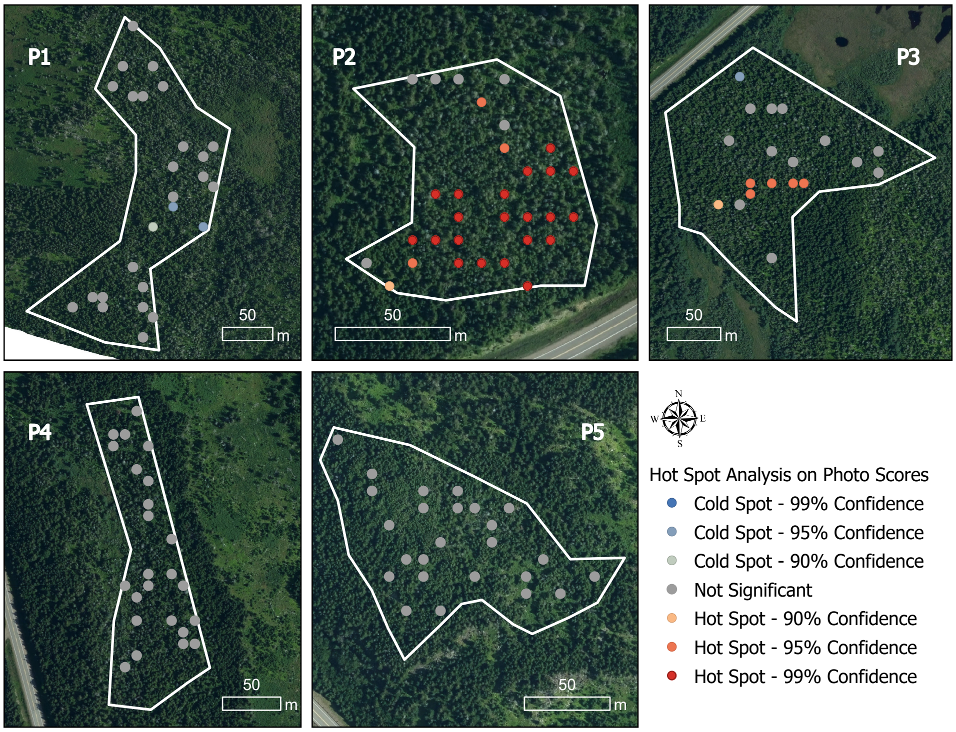

Figure 20 Output of hot spot analysis (Getis Ord Gi*) for the photo classification scores for each ground truthing stand.

The stem density (stems ha^{-1}) values showed relatively insignificant results for P2, P3, and P4 (Figure 21). However, a patch of cold spots were identified within P1 with a significance of 99% confidence. In addition, P5 showed multiple hot spots ranging in significance from 90-99% confidence.

