

Northern Goshawk (*Accipiter gentilis laingi*)
Habitat Models
for Coastal British Columbia.

Nesting and Foraging Habitat Suitability Models
and Territory Analysis Model

For:

Habitat Recovery Implementation Group
Coastal Northern Goshawk Recovery Team
BC Ministry of Forests, Lands and Natural Resource Operations

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Scope, Context and Caveats

An earlier version of this model report was produced in 2008 as part of initial model development. Since then, various projects associated with the model have been conducted including model verification, model revisions, and implementation of the model across the four Coastal Northern Goshawk Conservation Regions. Those projects have been documented to varying degrees in separate project reports. The purpose of this report (January 2015) is to consolidate the documentation of model work since 2008 into an updated comprehensive model report. Initial funding for this report was provided in 2012, however, much of the work was completed by the authors on our own time as we could fit it in over the last two years. As such we provide this document ‘as is’ with the caveat that time and resource constraints limited the level of detail in some sections and the degree to which some sections have been rewritten and integrated from other reports. For example, limited effort was expended in updating background sections, such as the species account; focus was placed on technical sections, such as the model parameters. In March 2019 additional technical updates were completed, as part of a coast-wide re-run of the model funded by Ministries of Environment and Climate Change Strategy and Forests, Lands, Natural Resource Operations and Rural Development.

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Executive Summary

The purpose of this project was to develop standardized habitat models for the Northern Goshawk (*Accipiter gentilis laingi*; hereafter goshawk) across this subspecies' range in coastal British Columbia (BC). The three models that were developed were a goshawk nesting habitat model, a foraging habitat model, and a "territory" model. The territory model is used for analysis purposes, to assess the amount, quality and distribution of nesting and foraging habitat relative to average goshawk territory sizes and spacing patterns, not to predict actual territory locations. The structures of the nesting habitat and foraging habitat models are based on the Habitat Suitability Index (HSI) methodology. This report summarizes the variables used in the models and the ratings assigned for each variable, which were based on observed habitat use by goshawks in coastal BC, relevant literature, and the expert opinion of the authors. Model development and implementation has been completed for all four Coastal Northern Goshawk Recovery Team Conservation Regions: Haida Gwaii, North Coast, South Coast and Vancouver Island. Two habitat scenarios were run in each Conservation Region: current conditions using current forest cover datasets (circa 2005) and capable habitat conditions, which were estimated by growing current forest stands out for 300 years. Capable conditions represent an estimate of the highest value habitat conditions for goshawks under optimal structural stage development of current stand types and can be used as a baseline against which current habitat conditions and relative number of potential territories can be compared.

Model development involved four stages over 6 years: 1) initial model development, implementation, and evaluation across the four Conservation Regions (2005-2008), 2) a detailed sensitivity analysis that examined the relative influence of different variables in the model and how sensitive model outputs were to changes in key model parameters (2008), 3) formal accuracy assessment of the nesting and foraging model outputs in each of the four Conservation Regions using field verification (2009-2012), and 4) a final comprehensive review and, where appropriate, revision of model parameters using the field verification data, new literature, and new local goshawk data (2012). At this point model development and evaluation are considered to be complete, however, we anticipate the models will be dynamic products that may evolve over time as more biological information becomes available, as model input data are updated or as models are tailored to specific areas or project objectives.

The performance of the nesting and foraging models were assessed in each of the four Conservation Regions using formal accuracy assessment procedures. The basis for the accuracy assessment was to compare model predictions of nesting and foraging habitat suitability to field ratings assessed by northern goshawk experts at the same location. Accuracy was scored using two different methods, to account for different ways the model outputs may be used, and at three different scales (site, stand and regional scales), to account for potential spatial accuracy issues and to provide guidance for management activities conducted at those scales. Using the primary scoring method (based on the

difference between the model and field ratings) and the stand-level scale, the nesting model averaged 82% accuracy and overestimated suitability by 0.01 – 0.09 HSI units (depending on Conservation Regions); the foraging model averaged 85% accuracy and underestimated suitability by 0.04-0.06 HSI units. Accuracy scores and patterns of bias were quite consistent across Conservation Regions, suggesting that the models are fairly robust across coastal BC. Model errors appeared to be largely driven by errors in forest cover data, which has two significant implications: 1) errors in the underlying data limit potential model revisions to improve performance, and 2) use of the model outputs should be consistent with generally accepted practices and limitations associated with using forest cover data for other forest and habitat management activities. Although the accuracy of the HSI models exceeds the *a priori* target of 80% initial set by the Recovery Team, precautionary use of model outputs is recommended, including verification of model predictions via ground truthing or aerial imagery.

Considerations for using model outputs for forest management and planning are discussed. Model outputs (nesting and foraging habitat suitability ratings and estimated numbers of potential territories) were primarily designed to be used to make relative comparisons among scenarios (e.g. between current and capable conditions, over multiple time periods, or among different management scenarios) at large spatial scales. Relative comparisons among model outputs should be fairly insensitive to model errors and biases, assuming model errors and biases are similar among scenarios. If model outputs are used outside of the context of relative comparisons, users need to be aware of the implications of model errors and biases and take measures to account for those issues, such as ground truthing to verify habitat quality predictions. Modelled territories should generally not be used in a spatial context, due to several limitations and stochastic factors inherent to the territory model. Also, territory model outputs should not be used at planning scales smaller than ca. 500,000 ha. Territory model outputs are too coarse an indicator to use for sub-regional planning scales, such as Landscape Units. Approaches for using amount and quality of nesting and foraging habitat outputs at Landscape Unit scales are provided.

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Introduction

This document describes habitat suitability models developed for the Northern Goshawk (*Accipiter gentilis laingi*; hereafter goshawk) in Coastal British Columbia. We developed models for goshawk nesting and foraging habitats as well as a “territory” model that was used primarily for analysis purposes to assess the amount and distribution of nesting and foraging habitat relative to average goshawk territory sizes and spacing patterns across the region. We also hoped that the territory model would assist the Northern Goshawk Recovery Team to determine approximate numbers of territories that could be supported within conservation regions at given times in harvest histories and under different forest management scenarios. The structures of the nesting and foraging habitat models are based on the Habitat Suitability Index (HSI) methodology (US Fish and Wildlife Service 1981). The variables used in the models and ratings assigned for each variable were developed based on observed habitat characteristics at goshawk nest areas in Coastal BC, relevant literature, and the expert opinion of the authors.

The study area for this project encompassed the entire Coast Forest Region (hereafter Coastal BC) and reflected the estimated range of *A. g. laingi* in BC. Due to differences in habitat characteristics, harvest histories and future harvest projections and data availability across this large region, the area was stratified into four conservation regions and model parameters for the three models were tailored for each conservation region. The four conservation regions are Haida Gwaii, North Coast, South Coast, and Vancouver Island. Generally, model parameters were very similar among areas, reflecting similar patterns of habitat use by goshawks across the area, however, in some circumstances model parameters were varied to account for differences in goshawk biology (e.g. differences in nesting density), habitat structure and ecology (e.g. different distribution of forest composition among biogeoclimatic variants), and data availability (e.g. stand age was not available in some TFL databases).

The intended use of these habitat models is to assess the relative quality, amount and distribution of goshawk breeding habitat in Coastal BC. Habitat ratings that result from these models represent relative values suitable for comparisons across the study area and for comparing habitat supply under different management scenarios. Ratings do not predict, or correspond to, absolute measures of habitat quality or absolute numbers of goshawk territories. The models were developed specifically for the Coastal Western Hemlock (CWH), Coastal Douglas Fir (CDF), Mountain Hemlock (MH) and Alpine Tundra (AT) biogeoclimatic variants (Pojar et al. 1987) found in the Coast Forest Region using forest inventory data from the Ministry of Forests and forest licensees and TRIM map databases. Application of these models to different biogeoclimatic variants or using other data inventories should be done cautiously.

Outputs from this model should generally be restricted to large-scale strategic purposes. This is primarily due to the relatively poor stand level accuracy of some of the forest cover data. In addition, some variables that are known to affect goshawk habitat suitability (notably canopy closure), and which we recommend should be included in models used for stand level purposes, such as operational management, could not be included in these models because they were not available in all forest cover databases across the study area.

Five goshawk habitat mapping projects have previously been conducted in Coastal BC (see review by Mahon 2005). The purpose of this project was to standardize model structure, model variables, variable ratings, input data, and analysis methods to facilitate region-wide evaluation of goshawk habitat. This was not possible using the outputs from the previous projects due to differences in several factors among those projects. The intent of this project was not to redo habitat mapping for any specific area on the basis that the previous output was of poor quality, or that this product would be superior; it was simply to provide a standardized set of outputs across the region, using the collaborative expertise of three provincial goshawk experts. As well, we provide a territory model which attempts to facilitate the interpretation of nesting and foraging habitat model outputs in a spatially explicit manner relevant to goshawk ecology.

Species Account

Several documents provide compressive accounts of the ecology, management and conservation of the Northern Goshawk internationally (Squires and Reynolds 1997), provincially (Cooper and Stevens 2000) and regionally (Iverson *et al* 1996; Mahon and Doyle 2003; McClaren 2005, McClaren et al. 2015). For detailed background information readers should refer to these documents. Below we provide a brief synopsis of key information. The following sections provide more detailed information specific to the ecology of goshawks in Coastal BC (*Accipiter gentilis laingi*) and the application of this information in the development of habitat models.

Species Overview: Description, Distribution, and Ecology

The Northern Goshawk (*Accipiter gentilis*) is a raven-sized forest raptor with a circumpolar distribution, and is found in both temperate and boreal forests (Brown and Amadon 1989). Across its range there are several morphologically different sub-species. Within BC the larger *A. g. atricapillus* is found throughout the interior of the province and the smaller Threatened *A. g. laingi* is found on Vancouver Island, Haida Gwaii (Queen Charlotte Islands) and along the mainland coast (Campbell et al. 1990; Cooper and Stevens 2000).

The goshawk is primarily adapted to forest habitats where its short, rounded wings, long tail, and powerful flying action make it an effective direct pursuit hunter, capable of quick acceleration and excellent maneuverability through the forest. Across their broad range goshawks take a variety of mid-sized forest prey ranging from small mammals and passerines to hares (Squires and Reynolds 1997). In coastal BC its main prey during the breeding season are red squirrels, forest passerines (typically thrushes, woodpeckers and jays) and grouse (Roberts 1997; Ethier 1999; Mahon and Doyle 2003). In southeast Alaska, Lewis (2001) also reported Northwestern Crows and Marbled Murrelets to be important components of goshawk's breeding diet (Lewis 2001).

Goshawks typically nest in mature and old-growth coniferous stands that have a closed canopy and open understory (Cooper and Stevens 2000, Penteriani 2002, McGrath et al. 2005). Within homogenous mature forest habitat goshawks are relatively evenly distributed (Reynolds and Joy 1998; Reich et al. 2004) with the distance between territories being primarily driven by prey and habitat availability within landscapes (Doyle and Smith 1994, 2001; Reich et al. 2004). In Coastal BC nest area spacing ranges from approximately 7 km on Vancouver Island (McClaren 2005) to approximately 11 km on Haida Gwaii (Doyle 2005). These spacing distances correspond to territory sizes of 3800 ha – 9200 ha, respectively, which are substantially larger than territories in interior BC (2300 ha; Mahon and Doyle 2003) and in the southwestern United States (1200 ha; Reynolds et al. 2005). The Northern Goshawk is probably a year-round resident in most years throughout most of its range (Squires and Reynolds 1997). This is supported by McClaren (2005) who tracked 68 birds on Vancouver Island over seven years using telemetry, and found that all birds remained resident (on Vancouver Island or on adjacent coastal mainland) over the winter, although some moved off of their breeding territories (McClaren 2005).

Taxonomy and Status

It is generally accepted that it is the *A. g. laingi* subspecies that occupies Coastal BC (Taverner 1940, Johnson 1989, COSEWIC 2013, Northern Goshawk *A. g. laingi* Recovery Team 2008). The original subspecies designation was based on morphological analysis by Taverner (1940), who first noted that *A. g. laingi* was darker and smaller than *A. g. atricapillus*. More recently, Whaley and White (1994), Flatten et al (1998) and Flatten and McClaren (2003) have conducted more detailed morphometric studies that support *A. g. laingi* subspecies delineation. Recent genetic analyses also suggest goshawks in Coastal BC and southeast Alaska share unique genetic characteristics that distinguish *A. g. laingi* from *A. g. atricapillus* and that populations are not panmictic, meaning gene flow does not currently occur among all coastal goshawk populations (Talbot et al. 2011; Sonsthagen et al. 2012). However, the genetic information available does not provide conclusive information about subspecies range delineation, partly due to

limitations associated with the number of samples and the location and density of samples across the range. .

A. g. laingi is designated Threatened (COSEWIC 2013) nationally and Red-listed (Threatened or Endangered (S2B)) provincially (BC Conservation Data Centre 2012). This sub-species is also listed as a Category of Species at Risk under the Forest and Range Practices Act (FRPA; BC Ministry of Water, Land and Air Protection 2004), due to its strong association with mature coniferous forests for foraging and nesting, and the possible impact to this habitat resulting from forest development.

Before the mid 1990s very few Northern Goshawk nest areas were known in Coastal BC. Since the mid 1990s approximately 165 nest areas have been discovered through a combination of intensive inventory programs and reports from forest workers. The numbers of known breeding areas by conservation region are: 102 in Vancouver Island, 17 in Haida Gwaii, 21 in North Coast, and 25 in South Coast.

Loss of mature forest breeding habitat (nesting and foraging) from logging is probably the most significant factor threatening goshawks in Coastal BC (Cooper and Stevens 2000, COSEWIC 2013, Northern Goshawk *A. g. laingi* Recovery Team 2008). In parts of Europe populations of goshawks have declined 50-60% in response to broad-scale forest harvesting (Widen 1997). Monitoring in most of Coastal BC has been inadequate to determine population trends, but Doyle (2004) estimated that timber harvesting over the last 40 years on Haida Gwaii has reduced the number of suitable territories from >50 to approximately 20. Further, nest productivity at the known nest areas over the last five years has been inadequate to sustain the population (Doyle 2004).

Territory Components

A goshawk territory is traditionally described as having several hierarchically arranged components (Figure 1; after Reynolds et al. 1992, Interior Northern Goshawk Science Team 2012). At the smallest scale is the nest tree. Most goshawk territories have 2-6 nest trees although a small proportion of territories contain a single nest tree. Most (90%) nest trees are spaced 0-800 m apart (McClaren et al. 2015) and the area encompassing the cluster of nest trees is the nest area. Surrounding each nest tree is a post-fledging area (PFA), which is used by fledgling goshawks after they fledge, but before they disperse. The location of the PFA can be different each year depending on the location of the active nest tree and the stand type and topography surrounding it (McClaren et al. 2005). The breeding area is defined by the combined space of multiple post-fledging areas around each nest tree. The breeding area is the focal territory component for all breeding activities of adults and fledglings through the courtship, incubation, nestling and post-fledging periods – mid-February to September (McClaren et al. 2015). The estimated size range of breeding areas in coastal BC is 46-263 ha (McClaren et al. 2015). At the largest territory scale is the annual home range, which

includes the total area used by an adult goshawk pair throughout the year. At the annual home range scale there is considerable overlap among adjacent goshawk pairs. During the breeding season, space use contracts to a smaller breeding home range with reduced overlap among neighbouring pairs (Squires and Reynolds 1997).

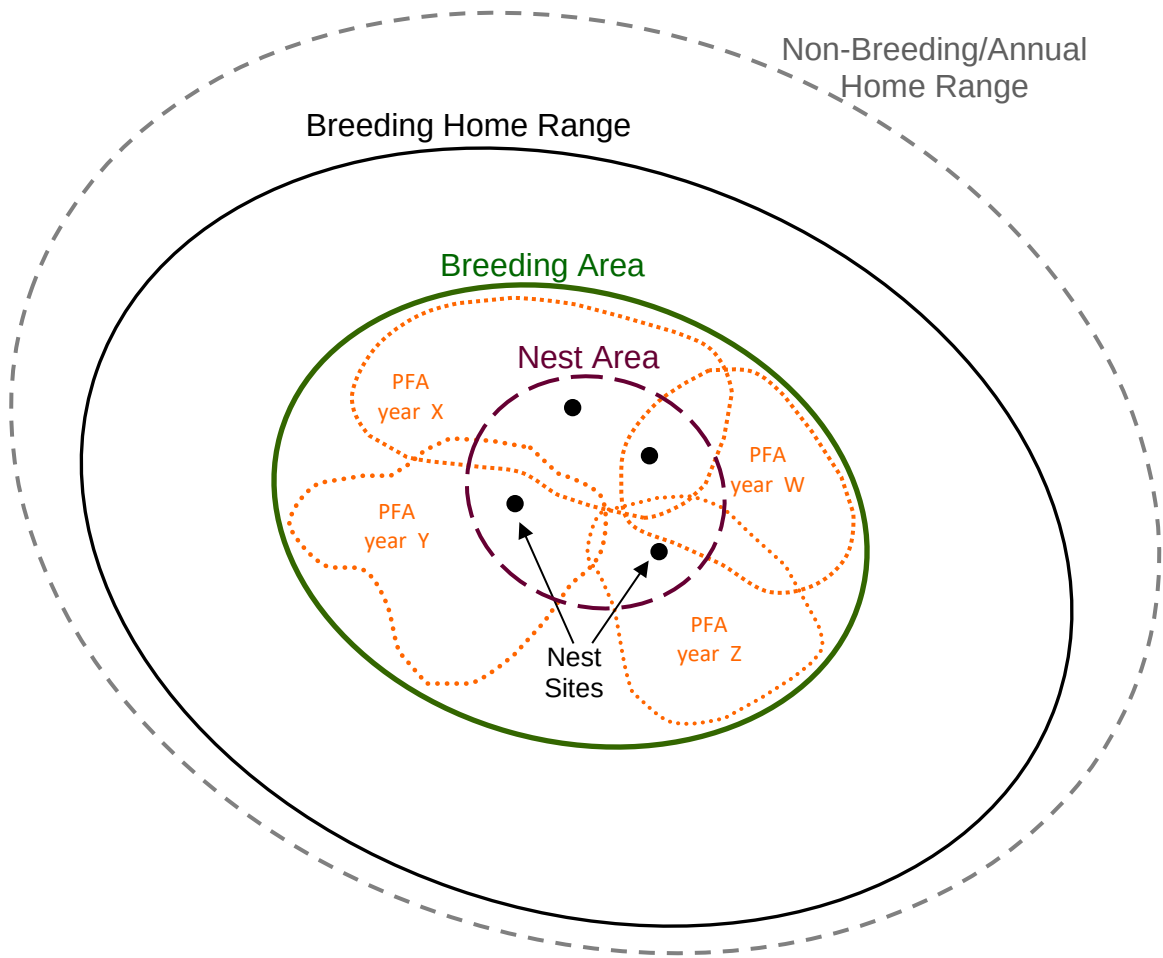


Figure 1. Conceptual arrangement of hierarchical components of a goshawk pair's territory. (after Stuart-Smith et al. 2012).

Nesting Habitat

Goshawks consistently select key structural attributes for their nesting habitat despite significant variation in forest types used for nesting across their geographic range. These attributes include mature/old-growth stand structure and relatively closed canopies with corresponding open sub-canopy flyways (Cooper and Stevens 2000, Penteriani 2002, McGrath et al. 2005, Northern Goshawk *A. g. laingi* Recovery Team 2008). At the regional level, selection of forest species composition is also evident (Schaffer et al. 1999, Mahon and Doyle 2003; McClaren 2005). A summary of stand characteristics for known goshawk nest areas in the CWH biogeoclimatic zone on Haida Gwaii and in northwestern BC is provided in Appendix 1. Nest stands are dominated by western hemlock or co-dominated by western red-cedar and western hemlock and are typically ≥ 90 years (age class 8), ≥ 32 m in height, and have $\geq 50\%$ canopy closure (canopy closure class 5). Photographs of high quality and low quality nest area stands are provided in Figures 2 and 3, respectively. These characteristics are generally associated with the more productive site series in mid to toe slope positions. Suitable nesting habitats are often constrained by site conditions that limit their extent and result in unevenly distributed patches of suitable habitat. For example, fjordland geography dominates much of coastal BC and suitable habitat is often limited to narrow bands of forest in toe and lower slope positions along these fjords (Figure 3).



Figure 2. Example of a high quality goshawk nesting habitat with high canopy closure and open sub-canopy fly-ways.



Figure 3. Example of a poor quality goshawk nesting habitat, with low canopy closure and diverse vertical stand structure within all canopy and shrub layers.

