A Prey-based Approach to Restoration: Prioritizing the Habitat Requirements of Prey Species to Assist in the Recovery of the Coastal Northern Goshawk (*Accipiter gentilis laingi*)

by
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Abstract

Forestry in British Columbia's old-growth forests has reduced critical foraging and breeding habitat for the coastal northern goshawk (*Accipiter gentilis laingi*) and restricted population growth. Now at-risk, efforts to recover this subspecies have focused on establishing suitable habitat and a well-distributed population within the province. However, regional diets and associated dynamics are also critical to goshawk recovery and remain poorly understood. Including a synchronous predator-prey recovery approach to current plans can bridge these knowledge gaps. A new model and methods were developed to translate prey biological requirements into structural surrogate features that could be parameterized and ranked within GIS software. Applying these ranks to known goshawk territories in the South Coast allowed for the visualization and quantification of areas with subpar predicted prey abundances. This provided insight on links between prey and forest structure and can be used to direct future restoration and research decisions for coastal goshawk prey-based recovery.

Dedication

I dedicate this work to my family, friends, and partner. Without their love, support, and unwavering belief in me, none of this would have been possible.

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To my supervisor, Dr. Doug Ransome, and the program coordinator, Dr. Anayansi Cohen-Fernández: thank you for guiding me and encouraging my scientific curiosity. This experience taught me so much, and I'll be forever grateful.

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Introduction

In British Columbia, old-growth forest designation depends on numerous factors including stand age, species composition, location, and the frequency and intensity of natural disturbances. Coastal forests are considered old-growth after 250 years and interior forests are considered old-growth after 140 (Government of British Columbia 2021). This definition has failed to capture the importance that these forests have for many different species and for global biodiversity. Forestry activity has resulted in the degradation and fragmentation of nesting, foraging, and shelter areas throughout the province, likely increasing both interspecific and intraspecific competition for available resources and contributing to population declines of old-growth-dependent species. In response, the British Columbia provincial government has protected old-growth forests in areas that support old-growth-dependent species in addition to developing and implementing species-specific plans to assist their recovery.

One such species is the coastal northern goshawk (*Accipiter gentilis laingi*), a forest-adapted raptor that has been adversely impacted by decades of forestry. Research about the impacts of forestry and forest management practices on this subspecies has been ongoing since the early 1970's (Squires and Reynolds 1997, Lewis et al. 2006, Parks Canada 2018, Mahon et al. 2019, Government of British Columbia 2021a). This has provided the foundation for the existing federal and provincial recovery plans developed to assist this subspecies' recovery (Northern Goshawk Recovery Team 2008, Parks Canada 2018). Despite ongoing research and active recovery efforts, the coastal goshawk continues to be a species of concern and remains Red-Listed in British Columbia and Threatened in Canada, likely to become endangered if action to reverse the factors leading to its decline are not made a priority (B.C. Conservation Data Centre 2005, COSEWIC 2013, Parks Canada 2018).

British Columbia's recent short-term forestry deferrals will aim to protect 2.6 million hectares of old-growth forests across the province to allow the provincial government, Indigenous Nations, and other partners time to develop new approaches for forest management (Government of British Columbia 2021b). Landscape-management strategies are being increasingly informed by ecological theory to follow more sustainable practices. Due to the complex nature of ecosystems, there are no singular management strategies that can address all the ecological challenges faced across all species. Even common approaches such as the umbrella species and focal species concepts have fundamental shortcomings that prevent them from being universally applicable. The umbrella species concept proposes that the conservation of one (typically charismatic) species will subsequently protect a significant number of species in the area. However, this approach does not adequately consider all of the ecological factors that influence the secondary species intended to be passively restored through the umbrella species' recovery (Roberge and Angelstam 2004). The focal-species approach builds off the umbrella species concept by considering more species within the ecosystem. It involves grouping at-risk wildlife into a suite of focal species that share common threats, and the minimal acceptable level of threat permissible to occur is determined by the species most sensitive to that threat. This approach was proposed to guide landscape-level restoration aimed at large-scale biodiversity conservation and has been praised as being useful to restore target species (Lambeck 1997, 2002, Watson and Freudenberger 2001). However, it has also been criticized for having the same limitations as the umbrella species concept as it fails to consider the unique limiting ecological factors of individual species (Lindenmayer et al. 2002).

Recovering wildlife populations can take a long time for a multitude of reasons, including socioeconomic factors influencing decision making. Additionally, plans may overlook ecosystem components that appear irrelevant to the focal species' recovery but impact other influencing factors and this may lead to a failed restoration. Therefore, the restoration process requires a lot of work and research before reliable recovery efforts are implemented, and then more time before any perceived improvement from degraded conditions are observed. Ultimately, restoration decisions should be informed by understanding as much as possible about the connections within ecosystems and their components. A mix of different strategies should be adopted and based on the unique factors of the site (Lindenmayer et al. 2002). Additionally, they should involve considering the dynamics among species within the landscape.

Trophic dynamics are inherent and critical within all functioning ecosystems and both the bottom-up and top-down implications should be understood. A trend with restoration ecology is to focus on restoration from the bottom-up (e.g., re-establishing the plant community; Fraser et al. 2015). This strategy makes sense as predator-first recovery strategies can be slow and put prey species at risk of increased mortality from the recovering predator population (Samhouri et al. 2017). This negatively impacts all species involved as the stability of a predator's population often depends on the abundance of their prey species. However, species loss typically follows a predator-first sequence where species at higher trophic levels experience local extinction earlier than those at lower levels (Estes et al. 2011). The abundance and distribution of predator species, as well as losing members of those populations, has a disproportionate impact on many different ecological and socioeconomic factors and directly influences ecosystem structure, function, species invasions, disease prevalence, food security, and economic yields (Estes et al. 2011, Samhouri et al. 2017). Therefore, focusing on synchronous predator and prey recovery is a useful strategy in conservation, particularly for at-risk species, and is generally a more direct and rapid strategy than focusing on one trophic level alone (Samhouri et al. 2017). As a top avian predator, restoring habitat for prey species of coastal goshawks within their territories should be a focal component of their recovery.

Such a multi-species ecosystem-based strategy has been used to assist the recovery of the northern goshawk subspecies in the southwestern United States (*Accipiter gentilis atricapillus;* Reynolds et al. 1992). Like the coastal subspecies, this population is food and habitat limited and influenced by many interconnected ecosystem components (Reynolds et al. 2006). As both populations are limited by the same factors, it is possible that they may be benefitted by using a similar strategy. However, factors like prey species composition, ecosystem structure, and vegetation dynamics vary and are influenced by local climate, elevation, forest types, and more. Predator-prey dynamics also change even within spatially close distances (Samhouri et al. 2017). As such, a multi-species ecosystem-based strategy needs to consider the unique factors influencing species within a particular region and under specific forest management, including the abundance of predator and prey species (Reynolds et al. 2006).

For the coastal goshawk, recovery efforts have focused primarily on managing, conserving, and recovering suitable habitat that meets the needs of the coastal goshawk throughout its annual cycle. They also focus on ensuring a well-distributed, viable goshawk population within coastal British Columbia (see Appendix 1 for Broad Strategies and Objectives, Parks Canada 2018). As this species is limited by habitat, these efforts are worthwhile and necessary (McClaren et al. 2015, Parks Canada 2018). However, the coastal goshawk's survival is also dependent on the availability and accessibility of prey (Cooper and Stevens 2000). To date, prey-specific research for the recovery plans have focused on identifying prey species across coastal British Columbia and examining at how invasive Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) on Haida Gwaii has impacted the local coastal goshawk population's prey structure (Parks Canada 2018).