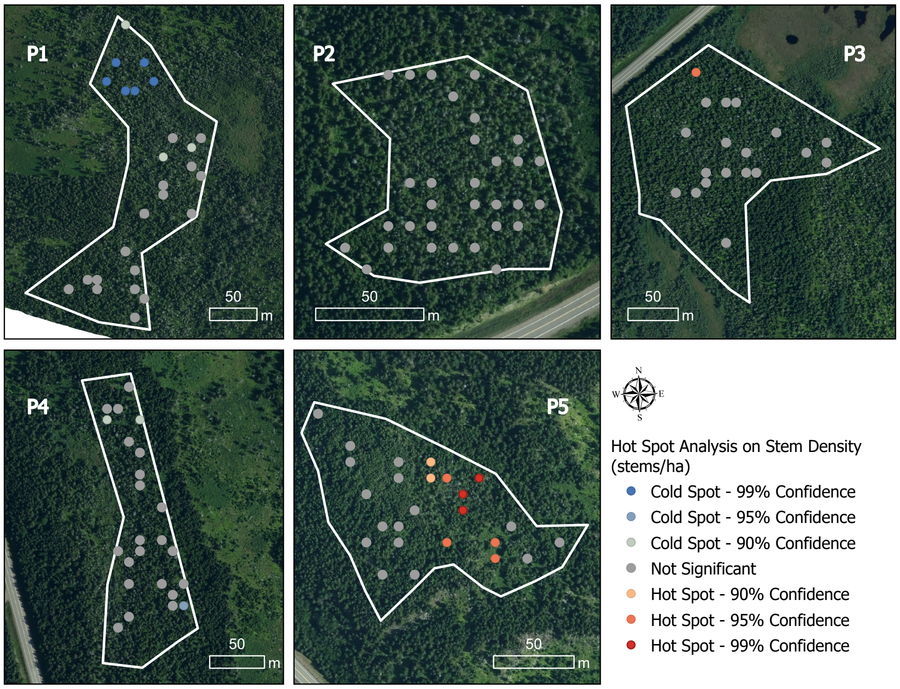

Figure 21 Output of hot spot analysis (Getis Ord Gi*) for the K-means analysis output for the stem density (stems ha-1) values for each ground truthing stand.

Discussion

This study aimed to answer the question of whether the critical habitat of the Bicknell's Thrush (*C. bicknelli*) within Cape Breton Highlands National Park could be identified through a habitat suitability model using forest characteristics of canopy height and closure and forest species composition, as well as elevation. While our habitat suitability model may not have been effective in identifying critical habitat, this study has provided a starting point that, with some fine-tuning, could be successful in identifying *C. bicknelli* habitat.

Validation of Habitat Suitability Model

Forest Composition

Based on the isolated Forest Inventory data, the study area fell within forest patches in which Balsam Fir (*Abies balsamea*) and Black Spruce (*Picea mariana*) were the dominant species. Table 1, showing recorded tree species of the study sites during the ground truthing surveys, supports these findings, with *Abies balsamea* and *Picea mariana* making up 94.2% of the 500 individual trees recorded. This complies with *Catharus bicknelli*'s well-recognized preference of *Abies balsamea* or *Picea spp.* dominated forest stands (Rimmer et al., 2005; Connolly, 2000; Lambert et al., 2005). The ecological land classification data (EER, 1978) illustrates potential patches of *C. bicknelli* habitat prior to the effects of the Spruce Budworm outbreak and subsequent impacts of hyperabundant moose populations within Cape Breton Highlands National Park based on airphotos from 1973. By focusing these data to only include forest characteristics associated with *C. bicknelli* habitat, multiple patches of habitat were identified outside of the study area. These patches were found further south of the Cabot Trail, indicating that suitable *C. bicknelli* habitat may have existed, and may still, in more isolated patches of Cape Breton Highlands National Park. This indicates that areas outside of our study area may provide more appropriate *C. bicknelli* habitat.

Canopy Height & Density

The three habitat suitability models, depicting canopy closure density within canopy heights of 2-3 m, 2-4 m, and 2-5 m, illustrated significant differences in percent canopy closure. When sorted by descending calculated stem density (stems ha^{-1}) groupings (high, medium, and low density), all three models followed the downward trend in canopy closure density. This validates that LiDAR derived canopy closure values can effectively model overall trends in stem density on the ground. However, average percent canopy closure associated with the High, Medium, and Low stem density groupings varied widely between the three models. A comparison of the average percent canopy closures of the three models at the high grouping illustrates that while a canopy height between 2-5 m may have a 'High' average of 61.92%, at the 2-3 m height range the same sites have an average of only 37.17%. Therefore, it is difficult to set a minimum percent canopy closure suitable for *C. bicknelli* populations without deciding on a set canopy height range.

Photo Classification

The canopy closure values of the three models were also sorted based on the photo classification score groupings (3 – good/excellent habitat, 2 – mediocre habitat, 1 – poor habitat). While it was determined that there was a significant difference between the three groups for all three models, the two-sample t-Test assuming equal variances illustrated that the photos scored as poor habitat had a significantly higher density (% canopy closure) than the photos scored as good/excellent or mediocre habitat. This raises some concerns regarding the accuracy of the models developed in this study in identifying critical *Catharus bicknelli* habitat.