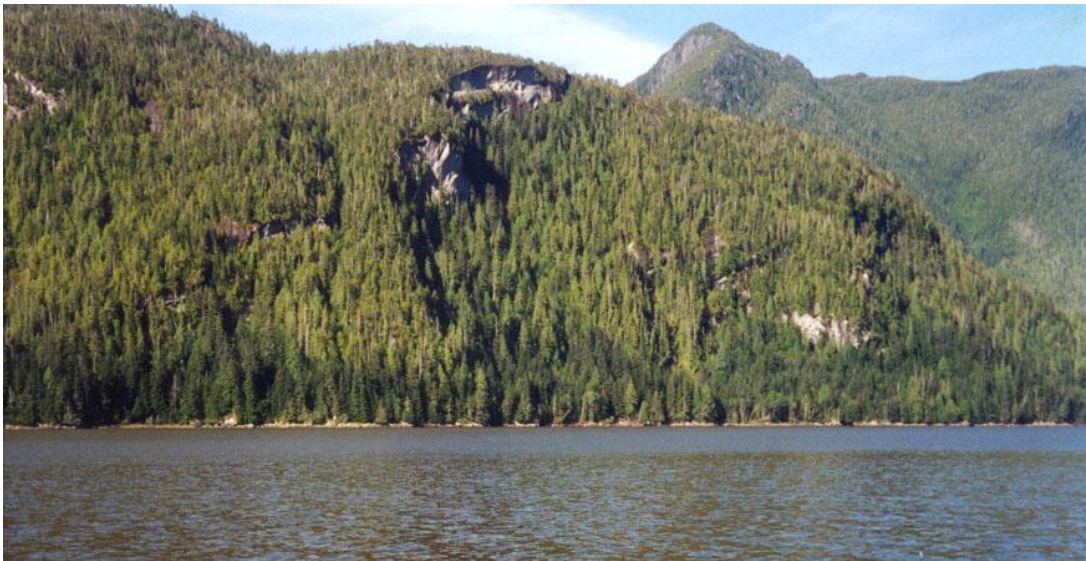


Figure 4. High quality nesting and foraging habitat for goshawks, identifiable here as the darker stands in the lower slope positions, is limited in extent and frequently constrained in linear distributions across Coastal BC.

Foraging Habitat

Foraging habitat can occur throughout the home range. Habitats used by goshawks for foraging are generally similar to those used for nesting, although foraging habitat is more variable, depending on fluctuating prey populations, and generally broader (i.e., a broader range of levels for a given variable are suitable for foraging than they are for nesting). In addition to foraging habitat being more general and more variable than nesting habitat, our knowledge of foraging habitat selection by goshawks is less than it is for nesting habitat (especially in coastal habitats). Furthermore, patterns of selection for some foraging habitat variables, from relatively few studies, appear to be contradictory, possibly reflecting high regional or temporal variation. For example, in Alaska Iverson et al. (1996) found selection for habitats within 300 m of shoreline and a negative relationship between habitat use and elevation. On Vancouver Island McClaren (2005) saw no selection for shoreline areas, and some goshawks actually moved into moderate to high elevation areas over the winter.

Notwithstanding regional and temporal variation, goshawks primarily forage in mature and old forests across their range (Squires and Reynolds 1997). In a review of goshawk habitat selection outside of the nest stand Greenwald et al. (2005) identified 12 studies that compared used habitat types to those available. All 12 studies showed selection for mature (including old-growth) habitats compared to non-forested or early seral habitats. Nine of the 12 studies demonstrated selection for stands with higher canopy closures and larger trees than found in random stands. It has also been shown that goshawks preferentially use forest stands where the structure makes prey more available than habitats where prey is most abundant (Beier and Drennan 1997, Good 1998, Drennan and Beier 2003). This favours hunting primarily in mature/old growth forest areas with high canopy closure, and an open understory; habitats that allows goshawks to move freely under the canopy, see their prey and have abundant opportunities for perching to ambush prey (Squires and Reynolds 1997). Five studies have demonstrated a positive relationship between amount of mature forest within the territory (defined at various scales) and nest area occupancy (Crocker-Bedford 1990, 1995; Ward et al. 1992; Patla 1997; Finn et al. 2002).

Two radio telemetry studies of goshawks (southeast Alaska, Iverson *et al.* 1996; Vancouver Island, McClaren 2005) showed that they selected mature/old forest habitat preferentially to its availability in coastal landscapes. This was also supported by prey remains and pellets observed at nest sites on Vancouver Island (Ethier 1999), Haida Gwaii (Doyle 2005), and in southeast Alaska (Iverson et al. 1996; Lewis 2001) that were dominated by prey associated with mature forest (red squirrels, forest grouse and forest passerines).

Northern Goshawk Habitat Models for Coastal BC

Overview

Three specific goshawk models were developed:

1. A nesting habitat suitability model
2. A foraging habitat suitability model, and
3. A territory analysis model, which requires the nesting and foraging model as inputs

The nesting and foraging models are deterministic models that estimate relative habitat suitability using a variety of environmental variables that relate to goshawk habitat quality and that are available in GIS databases (e.g. Vegetation Resource Inventory). The outputs of the nesting and foraging models are maps of relative habitat suitability across the study area, ranging from no value (0) to optimal value (1). The territory model is used for analysis purposes, to assess the amount, quality and distribution of nesting and foraging habitat relative to average goshawk territory sizes and spacing patterns. The primary outputs associated with the territory model are the estimated numbers and general distribution of potential territories. It is important to emphasize that both the habitat suitability models and the territory model represent relative estimates of goshawk habitat amounts and quality.

The following summary information outlines key components and criteria of this project and is consistent with the type and format of information recommended by the RISC Wildlife Habitat Rating Standards (RISC 1999).

Project Purpose

The purpose of this project was to develop standardized habitat assessment models for *A. g. laingi* across their range in B.C.. These models are being used as part of a larger project being conducted by the Habitat RIG of the Northern Goshawk Recovery Team to assess the amount, distribution and quality of goshawk habitat under historic, current, and future forest management scenarios. The territory analysis model was a new initiative developed by the Habitat RIG to estimate the number of potential territories that could be supported under historic, current and future forest management scenarios.

Focal Species, Life Requisites, and Season

Suitability ratings were developed solely for the Northern Goshawk (*A. g. laingi*). Separate habitat models were developed for nesting habitat (life requisite: reproduction, season: breeding) and foraging habitat (life requisite: hunting/feeding, season: year-round). In addition to these habitat models a territory model was also developed to facilitate analysis of habitat amount and distribution, to determine how many goshawk

pairs may potentially be supported by the landbase. The territory model may integrate with future population modeling exercises.

Project Area

The project area encompasses the entire Coast Forest Region, which corresponds to the BC range of *A. g. laingi*. This overall area has been divided into four conservation regions based on differences in habitat characteristics, harvest histories and future harvest projections: Haida Gwaii (Queen Charlotte Islands), North Coast, South Coast, and Vancouver Island Conservation Regions (Northern Goshawk *A. g. laingi* Recovery Team 2008). Habitat variable ratings were developed for each of these areas based on differences in habitats that occur across these areas and differences in the types of data available. The primary biogeoclimatic zones within these areas are Coastal Western Hemlock (CWH), Coastal Douglas Fir (CDF), Mountain Hemlock (MH), and Alpine Tundra (AT) (Banner et al. 1993; Green and Klinka 1994).

Project Scale

The project scale is 1:20,000. All mapping queries were conducted using 1:20,000 scale Forest Cover data and 50 x 50 m slope and elevation digital elevation models (DEMs) from TRIM. All environmental data were converted to 100 x 100 m rasters for model runs, except on Haida Gwaii where 50 x 50 m raster grids were used.

Rating Scheme

Output from the habitat models produced a continuous range of rating scores from 0-1. A scheme for categorizing the continuous ratings in 4 quartiles using a modified 4-class scheme from *RISC Wildlife Habitat Rating Standards* (Table 1, RISC 1999) is also presented.

Habitat Suitability Rating Methodology

The nesting habitat and foraging habitat models were based on the habitat suitability index (HSI) methodology (US Fish and Wildlife Service 1981). This methodology is commonly used in habitat assessment and has been used in several goshawk habitat mapping and supply analyses in British Columbia (e.g. North Coast LRMP (Mahon et al. 2003), Morice LRMP (A. Edie and Associates 2004), see review of others by Mahon (2005)).

HSI methodology involves three key steps:

1. Selection of relevant habitat variables to include in the model;
2. Development of rating scores for each habitat variable;
3. Building a mathematical relationship among habitat variables to produce overall habitat suitability scores.

The variables used in the models and ratings assigned for each variable were developed based on observed habitat characteristics at approximately 100 goshawk nest areas across Coastal BC (stratified by Conservation Region where appropriate), relevant literature, and the expert opinions of the authors.

Rating Definitions

We used numeric ratings from 0-1 at two levels within the HSI models: 1) to rate individual variables included in each model, and 2) as final scores for each model. At each level the ratings can be broken down into ranges for biological interpretation. Interpretations for final scores for nesting and foraging habitat are provided at the end of their respective sections.

For individual habitat variables we used two rating approaches depending on the strength of the relationship between habitat variables and use by goshawks. We defined variables as either ‘strong’ or ‘weak’. Strong variables were ones that appeared to play a primary role in determining habitat suitability for goshawks **and** for which we had good information (from local data and the literature) to base ratings on. Weak variables were ones that appeared to be secondary in determining suitability or ones that we did not have good information to base ratings on. For strong variables we generally applied ratings across the full range from 0-1 using biological criteria outlined in Table 1. Ratings for weak variables were generally applied within a narrow range (e.g. 0.7 – 1) and were meant to downgrade the final rating by a certain amount (often by 0.25, which represents one suitability class).

Table 1. HSI rating criteria for individual habitat variables

HSI Ratings	Class	Interpretation
0 - 0.249	Nil	Unsuitable. Condition fails to provide minimum requirements.
0.250 - 0.499	Low	Suitability Unknown. Condition of variable provides theoretical minimum requirements, but use by goshawks is unknown or rarely observed. Goshawks are not normally expected to use attributes in these conditions, but may do so if that is all that is available.
0.500 - 0.749	Moderate	Suitable. Suitability is lower than optimal conditions but exceeds minimum requirements. A small proportion of use by goshawks is expected to occur in areas with variables in this condition.
0.750 – 1.000	High	Suitable. Conditions at or near optimal (optimal = 1). Majority of use by goshawks is expected to occur in areas with variables in this condition.

Nesting Habitat Suitability Model

Selection of Relevant Nesting Habitat Variables

We identified potentially relevant nesting habitat variables from the published literature, regional studies and our personal experience. We provide a summary of the literature we reviewed, along with key findings, in Appendix 2. We identified 14 habitat variables as being potentially important for describing goshawk nesting habitat (Table 2). We evaluated the appropriateness of each variable in this model based on: 1) the strength and consistency of its relationships in other studies, 2) its general relevancy to coastal ecosystems, 3) its specific relationships to known nest areas in Coastal BC, 4) the current availability of the variable in GIS databases across all Conservation Regions, and 5) our ability to project variables into the future for time sequence analysis. Based on this review, we included stand age, stand height, forest composition, slope, elevation and BEC Variant.

Table 2. A summary of habitat variables commonly associated with goshawk nesting habitat from published literature and regional studies. A list of the studies we reviewed and their key findings is provided in Appendix 2.

Habitat Variable	Included in Model?	Comments
Stand Age	Yes	Frequently used to assess structural maturity of a stand.
Stand Height	Yes	Frequently used to assess structural maturity of a stand.
Forest Composition	Yes	Suitability of branching platforms for nests and subcanopy flyways are related to the form of different tree species.
Canopy Closure	No	Mid-high canopy closures were consistently identified as a common characteristic of used nesting habitat (relates to subcanopy flyways), but this variable was often not available or inaccurate in many forest cover databases
Average Stand Diameter/ No. Large Trees	No	These two variables were commonly associated with goshawk nesting studies in the USA. Not available in FC database; correlated to height, and age
Distance from Forest Edge	Yes	Data from Coastal BC show strong avoidance of edges for nest sites.
Patch Size	No	Issue more appropriately captured by edge.
Slope	Yes	Nest sites often on low-moderate slopes. Local data indicate no nests on slopes >60%.
Aspect	No	Identified as a significant variable in dry SW USA. No selection noted in any study in BC.
Elevation	Yes	Local data indicates avoidance of higher elevations.
Mesoslope Position	No	Weak selection noted in a couple of studies but no consistent relationship; no relationship in BC studies. Effect observed likely related to slope.
Site Index	No	Considered as a local variable. No nests in poorest or richest sites, but forest composition and height more directly capture structure.
Distance to Water	No	Significant variable only in dry SW USA; no relationship in BC studies. Water sources not likely limiting in Coastal BC.
Biogeoclimatic Variant	Yes	Apparent avoidance of the higher elevation Mountain Hemlock and hypermaritime Coastal Western Hemlock zone; none of the ca.165 nest areas occur in these variants.

Stand Age and Height

(*Strong Variables*) The structural maturity of a stand, and trees within a stand, form the fundamental basis for nesting suitability for goshawks (Squires and Reynolds 1997). Individual trees must have large enough branches to support the nest structure. Suitable stands will have progressed through the self-thinning stage and be tall enough to provide open flyways below the main canopy layer (Penteriani 2002). We used both stand age and stand height in the model as predictors of stand maturity and, more specifically, suitability of nesting platforms and subcanopy flyways. We choose to use both variables, instead of just stand age or just stand height, to account for variation in stand structure in relation to site productivity. For example, on poor sites suitability tended to be overestimated if just age was used and underestimated if just height was used. On productive sites suitability tended to be underestimated if just age was used and overestimated if height was used. Using both variables tended to provide a more balanced rating across the range of sites that occur in Coastal BC. Because the two variables are strongly correlated, however, we used an average of the ratings for the two variables to avoid overweighting the model by these factors.

The ratings for stand age and stand height were estimated based on a combination of 1) field evaluations by goshawk biologists (i.e. assessments of branch platforms and subcanopy flyways in relation to stand age and height) and 2) observed values of stand age and height at known nest sites. The ratings curves and observed values from known nest sites are provided for stand age in Figures 5 and 6 and for stand height in Figures 7 and 8. For age, suitability increases linearly from 0 at 40 years to 1 at 90 years and then plateaus. For height, suitability increases from 0 at 14 m to 1 at 32 m. The following figures and discussion are ‘final’ curves that reflect revisions from original ‘2008’ rating curves, based on field verification data (Mahon et al. 2008; Mahon 2009, 2010, 2012). Although the final rating curves fit the data better than the 2008 curves, this translates to very modest improvements of overall model accuracy and bias. The limited improvement occurs because the original age and rating curves had opposite biases that balanced each other out. The 2008 age curve tended to underestimate suitability and the 2008 height curve tended to overestimate suitability.

It is important to note that for both stand age and height the majority of nest sites occur in stands that are older and taller than what the rating curves attribute optimal ratings (i.e. 1) to. For example, for stand height 78% of known nests occur in stands taller than 32 m (Figure 8), the height at which the rating curve reaches the optimal rating of 1 (Figure 7). If the distribution of used stand ages and heights reflects selection by goshawks, or if stands older than 90 years and taller than 32 m continue to increase in habitat quality, then our rating curves could be overestimating suitability (i.e. predicting more habitat than actually occurs).

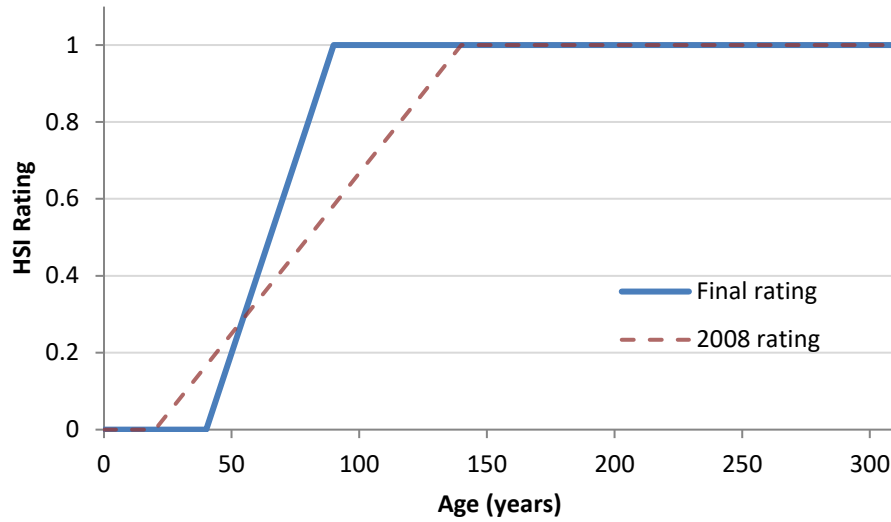


Figure 5. Northern goshawk nesting habitat suitability rating curve for stand age in Coastal BC. Suitability increases linearly from 0 at 40 years to 1 at 90 years.

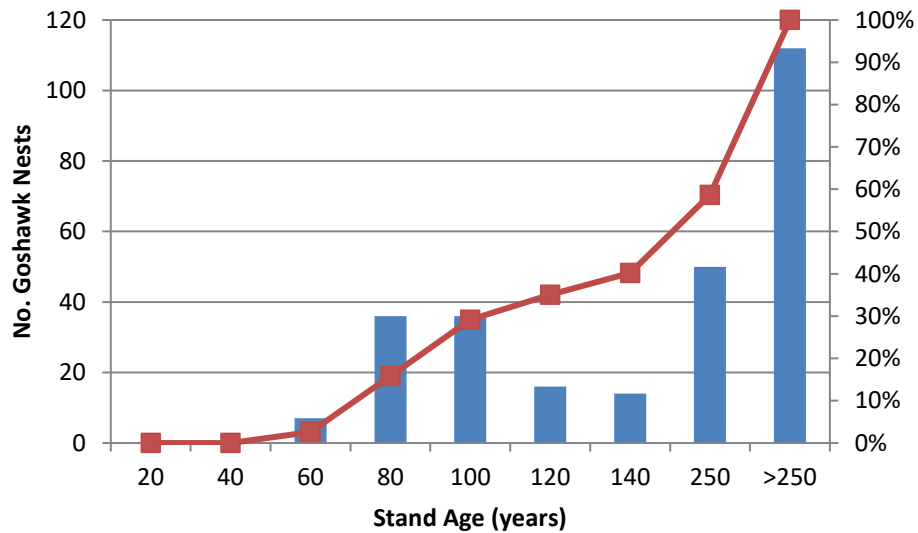


Figure 6. Stand age (from forest cover data) of 271 goshawk nests in Coastal BC.

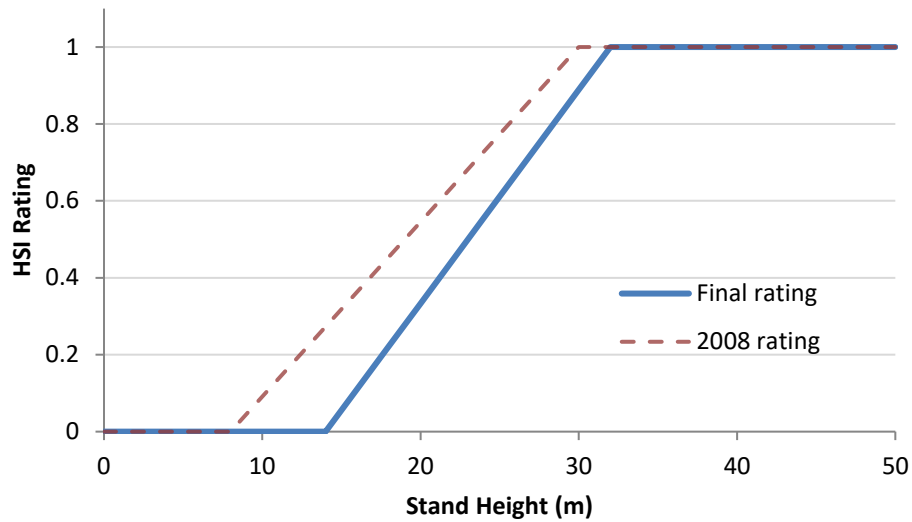


Figure 7. Northern goshawk nesting habitat suitability rating curve for stand height in Coastal BC. Suitability increases linearly from 0 at 14 m to 1 at 32 m.

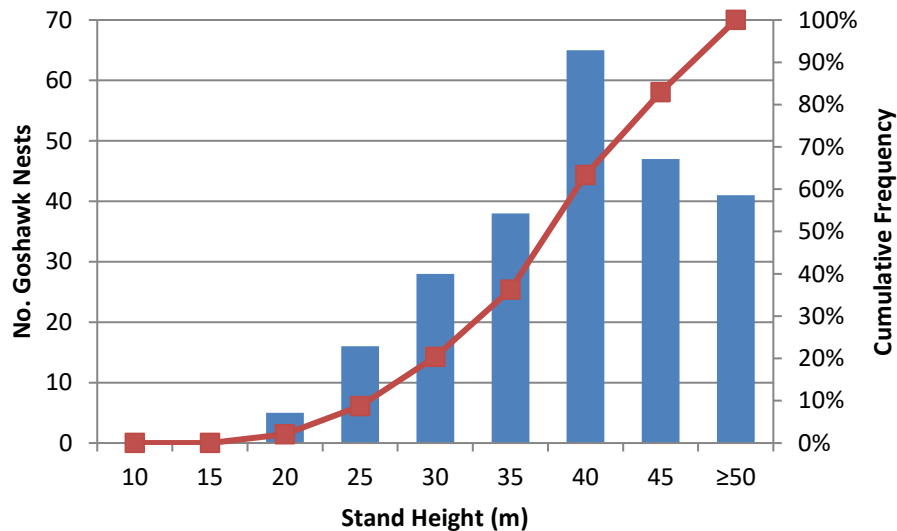


Figure 8. Stand height (from forest cover data) of 240 goshawk nests in Coastal BC

Distance from Edge

(*Strong Variable*) Data from both coastal and interior studies in BC suggest that goshawks tend to avoid locating nests near edges (McClaren et al 2015; Mahon and Doyle 2003). For 238 goshawk nests in Coastal BC, the proportion of nests within 200 m of cutblocks was much lower than a distribution of random points, suggesting goshawks were avoiding those edges (Figure 9). In addition, goshawks in Coastal BC may abandon existing nests when a new cutblock edge is created near them (E.L. McClaren, pers. obs.). These patterns were noted for what we defined as ‘hard’ or high contrast edges. Hard edges occur where mature forest meets non-forested or early seral habitats. For the purpose of this model we used a height difference of >12 m between adjacent stands to define a hard edge. Edges were differentiated into two types because observations suggested goshawks responded differently to: 1) anthropogenic edges resulting primarily from cutblocks (roads were not included), and 2) natural edges such as those adjacent to lakes, swamps, etc. A stronger edge effect was applied for 0 - 100 m compared to 100 – 200 m to reflect observed patterns of nest locations. Ratings for each edge distance and type are provided below (Table 3).