By prioritizing research about coastal goshawk prey and what factors influence their abundances within a landscape, it may be possible to restore local prey population within current and potential coastal goshawk territories. This, in addition to developing models specific to different regions and sensitive to the variances between biotic and abiotic factors across a landscape, may help bridge the long timelines often necessary for wildlife population restoration and further the recovery of the coastal goshawk.

Species Profile

The northern goshawk is a raptor species found in temperate and boreal forests across the Holarctic region (Cooper and Stevens 2000). It is the largest of the three *Accipiter* species found in North America. Like the Cooper's hawk (*Accipiter cooperi*) and the sharp-shinned hawk (*Accipiter striatus*) the northern goshawk has relatively short wings and a proportionally long tail that make these birds well adapted to forest habitats (Snyder and Snyder 2006). These adaptations allow the northern goshawk to accelerate and maneuver through forests to hunt and avoid injury in areas containing dense tree cover and foliage (Snyder and Snyder 2006, Mahon et al. 2019).

In North America, the northern goshawk has two recognized subspecies that are differentiated by appearance, geographical range, and genetic structure (Squires and Reynolds 1997, Sonsthagen et al. 2012, Geraldes et al. 2019). The coastal goshawk is smaller than the interior subspecies (*A.g. atricapillus*) had has a proportionally longer tail. It is believed this may allow the subspecies to maneuver better within denser coastal stands (McClaren et al. 2015). Additionally, the coastal goshawk is darker throughout all life stages, which may result in increased camouflage and assist with thermoregulation within coastal forests. The interior goshawk subspecies is Blue-Listed and have the largest range of the two subspecies. They are found throughout forested regions across Canada and the mainland United States (Wheeler 2003, Parks Canada 2018). The coastal goshawk subspecies is restricted to the Pacific Northwest coastline and ranges from coastal Washington to southeast Alaska. Its Canadian distribution is localized west of the Coast Mountain Range (Campbell et al. 2007, Daust et al. 2010, McClaren et al. 2015). The interior and coastal goshawk populations slightly overlap at the boundaries of their distributions, but otherwise occupy distinct and separate areas of British Columbia (fig. 1; McClaren et al. 2015). Hybridization is possible within these two subspecies, and the Haida Gwaii population is considered genetically isolated and distinct from all other areas (Geraldes et al. 2019).

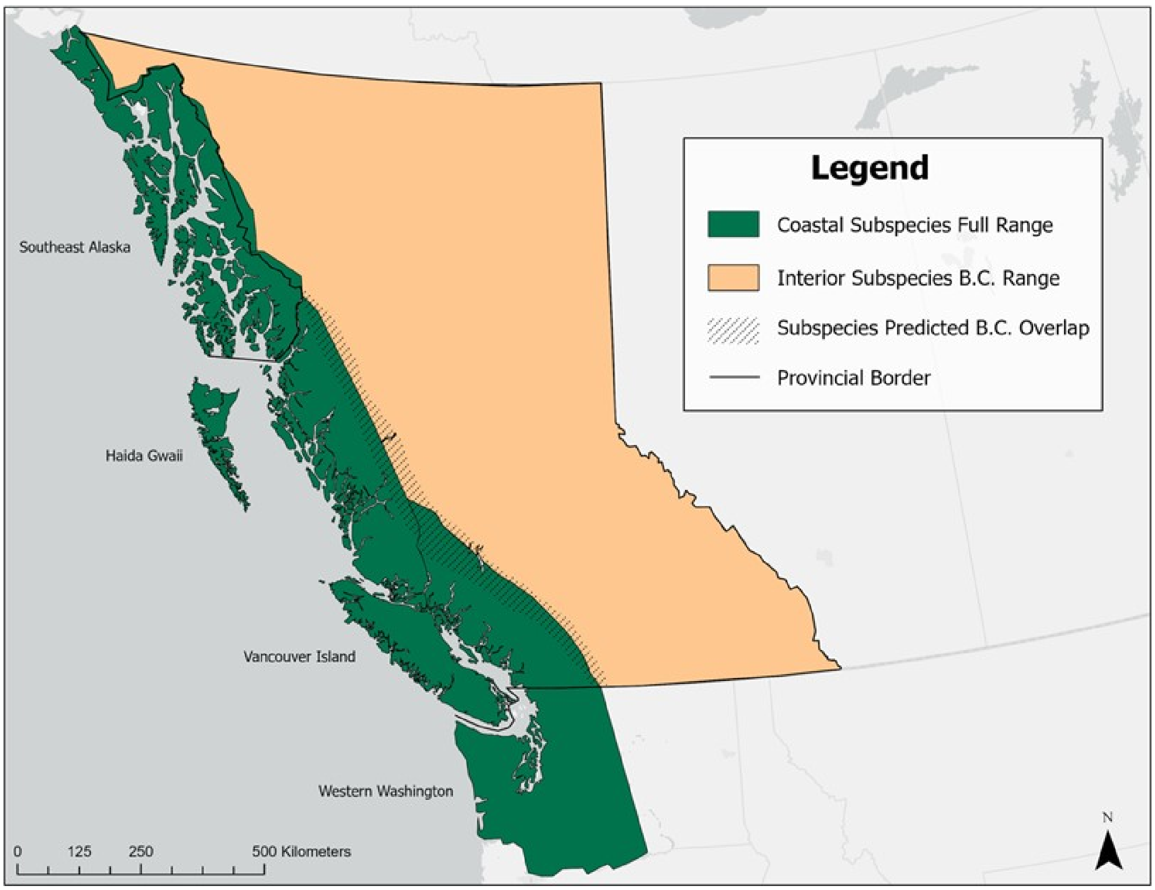

Figure 1. Range of the interior (yellow) and coastal (green) northern goshawk in British Columbia, Washington, and Alaska, and where they are predicted to overlap in British Columbia (black hatch). Range boundaries from McClaren et al. 2015 and Parks Canada 2018.

Coastal Goshawk Ecology

Coastal goshawks are non-migratory in British Columbia and are monogamous. Females have been observed leaving their territory during non-breeding season from October to January and temporarily locating to a nearby wintering area, or staying with males in their territory year-round (Wheeler 2003, Daust et al. 2010). They exhibit high breeding-site fidelity and tend to stay within their chosen territory for years to decades if suitable conditions persist (Parks Canada 2018; Harrower pers comm. Oct. 27, 2021). Breeding pairs may also re-occupy a previously used area after consecutive years of apparent absence (Taverner 1940, Campbell et al. 1997, McClaren et al. 2010, 2015). Thus, areas where coastal goshawks have been previously detected are likely to continue to be used even if they are not observed during surveys (McClaren et al. 2015, Parks Canada 2018).