Songmeters

As of March 27, 2020, we are still waiting on complete results of the songmeter data. Initial results have determined a lack of presence within stands P1-P3, with P4 excluded from analysis due to technical failure. P5 has yet to be analyzed as of this date. Based on these initial results, it appears as though *Catharus bicknelli* populations were not present within our study area. This may be due to a limited area of critical habitat within the study area of 500 m on either side of the Cabot Trail, or it may be related to other factors, such as road noise or human disturbance. While the effects of road noise on *C. bicknelli* populations and their habitat have not been studied, there is a growing body of research looking at the effects of road noise on avian species (Forman et al., 2002; Francis et al., 2009; Khanaposhtani et al., 2019). However, songmeter results from sites outside of our study area identified the presence of *C. bicknelli* populations within Cape Breton Highlands National Park, confirming the presence of the species within the Cape Breton Highlands.

Spatial Distribution

The spatial analysis component of this study found that while many of the variables tested positive for spatial autocorrelation, the cluster of these variables did not overlap. This indicates that there is no spatial relationship between percent canopy closure, stem density (stems ha^{-1}), or the photo scores. If the model had been successful, the clusters of these variables would have had a similar distribution. This suggests the need for further investigation and fine-tuning the parameters of canopy height and preferred canopy closure density of the model in order to better identify *C. bicknelli* habitat.

While we have determined a lack of presence of *Catharus bicknelli* populations in ground truthing stands P1-P3 (P4 excluded), we are still waiting on results for P5. Past literature has identified common trends or characteristics of sites occupied by *C. bicknelli* populations, including high elevation, dense stunted spruce-fir forests (approximately between 1.5-5 m in height) with a greater abundance of snags and dead trees and predominantly moss covered ground (Connolly, 2000; Hale, 2006; Noon, 1981; Rimmer et al., 2005). Latitude has also been identified as an important factor in regions within the United States, showing a strong negative linear relationship between higher latitude and the lowest elevations occupied by *C. bicknelli* (Lambert et al., 2005). Many of these factors were considered in the photo classification component of this study. However, when sorted into the three photo classification groupings, the 2-5 m model had an average percent canopy closure of 47.80% (SD = 16.73) for sites scored as good/excellent habitat compared to an average 67.06% (SD = 17.72) canopy closure for sites scored as poor habitat. This may indicate that percent canopy closure is not an effective measure of density in terms of *C. bicknelli* habitat. When comparing the good/excellent habitat photos (ex. Figure 8) from the poor habitat photos (ex. Figure 9), the major difference is the age of the forest stand or density of foliage from the ground to the maximum canopy height. While many of the sites scored as poor habitat were identified as high canopy closure density, they had begun self-thinning and had very little foliage within the span of the photo. While percent canopy closure was found to be an effective measure of stem density (stems ha^{-1}) at breast height, it may not be an appropriate measure of stand age or density of foliage.

Uncertainties

The Cape Breton Highlands are a relatively unexplored region in terms of *Catharus bicknelli* breeding habitat, and it is unclear whether the characteristics identified as good habitat in other regions of the species' range are appropriate indicators of *C. bicknelli* habitat in Nova Scotia. As Connolly (2000) stated, we must take caution in making generalizations of *C. bicknelli* habitat preferences across the breeding range of the species. While this model has identified areas of interest in regard to focusing further studies of *C. bicknelli* populations within the Cape Breton Highlands, specifically the two areas where songmeter recordings identified present *C. bicknelli* populations, there are still many unknowns in terms of habitat preferences specific to this region and how these preferences can be translated into a model in order to identify areas of critical habitat.

This study has also not considered biotic factors or influences within the community in terms of *C. bicknelli* habitat, such as predator or competitor presence and distribution. For example, a study by Aubrey et al. (2016) assessed the presence of Swainson's Thrush (*Catharus ustulatus*), a potential competitor, in their analysis of *C. bicknelli* habitat in Quebec, and found that *C. ustulatus* were present at all sites that *C. bicknelli* populations were reported. Understanding the interactions and spatial relationships between *C. bicknelli* and their predators or competitors may provide more insight into their habitat preferences.