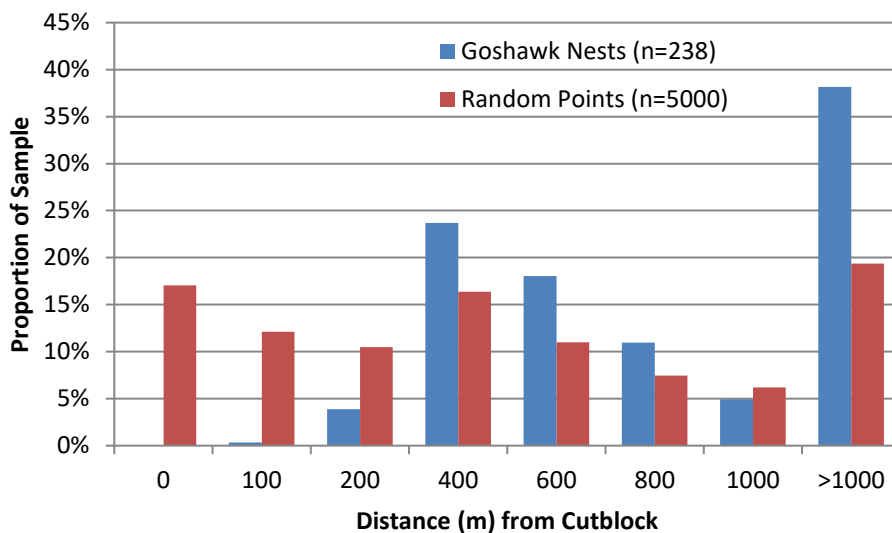


Figure 9. Lower proportion of nest locations within 200 m of cutblocks compared to random points suggests that goshawk are avoiding those edges.

Table 3. Nesting habitat model edge ratings.

Edge Distance (m)	Edge Type	
	Anthropogenic	Natural
0-100	0.4	0.6
100-200	0.8	0.9

Forest Composition

(*Strong Variable*) Some of the key structural requirements goshawks have for nesting (e.g. branch platforms, subcanopy flyways) are strongly related to tree species composition. These structural attributes (and relative use (Appendix 1)) seem to be most common in Western Hemlock (Hw) and Douglas fir (Fd) dominated stands. Stands that are dominated by Cw and Subalpine Fir (Bl) or Balsam Fir (Ba) tend to have more broken canopies, greater vertical stand structure (with poorer sub-canopy flyways) and poorer branch structures for nests. Yellow cedar (Yc) and Lodgepole pine (Pl) stands tend to have the lowest suitability due to both tree form and stand-level heterogeneity (multi-storied canopy, low canopy closure; Figure 3). We evaluated several ways of incorporating tree species composition into the model (mostly to account for the different ways these data were recorded in different data sets). In the end we decided Inventory Type Group (ITG) from the provincial Forest Cover database provided the best base categorization to work from, but we needed to modify some categories to factor Yellow cedar more prominently in the classes. A list of the main forest composition groups and their ratings is provided in Table 4. A list of ratings for all the ITGs is provided in Appendix 3.

Table 4. Nesting habitat ratings for forest composition.

Name	First Sp	Second Sp	Rating
Hw dominant	Hw	any except Yc or Pl	1
Cw pure	Cw >80%	any <20%	0.45
Cw dominant	Cw <80%	any except Yc or Pl	0.65
B dominant	B	any except Yc or Pl	0.8
S dominant	S	any except Yc or Pl	1
Fd dominant	Fd	any except Yc or Pl	1
Yc dominant	Yc	any	0.4
Yc secondary	any	Yc	0.6
Pl dominant	Pl	any	0.5
Pl secondary	any	Pl	0.7
Deciduous	Dr, Ac, At	any deciduous	0.7
Mixed forest	Dr, Ac, At	any coniferous	0.9

Elevation

(*Weak Variable*) The observed pattern of goshawk nest sites suggest they are avoiding higher elevation areas, however, this pattern is relative to the range of elevations in each conservation region rather than to absolute elevations. The observed patterns likely reflect correlations between elevation and tree species, such as subalpine fir, and BEC variants, such as MH, which generally offer suboptimal nesting habitat. Another possible reason is greater energy expenditures required to carry prey upslope to higher elevation nests. We treat elevation as a weak variable to avoid overweighting the model with factors correlated to elevation (forest composition and BEC variant), but still include it as a variable because forest composition and BEC variant do not adequately account for the observed pattern of nest area selection. The ratings curves that were used apply weak downgrades to areas above 400 m for Haida Gwaii, 600 m for North Coast (Figure 10), and 800 m for South Coast and Vancouver Island. Irrespective of the lower elevation where suitability first becomes reduced, ratings decrease linearly to 0.5 at 1300 m.

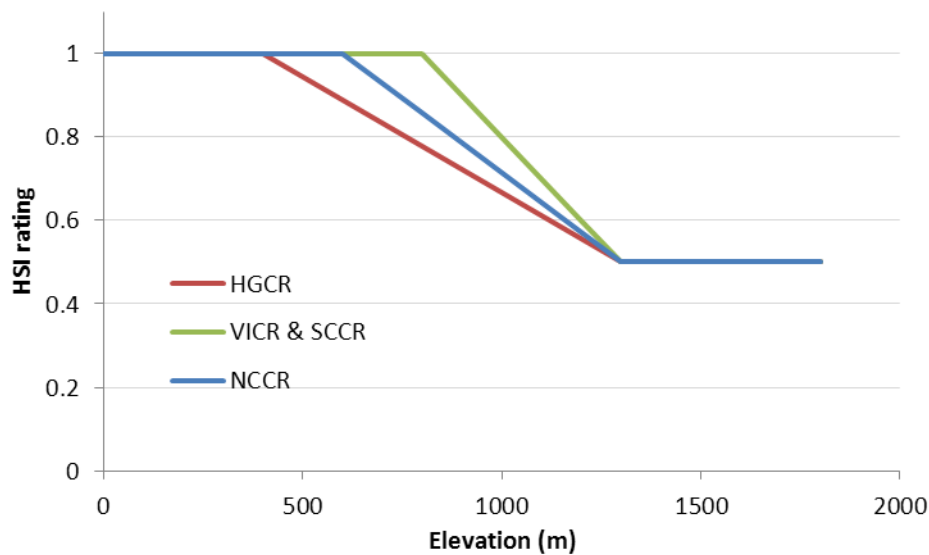


Figure 10. Northern Goshawk nesting habitat suitability rating curve for elevation.

Slope

(*Weak Variable*) All known goshawk nest sites in Coastal BC occur on slopes <100% (45 degrees) and the majority (89%) are on slopes <60% (31 degrees). Where nests occur on slopes 60-100% they tend to occur in areas with broken slopes with small benches as opposed to areas of straight slope. The rating curve in Figure 8 is transformed to degrees to address the complication of percent slope going to infinity (inflection points at 31 and 60 degrees).

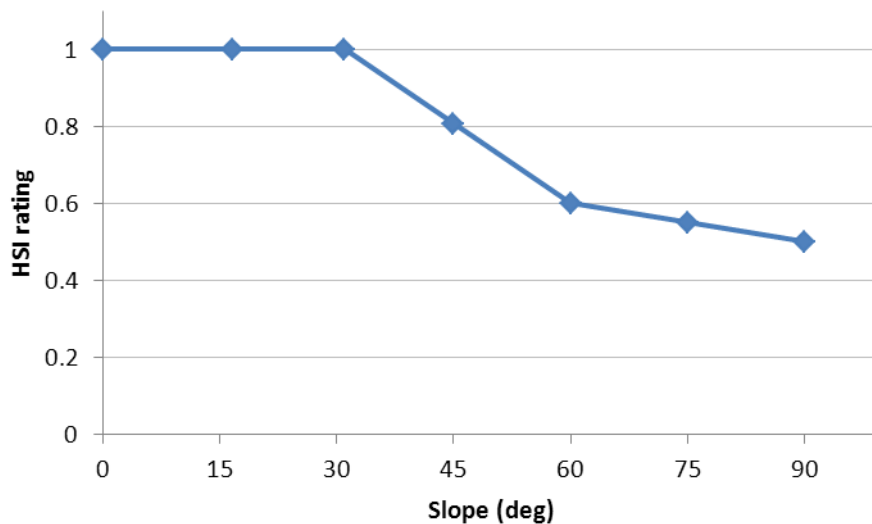


Figure 11. Northern Goshawk nesting habitat suitability rating curve for slope (degrees). Suitability decreases linearly between the inflections points at 31, 60, and 90 degrees.

BEC Variant

(*Weak Variable*) Of the approximate 165 known goshawk nest areas in Coastal BC, none are within the hypermaritime CWH or MH BEC variants (although a few nest areas occur in transitional areas to these variants). The lack of known goshawk nests in the hypermaritime CWH and the MH makes it appear that these BEC variants are avoided even where otherwise suitable nesting stands occur. The mechanisms behind the lack of use, or at least reduced use, of these areas for breeding are not known. It is possible that other factors in our model that are linked to BEC variants such as tree species and elevation, have accounted for the patterns we observe. For example, hypermaritime forests tend to have significant components of yellow cedar with low canopy closure and dense understory vegetation. As well, within mountain hemlock stands, canopy closure appears to be reduced and dense understory vegetation prevails. However, canopy closure and understory vegetation density, which affects access to prey, are not available. Our ratings for BEC variant (Table 5) reflect a compromise between the relatively strong pattern of low use by goshawks and our poor understanding of why that occurs. These ratings are designed to downgrade the final suitability score by one class for hypermaritime CWH, MH and ESSF if the ratings for any other variable are <1, which will usually occur for elevation or forest composition, and two classes for alpine.

Table 5. Northern goshawk nesting habitat ratings for BEC variant.

BEC Variants	Rating
Alpine Tundra (all except parkland)	0.4
Alpine parkland	0.4
CDF (all)	1
CWH (all except vh)	1
CWH vh1 + vh2	0.8
ESSF (all except parkland)	0.7
ESSF parkland (all)	0.4
ICH (all)	1
IDF (all)	1
MH (all)	0.8

Nesting Habitat Model Equation

The nest area model uses a limiting factor, non-compensatory structure. From an ecological perspective this means that when the suitability rating of one variable falls below its optimal range it decreases the overall suitability by that amount. Further, suboptimal ratings in two or more variables are combined, through a multiplicative function, to decrease the overall value. The function is non-compensatory in that the value of one variable cannot compensate for a deficiency in another. The equation used to calculate the nesting suitability ratings is:

$$HSI_n = \text{mean}(\text{Age}_r, \text{Height}_r) * \text{Edge}_r * \text{ITG}_r * \text{Elev}_r * \text{Slope}_r * \text{BECvar}_r$$

n=nesting, r=rating

Both the nesting and foraging model forms are completely deterministic (i.e. model parameters all have fixed relationships with no variability).

Nesting Habitat Score Interpretations

For interpretation purposes the final HSI scores can be categorized into a 4-class rating scheme (Table 6).

Table 6. Interpretation of final HSI scores for nesting habitat.

HSI Ratings	Class	Interpretation
0 - 0.249	Nil	Unsuitable. Habitat fails to provide minimum requirements.
0.250 - 0.499	Low	Suitability Unknown. Habitat provides theoretical minimum requirements for supporting a nest, but use by goshawks is rarely observed. Suitability of two or more habitat variables is suboptimal, substantially reducing the overall suitability of the stand. Goshawks are not normally expected to use Low class habitats, but may do

		so if that is all that available.
0.500 - 0.749	Moderate	Suitable. Suitability of one or two habitat variables is slightly lower than optimal conditions but minimum requirements still exceeded. Minority of nest sites expected to occur in Moderate class habitat.
0.750 – 1.000	High	Suitable. All habitat variables meet optimal conditions. Majority of nest sites are expected to occur in High class habitat.

Although categorized HSI scores can be used for habitat amount summaries (i.e. area of nil, low, moderate, high across a study area), categorization results in loss of data resolution and a bias of overestimating habitat quality (i.e. saying HSI of 0.76 is equivalent to 1). The preferred method of examining habitat amount by quality is to weight areas by their HSI value (US Fish and Wildlife 1981b). For example, 10 ha with HSI=1 would count as 10ha of suitable habitat; 10 ha with HSI=0.6 would count as 6 ha of suitable habitat.

Foraging Habitat Suitability Model

Selection of Relevant Foraging Habitat Variables

Habitats used by goshawks for foraging are generally similar to those used for nesting, although foraging habitat is more variable, depends on fluctuating prey populations, and is generally broader (i.e. a broader range of levels within a variable are often more suitable for foraging than they are for nesting). In addition to foraging habitat being more general and more variable than nesting habitat, our level of knowledge of foraging habitat selection by goshawks is lower than it is for nesting habitat (especially in coastal habitats). Further, from the relatively few studies, patterns of selection for some variables appear to be contradictory, possibly reflecting high regional or temporal variation. For example in Alaska, Iverson et al. (1996) reported selection for habitats within 300 m of shoreline and a negative relationship between habitat use and elevation. On Vancouver Island McClaren (2005) saw no selection for shoreline areas, and some goshawks actually moved into moderate to high elevation areas over the winter, presumably to hunt grouse and ptarmigan.

We selected variables for the foraging habitat model using the same approach as we used for the nesting habitat model. We identified potentially relevant foraging habitat variables from the published literature, regional studies and our personal experience. A summary of the literature we reviewed, with their key findings, is provided in Appendix 4. We identified 8 habitat variables as being potentially important for describing goshawk foraging habitat (Table 8). We evaluated the appropriateness of each variable in this model based on: 1) the strength and consistency of its relationships in other studies,

2) its general relevance to coastal ecosystems, 3) specific relationships that were identified for coastal habitats, and 4) the availability of the variable in our GIS databases. Based on this review, we included stand age, stand height, forest composition, and BEC variant in the model. In addition, we developed ratings for all of the non-forest types (e.g. alpine, swamp, meadow) included in the Forest Cover database.

Table 7. A summary of habitat variables we considered for the foraging habitat model based on published literature and regional studies. A list of the studies we reviewed and their key findings is provided in Appendix 4.

Habitat Variable	Included in Model?	Comments
Stand Age	Yes	All studies we reviewed indicated that goshawks selected mature and old forests.
Stand Height	Yes	Several studies observed that goshawks selected stands with larger diameter trees. Tree diameter is not available in our GIS databases but diameter is strongly correlated to height, which was available.
Forest Composition	Yes	Local data is available quantifying relative abundance of prey in different forest types (Doyle 2004).
Canopy Closure	No	Several studies indicated that goshawks selected stands with higher canopy closure than random areas, although range of use was quite broad. Variable not available.
Site Index	No	Considered as a local variable that may influence prey. Doyle (2004) indicates forest type is a better predictor.
Slope	No	No data to support this variable.
Elevation	No	Few studies examined elevation, and those that did showed different patterns.
Biogeoclimatic Variant	Yes	Apparent avoidance of the Mountain Hemlock and hypermaritime Coastal Western Hemlock zones, possibly related to prey access and subcanopy flyways.

Stand Age and Height

(*Strong Variables*) Similar to the nesting habitat model, though to a lesser extent in some areas, mature and old forest habitats are the primary habitats that goshawks use for foraging. In coastal ecosystems mature forest structure typically offers the highest abundance and diversity of prey (red squirrels, jays, thrushes, woodpeckers; Doyle 2004), and the type of structure that makes those prey accessible to goshawks (semi-concealed hunting perches, appropriate sightlines and flyways for detecting and pursuing prey; Greenwald et al. 2005). Similar to nesting habitat we used a combination of stand height and stand age as surrogates for structural stage to estimate the suitability of stands for goshawk foraging. The ratings curves for age and height are shown below in Figures 8 and 9. The biggest difference in these ratings from the nesting ratings is that foraging ratings start at 0.3 compared to 0 for nesting. This reflects the fact that early seral habitats can offer some limited foraging potential (Bloxtton 2002), whereas they have no value as nesting habitat. For age, suitability increases linearly from 0.3 at 40 years to 1 at 90 years and then plateaus (Figure 12). For height, suitability increases from 0.3 at 14 m to 1 at 32 m (Figure 13). Current ratings reflect slight revisions from original Mahon et al. (2008) ratings, based on field verification work where we found the original age ratings were slightly underestimating suitability and the original height ratings were slightly overestimating suitability. The original age and height ratings also had separate rating curves for Sitka spruce, but the current ratings curves are now applied to all stand types.

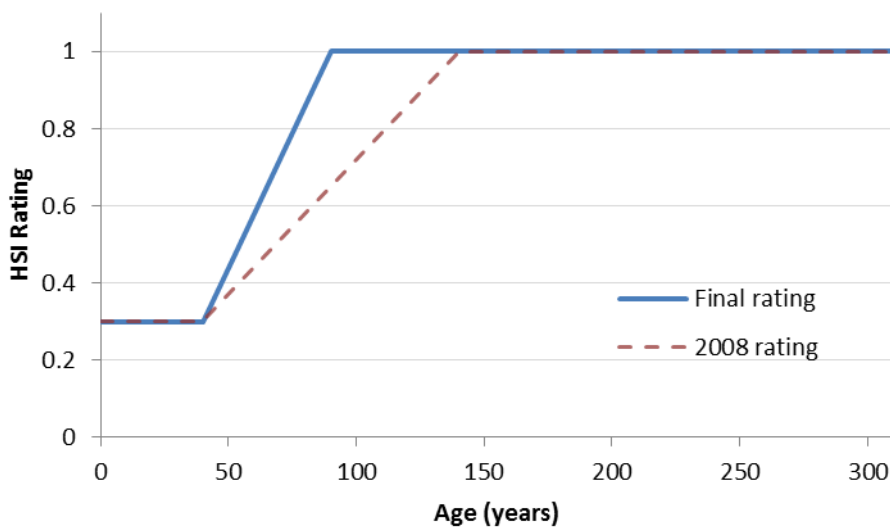


Figure 12. Northern Goshawk foraging habitat suitability rating curve for stand age.

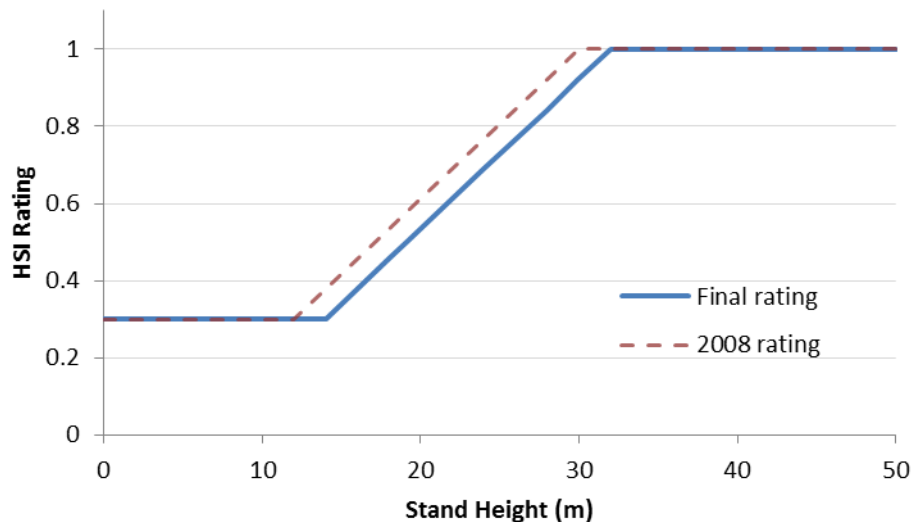


Figure 13. Northern Goshawk foraging habitat suitability rating curve for stand height.

Forest Composition – Inventory Type Group

(Weak Variable) We applied a range of foraging habitat suitability ratings from 0.6 – 1.0 to forest composition using the ITG categories described for the nesting habitat model section. This rating range means that even the least preferred forest types could have a rating of moderate if stand age and height are in optimal conditions. The relative ratings here are based primarily on prey surveys conducted on Haida Gwaii (Doyle 2004). That study indicated that overall prey abundance was highest in stands with spruce (largely due to higher relative abundance of red squirrels) and lowest in yellow-cedar. A list of the main forest composition groups and their ratings is provided in Table 8. A list of ratings for all the ITGs is provided in Appendix 3.

Table 8. Northern goshawk foraging habitat ratings stand composition.

Name	First Sp	Second Sp	Rating
S 1° or 2°	S	any except Yc or Pl	1
H dominant	H	any except S, Yc, or Pl	1
Cw	Cw >80%	any <20% expect Yc or Pl	0.7
B dominant	B	any except S, Yc, or Pl	0.95
Fd dominant	Fd	any except S, Yc, or Pl	1
Yc dominant	Yc	any	0.6
Yc secondary	any	Yc	0.7
Pl dominant	Pl	any	0.7
Deciduous	Dr, Ac, At	any deciduous	0.8
Mixed forest	Dr, Ac, At	any coniferous	0.95

BEC Variant

(*Weak Variable*) As mentioned previously, none of the ca. 165 known goshawk nest areas in Coastal BC are within the hypermaritime CWH or MH BEC variants. Hypermaritime forests tend to have low canopy closure stands dominated by western redcedar and yellow cedar and dense understorey vegetation, which likely limits goshawk access to prey (F. Doyle and E. McClaren, pers. obs.). However, canopy closure and understorey vegetation density, are not available in the forest cover databases and therefore, we used BEC variants as the closest surrogate. Our ratings for BEC variant (Table 9) reflect a compromise between the relatively strong pattern of low use by goshawks and our poor understanding of why that is occurring. These ratings are designed to downgrade the final suitability score by one class for hypermaritime CWH, MH, and ESSF and two classes for alpine.