The goshawk selects mature and old-growth conifer stands with closed canopies and open understories, particularly for their breeding areas that are central within their overarching territory (Cooper and Stevens 2000). The structural characters of mature and old-growth stands that are associated with suitable goshawk breeding habitat include coniferous-predominated stands with trees large enough to hold the goshawk's large stick nests. These forests also tend to have a relatively closed canopy (>50-75%) paired with an open understory and numerous under-canopy flyways, which are important for this species to hunt and take shelter (Iverson et al. 1996, Mahon and Doyle 2005, Harrower et al. 2010, McClaren et al. 2015).

Coastal goshawk territories are also commonly referred to as home ranges in the literature. These areas consist of predictable and use-based hierarchical components (fig. 2, McClaren et al. 2015). At the center of a home range, a pair will have a nests or cluster of nests high up in the tree canopy. This is within the active breeding area, which includes a post-fledging area and prey plucking posts. This is considered the primary unit where all breeding activities occurs (i.e., courtship, nesting, fledging, post-fledging; Daust et al. 2010, McClaren et al. 2015). The space surrounding the breeding area is the breeding foraging area, where adults hunt during breeding season. Unlike suitable breeding areas, the foraging area may be open, near edges, within non-forested openings, and at higher elevations than breeding habitats (Daust et al. 2010). Although the breeding and foraging areas are considered separate units, all breeding areas are overlapped by its associated foraging area (Parks Canada 2018). Both breeding and foraging areas are considered critical to ensure successful breeding and survival for this species (Squires and Reynolds 1997, Daust et al. 2010, McClaren et al. 2015). A non-breeding area home range surrounds all these home range components and is used for foraging outside the breeding season, when mated pairs have more freedom to move away from the nest (Daust et al. 2010, McClaren et al. 2015, Parks Canada 2018, Mahon et al. 2019).

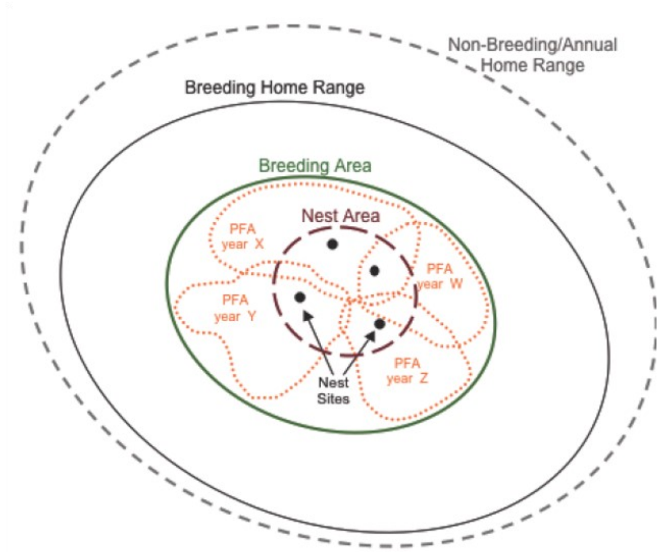

Figure 2. Conceptual diagram of a coastal goshawk home range. From center to outer circle, the components include nests, nest area, post-fledging areas (PFA), breeding area, breeding home range, and non-breeding/annual home range. Not to scale. Conceptual design taken from McClaren et al. 2015

Male coastal goshawks begin breeding at three years of age. Some females may begin breeding as early as 1-2 year old subadults (COSEWIC 2013). Males are smaller than females, which is believed to partition prey and reduce competition. Monogamous pairs do not necessarily breed each year, but when they do courtship and breeding begins late February-April and the incubation period begins in May. Females lay one clutch of 1-4 eggs during breeding season and incubate the eggs for 30-32 days while the male hunts throughout the foraging area and provides the female with food (Daust et al. 2010, McClaren et al. 2015, Parks Canada 2018, Mahon et al. 2019). The altricial chicks hatch and remain in-nest for 38-42 days and are fed by both adults. Fledging begins in late June to mid-August when chicks begin to explore the Post-Fledging Areas. Juveniles begin to disperse starting mid-August as adults stop feeding them and their feathers harden enough to allow for sustained flight. Overall breeding success is influenced by prey availability, nest predation, pests, and weather (Daust et al. 2010).

Like other subspecies of norther goshawk, coastal goshawks exhibit a relatively even distribution within homogenous mature forests. The distance between territories, as well as their size, is driven primarily by local prey and habitat availability (Doyle and Smith 1994, 2001, Reich et al. 2004, Mahon et al. 2019). The overall size of their home range varies further based on differences between individuals (e.g., differences in hunting efficiency, the food requirements of varying brood sizes) and the geographical differences in prey availability and food requirements (Iverson et al. 1996, Bloxton 2002, Province of British Columbia 2004, Parks Canada 2018).

In coastal British Columbia, the estimated size of the total amount of contiguous breeding habitat within the breeding area ranges from 46 ha to 263 ha. The likelihood of continued occupancy increases as this breeding reserve size increases, where territories less than 50 ha are considered ineffective and those greater than 176 ha have the highest likelihood of continuous occupancy (McClaren et al. 2015). Ideally, breeding-area reserves should be connected to adjacent forest that provides connectivity to foraging habitats. This will provide alternative breeding areas to use in the future in case current areas become unsuitable after degradation by natural processes (e.g., fire, pathogens, windthrow, etc.; McClaren et al. 2015).

Guidelines for managing the breeding areas for coastal goshawk in British Columbia recommend that breeding-area reserves are large enough to maintain long-term occupancy. They also require connectivity of suitable habitat maintained between all nest trees within each breeding-area reserve (McClaren et al. 2015). The long-term occupancy of breeding areas and the continued survival of coastal goshawks in British Columbia will rely on structural characteristics of the territories as well as prey availability at large spatial scales (McClaren et al. 2015). For a territory to be considered suitable it needs to have >70% suitable breeding and foraging habitat. These areas have been observed to have the highest probability of coastal goshawk occupancy, and this probability is believed to decline until it is zero at <20% (Daust et al. 2010). A suitability of 100% is considered the historic natural condition with an abundance of suitable territories (Daust et al. 2010).

In British Columbia, the low to mid-elevation forests are where the highest timber values overlap with coastal goshawks (Demarchi et al. 2013). Consequently, the coastal goshawk's primary threat is the historic and ongoing commercial logging in its mature second-growth and old-growth conifer territories (COSEWIC 2013, Parks Canada 2018). For the coastal goshawk, habitat loss and fragmentation caused by forestry has a threefold impact: it reduces nesting, foraging, and roosting habitat, thus lowering habitat suitability and availability across the landscape. Forestry also reduces availability and abundance of their prey by impacting nesting, foraging, and shelter of these species (B.C. Conservation Data Centre 2005, COSEWIC 2013, McClaren et al. 2015, Parks Canada 2018).

In addition to habitat and prey abundance and availability, coastal goshawk populations are impacted by breeding success and mortality risks associated with starvation. Like most raptors, the highest risk of mortality occurs during the first year (Squires and Reynolds 1997). It is believed that starvation is the primary source of mortality for adults and juveniles, followed by depredation, disease, collisions, and severe weather (Wiens et al. 2006, Daust et al. 2010).