The influence of forestry practices and management is a well discussed topic in other *C. bicknelli* literature in terms of their protection (Aubry et al., 2016; Connolly, 2000; ECCC, 2016; COSEWIC, 2009). There are no forestry practices or management conducted within Cape Breton Highlands National Park, and therefore forestry is not a factor of habitat loss or fragmentation for Cape Breton *C. bicknelli* populations. However, the loss of the boreal forest ecosystem within the Cape Breton Highlands due to the hyperabundant moose populations could threaten *C. bicknelli* populations through the loss or fragmentation of habitat (COSEWIC, 2009; ECCC, 2016). Climate change may also pose a threat to *C. bicknelli* populations within the Cape Breton Highlands as warmer climates may push the boreal forest range further north (Lambert et al., 2005). These factors will play an important role in the long-term monitoring of *C. bicknelli* populations and identification of critical habitat.

Future Studies

While this study provided a starting point for further analysis of *Catharus bicknelli* populations and habitat distribution within the Cape Breton Highlands, there are still many uncertainties regarding the identification of critical habitat. Further ground truthing analysis of the habitat preferences of *C. bicknelli* within Cape Breton and how to model this habitat with LiDAR data or other methods are essential to more accurately identifying areas of critical habitat, especially as LiDAR data for the entirety of Cape Breton becomes available. As we have identified the presence of *C. bicknelli* within Cape Breton Highlands National Park in areas outside the bounds of currently available LiDAR data, these sites can aid in setting model parameters and identifying other areas of critical habitat. In addition, it is important to further assess spatial relationships between *C. bicknelli* and the boreal forest community, especially in terms of the habitat preferences and behaviours of predators, competitors, and other potential threats/influences such as moose. Finally, it is important that monitoring, both at the species and habitat level, are continued in order to assess changes in populations or the environment.

Conclusion

As a species at risk, understanding the range and distribution of *Catharus bicknelli* and its preferred habitat is essential to the monitoring and recovery of the species. This study adapted characteristics that have been identified as preferred *C. bicknelli* habitat in other regions within its range into parameters of a LiDAR data-based model in an attempt to identify areas of critical habitat within the Cape Breton Highlands. These parameters included canopy height, percent canopy closure, elevation, and forest composition. When compared to ground truthing data and photo analysis of a selection of 125 study sites, it was found that while the model was effective in identifying general trends in stem density, it was not necessarily effective in identifying good/excellent *C. bicknelli* habitat. Songmeter recording analysis identified a lack of presence of *C. bicknelli* populations within the study area. However, presence was confirmed in other, more remote areas within Cape Breton Highlands National Park. The lack of presence of *C. bicknelli* within the study area may be a result of its proximity to the Cabot Trail, increasing the presence of road noise and human disturbance in these areas. Further research is recommended once greater areas of LiDAR data become available for the Cape Breton Highlands. This research should focus on fine-tuning the parameters of the model to better represent the habitat preferences of *C. bicknelli*, using the sites with confirmed presence of *C. bicknelli* populations as a guide. Further research should also focus on identifying and increasing our understanding of other environmental factors, such as potential influences of predators, competitors, and other environmental or anthropogenic factors such as changes in or deterrents caused by human activities or hyperabundant moose populations. The identification and conservation of critical habitat, as well as long-term monitoring of *C. bicknelli* populations in Cape Breton, are necessary for the recovery of the species, and will become increasingly important in the face of climate change.