Table 9. Northern goshawk foraging habitat ratings for BEC variant.

BEC Variants	Rating
Alpine Tundra (all except parkland)	0.4
Alpine parkland	0.7
CDF mm	1
CWH (all except vh)	1
CWH vh1 + vh2	0.7
ESSF (all except parkland)	0.7
ESSF parkland (all)	0.7
ICH (all)	1
IDF (all)	1
MH (all)	0.7

Non-Forested Habitats

Several non-forested habitats occur in Coastal BC that may be used to some degree by goshawks for foraging. Examples of these include wetlands and bogs, non-productive brush patches and alpine. While these habitat types may offer some prey for goshawks, we are not aware of any situations in Coastal BC where enough prey occurs in these habitat types to warrant a rating higher than Low. Originally, forage ratings were developed for the Non-Productive (NP) and Non-Forest (NF) field in the ‘old’ provincial forest cover database. These fields were not carried forward into the ‘new’ Vegetation Resource Inventory (VRI) database. During a model re-run in March 2019 the original NP and NF ratings were cross-walked to B.C. Land Classification Scheme (BCLCS) Level 4 and Level 5 categories (Table 10). Where these categories overlap with the forested criteria above, the highest rating of either the multiplicative model, below, or the rating of 0.3 from Table 10 was applied.

Table 10. Northern goshawk foraging habitat ratings for non-forested habitats.

BCLCS Level 4	BCLCS Level 5	Forage Score
Treed - Coniferous	Dense	0.3 (Low)
Treed - Coniferous	Open	0.3 (Low)
Treed - Coniferous	Sparse	0.3 (Low)
Treed - Broadleaf	Dense	0.3 (Low)
Treed - Broadleaf	Open	0.3 (Low)
Treed - Broadleaf	Sparse	0.3 (Low)
Treed - Mixed	Dense	0.3 (Low)
Treed - Mixed	Open	0.3 (Low)
Treed - Mixed	Sparse	0.3 (Low)
Shrub Tall	Dense	0.3 (Low)
Shrub Tall	Open	0.3 (Low)
Shrub Tall	Sparse	0.3 (Low)
Shrub Low	Dense	0.3 (Low)
Shrub Low	Open	0.3 (Low)
Shrub Low	Sparse	0.3 (Low)
Herb	Dense	0.3 (Low)
Herb	Open	0.3 (Low)
Herb	Sparse	0.3 (Low)
Herb - Forb	Dense	0.3 (Low)
Herb - Forb	Open	0.3 (Low)
Herb - Forb	Sparse	0.3 (Low)
Herb - Graminoids	Dense	0.3 (Low)
Herb - Graminoids	Open	0.3 (Low)
Herb - Graminoids	Sparse	0.3 (Low)
Bryoid	Closed(Bry)	0 (Nil)
Bryoid	Open	0 (Nil)
Bryoid - Moss	Closed(Bry)	0 (Nil)
Bryoid - Moss	Open	0 (Nil)
Bryoid - Lichens	Closed(Bry)	0 (Nil)
Bryoid - Lichens	Open	0 (Nil)
Snow/Ice	Glacier	0 (Nil)
Snow/Ice	Snow Cover	0 (Nil)
Rock/Rubble	Bedrock	0 (Nil)
Rock/Rubble	Talus	0 (Nil)
Rock/Rubble	Blockfield	0 (Nil)
Rock/Rubble	Rubbly Mine Spoils	0 (Nil)
Rock/Rubble	Lava Bed	0 (Nil)

BCLCS Level 4	BCLCS Level 5	Forage Score
Exposed Land	River Sediments	0 (Nil)
Exposed Land	Exposed Soil	0 (Nil)
Exposed Land	Pond or Lake Sediments	0 (Nil)
Exposed Land	Reservoir Margin	0 (Nil)
Exposed Land	Beach	0 (Nil)
Exposed Land	Landing	0 (Nil)
Exposed Land	Burned Area	0.3 (Low)
Exposed Land	Road Surface	0 (Nil)
Exposed Land	Mudflat	0 (Nil)
Exposed Land	Cutbank	0 (Nil)
Exposed Land	Moraine	0 (Nil)
Exposed Land	Gravel Pit	0 (Nil)
Exposed Land	Tailings	0 (Nil)
Exposed Land	Railway Surface	0 (Nil)
Exposed Land	Urban	0 (Nil)
Exposed Land	Airport	0 (Nil)
Exposed Land	Open Pit Mine	0 (Nil)
Exposed Land	Other(NV)	0 (Nil)
Exposed Land	-	0 (Nil)
-	Lake	0 (Nil)
-	Reservoir	0 (Nil)
-	River/Stream	0 (Nil)
-	Ocean	0 (Nil)

Foraging Habitat Model Variables and Equation

The foraging model also uses a limiting factor, non-compensatory structure. From an ecological perspective this means that when the suitability rating of one variable decreases below its optimal range it decreases the overall suitability by that amount. Further, suboptimal ratings in two or more variables are combined, through a multiplicative function, to decrease the overall value. The function is non-compensatory in that the value of one variable cannot compensate for a deficiency in another. The equation used to calculate the foraging suitability ratings is:

$HSI_f = \text{mean}(\text{Age}_r, \text{Height}_r) * ITG_r * BECvar_r$ **or** Non-Forest rating, whichever is greater.

Foraging Habitat Score Interpretations

For interpretation purposes the final HSI scores can be categorized into a 4-class rating scheme (Table 11).

Table 11. Interpretation of final HSI scores for foraging habitat.

HSI Ratings	Class	Interpretation
0 - 0.249	Nil	Unsuitable. Habitat fails to provide even minimum requirements for prey (e.g. non-vegetated areas such as lakes, gravel bars, urban areas).
0.250 - 0.499	Low	Suitable. Habitat believed to contain some prey, but prey is often at low density and structure of habitat offers low availability of prey to goshawks (e.g. alpine, pole-sapling stage forests).
0.500 - 0.749	Moderate	Suitable. Either density or availability of prey lower than optimal conditions but minimum requirements still exceeded. (e.g. second growth forest, mature forest with less productive tree species, such as Yc).
0.750 – 1.000	High	Suitable. Density and availability of prey both good. Includes a broad range of forest types in mature and old growth structural stages. Due to high annual and regional variation in prey and only modest knowledge of goshawk foraging habitat selection, this rating class is intentionally broad.

Although categorized HSI scores can be used for habitat amount summaries (i.e. area of nil, low, moderate, high across a study area), categorization results in loss of data resolution and a bias of overestimating habitat quality (i.e. saying HSI of 0.76 is equivalent to 1). The preferred method of examining habitat amount by quality is weight areas by their HSI value (US Fish and Wildlife 1981b). For example, 10 ha with HSI=1 would count as 10ha of suitable habitat; 10 ha with HSI=0.6 would count as 6 ha of suitable habitat. Normally, for the foraging model output, we recommend that areas with HSI<0.5 be counted as zero, which is consistent with how the territory model evaluates whether there is enough foraging habitat to form a potential territory (see below).

Territory Model

The primary purpose of the territory model is to assess the amount and distribution of nesting and foraging habitat relative to observed spacing patterns of goshawks, namely their territories. The territory model incorporates several aspects of goshawk ecology as criteria or constraints. These include nest area patch size, territory spacing patterns, territory size, territory overlap, habitat suitability, relationships between nesting and foraging habitat, and territory-level habitat threshold requirements. The primary output of the territory model is a prediction of the number and distribution of potential goshawk territories across a region. The model uses an iterative, pseudo-optimization procedure to find a configuration of territories that maximizes the number of territories that are realized given certain constraints such as territory spacing and habitat threshold requirements.

The way the territory model works is as follows:

1. Nest areas, which serve as territory centroids, are first located across the conservation region. Locations are random except that they must meet two criteria:
 - a. Occur in a ≥ 50 ha patch with nesting habitat suitability of high or moderate.
 - b. Meet observed territory spacing distances (HGCR and NCCR=10.8 km, SCCR and VICR=6.9 km). Spacing distances are stochastic, drawn from a normal distribution around the means, above.
2. Territories then spread out from all of the centroids simultaneously in an attempt to acquire enough suitable foraging habitat (see next section – Habitat Thresholds). Territories that acquire sufficient habitat are realized and fixed on the map. As a territory spreads out from a centroid it is subject to three constraints that are represented by a cost surface, which is meant to reflect travel costs of goshawks moving out and back from the nest area. It is important to note that costs are relative, and should be viewed in terms of order of magnitude of differences among cost types. A base cost of 1 represents no constraint on spread.
 - a. *Distance from centroid.* This cost was used to represent the energetic costs of carrying prey back to the nest (Bloxtun 2002) and of overlap into core areas of neighbouring territories, which is likely to be increasingly defended as individuals approach the nest area of their neighbours. For 0-5 km from the centroid we applied a cost of 1 (no constraint); from 5-10 km we applied a linearly increasing cost from 1 to 2; from 10-15 km we applied a linearly increasing cost from 2 to 4; and distances >15 km received a cost of 4.
 - b. *Spreading across different habitat types.* We also applied travel costs based on the foraging HSI scores. Areas with foraging HSI scores of 0.5 - 1 (Moderate and High) were assigned a cost of 2 (initially we assigned high and moderate foraging habitat a cost of 1 but in order to weight the relative influence of habitat vs

distance from centroid in the spreading model we doubled all of the habitat costs). Areas with foraging HSI scores of 0.25 - 0.5 (Low) were generally non-forest habitats or early seral regenerating forest and were assigned a cost of 3. Areas with scores of 0.01 - 0.25 were typically recent clearcuts and were given a cost of 4. Non-vegetated areas such as ocean, mountain, and urban areas had foraging HSI scores of 0 and were assigned cost scores of 10.

- c. *Territory overlap.* In addition to the spreading costs, we applied a constraint of a maximum 5 % overlap between any two territories and 20 % total overlap for any individual territory. These overlaps may underestimate actual territory overlap, because territory defence is believed to be relatively weak in outer portions of territories, but allowing too much territory overlap over the same area reduced the sensitivity of our analyses.

Whether or not a territory was realized around a nest area depended on whether enough suitable habitat could be acquired within a given maximum territory size (see habitat thresholds, next section). We constrained territory size with both a maximum and minimum size. The maximum size represents the distance and area over which a breeding pair of goshawks could realistically travel to obtain enough suitable habitat. This establishes a spatial constraint on the distribution of foraging habitat from nests, for it to be useful to a breeding pair. For example, it is unlikely for a pair of goshawks to successfully breed if they had to travel in a 20 km radius out from a nest to meet their foraging habitat requirements. The minimum territory size represents the degree to which territory size can shrink under favourable conditions (i.e. when the amount of suitable habitat is dense close to the nest). Behavioural spacing limits the degree to which territories are compressible (Reich et al. 2004). We based the maximum and minimum territories sizes on $\pm 20\%$ the estimated average size of territories on HGCR/NCCR=9150 ha and SCCR/VICR=3740 ha. For each territory the minimum and maximum size is drawn randomly from the $\pm 20\%$ size range. the size of each territory is drawn randomly from that range.

3. Territory Packing. To ensure the territory configurations generated by the model approximated the observed pattern of goshawk territories in reality, three optimization loops were incorporated into the model:
 - a. First, the nest placement sub-model was run multiple times and a set of five configurations with the highest number of nest areas are selected.
 - b. Second, for each of the five nest area subsets, territories are simultaneously formed around each nest area. At some nest areas territories are successful (acquire enough foraging habitat) and are realized, at others the territory attempt fails.

- c. Third, for the territory formation output with the greatest number of successful territories from the last step, the model then attempts to locate additional nest areas among the successful territories (still subject to the initial constraints in 1, above) and territories are attempted for the new nest areas.

Habitat Thresholds

There is little information quantifying the minimum amount of suitable habitat required within a territory to support a breeding pair of goshawks. Minimum requirements, or thresholds, likely vary regionally and temporally in response to prey abundance and availability. For example Bloxton (2002) observed that foraging areas of goshawks in Western Washington doubled following a strong La Nina event and declines in the relative abundance of prey. Five studies have demonstrated a positive relationship between amount of mature forest within territories and nest area occupancy (Crocker-Bedford 1990, 1995; Ward et al. 1992; Patla 1997; Finn et al. 2002). Minimum threshold requirements were generally not evident in these studies, although Finn et al. (2002) noted “Late-seral forest was consistently >40 % of the landscape (unspecified scale) surrounding occupied nest sites”. In a management paper for Arizona Reynolds et al. (1992) recommends that 40 % of the foraging area be in mature to old.

We have explored potential threshold relationships between habitat amount and occupancy at the territory level. Mahon (2003) found no relationship between occupancy and amount of mature forest in territories at 2400 ha, 4000 ha and 6500 ha scales for 80 territories in west-central BC. Similarly, there was no relationship between occupancy and amount of habitat in early, mid, or mature seral stages at 201 ha, 707 ha, 3848 ha scales for 66 territories on Vancouver Island (McClaren and Pendergast 2003), although nest areas within fragmented landscapes (patches <50 ha surrounded by unsuitable habitat) had significantly lower occupancy rates than nest areas in contiguous mature and old forests (McClaren 2005). Doyle (2005) noted weak evidence for a threshold response to occupancy at 60 % mature forest and stronger evidence at 40 % for nest areas in Haida Gwaii. As well, an analysis of amounts of suitable foraging habitats (as predicted by the habitat suitability model) around regularly occupied goshawk breeding areas (defn = >3 occupancy years in 10 years?) suggests these breeding areas are surrounded by landscapes with 40-60% suitable foraging habitat (see Daust et al. 2010).

Based on this limited information, we identified and used three potential habitat thresholds in the territory model: 60 %, 40 %, and 20 % suitable habitat. These correspond to high, moderate, and low probabilities of territory occupancy. We considered areas with a foraging habitat HSI >0.50 as potentially suitable habitat, and weighted those areas by the HSI score to account for the differences in quality (e.g. 10 ha of foraging HSI = 0.75 equals 7.5 ha of suitable habitat). To incorporate these three habitat thresholds into the territory model runs, the model was run once for each

threshold. It is important to note that territory model outputs provide a range of predicted numbers of goshawk territories that could be supported, and general, broad-scale distributions of where territories are likely to occur, rather than predictions of actual locations of individual goshawk territories.

Model Implementation and Model Outputs

All components of the goshawk model were implemented in SELES (Fall and Fall 2001) by Cortex Consultants for each Conservation Region. For technical information about model form, implementation details, and model output results for each Conservation Region refer to (Smith and Sutherland 2008; Smith 2012). All models were run for two habitat scenarios in each Conservation Region: current conditions using current forest cover datasets (circa 2005) and capable habitat conditions, which were estimated by growing current forest stands out for 300 years. Capable conditions represent an estimate of the best habitat conditions for goshawks under optimal structural stage development of current stand types (i.e. the capable scenario did not incorporate any seral successional stages associated with natural disturbances). Although capable conditions did not include natural disturbance regimes, stand initiating disturbances are relatively infrequent in coastal forests. Capable conditions can be used as a baseline to compare current habitat conditions against and as a tool to estimate the maximum number of potential territories the landscape could support under optimal conditions. Example model results from Smith and Sutherland (2008) for NCCR are presented below (Figures 14-19). All model outputs are in raster format with 100 m cells. Nesting and foraging habitat outputs are shown classified into four equal sized classes, however, raw HSI scores are continuous values from 0 to 1.

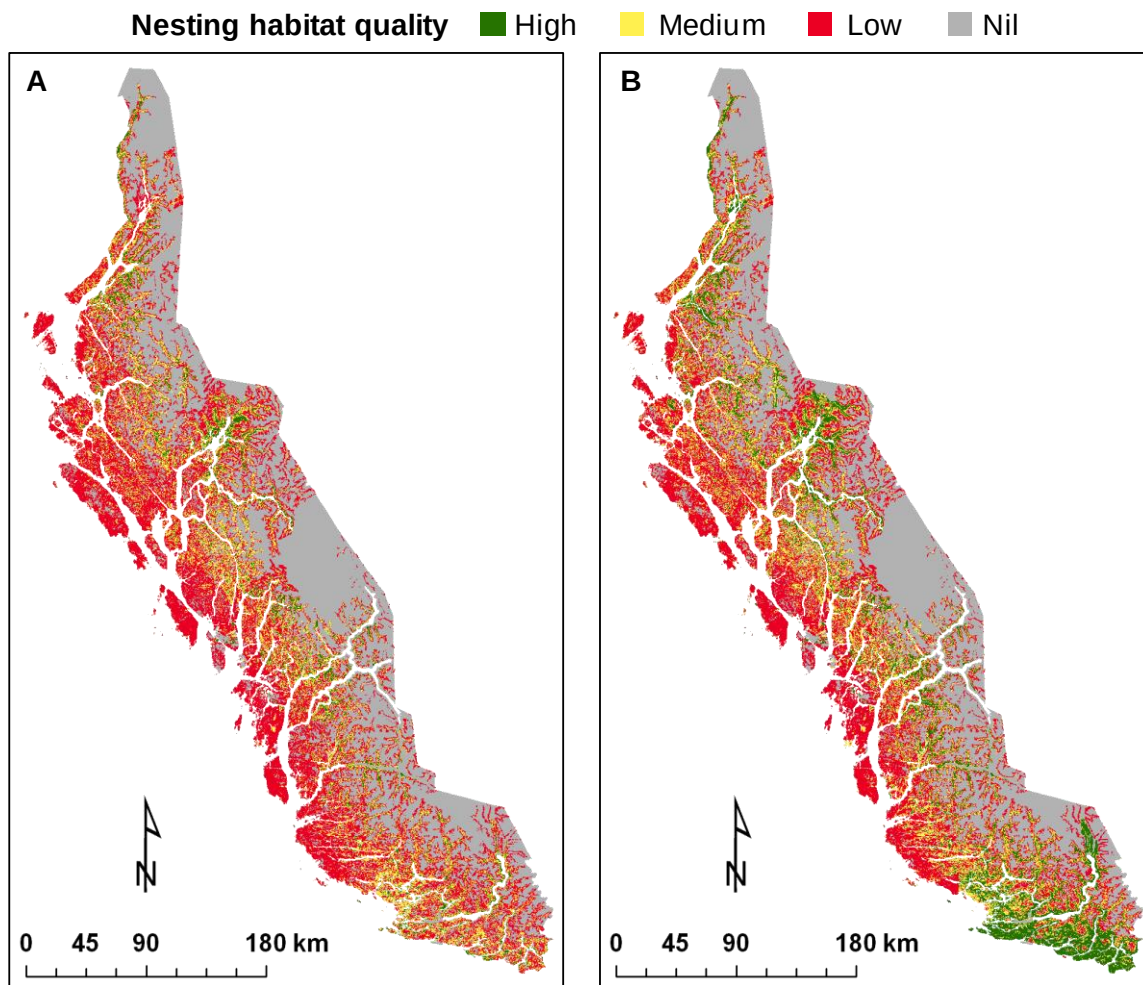


Figure 14: Distribution of nesting habitat in the NCCR for the current landscape (A) and capable habitat (B) scenarios (from Smith and Sutherland 2008).

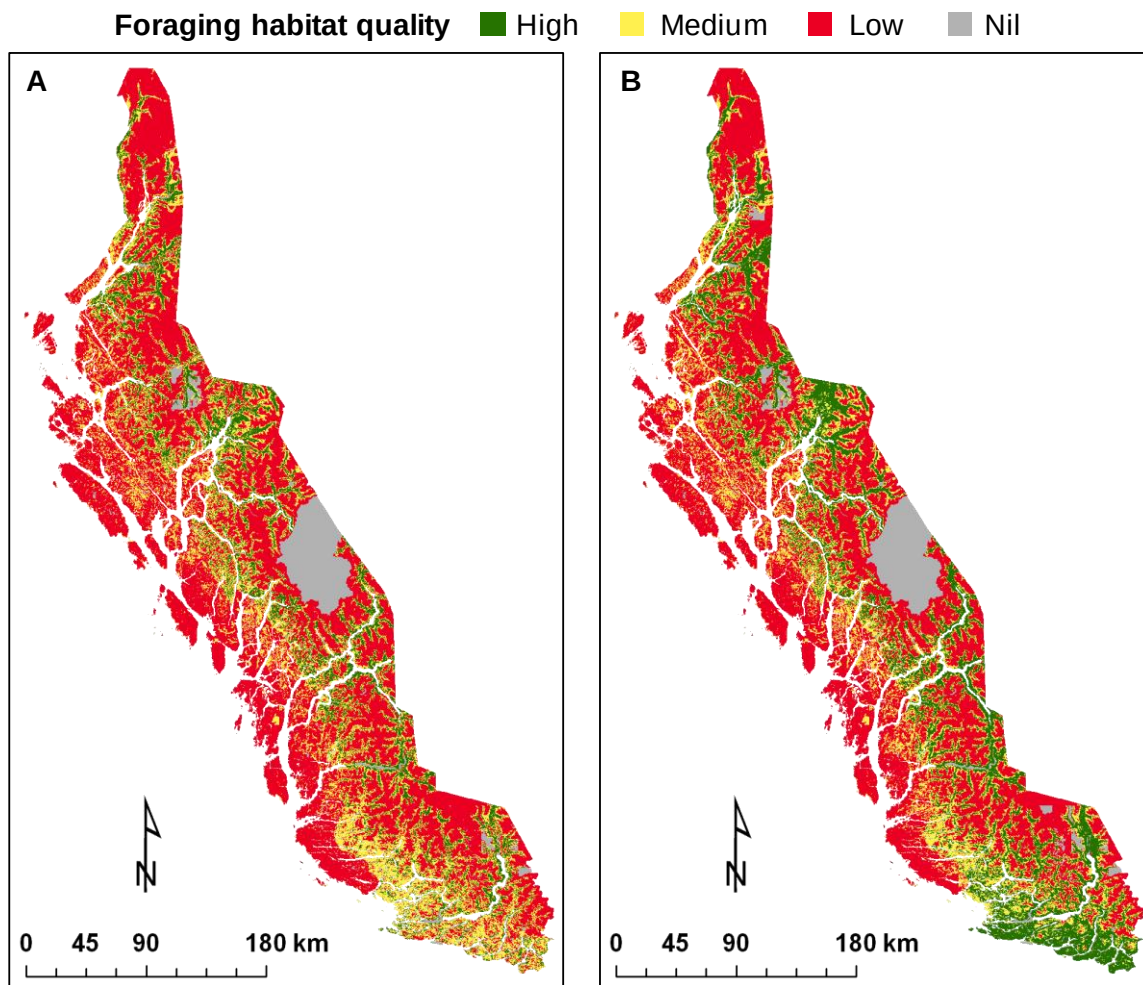


Figure 15: Distribution of foraging habitat in the NCCR for the current landscape (A) and capable habitat (B) scenarios (from Smith and Sutherland 2008).