It is uncertain whether climate change will negatively or positively impact coastal goshawk and their associated prey, but it is possible that if climate change results in higher prey abundance the coastal goshawk will benefit accordingly (Daust et al. 2010). However, climate change has been speculated to indirectly increase nest mortality. Changes in precipitation and earlier warming temperatures have altered the hatch cycles of blackflies (family Simuliidae) in the former Kispiox Forest District, increasing their abundance during critical times during nesting and leading to significant blood loss, stress, and mortality for coastal goshawk juveniles (Doyle 2008). Human disturbance (e.g., those associated with logging, blasting, etc.) may result in goshawks avoiding portions of their home range. If these disturbances are frequent, occur during sensitive times (e.g., breeding), or permanently alter the breeding area’s habitat characteristics, goshawks may move nest sites or abandon their territory altogether (Daust et al. 2010).

Coastal Goshawk Diet

The northern goshawk species consumes a variety of small to medium-sized forest birds and mammals across their global range (Squires and Reynolds 1997, Lewis et al. 2006, Squires et al. 2020). Regional diets are narrowed by the availability and abundance of prey species, which is influenced by and varies due to landscape changes, climate, and seasonal and annual weather patterns. At times, this can restrict a population to a specialist diet despite the northern goshawk being a generalist predator. (Squires and Reynolds 1997, Keane et al. 2006, Lewis et al. 2006, McClaren et al. 2015, Parks Canada 2018). For example, the northern goshawk populations in Alaska and southern Finland exhibit population fluctuations that mirror the cyclic patterns of their limiting prey species, snowshoe hare (*Lepus americanus*) and grouse (family Tetraonidae) respectively (Linden and Wikman 1983, Lewis et al. 2006). Alternatively, northern goshawk populations that have access to diverse and abundant prey options can readily substitute prey species in their diet and experience positive reproductive consequences when compared to northern goshawk populations that have a forced specialist diet (Salafsky et al. 2007). This is because prey availability and abundance affects the timing and success of breeding, as females must eat enough food to reach the critical body mass required for egg production (Marcström and Kenward 2008).

The availability and abundance of prey also influences the occupancy rates of territories and the spatial arrangement of where breeding pairs are found within a landscape, as well as their densities (Marcström and Kenward 2008, McClaren et al. 2015). In British Columbia, the coastal goshawk has less abundant and diverse prey than the interior subspecies (Ethier 1999, Lewis et al. 2006, Parks Canada 2018). Coastal forests contain a lower abundance of mammalian prey species like snowshoe hare, which necessitates that the coastal goshawk consume a greater amount of smaller avian prey than the interior subspecies (Ethier 1999, Nagorsen 2005, Lewis et al. 2006, McClaren et al. 2015, Parks Canada 2018). This can mean that coastal goshawks can receive lower caloric value compared to energy expended. Because of these factors, food is an especially limiting factor to the coastal goshawk (Parks Canada 2018).

Study Area and Associated Prey Structure

The coastal goshawk's Canadian range is separated into four different Conservation Regions: Haida Gwaii (HGCR), Vancouver Island (VICR), and the mainland's North (NCCR) and South Coasts (SCCR; fig. 3). They are differentiated in this way due to the natural differences that exist across BEC zones which influence forest structure and ecological composition, and this is further differentiated based on anthropogenic influences like forestry practices (Mahon et al. 2019). Additionally, the accessibility and availability of data about structural features (e.g., stand age) varies across the province. All these differences indicate potentially different methods and recovery focuses (Parks Canada 2018).

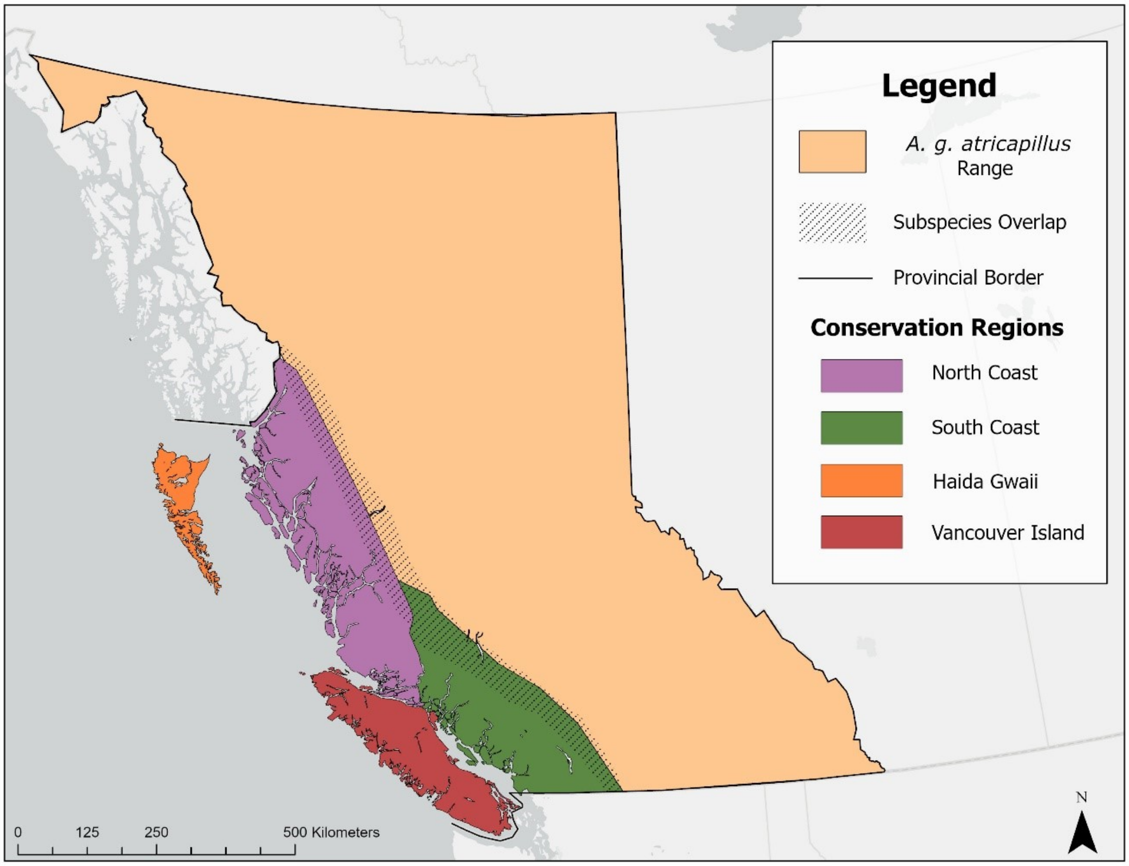

Figure 3. Coastal Goshawk Conservation Regions of British Columbia: Haida Gwaii (orange), Vancouver Island (red), and the mainland's North (purple) and South (green) Coasts with the range of the interior subspecies (yellow) and predicted subspecies overlap. Region boundaries from Parks Canada 2018.

Regional and temporal factors influence northern goshawk prey options and results in different diets across Conservation Regions. The island conservation regions (VICR and HGCR) experience lower prey diversity than those on the mainland. Overall, the most common prey species across all conservation regions are squirrels (*Tamiasciurus* species), forest passerines (families Picidae, Turdidae, and Corvidae), and grouse (Ethier 1999, Mahon et al. 2019). It is important to note that most data collection for coastal goshawk diet occurs during breeding season and only anecdotal evidence is available to determine year-round prey options, especially during winter (Parks Canada 2018). There are fewer prey species available in winter as some avian prey migrate, which indicates that certain prey species may be more critical to coastal goshawks during these months (Province of British Columbia 2004). Prey available in late winter/early spring influences the onset of breeding each year as females need to reach a critical body mass that allows for egg-laying (Keane 1999).