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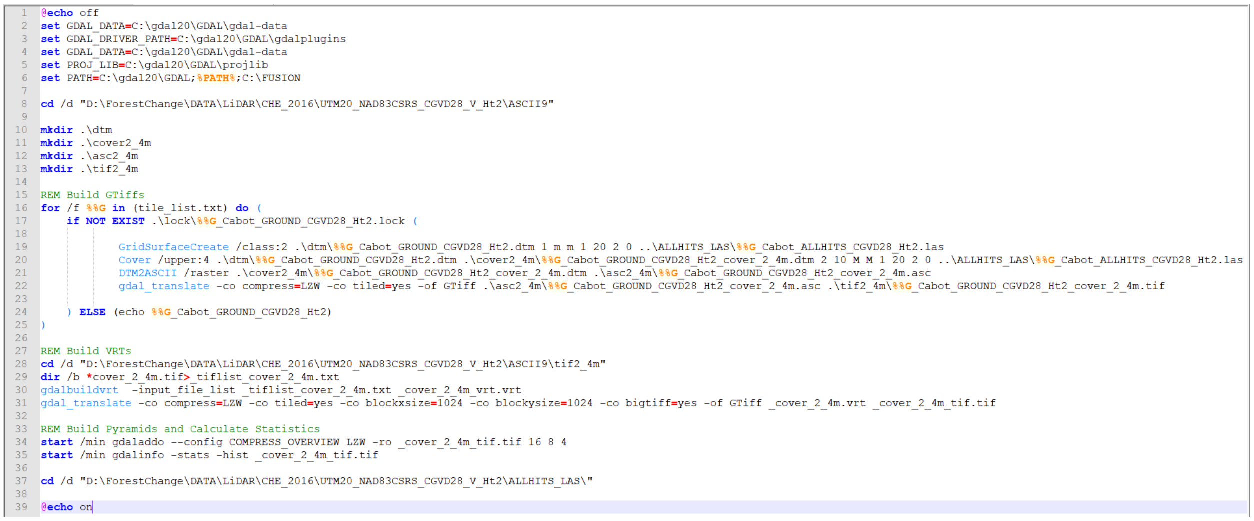
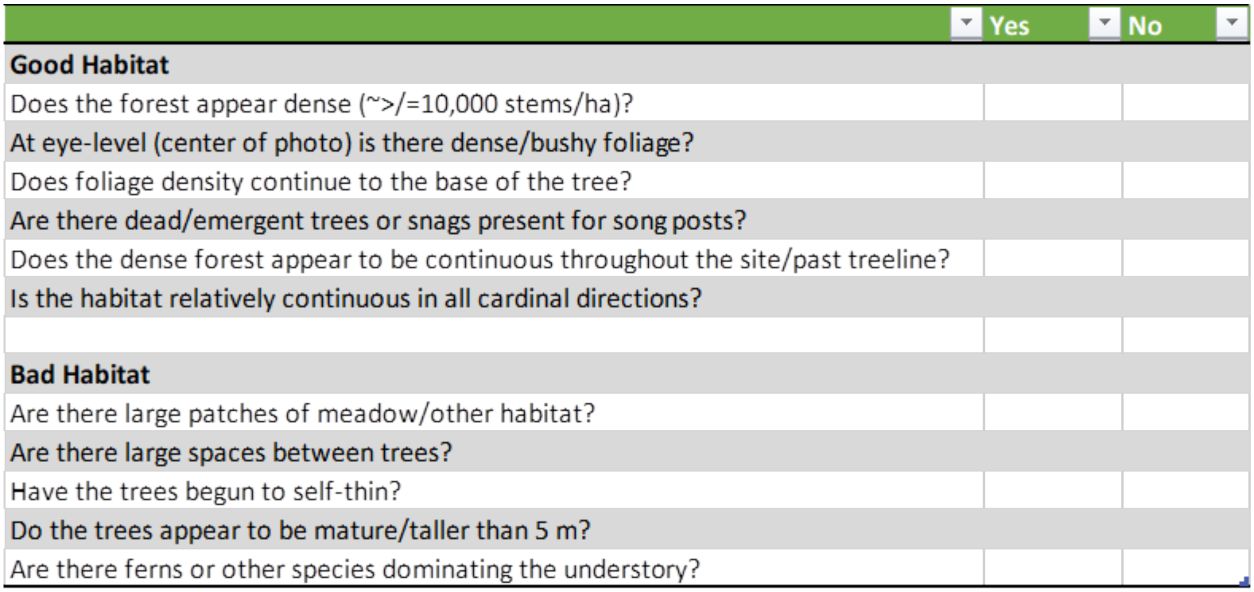
Appendices