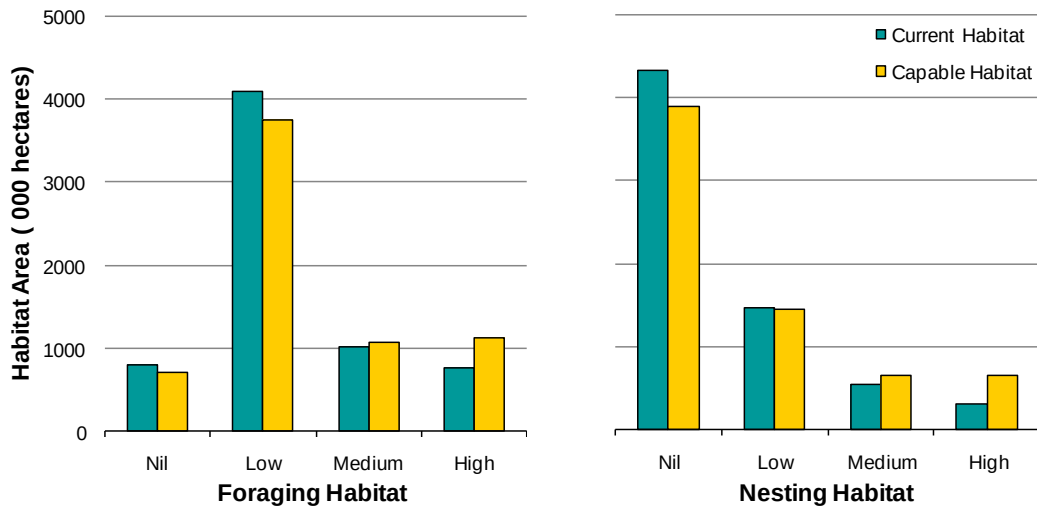


Figure 16: Area of foraging and nesting habitat classes for the current landscape and capable habitat scenarios in the NCCR (from Smith et al. 2008).

Some key patterns of the nesting and foraging model outputs for the NCCR (Figures 14-16) are:

- Suitable nesting and foraging habitat (medium and high) are quite limited in the NCCR, even under the capable habitat scenario. This reflects the extensive amounts of non-productive habitat (e.g. treed bogs) and non-forested habitat (e.g. alpine) in the region. These non-productive and non-forested areas are normally rated as low value foraging habitat and nil value nesting habitat, explaining the relative amounts of nil and low habitat observed for nesting and foraging habitat in Figure 16.
- Concentrations of suitable nesting and foraging habitat are limited to the southern portion of the Conservation Region and lower slopes along major inlets and stream drainages.
- The reduction in high quality habitat from capable to current scenarios is >50% for nesting habitat and ca. 25% for foraging habitat.

The distribution of potential territories in the NCCR using the three habitat thresholds (60% suitable foraging habitat = high probability of occurrence, 40%=medium, 20%=low) for the current and capable habitat scenarios is presented in Figure 17.

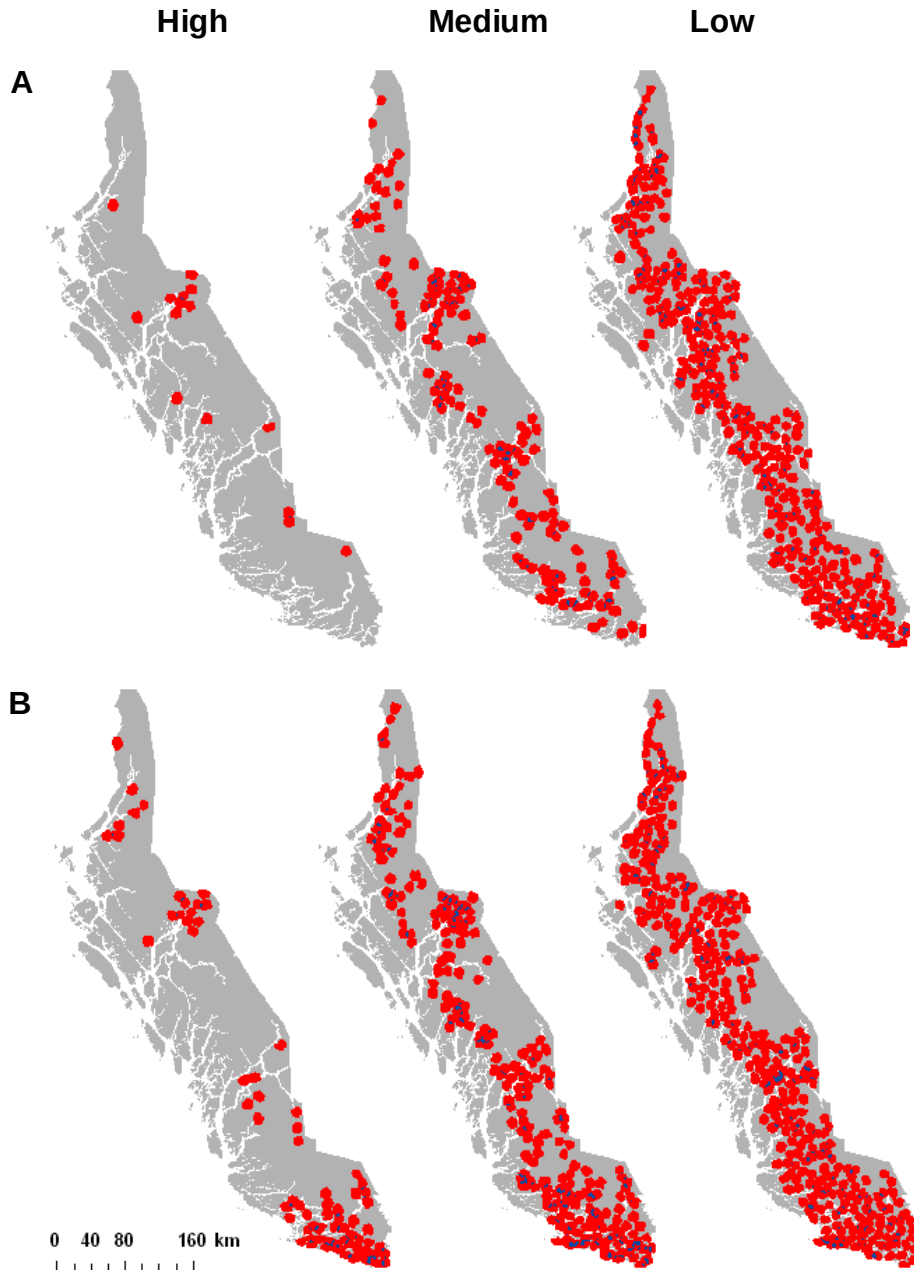


Figure 17. Distribution of goshawk territories in the North Coast Conservation Region for one iteration of the model for the current conditions (A) and capable habitat (B) scenarios, for three habitat thresholds (from Smith and Sutherland 2008)..

The habitat threshold used for determining whether a potential territory could form had a very large effect on the number of territories produced by the model (Figure 18). In addition, the habitat threshold levels show a non-linear relationship with the amount of habitat in a scenario (i.e. current vs capable). For the low habitat threshold (20% habitat requirement) the reduction in numbers of territories from the capable to current scenario was only 5% (341 vs 324 territories; Figure 14). For the high habitat threshold (60% habitat requirement) the reduction in numbers of territories from the capable to current scenario was 81% (74 vs 14 territories). These results highlight the sensitivity of the territory model to the habitat requirement thresholds.

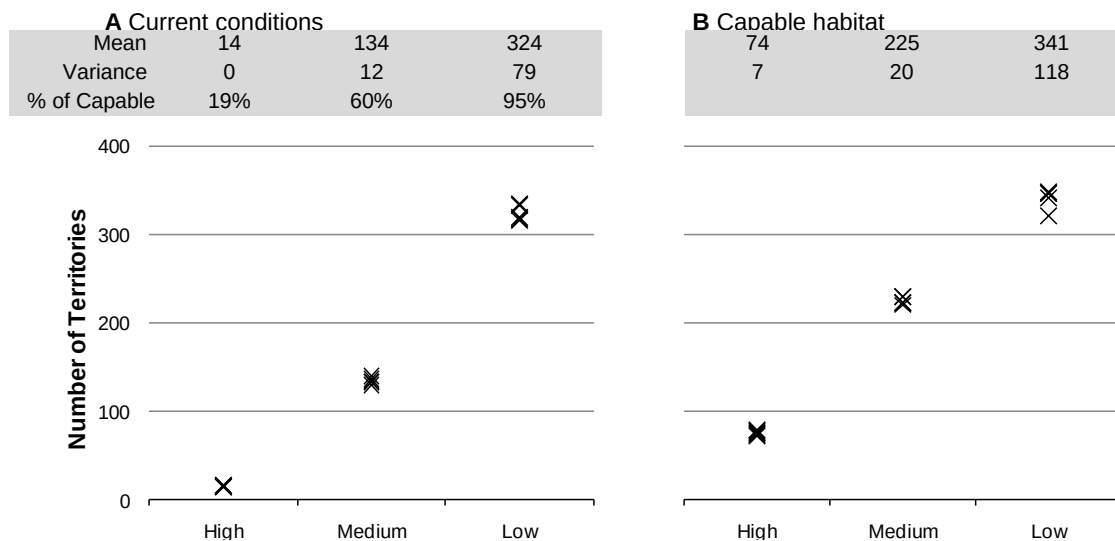


Figure 18: Effect of habitat threshold on the number of territories supported in the NCCR for the current conditions and capable habitat scenarios (N= 5) (from Smith and Sutherland 2008). Mean number of territories and associated variance for each scenario are indicated at the top of the figure.

A finer scale overlay of territory locations on foraging habitat is presented in Figure 15. This illustrates how territory locations and shapes are associated with the underlying pattern of foraging habitat.

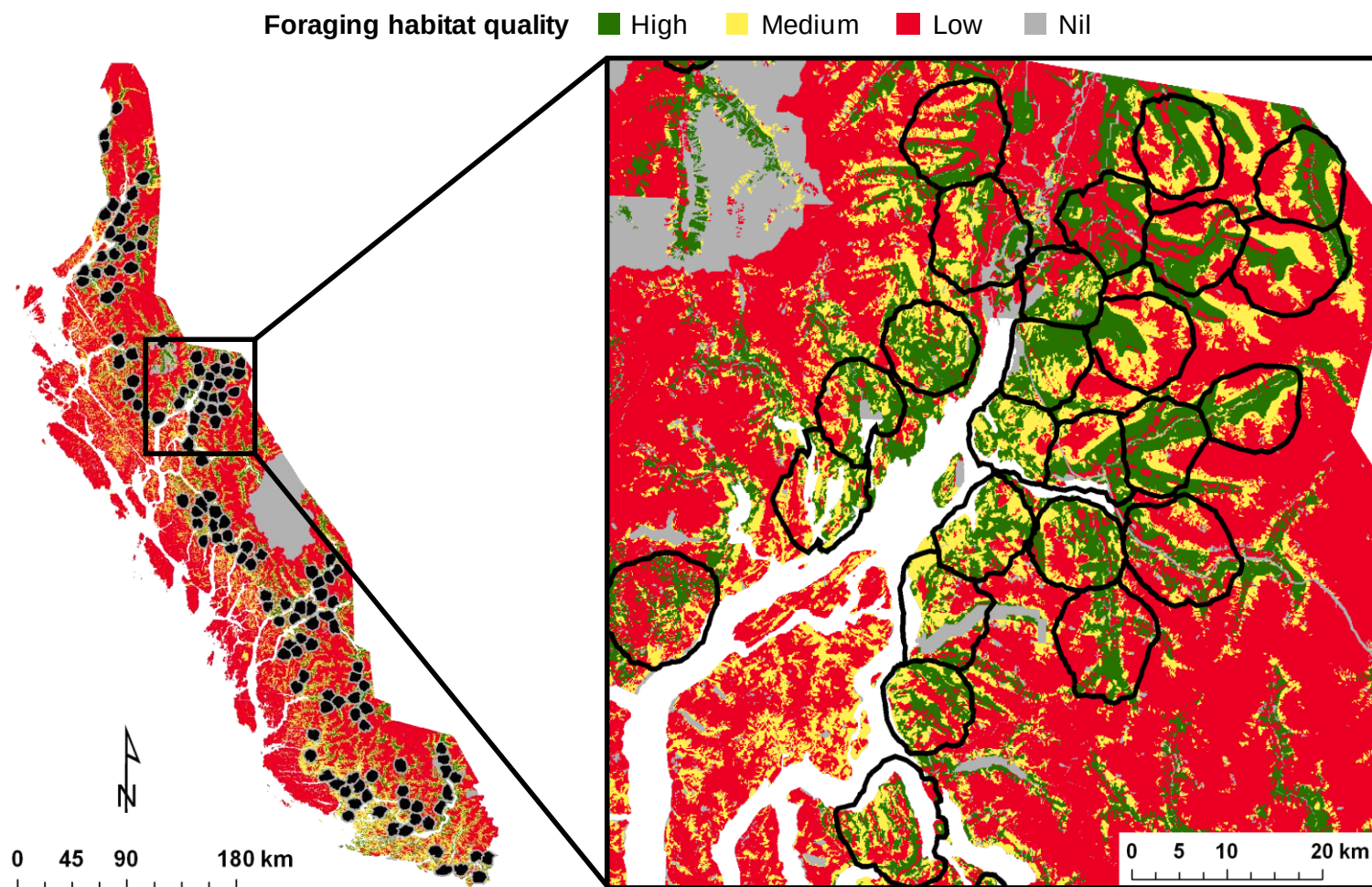


Figure 19: Close up of territory shape and arrangement in relation to the distribution of foraging habitat (from Smith and Sutherland 2008). Black polygons indicate individual territories, with overlap between adjacent territories not shown.

Model Review, Verification and Revision

Model development has involved four formal review, verification, and revision components: 1) review of model outputs during model implementation to ensure the model was working correctly and that model predictions were consistent with ecological expectations, 2) a detailed sensitivity analysis that examined how sensitive model outputs were to changes in key model parameters, 3) formal accuracy assessment of the nesting and foraging model outputs in each of the four Conservation Regions using field verification, and 4) a final comprehensive review and, where appropriate, revision of model parameters using the field verification data.

Model Implementation Review

Model implementation involved two formal review components. One was conducted by Cortex and involved assessing the underlying data at 10,000 random points in each Conservation Region and recalculating the nesting and foraging HSI scores in an Excel worksheet to verify that the outputs from the model were correct. The second component was more biologically based and consisted of an evaluation of the behaviour and outputs of each of the three components of the model relative to the initial variable ratings, model structures and expectations of results. This second review was conducted for each Conservation Region by the model developers (authors of this report) and involved several hours of reviewing model outputs including comparison to areas where habitat quality was known, such as goshawk nest sites. Also, during initial model development for the first Conservation Region, Haida Gwaii, interim output was reviewed by all Habitat RIG members during three model review workshops in 2006 and 2007. This review process resulted in several minor revisions to the variable ratings and model structure of the HSI model. As well, the RIG identified issues associated with territory packing and shape with the territory model that were investigated by performing sensitivity analyses for specific territory model parameters.

Sensitivity Analysis

Formal sensitivity analysis was conducted as part of initial model development to assess the relative influence of different variables in the model (Smith 2008). The relative influence of different model variables was examined by comparing how predictions of reduced models (i.e. versions of the model with one variable removed) compared to the full model (model with all the variables) and by examining the difference in the number of territories predicted to occur between the full and reduced model. Key results from the sensitivity analysis were:

- Stand height was the most influential variable in both the nesting and foraging models, followed by age. This emphasizes the importance of accurate forest cover data and parameter ratings curves for these variables to obtain accurate suitability

predictions. Another implication relates to the source and quality of the height/age data source (i.e. forest cover values or modeled from VDYP or TIPSYS).

- Sequential reduction/addition of age and height highlighted the complementary role the two variables play in the model. When height was removed from habitat models it resulted in an increase in the quality of habitat in high elevation and poor productivity sites (which likely resulted in an overestimate bias), and a decrease in habitat quality on high productivity sites (likely an underestimate bias) and vice versa when removing age. This interaction between height and age indicates they play complementary roles in accounting for the influence of site productivity on habitat quality. This effect was further manifested in the territory model, where removal of height from the habitat models resulted in a substantial decrease in the number of territories predicted in the study area.
- The territory model exhibits very little response to the amount of nesting habitat in the landscape. This is consistent with our expectation, since a breeding area is <5% of a breeding home range.
 - However, increasing the size of a suitable nesting habitat patch from 50 ha to 250 ha did result in a significant reduction in the number of predicted territories. This highlights the importance of nesting habitat distribution (i.e. larger patch sizes), not just amount.
- As expected, the number of potential territories predicted by the territory model was very sensitive to the territory size and spacing used. The number of potential territories using the 6900 m size/spacing was more than twice as many as using the 10800 m size/spacing. This emphasizes the rationale behind our recommendation to use territory model outputs primarily for relative comparisons (e.g. comparing number of potential territories between current and capable conditions or between different management scenarios), which are fairly insensitive to biased territory sizes. For exercises that use absolute numbers of territories, this analysis emphasizes the importance of accurate territory sizes and spacing distances for the area being examined.

For a more detailed description of the rationale behind the sensitivity analyses, methods and results refer to Smith (2008).

Model Verification / Accuracy Assessment

With any model it is desirable to know how well the model performs in terms of its accuracy and bias (consistent direction of errors [i.e. over- or underestimating]). Formal accuracy assessment projects were conducted to assess the performance of the goshawk nesting and foraging models in each Conservation Region (Doyle et al. 2010 [HGCR], Mahon 2010 [NCCR], Mahon 2011 [VICR], Mahon 2012 [SCCR]). The purposes of these projects were to quantify the accuracy and bias of the model outputs and to provide modellers with additional data to evaluate and refine the model parameters and structure to improve its performance. As part of early accuracy assessment design discussions, the Habitat RIG identified an *a priori* accuracy target of 70% model accuracy, 80% of the time, against which to benchmark model performance. However, at the time the RIG

established that benchmark, the group had not considered which statistical method would be used to evaluate model accuracy. Subsequently, the RIG learned that accuracy scores were extremely sensitive to different analysis methods. As a result, discussion here focuses on implications of model error and bias for planning and management exercises at varying scales, rather than comparison to a specific accuracy target.

Approaches for assessing model performance are usually classified as either model **verification** or model **validation**, depending on the type of information used to compare to model outputs. Habitat model verification tests model performance using an indirect measure of use by the species of interest, such as sign (e.g. cone bract piles for a foraging model for red squirrels) or field assessments of habitat quality by a species expert (Brooks 1997). Validation examines model performance using a direct measure of density of, or use by, the species of interest (Brooks 1997). Although habitat model validation is normally preferred, it generally requires much more intensive work to obtain the required data than for model verification. For example, validation of the goshawk nesting habitat model would require locating an independent sample of nest areas; validation of the foraging habitat model would require a telemetry study that compared habitat use by goshawks relative to the foraging HSI ratings. Although collection of validation data remains a longer term goal, neither of these validation data types could be obtained within the desired timeframes or available budgets of the Habitat RIG. Therefore, the Habitat RIG chose to assess the performance of the nesting and foraging habitat models using field ratings by species experts.