The SCCR will be the focal study for this project. A recent coastal goshawk diet study assessed egested pellets, prey remains, and nest camera photos during the 2019 and 2020 breeding seasons in the SCCR and has developed a list of all prey types from genus to species level observed (Case 2021). This is the most thorough and recent coastal goshawk diet study available and will provide an excellent starting point for determining a suite of key prey species for this region. Additionally, it is of long-running interest for the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNROD) project partners to get links between key prey and forest type and providing a prey abundance map will complement the work already done in this region by Case (Harrower pers. comm. December 22, 2021).

The SCCR has a maritime climate that supports temperate rainforests predominated by Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and Western redcedar (*Thuja plicata*). Coastal goshawk home ranges are found in the Coastal Western Hemlock (CWH) and Coastal Douglas-Fir (CDF) biogeoclimatic zones (Mahon et al. 2019). The CWH BEC zone is on average the rainiest in British Columbia, and temperatures are characterized by cool summers with dry spells and mild winters.

The 2020 diet study grouped prey into eight broad categories: squirrels (genus *Tamiasciurus*), hares (genus *Lepus*), grouse (subfamily *Tetraoninae*), thrushes (family *Turdidae*), corvids (family *Corvidae*), all other birds, all other animals, and unidentified items (Case 2021). The results showed that SCCR coastal goshawks consume more small and medium-sized prey compared to those in the transition zone and interior, where mammalian prey is more abundant (Case 2021). Suitable foraging habitat for the SCCR coastal goshawk is estimated to decline by 1% each year, primarily as a result of ongoing logging practices (Parks Canada 2018). In addition to recommendations from FLNROD biologists, the findings from this study and other similar studies done throughout British Columbia have provided the basis for determining the focal key prey species in the SCCR.

Although the coastal goshawks in the SCCR were found to consume more small and medium-sized avian prey than interior goshawks, the predominant prey species consumed were from the *Tamiasciurus* genus. Over 60% of SCCR prey was Douglas squirrel, which differs from some other areas in the Pacific Northwest where key species are typically grouse (Bloxton 2002, Case 2021). However, it shows a comparable trend compared to VICR, where a similar study found that red squirrels constituted 69% of coastal goshawk prey (Bloxton 2002). Douglas squirrels made up the bulk of diet items found in the 2021 study by a wide margin: a total count of 255 Douglas squirrel prey items in comparison to the next highest species, the varied thrush (*Ixoreus naevius*) had a total count of 22 (Case 2021). Because of this the Douglas squirrel was determined to be a key species, if not the most important for coastal goshawk in this area.

Douglas Squirrel (*Tamiasciurus douglasii*)

The Douglas squirrel is found in coniferous forests of the Pacific Coast. It ranges from California to the southwestern reaches of mainland British Columbia, where it is restricted to west of the Cascade Mountains (Smith 1968, Banfield 1974, Steele 1999). It is diurnal with bimodal activity in spring through fall in morning and late afternoon and unimodal in winter with a midday peak (Smith 1968, Gurnell 1983). On Vancouver Island and areas beyond the southwestern mainland, the Douglas squirrel is replaced by the red squirrel (*Tamiasciurus hudsonicus*) and there is little overlap between their occupied regions (Lindsay 1986). This corresponds to the distribution of lodgepole pine (*Pinus contorta*), which is a main food source for the red squirrel but is inaccessible to the Douglas squirrel due to weaker jaw musculature unable to open the hard pine cones (Smith 1970, Sullivan and Sullivan 1982).

The Douglas squirrel is limited by food supply, particularly the availability of conifer seeds in winter (Smith 1968, 1970, Buchanan et al. 1990). In part due to their inability to rely on cone crops from pine during low-crop years, Douglas squirrels are limited by the availability and abundance of food more than any other factor. Douglas squirrel population densities and annual cycles are directly linked to the abundance and availability of conifer seeds (Sullivan and Sullivan 1982). Food availability has more influence over local densities than territoriality, even though Douglas squirrels do defend their territory from male and female squirrels (Smith 1968, 1970, Kemp and Keith 1970, Sullivan and Sullivan 1982, Nagorsen 2005).

Objectives and Methods

The main objectives of this project are as follows:

1. Determine the key prey species of coastal goshawks and their associated biological needs (e.g., limiting factors) in the SCCR.

2. Create a spatial model that represents the predicted abundance of key prey species by ranking biologically relevant structural characteristics found throughout the SCCR.

3. Provide recommendations for restoration and future research based on the finished model's outputs.

To accomplish the first objective, a literature review was conducted to compile information about the coastal goshawk and their key prey. This review focused on prey species (specifically the Douglas squirrel, *Tamiasciurus douglasii*) found within SCCR and facilitated determining the biological needs of the prey species, primarily based on their individual limiting factors (e.g., food availability).

With the information gathered from the literature review, structural surrogate features were selected and chosen to represent landscape characteristics necessary for the persistence of prey species (e.g., specific tree species compositions were picked to represent prey species food requirements). Data representing these structural features were sourced from British Columbia's 2020 Vegetation Resource Inventory (VRI). The chosen structural features were parameterized and assigned to different ranks within a ranking system representing predicted prey abundance across the SCCR.

Esri's ArcGIS Pro 2.9.2 was used for all data visualization, ranking, and map creation and analyses. The Definition Query feature was used to query the rank parameter combinations and show areas of Unsuitable to Optimal Douglas squirrel habitat territory quality (i.e., predicted prey abundance) across the SCCR. A dataset of known SCCR coastal goshawk nest centroid locations was provided by FLNROD's coastal goshawk recovery team and all centroids were assigned a series of buffers that represented breeding and foraging home range extents. Prey species rank outputs were visually and quantitatively analyzed within these coastal goshawk territories and trends and discrepancies were reported. Visual analysis involved examining the SCCR's rank outputs at SCCR- and territory-scale levels to observe apparent patterns. Quantitative analysis involved examining the stand characteristics provided by VRI data at all goshawk territories within the 2.5 km home range buffer. Examining the VRI polygons and associated prey-specific rank parameters at this scale showed common trends and discrepancies across the territories in the SCCR. Maps were generated that showed territories representative of common structural features that indicated subpar predicted prey abundance.

This model and the associated analyses highlighted areas that are subpar for the focal prey species and indicate expected low prey abundance. They were used to provide initial recommendations for restoration activities in these subpar areas and generated recommendations for future research.

Model Parameters

Structural Features

The structural features chosen to represent the predicted abundance of Douglas squirrels include tree species and composition, stand age, and crown cover. These structural features were chosen because of the importance that cone crops have on the persistence and abundances of Douglas squirrels within a landscape. Tree species and age influence the production of cone crops as well as the amount of cone crop produced annually. Stand density was included as Douglas squirrels require relatively closed canopies to travel from tree to tree without spending energy on returning to the ground. It also helps them avoid predators and is important for shelter (Steele 1999).