Appendix A: Script for habitat suitability model (between 2-4 m in canopy height)



```
@echo off
set GDAL_DATA=C:\gdal20\GDAL\gdal-data
set GDAL_DRIVER_PATH=C:\gdal20\GDAL\gdalplugins
set GDAL_DATA=C:\gdal20\GDAL\gdal-data
set PROJ_LIB=C:\gdal20\GDAL\projlib
set PATH=C:\gdal20\GDAL;%PATH%;C:\FUSION

cd /d "D:\ForestChange\DATA\LiDAR\CHE_2016\UTM20_NAD83CSRS_CGVD28_V_Ht2\ASCII9"

mkdir .\dtm
mkdir .\cover2_4m
mkdir .\asc2_4m
mkdir .\tif2_4m

REM Build GTiffs
for /f %%G in (tile_list.txt) do (
    if NOT EXIST .\lock\%%G_Cabot_GROUND_CGVD28_Ht2.lock (

            GridSurfaceCreate /class:2 .\dtm\%%G_Cabot_GROUND_CGVD28_Ht2.dtm 1 m m 1 20 2 0 ..\ALLHITS_LAS\%%G_Cabot_ALLHITS_CGVD28_Ht2.las
            Cover /upper:4 .\dtm\%%G_Cabot_GROUND_CGVD28_Ht2.dtm .\cover2_4m\%%G_Cabot_GROUND_CGVD28_Ht2_cover_2_4m.dtm 2 10 M M 1 20 2 0 ..\ALLHITS_LAS\%%G_Cabot_ALLHITS_CGVD28_Ht2.las
            DTM2ASCII /raster .\cover2_4m\%%G_Cabot_GROUND_CGVD28_Ht2_cover_2_4m.dtm .\asc2_4m\%%G_Cabot_GROUND_CGVD28_Ht2_cover_2_4m.asc
            gdal_translate -co compress=LZW -co tiled=yes -of GTiff .\asc2_4m\%%G_Cabot_GROUND_CGVD28_Ht2_cover_2_4m.asc .\tif2_4m\%%G_Cabot_GROUND_CGVD28_Ht2_cover_2_4m.tif

    ) ELSE (echo %%G_Cabot_GROUND_CGVD28_Ht2)
)

REM Build VRTs
cd /d "D:\ForestChange\DATA\LiDAR\CHE_2016\UTM20_NAD83CSRS_CGVD28_V_Ht2\ASCII9\tif2_4m"
dir /b *cover_2_4m.tif> tiflist_cover_2_4m.txt
gdalbuildvrt  -input_file_list _tiflist_cover_2_4m.txt _cover_2_4m_vrt.vrt
gdal_translate -co compress=LZW -co tiled=yes -co blockxsize=1024 -co blockysize=1024 -co bigtiff=yes -of GTiff _cover_2_4m.vrt _cover_2_4m_tif.tif

REM Build Pyramids and Calculate Statistics
start /min gdaladdo --config COMPRESS_OVERVIEW LZW -ro _cover_2_4m_tif.tif 16 8 4
start /min gdalinfo -stats -hist _cover_2_4m_tif.tif

cd /d "D:\ForestChange\DATA\LiDAR\CHE_2016\UTM20_NAD83CSRS_CGVD28_V_Ht2\ALLHITS_LAS\"

@echo on
```

Appendix B: Photo Classification Key



	Yes	No
Good Habitat		
Does the forest appear dense (~>/=10,000 stems/ha)?		
At eye-level (center of photo) is there dense/bushy foliage?		
Does foliage density continue to the base of the tree?		
Are there dead/emergent trees or snags present for song posts?		
Does the dense forest appear to be continuous throughout the site/past treeline?		
Is the habitat relatively continuous in all cardinal directions?		
Bad Habitat		
Are there large patches of meadow/other habitat?		
Are there large spaces between trees?		
Have the trees begun to self-thin?		
Do the trees appear to be mature/taller than 5 m?		
Are there ferns or other species dominating the understory?		