Model verification was conducted within a formal accuracy assessment framework, consistent with provincial methods developed to formally assess accuracy of ecosystem maps (Meidinger 2003; Moon et al. 2005) and, more generally, with the principles and practices of thematic map accuracy assessment (Congalton and Green 2009). The basis of the accuracy assessment was a comparison of ratings predicted by the habitat models to field ratings, as assessed by goshawk experts. Both model and field ratings used continuous scores between 0 and 1. Formal field assessment training was conducted to standardize rating criteria and calibrate estimates among field personnel prior to and during field work to reduce bias and variation among observers. The field assessments were ‘blind’ – field personnel did not know the model predictions for the areas they assessed. Model accuracy was examined at three scales (0.8 ha subsample, 10 ha sample unit, and >1 million ha project scales) to address spatial accuracy issues identified during the Haida Gwaii project and to provide information for potential use of the model outputs at those scales. The primary scale of interest was the 10 ha sample unit scale because that was large enough to address plot-level spatial accuracy issues but still small enough to be relevant to stand-level management activities. The sampling design consisted of >50 sample units per Conservation Region, with 9 subsamples in each sample unit, and with sample unit located across the project area using a stratified, random design. Two accuracy assessment methods were used: 1) a score based on the difference between model and field ratings, and 2) correspondence of model to field ratings using 2- (suitable,

unsuitable) and 4-(nil, low, moderate, high) class bins . Upon further examination and consultation with a statistician, difference-based scoring was identified as the most appropriate approach used to evaluate overall model performance (see discussion below and Table 12). The correspondence-based approach provides an indication of accuracy when ratings are categorized into bins, which are commonly used for management purposes. For more detailed information about accuracy assessment methods and results refer to the following documents for each Conservation Region:

Haida Gwaii: Doyle et al. 2010

North Coast: Mahon 2010

Vancouver Island: Mahon 2011

South Coast: Mahon 2012

The results of the accuracy assessments for the North Coast, South Coast, and Vancouver Island using the difference-based method for the 10 ha scale are provided in Table 12. Results from Haida Gwaii are not provided because model evaluation within this conservation region used a different design and the results are not comparable.

Table 12. Accuracy assessment scores for Northern Goshawk (*A. g. laingi*) nesting and foraging models by Conservation Region.

Conservation Region	Accuracy Score (bias HSI units)	
	Nesting Model	Foraging Model
North Coast	82% (9 units overestimate)	88% (6 units underestimate)
Vancouver Island	82% (no bias)	84% (6 units underestimate)
South Coast	81% (3 units overestimate)	84% (6 units underestimate)

Accuracy scores and patterns of bias were quite consistent across Conservation Regions. This suggests that the models are fairly robust and broadly applicable. Overall, the nesting model tended to overestimate suitability and the foraging model tended to underestimate suitability. Model errors appear to be largely driven by errors in forest cover data, which has two implications: 1) errors in the underlying data restrict the ability of potential model revisions to improve performance, and 2) use of the model outputs should be consistent with generally accepted practices and limitations associated with using forest cover data for other forest management and habitat management activities. Although the accuracy of the models exceeds the benchmarks set by the Recovery Team, precautionary use of the models is recommended, possibly including verification of model predictions via ground truthing or aerial imagery. Additional implications of model accuracy when using model outputs are discussed in the section below – *Considerations for Using the Coastal Goshawk Models and Model Outputs*.

Final Model Revisions (2012)

From 2006-2011 the coastal goshawk models were effectively a work in progress, pending completion of field verification in each Conservation Region. With field verification completed, the final phase of model development was a comprehensive review and finalization of model parameters and documentation. This work included:

- Systematic review of all model parameters relative to field verification data, new literature, and expert opinion and, if appropriate, revision of model parameters,
- Evaluation of potential model revisions by testing revised model output against the field verification data. This focused on revisions to age and height, which the sensitivity analysis identified as being the most influential model variables, and which model verification reports suggested could be refined (Mahon 2009, Mahon 2011). A total of twelve different combinations of age and height rating curves and one version with higher Fd ratings were examined for both the nesting and foraging models for NCCR, SCCR and VICR (78 total revision versions),
- Verification that current model parameters are documented and implemented in Cortex's model scripts and are ready for future model runs,
- Update of model reports (ecological report – this document and the technical model report – Cortex 2008) to reflect final model structure, parameters and outputs.

Model revisions associated with the final review included:

- revision to the age rating curves in both the nesting and foraging models so that optimal suitability was reached at 90 years. The original ratings became optimal at 140 years (i.e. the original ratings underestimated suitability of young forests),
- revision to the height rating curves in both the nesting and foraging models so that optimal suitability was reached at 32. The original ratings became optimal at 30 m (i.e. the original ratings overestimated suitability),
- For the foraging model the rating of Fd leading stands was increased from 0.95 to 1.0,
- For non-productive and non-forested habitats the foraging suitability was changed from 0.4 to 0.3. This makes ratings for these habitats consistent with herb and shrub stage regenerating forest stands,
- For elevation, the slope of the rating curve was revised to change linearly between the inflection points. The original rating were treated categorically,
- For the NCCR the territory size (and associated parameters) used in the territory model was split across the conservation region – for areas south of Bella Coola the 6900 m diameter territory size from VICR&SCCR was used; for areas north of Bella Coola the 10800 m diameter territory size from HGCR was used. (Originally the 10800 m territory size was used across the entire NCCR),
- For the territory model, the minimum patch size of suitable nesting habitat for a territory to initiate in was increased from 50 ha to 100 ha to better represent the estimated size of breeding areas (McClaren et al. 2015),

All of these model revisions are reflected in the preceding sections of this report, and have been implemented in model runs across all four conservation regions (Smith 2012). Although it was important to incorporate the ground verification work in model

revisions, the revisions to the nesting and foraging model parameters are considered minor refinements and, overall, resulted in small changes in model predictions. In the case of the revisions to the age and height ratings, the original ratings had opposite biases (age underestimating, height overestimating) that tended to counteract each other. As a result, the revised age and height ratings result in only slight improvements to overall model performance. The change to using two territory sizes for different portions of NCCR will have a substantial effect on the absolute number of predicted territories, however, comparisons of relative territory numbers (which we recommend as the most appropriate use of territory outputs) should only be slightly affected.

Considerations for Using the Goshawk Habitat Models for Forest Planning and Management

The coastal goshawk models were developed primarily as strategic, large-scale planning tools. The primary intended use of model outputs was to compare relative amounts of nesting and foraging habitat and relative numbers of potential territories among different management scenarios or over time. We recommend focussing on relative comparisons of model outputs over absolute model predictions because relative comparisons are normally much less sensitive to model uncertainty and bias. For example, the total number of territories predicted for a given conservation region could under- or overestimate the actual number of territories by some value, however, in a relative comparison of numbers of territories between current and capable habitat conditions, the difference between the two scenarios should be relatively unbiased. Examples of relative comparisons potentially useful for resource planning are:

- comparing the number of territories under current conditions to capable conditions,
- comparing numbers of territories over time in a forest harvest-succession framework,
- comparing numbers of territories that result from different management scenarios modelled for the same area,
- examining broad patterns of territory numbers, densities, and distributions within or among large regional areas (e.g. comparing numbers of territories among Conservation Regions or across BEC subzones).

Notwithstanding our emphasis on relative comparisons of model outputs, absolute predictions from the models may provide the best available information for Landscape Unit-scale and stand-level projects (e.g. using nesting habitat model outputs to help define the breeding area around known nest sites), so long as users understand the limitations of model outputs at smaller scales and when used for spatially explicit purposes.

In the following sections we provide examples of appropriate ways to use model outputs for planning and management exercises at strategic, Landscape Unit, and stand levels. These examples are based on the range of planning and conservation initiatives in

Coastal British Columbia that have included considerations for goshawk habitat over the last decade. The most informative way to use the goshawk model outputs for different projects will depend of the specific questions and circumstances of those projects and we provide the following information as general guidance about how to use the model outputs appropriately.

Using Model Outputs for Strategic Planning

For strategic planning exercises at large scales (i.e. coast wide or Conservation Region; >500,000 ha) it is often informative to examine outputs from all three models. In most cases, the number and distribution of potential territories generated by the territory model should be the primary output to consider because the territory model incorporates the amount, quality and distribution of nesting and foraging habitat relative to goshawk spatial requirements in one indicator. Again, we normally recommend using the number of potential territories for relative comparisons, such as differences among management scenarios, changes over time, or changes from some benchmark condition, such as capable/historic or current conditions.

One circumstance where it may be informative to use the territory model outputs in an absolute context is as a rough estimate of the carrying capacity of breeding pairs. The number of potential territories should not be used as a population estimate, because it does not account for territory occupancy and non-breeders. However, it does provide an estimate of how many territories could occur given the assumptions of habitat requirements and territory size and spacing patterns inherent to the model.

Although the territory model does produce mapped potential territories we strongly recommend against using territory outputs for any type of spatial purpose. There are several reasons for this:

1. **The territory model was not designed to predict the actual location of goshawk territories.** It was designed as an analysis tool to assess the amount, quality, and distribution of nesting and foraging habitat relative to average goshawk territory sizes and spacing patterns. Amount and quality of habitat alone could lead to ambiguous interpretations without some formal assessment of habitat distribution. For example, if 3800 ha of suitable foraging habitat occurred on Vancouver Island that could support 0, 1, or 2 territories depending on how the habitat was distributed.
If numerous model runs were conducted, the total area of all the modeled territories may approximate the area covered by real goshawk territories, but boundaries of territories and centroids (nest areas) could not be modelled accurately.
2. Several aspects of territory location, size and shape are stochastic and each territory model run results in a different set of potential territories.
3. In some situations the territory model does not ‘pack’ territories as optimally as some goshawk territories have been observed in certain areas. This appears to

leave some areas with adequate habitat to support a territory without one being produced by the model. The territory model attempts to balance some flexibility in territory parameters to adapt to varying habitat amounts while constraining bounds on territory size and spacing to ensure territory sizes and spacing reflect the average of observed territory size and spacing patterns from local studies.

4. The territory model has not been evaluated to determine how reliable predictions of territory occurrence, boundaries and centroids (nest areas) are and it would be virtually impossible to do so.

Evaluating the nesting and foraging model outputs for strategic purposes at large scales may also provide useful information under a variety of situations. For example, the patterns of nesting and foraging outputs may be useful for understanding changes in territory model outputs among scenarios. Another circumstance is for conducting certain types of analyses and screening exercises where the nesting and foraging model outputs can be assessed much more quickly than running the territory model. For example, a set of different timber harvesting options could be superimposed on existing nesting and foraging outputs to assess their relative impacts with much less time and effort than by running the territory model. Further, the results of the simple overlay assessment may guide in the decision of whether or not to run the territory model. The nesting and foraging model outputs may also provide finer precision than the territory model when evaluating certain management scenarios. For example, in two scenarios where similar numbers of potential territories result, there could be a difference in average foraging scores between the two scenarios that could be used to assess their relative impacts.

Although the nesting and foraging HSI scores can be categorized (e.g. 0-0.5=suitable, 0.5-1=unsuitable) to summarize habitat amounts, categorization results in considerable loss of data resolution and a bias of overestimating habitat quality (i.e. saying HSI of 0.6 is equivalent to 1). Instead, we recommend that summaries of habitat amounts be weighted by their HSI value, which is the standard approach for integrating HSI models into habitat evaluation exercises (US Fish and Wildlife 1981b). For example, 10 ha with HSI=1 would count as 10ha of effective habitat; 10 ha with HSI=0.6 would count as 6 ha of effective habitat. Normally, we recommend that areas with HSI<0.5 be counted as zero, which is consistent with how the territory model evaluates whether there is enough foraging habitat to form a potential territory.

Using the Model Outputs for Landscape Unit Scale Initiatives

In general, we recommend that emphasis should be placed on the nesting and foraging model outputs (vs the territory model) when evaluating goshawk habitat at the Landscape Unit scale (ca. 1000-100,000 ha). We recommend focussing on foraging habitat instead of territory model outputs because goshawk territories are quite large

relative to LUs and provide too coarse an indicator to detect differences among management scenarios. Several factors relate to this:

1. At LU scales many territories often straddle two or more LUs and it may be difficult to develop rules to allocate which LUs a territory should be counted in.
2. Often, only a small number of territories occur in a LU (often <5) and these small numbers provide too coarse a resolution to be a good indicator of habitat change or differences among management scenarios. For example, consider a LU with 5 territories in it under one management scenario. In a second management scenario with 5% less suitable foraging habitat, likely outcomes of the territory model are 5 territories again, which potentially fails to recognize a habitat impact, or 4 territories (a 20% reduction), which potentially overemphasizes the potential impact.
3. The territory model is stochastic and territories can shift substantially among runs, resulting in high variation in territory numbers/LU among runs. For example a LU with 5 territories on average could have a range of 3-7 territories on different runs. That variation could easily mask any change in territory number attributable to differences in management scenarios.

We provide three potential approaches for incorporating goshawk habitat evaluations into LU planning initiatives using foraging habitat model outputs. Each approach has pros and cons, which are outlined. Two key issues associated with all approaches are 1) the basis for setting habitat targets (e.g. comparison to capable) and 2) the rationale for setting a specific target(s) (e.g. 60% of capable).

Regarding the basis for setting habitat targets, two possible approaches are 1) choosing a target relative to a habitat condition at some benchmark time (e.g. current condition or capable condition) or 2) choosing an absolute habitat amount that relates to a goshawk habitat requirement. Unfortunately, data is limited to support setting specific targets using either approach. The rationale behind the first approach (target relative to a benchmark) requires an assumption that changes in habitat condition from the benchmark will roughly correspond to changes in fitness or population size of goshawks. For example, if a goshawk population goal was to maintain 60% of historic carrying capacity a corresponding habitat target could be to maintain 60% of capable habitat (assuming a 1:1 habitat:population size relationship). Three limitations of this approach are that habitat:population/fitness relationships are poorly understood, the basis for setting a target is often arbitrary (60%, 50%?) and lack an ecological basis, and the choice of benchmark has a strong effect on outcomes. The second approach, choosing a habitat target that relates to a goshawk habitat requirement, has a stronger ecological basis and more local data to support a target. We recommend setting targets following the rationale outlined in the territory model threshold section. Information from local studies suggests that areas with <20% suitable habitat do not support goshawk territories, areas >60% have high probability of territory occurrence and occupancy, and areas with 40-60% suitable foraging

habitat have moderate probability of territory occurrence and occupancy (McClaren and Doyle *in* Daust et al. 2010). Using that data, we recommend potential habitat targets between 40 and 60% depending on risk tolerance and trade-offs with other resource values.

In terms of the setting habitat targets, two targets may be appropriate under certain planning scenarios. The obvious first type of target is a higher value target beyond which habitat is deemed as being surplus to what goshawks require and available for timber harvesting. An example of this could be a LU that has a 60% of capable habitat target that currently contains 66% foraging habitat. Under this approach 6% is surplus to the target and would be available for timber harvesting. The second type of target could be a low value target below which there is insufficient habitat for goshawks to occur (e.g. <20% suitable habitat) and forest that does occur is made available for harvesting under the assumption that goshawks are not present and therefore would not be impacted. This second type of habitat management target (write-off scenario), should be viewed as riskier type of approach because if the target is wrong and goshawks are actually present there is a high risk of extirpating them. This approach is also likely to impact habitat recruitment and delay or preclude goshawks from occupying the area in the future. Recognizing these potential impacts, there could still be an argument for using this approach in a trade-off situation where you either log areas where you believe goshawks occur, but there is no surplus habitat, or you log in areas where you believe habitat is already insufficient and goshawks are unlikely to occur.

Three possible approaches for incorporating goshawk habitat evaluations into LU planning initiatives using foraging habitat model outputs are:

1. Setting a habitat target as a percentage of available habitat at a benchmark time
2. Setting a habitat target based on a minimum habitat requirement
3. Using a 'moving window' analysis to add a spatial component to minimum habitat requirement approach.

Details of each approach and their major pros and cons are provided below.

1) Compare current foraging habitat to capable (or other benchmark) by LU.

The habitat target under this approach is based on defining an 'acceptable' level of habitat reduction from total capable habitat. Other benchmarks may be substituted for capable, such as current conditions, but the capable scenario represents an obvious bookend reference (i.e. maximum amount of suitable habitat) and outputs of the capable scenario are available for all conservation regions. Defining a habitat target normally makes an assumption that changes in habitat condition from the benchmark will roughly correspond to changes in fitness or population size of the species of interest. Whenever possible, targets should be guided by ecologically-based criteria (e.g. population targets). The typical management strategy under this approach would be to not allow habitat reduction below the target.

Computing the current proportion of suitable habitat is simply the current habitat amount divided by capable habitat amount. Tallies of both current and capable habitat should use the approach of weighting area by HSI, described previously.

Pros	<ul style="list-style-type: none"> • easy analysis
Cons	<ul style="list-style-type: none"> • sensitive to benchmark condition used, which planners may disagree about • target may lack a strong ecological basis • often requires an assumption that population/fitness are strongly correlated to habitat • does not account for spatial distribution of habitats within LU • LU boundaries arbitrarily break up habitat distributions

2) Assess current foraging habitat in LU relative to 40% (or other) habitat threshold.

The basis for setting habitat targets under this approach is to identify potential habitat thresholds that relate to goshawk occurrence on the landscape. This idea is similar to the habitat threshold requirement employed in the territory model, but expanded to reference several territories that could occur within a Landscape Unit. Under this approach the rationale for the two habitat targets previously discussed (minimum requirement and write-off levels) may be applicable. Following the discussion of habitat requirements in the territory model section, above, appropriate minimum habitat requirements would be in the 40-60% range and the value below which goshawk occurrence is unlikely would be 20%. Using these two targets, timber harvest could potentially occur in Landscape Units with surplus habitat above the 40-60% target and in Landscape Units with <20% foraging habitat (but recognizing that harvesting under the latter target would delay/preclude habitat recruitment).

A potential concern with this approach is that if suitable habitat are not relatively evenly distributed across the Landscape Unit it could result in reduced goshawk densities due to some areas having surplus habitat and other areas not having enough habitat. A precautionary measure to account for this potential issue would be to raise the habitat threshold target slightly from the ecological baseline (e.g. use 45% instead of 40%).

The recommended method for computing the existing proportion of foraging habitat per Landscape unit is: the total of HSI weighted area divided by the total vegetated landbase (i.e. excluding non-vegetated/sparsely vegetated areas such as water, rock, ice, urban, alpine, etc, but including vegetated, non-forested areas such as brush and wetlands.

Pros	<ul style="list-style-type: none"> • target has an ecological basis (albeit data for choosing a specific target is limited) • does not require a comparison to a benchmark • easy analysis
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Cons	<ul style="list-style-type: none"> • limited data to support a specific habitat target • does not account for spatial distribution of habitats within LU • LU boundaries arbitrarily break up habitat distributions
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3) Moving window analysis of foraging habitat using a habitat threshold

This approach builds on the previous approach, of choosing targets based on habitat requirements, by adding a spatial component to it. It uses a ‘moving window analysis’ to summarize the proportion of goshawk foraging habitat within a circular, territory-sized area surrounding each pixel on the map, instead of summarizing the proportion of foraging habitat for an entire Landscape Unit. This approach is analogous to the territory model except that it is much simpler (e.g. uses a fixed size, circular shape) and can be run across every pixel in the study area. The output from the analysis shows the proportion of suitable foraging habitat in the surrounding 3847 ha area (average goshawk territory size in the southern portion of its range) (Figure 20). The major difference of this approach over the previous two approaches is that it incorporates the spatial distribution of habitat, as well as the amount and quality.

The way the proportion of suitable foraging habitat is calculated is similar to the previous approach, but done for each pixel via a moving window: the total of HSI weighted area within the 3847 circle divided by (3847 ha – non-vegetated area). It is important to net out the non-vegetated area from the denominator of this calculation to account for the extensive areas of ocean and alpine in the coastal landscape. For example, for a map unit adjacent to a large inlet approximately half of the 3847 ha analysis area would be ocean, which is non-habitat to a goshawk. If the ocean were not excluded from the denominator it would dramatically deflate the estimate of the proportion of suitable foraging habitat.

Similar to the previous approach, timber harvest could potentially occur in areas with surplus habitat above the 40-60% target and in areas with <20% foraging habitat (but recognizing that harvesting under the latter target would delay/preclude habitat recruitment). In this approach the applicable management areas are defined spatially within Landscape Units, instead of broadly at the Landscape Unit level. As a result of the finer resolution, timber harvesting could still be viable in limited areas with surplus habitat even in Landscape Units that were below a broad habitat target overall.

Pros	<ul style="list-style-type: none"> • target has an ecological basis (albeit data for choosing a specific target is limited) • does not require a comparison to a benchmark • accounts for spatial distribution of habitat • LU boundaries do not affect analysis and results are easily applied to LUs
Cons	<ul style="list-style-type: none"> • limited data to support a specific habitat target

- moderately complicated analysis
 - results are sensitive to assumptions and decisions of the analysis (e.g. netting out unsuitable areas from denominator in habitat percent calculation).