Tree Species and Composition

Douglas squirrels are associated with forests predominated by fir (*Pseudotsuga, Abies*), spruce (*Picea*), and hemlock (*Tsuga*) stands (Steele 1999). Throughout their range, Douglas squirrels are smallest in British Columbia compared to all other areas within their range (e.g., Washington) and are better suited for forests where there are small-energy-per-package cones that are easy for them to cut, carry, and open. These stands are often redwood, spruce, and hemlock (Lindsay 1986). The same study found that intermediate-sized Douglas squirrels are found in fir and Douglas-fir forests.

Engelmann spruce (*Picea engelmannii*) cones are also selected by Douglas squirrels (Smith 1970).

Like the other *Tamiasciurus* species, the red squirrel, Douglas squirrels show a strong selective preference for harvesting cones. They have been observed to prioritize harvesting from tree species with the highest seed energy per cone available and appear to be able to recognize cone hardness and use this information to improve feeding efficiency (Smith 1968, 1970, 1981). Overall, cone selection is believed to be based on the number of seeds per cone, the ratio of seed weight to cone weight, cone hardness, arrangement of cones on the branch, and the distance from the midden where the cones are harvested (Elliott 1988).

Coastal goshawks avoid higher elevations. It is believed that this is because of the energetic costs required to carry prey to higher elevation nests in addition to the correlation between elevation and tree species (e.g., Engelmann spruce and Subalpine fir, *Abies lasiocarpa*) and BEC variants (e.g., Mountain Hemlock), which provide suboptimal nesting habitat (Mahon et al. 2019.). In the SCCR, optimal goshawk habitat is restricted between sea level to 800 m. This excludes both subalpine fir and Engelmann spruce, two species that provide foraging opportunities for the Douglas squirrel. These tree species were excluded from the model parametrization as the VRI data showed no forests with these two species were near the known coastal goshawk territories (See Appendix 2 for Distribution of Engelmann Spruce and Subalpine Fir Across the SCCR).

Tree species selection for this Applied Research Project included the above information to guide specific choices and was further guided by what tree species are available within the study area. In the map layers, key tree species that represent areas where Douglas squirrels may be found have stands predominated by Douglas-fir, western hemlock, pacific silver fir, grand fir (*Abies grandis*), Sitka spruce (*Picea sitchensiis*), and western redcedar.

Two angiosperm species, the red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*), have been reported as being important species when conifer cone crops fail (Smith 1981, Carey 2001). However, unlike conifer cones, their seeds are unlikely to remain edible throughout winter. Pine forests are likely unsuitable because although they are energy-rich, the cones here are large and hard to impossible for the Douglas squirrel to harvest from (Lindsay 1986). Areas that may be unsuitable for the Douglas squirrel include those with pine species, namely lodgepole pine, western white pine (*Pinus monticola*), and ponderosa pine (*Pinus ponderosa*).

It is likely that the Douglas squirrel is positively or negatively influenced by more tree species than those listed here. This list was developed from species found in the current literature review and should be adapted as more research is completed.

Stand Age

Stand age is an important parameter when attempting to predict the abundance of Douglas squirrels as tree age directly influences when trees begin producing cones. Although members of the Pinaceae family follow similar patterns, there are notable differences across species when lifestyle stages occur. Conifers do not produce reproductive structures (e.g., seed-containing cones) during a species-specific juvenile period (Puritch 1977). In addition to differences between species, this cone-crop periodicity is influenced by climate, wildlife damage, tree metabolism, and site-specific conditions influencing nutrient and hormone cycles (Puritch 1977). Furthermore, mature conifers typically experience fluctuations in yearly cone production that can result in high vs. low vs. no cone crop years. Often, highly productive cone crops are followed by crop failures or light productions the following year (Eis et al. 1965).

For the map layers associated with stand age, high ranking areas predicted to support high abundances of Douglas squirrel are mature and old-growth areas. Some studies have found that old-growth stands provide optimal suitability for the Douglas squirrel as they are believed to provide greater and more reliable quantities of conifer seeds compared to younger stands (Buchanan et al. 1990). However, other studies have shown no significant difference between mature second-growth stands versus old-growth stands when it comes to the abundance of Douglas squirrels (Anthony et al. 1987, Carey 1995, Ransome and Sullivan 2003). Furthermore, some studies found that mature second-growth stands provided better foraging habitat and resulted in higher Douglas squirrel abundances than old-growth stands during some years (Waters and Zabel 1998, Ransome and Sullivan 2003). It is possible that results of these studies were confounded slightly by the years they took place as the abundance of Douglas squirrels is dependent on the quality of the cone crop, which differs year-to-year.

Additionally, the qualification of what was considered young vs. mature vs. old stands were different across studies. Regardless, it does appear that Douglas squirrels can be as abundant in mature second-growth stands as they are in old-growth stands so long as structural characteristics are like old-growth.

Crown Cover

Like other squirrel species, the Douglas squirrel selects for forests with dense forest canopies. This allows them to travel from tree to tree without expending energy descending to the forest floor and provides them with protection from predation (Steele 1999). Studies that specifically consider Douglas squirrels and crown cover are limited, but studies on other squirrel species have found that individuals avoid thinned, opened stands and centered midden sites within areas of high canopy closure (>70%; Gurnell et al. 2002, Flaherty 2012).

Ranks

The structural characteristics of tree species/composition, tree age, and crown cover were parametrized and different combinations of each were determined to create a ranking system for foraging habitat quality and, correspondingly, predicted prey abundance. Model ranks were Unsuitable, Suboptimal, Medium, Good, and Optimal. (See Appendix 3 for Definition Query codes used in ArcGIS Pro 2.9.2).

Unsuitable

Areas that do not support Douglas squirrels for forage, shelter, or breeding. This includes forests predominated by unsuitable species (e.g., pine) and low crown cover. It also includes areas where the structure of the landscape is unsuitable. For example, alpine regions are above the maximum elevation for tree species and are mostly non-vegetation, primarily covered with rock, ice, and snow (FLNROD 2019). Includes:

- Pine forests or mixed forests with pine species >50% at any age.
- Land features that include areas that are: non-vegetated; alpine; rocky; exposed land; shrub-predominated; herb-predominated; forb-predominated; bryoid/moss-predominated; snow/ice.
- Areas with crown closure between 1% and 10%.

Suboptimal

Areas that may support individual elements of Douglas squirrel biological requirements (foraging, shelter, or breeding) but are insufficient to sustain populations throughout their life histories or in significant densities and abundances. Proposed restoration or silviculture methods for these areas may promote higher abundances of Douglas squirrel and increase coastal goshawk prey availability/abundance. Includes:

- Mixed stands <70 y/o where pine is a secondarily predominant species (<50%).
- Juvenile stands (non-reproductive; table 1) where members of the key species list are within the top three predominant species or the sole species.
- Stands predominated by or are solely red alder or bigleaf maple (>50%).
- Areas where crown closure is between 10% and 35%.
- Areas that have stands <70 years old with a crown cover >10% or >70 with crown closure <35%.
- Areas designated as shrub predominated within the VRI. These areas often do not have species listed and are thus associated more with low crown closure than species composition.

Table 1. List of Key Tree Species known to be used by the Douglas squirrel and their range of juvenile years.

Key Tree Species	Juvenile Period (*Purtich 1997*)
Douglas-fir (*P. menziesii*)	0-20
Sitka spruce (*P. sitchensiis*)	0-20
Western redcedar (*T. plicata*)	0-20
Western hemlock (*T. heterophylla*)	0-25
Pacific silver fir (*A. amabilis*)	0-40
Grand fir (*A. grandis*)	0-40

Medium

Areas that can support multiple elements of Douglas squirrel biological requirements (foraging, shelter, and/or breeding) but can be manipulated to support higher densities and abundances. Includes:

- Stands where key species are between the ages of initial maturation to 70 years old within mixed forests where key species are within the top three predominant species or are the sole species.
- Stands where red alder and bigleaf maple are the second most predominant species and make up >40% of stand composition.
- Areas with crown cover between 35% and 50%.

Good

Areas that are expected to provide foraging, shelter, and breeding habitat for Douglas squirrels year-round. Some restoration or silviculture may increase suitability and provide structural characteristics that can support greater densities of Douglas squirrels. Includes:

- Forests consisting of sole key species or with key species as the first predominant species (>50%) between the ages of 70 y/o and 100 y/o with crown closure between 50% and 65%.
- Other areas with crown closure between 50% and 70%.
- Areas with stands between 70 y/o and 100 y/o.
- Areas with stands less than 100 y/o with crown closure over 70%.

Optimal

Areas expected to provide the most optimal foraging, shelter, and breeding habitat for Douglas squirrels year-round.

- Forests consisting of sole key species or where species are the first predominated species in mixed stands (>50%) where stands are over 100 y/o and have a crown closure of over 70%.

It is probable that some conifer species do not begin delivering species-level normal amounts of cones until some time after they leave their juvenile period. However, when considering the natural fluctuations that happen because of nutrient availability, climate, elevation, and the cyclic nature of conifers that experience mast years vs. low-crop years, assigning a specific year to specific tree species that represent when they go from capable to optimal is difficult without doing thorough research on the stands surrounding these goshawk territories. As such, stands with predominant key species are assigned to the Good rank if they are between 70 and 100 years old, and as Optimal if they are over 100 years old. Alternatively, young stands with juvenile key species are likely unable to support high abundances of Douglas squirrel. Because trees start producing cones after leaving their species-specific juvenile period, a Suboptimal rank represents areas that are unsuitable for the persistence of Douglas squirrels. In terms of age, this is represented by a range between 0 years old to the end of the species-specific juvenile period. For most conifers, this juvenile range is between 0 to 20-40 years.

Buffers

In addition to the above parameters, Euclidean buffers were used to represent the estimated breeding and foraging boundaries around individual nest centroid. The first three were suggested by the FLNROD project partner to represent immediate breeding area (200 m and 500 m from nest centroid) and possible foraging distance (2.5 km; Harrower pers. comm. January 24, 2022). Another buffer was used to represent the predicted average home range boundary for coastal goshawks in the SCCR (6.6 km; Parks Canada 2018). For the purposes of this study, areas encompassing the nest centroid and all buffers within the home range will be referred to as Territories.

Results and Discussion

Rank Outputs and Analysis

Using the previously defined parameters to guide query development within ArcGIS Pro provided a series of map layers that allow for immediate visualization of the structural characteristics across the SCCR ranked from 1 (red; Unsuitable) to 5 (bright green; Optimal) in relation to predicted abundances of Douglas squirrels (fig. 5). This visualization provides insight on where predicted abundances of Douglas squirrel are throughout the region based on the assumed structural surrogates chosen from the literature. At a large scale, the structural characteristics corresponding with high predicted Douglas squirrel abundance (green) are found within approximately 70 km proximity to the coast, within 10 km of other bodies of water (e.g., lakes, rivers), and distributed throughout the southern extent of the SCCR. Unsuitable areas (red) are found in the alpine areas of the SCCR and the urban Metro Vancouver region. Medium and Suboptimal (gold and orange) areas are visible throughout the region, including near or within suitable areas for Douglas squirrel occupancy as well near and within coastal goshawk centroid areas.

Areas that have high predicted Douglas squirrel abundance and where coastal goshawk nest centroids are located appear to be found in similar areas. For the purposes of this study, Territory will refer to areas around nest centroids that include all home range buffers to the 6.6 km extent (refer to Appendix 4 for the Territory Location Key). Aside from the centroids at Territories 1, 3, and 5, centroids were not found within areas that are surrounded by Unsuitable characteristics. More centroids were observed within and near Suboptimal and Medium areas and within and near the same areas as those ranked as Good and Optimal for Douglas squirrels.

Similar trends were observed at finer scales, where the 200 m and 500 m buffers had more Good and Optimal area than adjacent areas. This apparent correlation should not be mistaken for causation, e.g., that coastal goshawks choose territory locations based on Douglas squirrel inhabitancy. Not enough is known about their relationship to come to this conclusion. At this time, this correlation can be attributed to the similarities between stand requirements between coastal goshawks and Douglas squirrels (e.g., relatively closed canopies, mature to old-growth stands; McClaren et al. 2015).