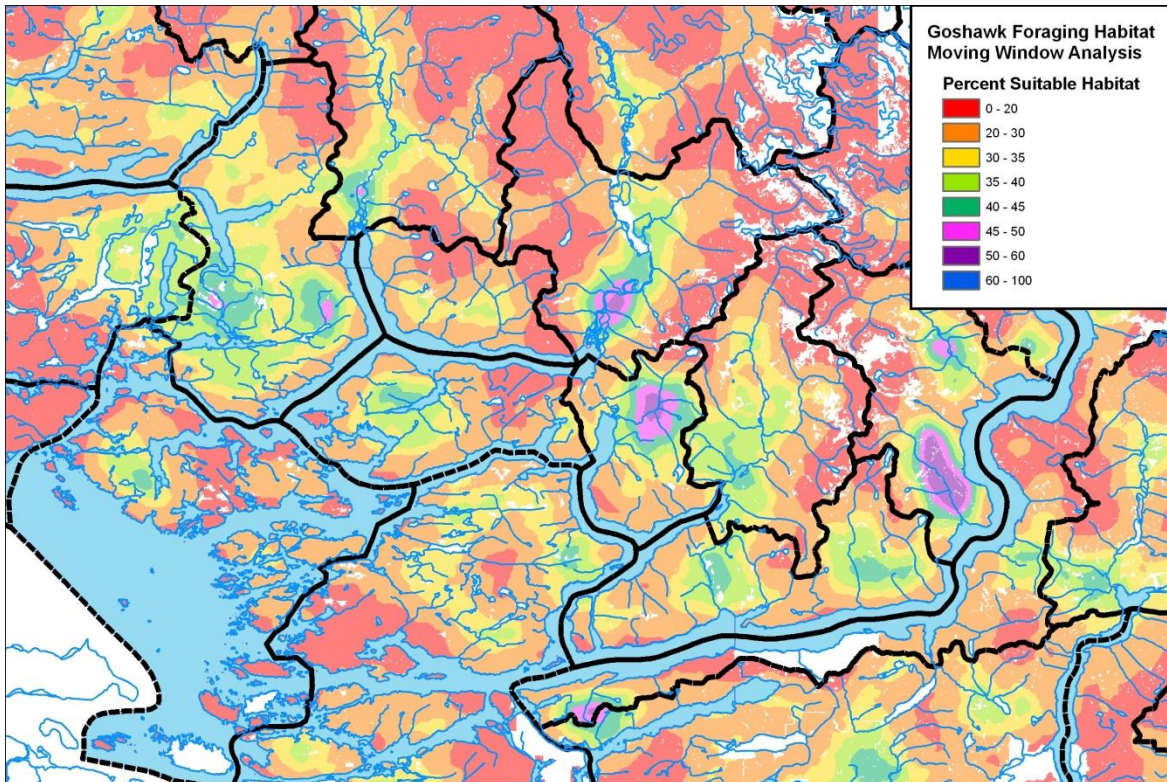


Figure 20. Moving window analysis of goshawk foraging habitat for the southern portion of the NCCR. Cell values are the proportion of the surrounding 3847 ha in suitable foraging habitat (sum of suitable foraging habitat / [3847 – non-habitat area]). Thick black lines are Landscape Unit boundaries. One management approach could be to treat areas >40% suitable habitat as ‘surplus’ habitat available for logging.

Using Nesting and Foraging Model Outputs for Stand-Level Management

At stand-level scales (i.e. one to several forest cover polygons; 10-500 ha) the use of models should be limited to the nesting and foraging models. Normally the emphasis should be placed on the nesting model because it targets a more specific range of habitat conditions than the foraging model. It is generally inappropriate to use any of the territory model outputs at stand-level scales. Examples of stand-level uses of the nesting and foraging habitat model outputs include:

- stratifying areas for goshawk inventory surveys,

- aiding in the delineation of conservation areas around known goshawk breeding areas, and
- evaluating the relative impacts of different cutblock locations on goshawk habitat.

Although the accuracy of both the nesting and foraging models met *a priori* benchmarks, there is still a significant error rate in model outputs at stand level scales. The primary factor affecting the accuracy of the nesting and foraging model outputs is the accuracy of the underlying forest cover data. Therefore, use of the model outputs should be consistent with generally accepted practices and limitations associated with using forest cover data for other forest management and habitat management activities. We strongly recommend that use of the model outputs at stand-level scales include verification of model predictions including ground truthing and air photo assessment.

Tailoring the Models for Local Areas and Management Projects

Development of this overall model has involved several goshawk and modelling experts, thorough review of local goshawk data and goshawk literature, extensive model testing, detailed sensitivity analysis, formal field accuracy assessment and thorough final model review and refinement, all of which required several years to complete. It is unlikely that potential model users will be able supply commensurate expertise and resources to make model improvements beyond the efforts of the Habitat RIG. Model users are strongly cautioned that changes to the model can have unintended and sometimes large effects due to interactions among model variables and other model behaviour. Despite this caution, there may be cases where users have a specific rationale for tailoring the model to a specific area or project. One example may be the availability of a variable in a local dataset that has a strong basis for improving the model, such as canopy closure for the nesting model. If model revisions are conducted, the Habitat RIG recommends users follow generally accepted standards for model development and revision including:

- Involvement of appropriate goshawk experts (ideally more than one) and habitat modeling experts.
- Review and testing of revised model to ensure the revision is implemented correctly (e.g. independent calculation of model outputs for a number of random locations in the study area).
- Comparison of the revised model outputs to the original model outputs to assess model behaviour and verify the revisions have the intended outcomes. Due to interactions with other variables, model revisions can often have unintended consequences.
- Field verification/validation of the revised model outputs.
- Documentation of the model revision process including:
 - rationale for revision including supporting data

- revised variable parameter values, model equation, and associated computer/GIS scripts
- model implementation testing procedures and results
- methods, results, and discussion of comparisons between revised and original model outputs
- methods, results and discussion of field verification/validation assessments.

Obtaining Models and Model Outputs

All components of the goshawk model and outputs are available for use and distribution under a data sharing agreement with the Habitat RIG. To ensure the models and outputs are used appropriately, the Habitat RIG normally provides advice and guidance on model use and interpretation that is tailored to specific projects. As part of a request to obtain the model or model outputs, proponents are requested to provide the following information:

- the planning initiative involved and a list of proponents
- the specific goshawk habitat questions being examined, including details of the various scenarios being examined
- the proposed approach for using the goshawk model to evaluate the management question
- the study area being examined (including local BEC variants)
- key technical personnel (i.e. goshawk and modelling personnel) who will be conducting the analyses
- type and source of input data for new model runs
- details of any model revisions, including the rationale for revisions (see previous section)
- anticipated model outputs, data analyses, and documentation

A normal condition of the data sharing agreement is that any GIS model outputs, model data summaries, scenario analyses, and associated reports are provided to the Habitat RIG. This will allow the RIG to assess user needs and experience, as well as model performance and behaviour, which may lead to future model improvements.

Literature Cited

- A. Edie and Associates. 2004. Morice Land & Resource Management Plan. Environmental risk assessment. unpubl. rep. for Min. Sustainable Resource Management, Skeena Region, Smithers, BC.
- Austin, K.K. 1993. Habitat use and home range size of breeding northern goshawks in the southern Cascades. M.Sc. Thesis, Oregon State Univ., Corvallis, OR.
- Banner, A., W. MacKenzie, S. Haeussler, S. Thompson, J. Pojar and R. Trowbridge. 1993. A field guide to site identification and interpretation for the Prince Rupert Forest Region. BC Ministry of Forests, Research Branch, Victoria, BC.
- B.C. Conservation Data Centre. 2012. BC Species and Ecosystems Explorer. B.C. Minist. of Environ. Victoria, B.C. Available: <http://a100.gov.bc.ca/pub/eswp/> (accessed March 9, 2012).
- BC Ministry of Environment and BC Ministry of Forests. 1995. Biodiversity guidebook. Forest Practices Code of British Columbia. Victoria, BC.
- BC Ministry of Environment, Lands and Parks and BC Ministry of Forests. 1999. Managing Identified Wildlife Strategy. Forest Practices Code of British Columbia. Victoria, BC.
- BC Ministry of Environment, Lands and Parks, and BC Ministry of Forests. 1998. Field manual for describing terrestrial ecosystems in the field. Land Management Handbook 25. Province of British Columbia, Victoria, BC.
- British Columbia Ministry of Water, Land and Air Protection. 2004. Order for category of species at risk. Available: http://www.env.gov.bc.ca/wld/identified/approved_order.html (April 10, 2006).
- Beier, P. and J.E. Drennan. 1997. Forest structure and prey abundance in foraging areas of Northern Goshawks. *Ecological Applications* 7(2):564-571.
- Bloxtton, T. D. 2002. Prey abundance, space use, demography and foraging habitat of Northern Goshawks in western Washington. MSc Thesis. University of Washington, Washington.
- Bosakowski, T. and J. Rithaler. 1997. Goshawk and raptor inventory in the Cariboo, 1996. Unpubl. rep. for BC Ministry of Environment, Williams Lake, BC. 28pp.
- Bosakowski, T., B. McCullough, F.J. Lapsansky and M.E. Vaughn. 1999. Northern Goshawks nesting on a private industrial forest in western Washington. *Journal of Raptor Research* 33(3):240-244.
- Bright-Smith, D.J. and R.W. Mannan. 1994. Habitat use by breeding male northern goshawks in Arizona. *Stud. Avian Biol.* 16:58-65.
- Brooks, R.P. 1997. Improving habitat suitability index models. *Wild. Soc. Bull* 25: 163-167.
- Brown, L., and D. Amadon. 1968. Eagles, hawks and falcons of the world. Volume 2. McGraw-Hill Book Company, New York, NY.
- Campbell, R.W., N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser, and M.C.E McNall. 1990. The Birds of British Columbia. Vol II. Non-passerines. Diurnal

- birds of prey through woodpeckers. Royal B.C. Museum., Victoria, and Can. Wildl. Serv., Delta, BC, 636p.
- Chytky, P., and K. Dhanwant. 1999. 1998 Northern Goshawk population inventory of the Queen Charlotte Islands, Haida Gwaii. Unpublished report for B.C. Environ., Lands and Parks, Smithers, BC.
- Crocker-Bedford, D.C. 1990. Goshawk Reproduction and Forest Management. Wildlife Society Bulletin 18(3):262-269.
- Crocker-Bedford, D.C. 1995. Northern goshawk reproduction relative to selection harvest in Arizona. Journal of Raptor Research 29:42.
- Congalton, R.G. and K. Green. 2009. Assessing the accuracy of remotely sensed data: principles and practices. 2nd Edition. CRC Press. Boca Raton, FL.
- COSEWIC. 2013. COSEWIC assessment and status report on the Northern Goshawk *Accipiter gentilis laingi* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 56 pp. www.registrelep-sararegistry.gc.ca/default_e.cfm.
- Cooper, J.M. and V. Stevens. 2000. A Review of the Ecology, Management and Conservation of the Northern Goshawk in British Columbia. Wildlife Bulletin No. B-101, BC Environment, Lands and Parks, Wildlife Branch, Victoria, BC.
- Daust, D., L. Kremsater, C. Apps, K. Brunt, A. Burger, F. Doyle, K. Dunsworth, L. Dupuis, P. Friele, G. MacHutchon, T. Mahon, E. McClaren, V. Michelfelder, B. Pollard, D. Seip, J.D. Steventon, and L. Waterhouse. 2010. Focal species risk thresholds for B.C.'s North and Central Coast. Report to the Joint Coastal Land and Resource Forum Technical Liaison Committee. Integrated Land Management Bureau, Nanaimo, B.C.
- Daw, S.K. and S. DeStefano. 2001. Forest characteristics of northern goshawk nest stands and post-fledging areas in Oregon. Journal of Wildlife Management 65(1):59-65.
- Doyle, F. I. 2004. Northern Goshawk and Marbled Murrelet Habitat Models and Field Verification Surveys in Gwaii Haanas National Park Reserve and Haida Heritage Site. Parks Canada. Haida Gwaii, BC.
- Doyle, F. 2005. Breeding success of the goshawk (*A. g. laingi*) on Haida Gwaii/Queen Charlotte Islands: is the population continuing to decline? Goshawk productivity and habitat requirements 2004-2005. unpubl. rep. Wildlife Dynamics, Telkwa, BC.
- Doyle, F.I. and T. Mahon. 2001. Inventory of the northern goshawk in the Kispiox Forest District. Annual Report 2000. B.C. Ministry of Environment, Lands and Parks. Smithers.
- Doyle, F., E.L. McClaren, L. Waterhouse. 2010. Northern Goshawk (*Accipiter gentilis laingi*) Habitat Suitability Model Verification on Haida Gwaii. Unpublished report prepared for the Northern Goshawk Recovery Team.
- Doyle F.I. and J.N.M. Smith. 1994. Population Responses of Northern Goshawks to the 10-year cycle in numbers of snowshoe hares. Studies in Avian Biology 16:122-129.

- Doyle, F. I. and J. N. M. Smith. 2001. Raptors and Scavengers. Chapter 16 *In*: Ecosystem Dynamics of the Boreal Forest: The Kluane Project. Krebs, C. J., S. Boutin and R. Boonstra. Eds. Oxford University Press. 2001: pp 377-404.
- Drennan, J.E. and P. Beier. 2003. Forest structure and prey abundance in winter habitat of northern goshawks. *Journal of Wildlife Management* 67(1):177-185.
- Ethier, T.J. 1999. Breeding ecology and habitat of northern goshawks (*Accipiter gentilis laingi*) on Vancouver Island: a hierarchical approach. MSc. Thesis. University of Victoria. Victoria, BC: 91p.
- Fall, A. and J. Fall. 2001. A domain-specific language for models of landscape dynamics. *Ecological Modelling*. 141(1-3).
- Finn, S.P., J.M. Marzluff and D.E. Varland. 2002. Effects of landscape and local habitat attributes on northern goshawk site occupancy in western Washington. *Forest Science* 48(2):427-436.
- Flatten, C.J. and E.L. McClaren. 2003. Size and color variation of Northern Goshawks from southeast Alaska and Vancouver Island (Abstract). In Raptor Research Foundation 2003 annual meeting - Northern Goshawk Symposium. Anchorage, AK.
- Flatten, C., R. Lowell, K. Titus and G. Pendleton. 1998. Phenotypic and morphometric description of the Northern Goshawk (*Accipiter gentilis*) in southeast Alaska. Abstract from the Raptor Res. Found. Ann. Meeting. Ogden UT.
- Greenwald, D.N., D.C. Crocker-Bedford, L. Broberg, K.F. Suckling and T. Tibbitts. 2005. A review of northern goshawk habitat selection in the home range and implications for forest management in the western United States. *Wildlife Society Bulletin* 33(1):120-129.
- Green, R.N. and K. Klinka. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. BC Ministry of Forests, Research Branch, Victoria, BC.
- Good, RE. 1998. Factors affecting the relative use of northern goshawk (*Accipiter gentilis*) kill areas in southcentral Wyoming. MSc Thesis. Laramie: University of Wyoming. 153p.
- Gyug, L. 2001. Northern goshawk project, Merritt Forest District: Year 2001. Unpubl. Report for Weyerhaeuser Co., Kamloops, BC.
- Hall, P.A. 1984. Characterization of nesting habitat of goshawks (*Accipiter gentilis*) in Northwestern California. MSc Thesis. Humboldt State University. Arcata, CA. 70 pp.
- Hargis, C.D., C. McCarthy and R.D. Perloff. 1994. Home ranges and habitats of northern goshawks in eastern California. *Studies in Avian Biology* 16:66-74.
- Hayward G.D. and R.E. Escano. 1989. Goshawk Nest-Site Characteristics in Western Montana and Northern Idaho. *Condor* 91(2):476-479.
- Iverson, G.C., G.D. Hayward, K. Titus, E.D. Gayner, R.E. Lowell, D.C. Crocker-Bedford DC, P. Schempf and J. Lindell. 1996. Conservation assessments for the northern

- goshawk in southeast Alaska. Gen. Tech. Rep. PNW-GTR-387. Portland, OR: USDA, Forest Service, Pacific Northwest Research Station. 101 pp.
- Johnson, D. R. 1989. Body size of Northern Goshawks on coastal islands of British Columbia. *Wilson Bulletin* 101:637-639.
- Joy, S.M., Reynolds, R.T. and D.G. Leslie. 1994. Northern goshawk broadcast surveys: Hawk response variables and survey cost. *Studies of Avian Biol.* 16:24-30.
- Kennedy, P.L. 1988. Habitat characteristics of Cooper's Hawk and Northern Goshawks nesting in New Mexico. In: R.L. Glinski, B.G. Pendelton, M.B. Moss, M.N. LeFranc and S.W. Hoffman (eds). *Proceedings of the Southwest Raptor Management Symposium and Workshop. Natl. Wildl. Fed. Sci. Tech. Ser. No. 11.*
- Kennedy, P.L., J.M. Ward, G. Rinker, and J. Gessaman. 1994. Post-fledging areas in northern goshawk home ranges. *Studies in Avian Biology* 16:75-82.
- Lewis, S.B. 2001. Breeding season diet of Northern Goshawks in southeast Alaska with a comparison of techniques used to examine raptor diet. [Master of Science]: Boise State University.
- Machmer, M.M. and J. Dulisse. 2000. Northern goshawk inventory and breeding habitat assessment in the Invermere Enhanced Forest Management Pilot Project Area: final report (1998-1999). BC Min. Forests, Invermere, BC. 54 p.
- Mahon, T. 2005. A synopsis of Northern Goshawk (*Accipiter gentilis laingi*) habitat mapping projects in coastal British Columbia. Unpubl. rep. for the BC Northern Goshawk Recovery Team, Nanaimo, BC.
- Mahon, T. 2010. Accuracy assessment of the Coastal Northern Goshawk Habitat Model – Central Coast. Unpubl. rep. for the Habitat Recovery Implementation Group, Northern Goshawk Recovery Team, Nanaimo, BC.
- Mahon, T. 2011. Accuracy assessment of the Coastal Northern Goshawk Habitat Model – Vancouver Island. Unpubl. rep. for the Habitat Recovery Implementation Group, Northern Goshawk Recovery Team, Nanaimo, BC and Parks Canada, Vancouver, BC.
- Mahon, T. 2011. Accuracy assessment of the Coastal Northern Goshawk Habitat Model – South Coast. Unpubl. rep. for the Habitat Recovery Implementation Group, Northern Goshawk Recovery Team, Nanaimo, BC and Parks Canada, Vancouver, BC.
- Mahon, T. and F. Doyle. 2003. Northern Goshawks in the Morice and Lakes Forest Districts, 5-Year Project Summary. Unpubl. report for Morice and Lakes Innovative Forest Practices Agreement, Houston Forest Products. Houston, BC.
- Mahon, T., D. Morgan and F. Doyle. 2003. Northern Goshawk (*Accipiter gentilis* ??) habitat in the North Coast Forest District. Foraging area and nest area habitat suitability models. unpubl. rep. Wildfor Consultants Ltd., Smithers, BC. [http://srmwww.gov.bc.ca/ske/lrmp/ncoast/docs/reports/technical/nogo_foraging_nesting_hab_suit_models.pdf] accessed March 2005.
- Mahon, T. and F. Doyle. 2005. Effect of timber harvesting near nest sites on the reproductive success of northern goshawks. *J. Raptor Res.* 39(3):335-341.

- Manning, T., P. Chytryk and J. Cooper. 2002. Queen Charlotte Goshawk species-habitat model for Canfor TFL 37, Woss, BC. unpubl. rep. Manning, Cooper and Associates, Victoria, BC.
- Marquis, D., T. Piepjohn, and Bill Lasuta. 2005. Study of breeding habitat and possible long term threats from timber harvesting activities to the Northern Goshawk (*Accipiter gentilis laingi*) South Coast Conservation Region, British Columbia. Unpubl. rep. for Coast Forest Products Association, Vancouver, BC.
- McCarthy C, Carrier WD, Laudenslayer WF, Jr. 1989. Coordinating timber management activities with raptor nesting habitat requirements. Pages 229-235 in B.G. Pendleton, C.E. Ruibol, P.L. Krahe, K. Steenhof, M.N. Kochert and M.N. LeFranc, Jr. (Eds), Proceedings of the western raptor management symposium and workshop. National Wildlife Federation, Washington, DC U.S.A.
- McClaren, E. L. 2005. Northern goshawk (*Accipiter gentilis laingi*) population inventory summary for Vancouver Island, British Columbia (1994-2002). Wildlife Bulletin No. B-117. BC Ministry of Environment, Victoria, B.C.
- McClaren, E. and C. L. Pendergast. 2003. Relationship between forest age class distribution around Northern Goshawk nests and occupancy and nest productivity patterns at three spatial scales. Unpublished report. BC Min. Water, Land and Air Protection. Nanaimo, BC.
- McClaren, E.L., P.L. Kennedy, D.D. Doyle. 2005. Northern Goshawk (*Accipiter gentilis laingi*) post-fledging areas on Vancouver Island, British Columbia. Journal of Raptor Research 39(3):253-263.
- McClaren, E.L. and F. Doyle. 2007. Field verification of nesting and foraging habitat suitability models for Haida Gwaii. Unpubl. rep. for Parks Canada. Vancouver, BC.
- Meidinger, D. 2003. Protocol for accuracy assessment of ecosystem maps. BC Tech. Rep. 011. Res. Br. BC Min. Forests. Victoria, BC.
- Moon, D., D. Dunlop, K. Iles, and N. Phillips. 2005. A protocol for assessing thematic map accuracy using small-area sampling. B.C. Min. For., Res. Br., Victoria, B.C. Tech. Rep. 023.
- Northern Goshawk *Accipiter gentilis laingi* Recovery Team. 2008. Recovery strategy for the Northern Goshawk, *laingi* subspecies (*Accipiter gentilis laingi*) in British Columbia. Prepared for the B.C. Ministry of Environment, Victoria, BC. 56 pp.
- Peter Ott. May 2009. Senior Biometrician. BC Ministry of Forests, Victoria, BC.
- Patla, S.M. 1997. Nesting ecology and habitat of the northern goshawk in undisturbed and timber harvest areas on the Targhee National Forest, greater Yellowstone ecosystem. M.Sc. Thesis. Idaho State University. Boise, Idaho. 164 pp.
- Penteriani, V. 2002. Goshawk nesting habitat in Europe and North America: A review. Ornis Fennica 79(4):149-163.
- Pojar, J., K. Klinka and D.V. Meidinger. 1987. Biogeoclimtic ecosystem classification in British Columbia. For. Ecol. Manage. 22:119-154..

- Reich, R.M., S.M. Joy and R.T. Reynolds. 2004. Predicting the location of northern goshawk nests: modelling the spatial dependency between nest locations and forest structure. *Ecological Modelling* 176(1-2):109-133.
- Reynolds, R.T. 1983. Management of western coniferous forest habitat for nesting accipiter hawks. General Technical Report RM-102. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.
- Reynolds, R, C. Meslow, and H.M. Wight. 1982. Nesting habitat of coexisting *Accipiter* in Oregon. *Journal of Wildlife Management* 46(1):124-138.
- Reynolds, R.T., R.T. Graham, M.H. Reiser, R.L. Basset, P.L. Kennedy, D.A. Boyce Jr., G. Goodwin, R. Smith, & E.L. Fisher. 1992. Management recommendations for the northern goshawk in the southwestern United States. USDA Forest Service Gen. Tech. Rep. RM-217.
- Reynolds, R.T. and S.M. Joy. 1998. Distribution, territory occupancy, dispersal, and demography of northern goshawks on the Kaibab plateau, Arizona. Fort Collins, Colorado: Forest Service, Rocky Mountain Research Station. Arizona Game and Fish Heritage Project No. I94045. 58p.
- RISC (Resource Inventory Standards Committee). 1999. British Columbia Wildlife Habitat Rating Standards. Version 2.0. BC Ministry of Environment. Victoria, BC.
- Roberts, A-M. 1997. Food habits of northern goshawks in the Queen Charlotte Islands and in the Kispiox Forest District 1996. Unpubl. report. Smithers, BC. 13pp.
- Schaffer, W, B. Beck, J. Beck, R. Bonar, and L. Hunt. 1999. Northern goshawk reproductive habitat - habitat suitability index model - Version 3. Foothills Model Forest, Hinton, AB.
- Siders, M.S. and P.L. Kennedy. 1996. Forest structural characteristics of *Accipiter* nesting habitat: Is there an allometric relationship? *Condor* 98(1):123-132.
- Smith, J.R.. 2008. Northern Goshawk (*Accipiter gentilis laingi*) habitat and territory models – Sensitivity Analysis. Unpublished report for The Northern Goshawk Habitat Recovery Implementation Group.
- Smith, J.R. 2012. Northern Goshawk habitat and territory modeling results. Unpublished model outputs prepared for the B.C. Ministry of Forests, Lands and Natural Resource Operations, Victoria, B.C.
- Smith, J.R. and G. Sutherland. 2008. Northern Goshawk (*Accipiter gentilis laingi*) habitat and territory models - modelling methodology and implementation and scenario results for coastal British Columbia. March 2008. Prepared for The Northern Goshawk Habitat Recovery Implementation Group. Unpublished report. http://www.for.gov.bc.ca/hfd/library/FIA/2006/LBIP1_6443004a.pdf [Accessed December 11, 2012]
- Squires, J.R. and R.T. Reynolds. 1997. Northern Goshawk. In: A. Poole and F. Gill (eds.). *The birds of North America*. No 298. Academy of Natural Sciences and The American Ornithologists Union, Washington, DC.
- Squires, J.R., and L.F. Ruggiero. 1996. Nest-site preference of northern goshawks in southcentral Wyoming. *Journal of Wildlife Management* 60(1):170-177.

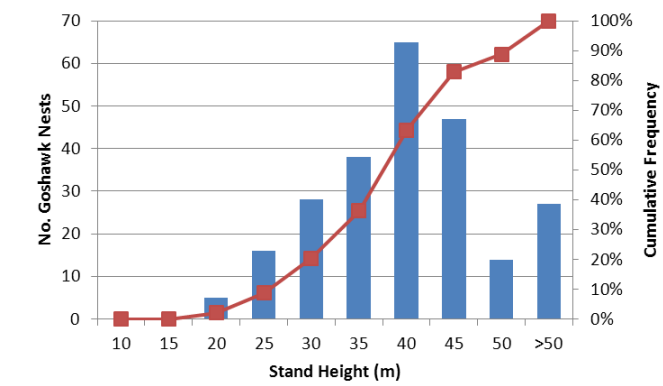
- Stephens, R.M. 2001. Winter ecology of northern goshawks in the Uinta Mountains. MSc Thesis. University of Wyoming. Laramie, WY. 63pp.
- Talbot, S. L. Gust, J. R. Sage, G. K., and S. A. Sonsthagen. 2005. Preliminary investigations of genetic relationships among goshawks of Alaska and British Columbia. Unpublished Report. U. S. Geological Survey, Anchorage, Alaska.
- Taverner, P.A. 1940. Variation in the American Goshawk. Condor 42:157-160.
- US Fish and Wildlife Service. 1981. Standards for the Development of Habitat Suitability Index Models. Ecological Services Manual 103. Dept of the Interior. Washington, DC.
- US Fish and Wildlife Service. 1981b. Habitat evaluation procedures. Ecological Services Manual 102. Dept of the Interior. Washington, DC.
- Ward, L.Z. D.K. Ward and T.J. Tibbits. 1992. Canopy density at goshawk nesting territories on the North Kaibab Ranger District, Kaibab National Forest. Final report, non-game and endangered wildlife program. Arizona Game and Fish Department, Phoenix, USA.
- Whaley, W.H. and C.M. White. 1994. Trends in geographic variation of Cooper's Hawk and Northern Goshawk in North America: a multivariate analysis. Proc. West. Found. Vert. Zool. 5(3):161-209.
- Widen, P. 1989. The hunting habitats of goshawks *Accipiter gentilis* in boreal forests of central Sweden. Ibis 131(2):205-213.
- Widen, P. 1997. How and why, is the goshawk (*Accipiter gentilis*) affected by modern forest management in Fennoscandia? Journal of Raptor Research. 31(2):107-113.
- Woodbridge, B. and P. J. Detrich. 1994. Territory occupancy and habitat patch size of northern goshawks in the southern Cascades of California. Stud. Avian Biol. 16:83-87.

Appendix 1. Habitat characteristics of goshawk nest sites in Coastal BC.

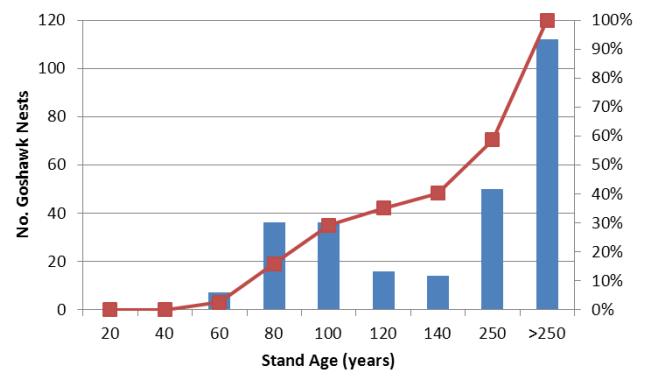
To document the range of environmental conditions at goshawk nest sites in Coastal BC, a GIS query was conducted by Forests, Lands and Natural Resource Operations staff that intersected nest locations with BEC variant (Table A1-1) and relevant variables from VRI (species composition, stand height, stand age, canopy closure; Figure A1-1). VRI data was only available for about 2/3 of the nest locations.

Table A1-1. Distribution of known goshawk nests within biogeoclimatic subzones in coastal British Columbia.

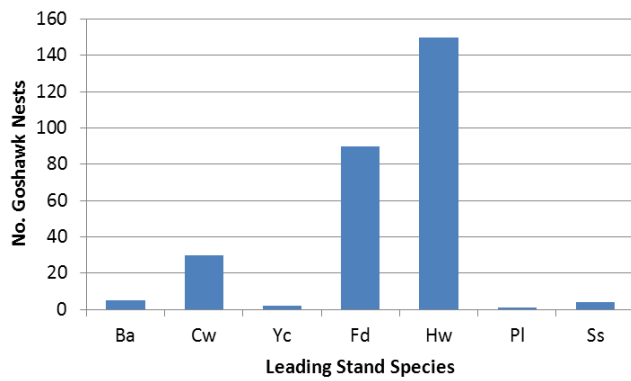
BEC Subzone	Number of goshawk nests
CWHdm	14
CWHds	14
CWHmm	26
CWHms	6
CWHvh	5
CWHvm	84
CWHwh	37
CWHws	12
CWHxm	158
IDFww	2
MHmm	1



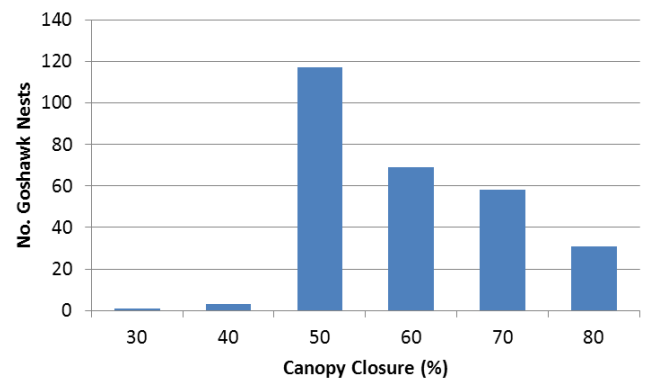
A



B



C



D

Figure A1-1. Stand characteristics associated with 280 goshawk nest sites in Coastal British Columbia.

Appendix 2. A summary of studies that have examined goshawk nesting habitat.

*note that this table was copied from Mahon et al. (2008) and has not been updated.

Study	Location	Forest Type	Canopy Closure	Tree diameter/ height	Basal Area/ Tree Density	Other Variables	Comments
Bosakowski 1997	British Columbia (Williams Lk.)	Lodgepole Pine, Douglas Fir	Range 33.3 – 70%	Dbh = 35.5cm Ht = 20.9m	BA range 21.9 – 68.3 m ² /ha	<u>Tree spp</u> - Lodgepole Pine	Lodgepole Pine preferentially chosen as nest sites over other tree species
Bosakowski et al. 1999.	Washington	Western Hemlock	86.7% (SD 5.77)	55.7cm (SD 16.17) Ht = 30.3m (SD 9.10)	Trees/ha = 764 (SD 329.4)	<u>Slope</u> – 36 % <u>Aspect</u> - N-NE <u>Tree Species</u> : Hw, Fd, Psf <u>Elevation</u> – 773m (SD189.1)	Nests in 40-60 year old stands. Mean 45.7 (SD7.37).
Daw and DesStefano . 2001.	Oregon	Ponderosa Pine- Doug Fir- Lodgepole Pine.	>50%	Dbh = >53cm			Nests with greater dense forest canopy and late forest structure than random sites.
Doyle and Mahon 2000	British Columbia (Kispiox)	Hemlock	Mean 75.4% (Range 35-85%)	Dbh = 58.8cm (39-72) Height = 27.6m (range 15.3 – 37.8m)	N/A	<u>Slope</u> – Avg. 12.1% <u>Aspect</u> – no relationship <u>Tree spp</u> – Hw, (Ba 6%)	
Finn 2000 and Finn et al. 2002.	Olympic Peninsula	Coastal rainforest	Mean 85%	Dbh = 60.9cm Ht = 45.9m		<u>Tree spp</u> – Douglas Fir, Western Hemlock, Alder	Nest sites with a deep overstory canopy depth. Low % shrub cover. Occupied nest sites had a higher proportion of late seral forest.
Gyug 2001	British Columbia (Merritt)	Douglas Fir, Lodgepole Pine, Engleman Spruce	=>50%	Dbh range 34 – 90 cm Ht =>34m		<u>Slope range</u> 12 – 32% <u>Elevation range</u> 1250 – 1600m <u>Tree spp</u> - Doug Fir, spruce, aspen	Nests mid-slope Lodgepole Pine form the largest portion of the canopy around nests
Hall 1984	California	Douglas Fir	Mean 88% (60 – 98%)	Dbh = 58cm (43 – 119cm) Ht =21m (SE 2.0)	BA=90 m ² /ha 279 trees/ha	<u>Slope</u> – 42% (11 – 80%) <u>Aspect</u> – NE <u>Elevation</u> – 824m (494 – 1036m) <u>Tree spp</u> – Douglas Fir	Nests were typically in dense single storied stands of Douglas Fir, scattered hardwoods, park-like understory. Tree density and canopy closure less in nest sites in surrounding nest stand.

Study	Location	Forest Type	Canopy Closure	Tree diameter/ height	Basal Area/ Tree Density	Other Variables	Comments
Hargis et al. 1994.	California	Jeffrey Pine- Lodgepole Pine	31% (SD 13)	Dbh = 87.2 cm(SD 27.2) Ht = Nest only 11.6m (SD 2.33)		<u>Slope</u> – 12% (SD 11)	Nests significantly closer to water than random.
Hayward and Escano 1989	Montana and Idaho	Hemlock-cedar and Douglas fir- lodgepole pine	80%	Hw-Cw >50, Fd- Pl 35-50	BA= 40 1125/ha	<u>Aspect</u> – 315-45 used more <u>Slope</u> – all ensts <50% lower slope positions preferred	Nest site char. vary widely across the goshawk range. However, within any region nest-site selection is predictable and depends on available habitat and local climate
Iverson et al. 1996.	SE Alaska	Costal Rainforest	49.6%				Areas within 30 acres of the nest had greater forest cover and greater productive old-growth than compared to random plots.
Machmer and Dulisse. 2000.	British Columbia (Invermere)	Interior Douglas Fir-Montane Spruce	Mean 54% (SD2.4)	Dbh = 52.7cm (SD 2.67) Ht = 29.4 m (SD 0.66)		<u>Slope</u> - 19.6% (SE 4.2) <u>Aspect</u> – Most west-south west <u>Tree Spp</u> - Doug Fir and Western Larch <u>Elevation</u> 849-1,072m	Nests predominately in mature-old forest stands. Mid to lower slope positions.
Mahon and Doyle. 2003.	British Columbia (Lakes Forest District)	Interior Sub- boreal Spruce.	>40% (100%)	Dbh = 29.7cm (SD 9.0). Ht = 23.9 (range 8.1-23.2)		<u>Slope</u> <30%, <u>Aspect</u> - Not significant <u>Tree spp</u> – 50% Pine, 36% Aspen, 14% Fir.	Nests in open uderstory locations. 34-1080m to clearcut edges. Average 2.0 nests per nest areas (range 1-6).
Manning, Cooper and Associates 2000	British Columbia (Chetwynd)	Lodgepole Pine	Mean 32 %	Dbh = 31.5cm Ht = 22.5m		<u>Slope</u> - 15% <u>Tree spp</u> - Lodgepole Pine	Nests mid-slope
McClaren 2005. . Ethier 1999.	British Columbia (Vancouver Island)	Coastal Rainforest .	Mean 49% (29- 69%)	Dbh = 70.7cm (SD 2.9) Ht = 39.0m (SD 1.6)	No. Trees/0.04 ha = 31 (SD 2)	<u>Slope</u> – 34%(0-61) <u>Aspect</u> – 358 (SD 41) <u>Tree spp</u> – Douglas Fir and Western Hemlock <u>Elevation</u> – 80-816m (Mean 358m).	Nests in contiguous old growth, second growth and Fragmented Landscapes. 97% of nests in live trees. Nests sites further from clearcuts than random. Nests centred is larger areas of contiguous forest >120 years at 800m scale, but not significant.

Study	Location	Forest Type	Canopy Closure	Tree diameter/ height	Basal Area/ Tree Density	Other Variables	Comments
Patla and Trost 1995	Idaho	Douglas Fir, pine, spruce	Mean 86% Range 64 -96%	Dbh = 48cm (range21-84cm) Ht = 26m (range 12-38m)	Tree density = 382 trees/ha (range 134 – 717trees/ha)	<u>Slope</u> – 24% (0 – 43%) <u>Elevation</u> – 2136m	Mean distance to water 152m Study found that nest sites were close to water – significant.
Schaffer 1999.	Alberta (Hinton)	Lodgepole Pine- Aspen-Fir	Mean 77.4% (SE 1.68)	Dbh = 30.0cm (SE 1.32) Ht = 21.9 m (SE 0.63)		<u>Slope</u> - N/A <u>Aspect</u> – all except W and SW <u>Tree Spp</u> – 90% in At	Nest sites and contrasting sites not significantly different.
Siders and Kennedy. 1996.	New Mexico	Ponderosa Pine- Doug Fir-White Fir	Mean 66.3% (SD 7.5)	Dbh = 50cm (SD 6.7) Ht = 28.4 m (SD 2.6)			Comparison in attributes selected by sympatric accipiters. Correlation between nest tree selection and tree size. Goshawks selecting largest trees.
Squires and Ruggiero 1996	Wyoming	Lodgepole Pine	66% sign. > random plots	Dbh = 32cm Ht = 19m both sign. > random plots	BA=50m ² sign. > random plots	<u>Slope</u> – gentler at NAs (12%) <u>Aspect</u> – no relationship <u>Tree spp</u> – At and Pl used prop to abound.	Nest stands were not old-growth in the classic sense of being multi-storied stands with large diameter trees, high canopy closure, and abundant woody debris. Rather, nest stands were in even-aged, single-storied, mature forest stands with high canopy closure and clear forest floors.

Appendix 3. Habitat suitability index ratings of forest inventory type groups for northern goshawks in Coastal BC

ITG	NestScore	ForageScore
NA	0	0
Fd	1	1
FdCw	0.9	1
FdH	1	1
FdS	1	1
FdPl	1	1
FdPy	1	1
FdL	1	1
FdDecid	1	1
Cw	0.45	0.6
CwFd	0.65	0.8
CwH	0.65	0.7
H	1	0.95
HFd	1	1
HCw	1	0.95
HB	1	0.95
HS	1	1
HDecid	0.85	0.95
B	0.7	0.95
BH	0.8	0.95
BS	0.8	0.95
S	1	1
SFd	1	1
SH	1	1
SB	1	1
SPl	0.7	1
SDecid	0.85	1

ITG	NestScore	ForageScore
Pw	0.4	0.6
Pl	0.5	0.7
PlFd	0.7	0.8
PlS	0.65	0.7
PlDecid	0.6	0.7
Py	0.6	0.7
LFd	0.8	1
L	0.8	0.8
AcConif	0.9	0.95
AcDecid	0.7	0.8
DrConif	0.9	0.95
DrDecid	0.7	0.8
Mb	0.4	0.6
E	0.4	0.7
AtConif	0.9	0.95
AtDecid	0.7	0.8
FdYc	0.6	0.8
Yc	0.4	0.6
YcFd	0.4	0.6
YcH	0.4	0.6
HPl	0.7	0.95
HYc	0.6	0.75
BYc	0.5	0.75
SYc	0.5	0.75
PlYc	0.4	0.6
CwYc	0.45	0.6
CwS	0.65	1

Appendix 4. A summary of studies that have examined goshawk foraging habitat.

*note that this table was copied from Mahon et al. (2008) and has not been updated.

Study	Location	Forest Type	Key Findings
Beier and Drennan 1997	Arizona	Ponderosa pine	n=20 individuals. Goshawks used mature and old-growth forest almost exclusively for foraging. Goshawks selected foraging sites that had higher canopy closure, greater tree density and more large trees (>40cm). Goshawks selected areas based on forest structure rather than prey abundance.
Bloxton 2002	Olympic and Cascade Mtns, Washington	Douglas fir and western hemlock	For a sample of 17 goshawks kill sites had higher canopy closure, greater basal area, larger diameter trees, and avoided areas with pole/sapling.
Bright-Smith and Mannan 1994	Northeast Arizona		Examined selection for 11 goshawks using LANDSAT coverages. Most birds showed no selection. 3 selected for higher canopy cover, 3 avoided open canopy areas, 4 used core woodland more than its availability
Drennan and Beier 2003	Arizona	Ponderosa pine	Assessed winter habitat selection for 13 goshawks. Most males moved to lower elevation pinyon-juniper areas. Foraging sites had more medium-sized trees and higher canopy closure than random sites.
Good 1998	Southcentral Wyoming	Lodgepole pine and aspen	Goshawks returned most often to sites with more mature forests, gentler slopes, lower ground coverage of woody plants, and greater densities of large conifers
Hargis et al. 1994	Eastern California		Home range locations of goshawks were similar to nest sites and both had greater canopy cover, greater basal area, and more trees per ha than a random sample from the study area.
Iverson et al. 1996	Southeast Alaska	Coastal temperate forest; 1° western hemlock	Obtained 2333 locations on 67 goshawks. Strong selection for old growth, avoidance of non-forest, clearcut and alpine. Goshawks predominantly used gentle slopes, lower elevations and showed preference within old-growth for riparian areas and areas within 350m of shoreline.

Study	Location	Forest Type	Key Findings
Mahon and Doyle 2005	West-central BC	Lodgepole pine; SBSmc2	Obtained 455 locations of 12 goshawks and examined habitat selection based on structural stage. Mature and old-growth were used 55% more than available. All other structural stages were used less than available despite higher prey biomass in shrub stage areas.
McClaren 2005	Vancouver Island	Coastal temperate forest; 1° western hemlock	259 locations were obtained from 63 goshawks over 5 years. 74% were in old growth, 20% were in second growth, 5% in mixed OG/SG. On average birds were located ca. 13km from nest sites.
Stephens 2001	Northeast Utah	spruce, subalpine fir, lodgepole pine	Studied 18 goshawks during the winters of 98/99 and 99/00. 73% were migratory with a trend to lower elevations where they fed on cottontails. (compared to tahu's at higher elevation). Used a wide variety of habitats but showed selection for high canopy closure.