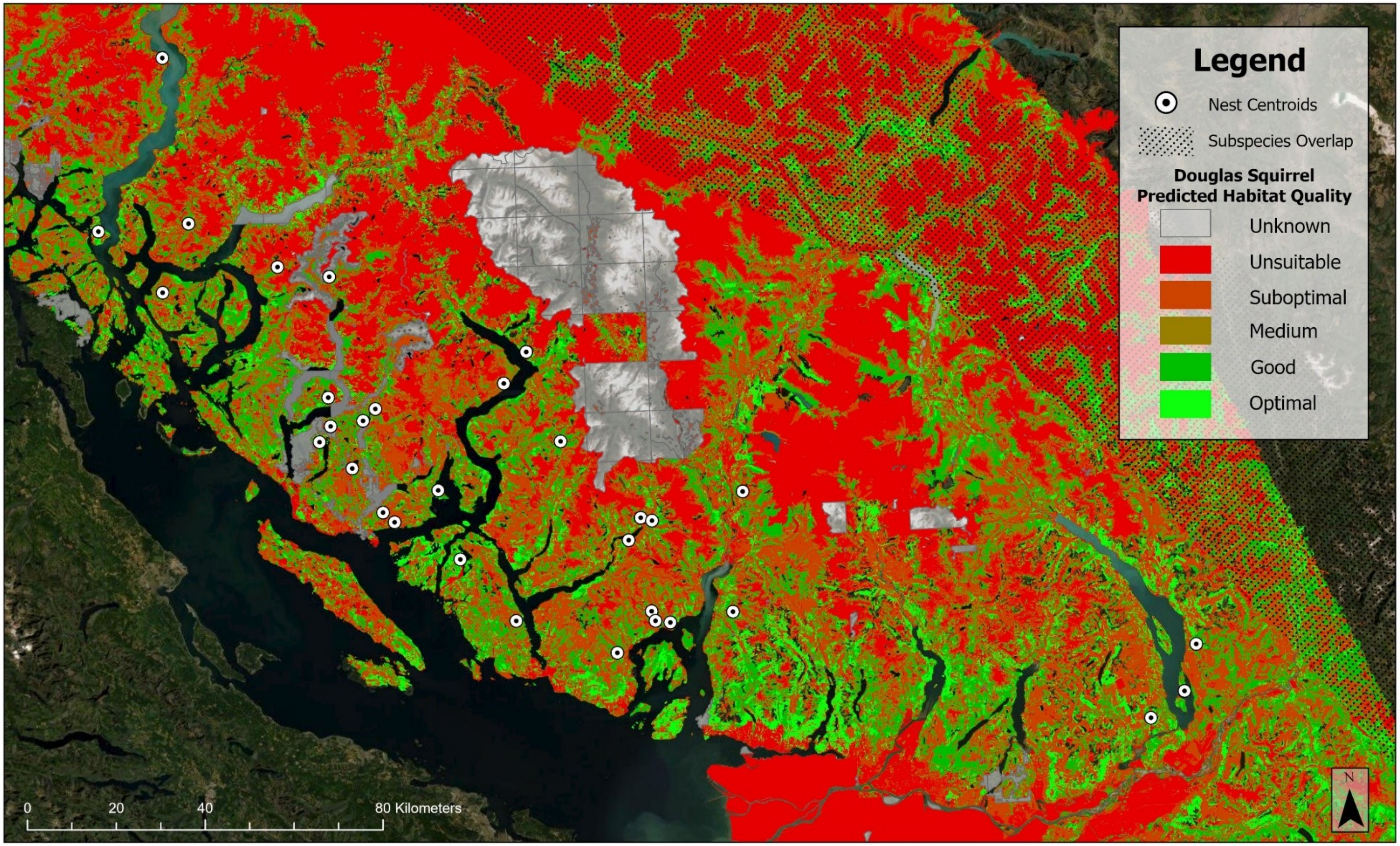

Figure 4. Visualization of habitat suitability for Douglas squirrels in the SCCR and their proximity to nest centroids (white marker). Habitat is ranked from unsuitable (red) to optimal (bright green).

Areas ranked as Medium, Suboptimal, or Unsuitable were the primary focus for analysis and discussion. Structural manipulation of these areas may be able to increase ranks to the target of Good or Optimal.

Medium Rank

The Medium rank highlighted areas that had structural characteristics that may support some combination of elements necessary for Douglas squirrel biological requirements (foraging, shelter, and/or breeding) but may be manipulated to support higher densities and abundances of Douglas squirrel. The Medium rank was given to inventoried areas that had mixed stands of key species between the age of initial reproduction potential (20-40) to 70 years old, areas where crown cover was between 35% and 50%, and areas where red alder and bigleaf maple were >40%.

Medium ranked areas were found within 100% of all Territories at the 6.6 km buffer, 27 (84%) at the 2.5 km buffer, 6 (19%) at the 500 m buffer, and 2 (6%) at the 200 m buffer. (See Appendix 5 for Site-Specific Quantifications of Parameters Associated with Medium, Suboptimal, and Unsuitable Ranks). The most common reason that areas were given this rank was because crown cover was between 35-50%. This occurred at all 27 Territories within the 2.5 km buffer. Although stands with mixed key species between age of initial reproductive potential to 70 years old were included within this rank, only one Territory (25) met this qualification at the 2.5 km buffer level. Three Territories (2, 3, and 32) had stands where red alder and bigleaf maple were the second most predominant species and made up >40% of stand composition.

Territory 32 had the most diverse Medium ranked parameters (fig. 7). East and north of the centroid has areas where bigleaf maple and red alder are at >40% at the 2.5 km buffer. Areas south of the centroid have stands where crown cover is between 35-50% at the 2.5 km buffer.

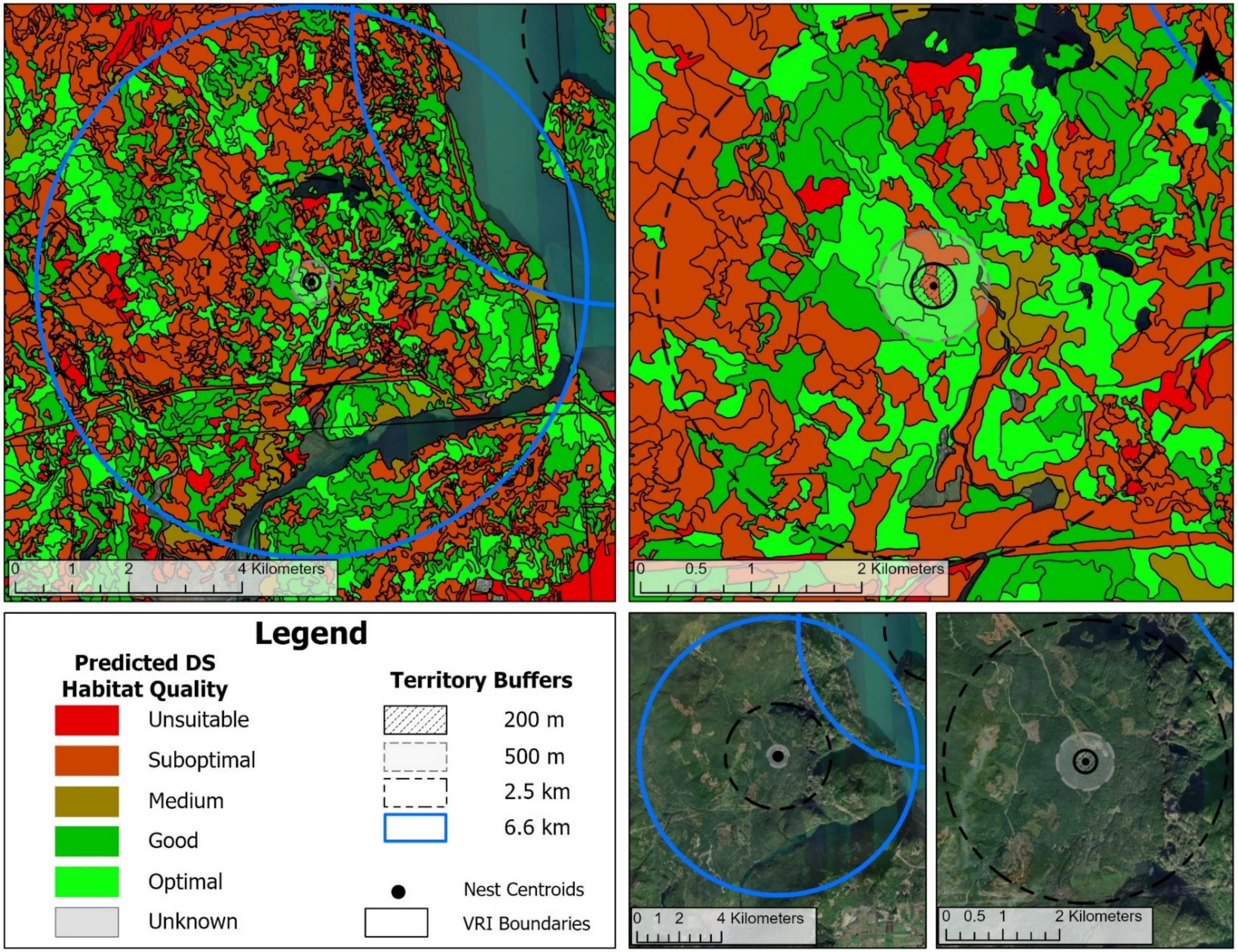

Figure 5. Predicted Douglas squirrel habitat quality in Territory 32. Ranks range from Unsuitable (red) to Optimal (Light Green) or unknown (Grey) within the 6.6 km, 2.5 km, 500 m, and 200 m breeding and foraging buffers. Imagery layers are from ArcGIS Pro World Imagery base and are from 9/25/2018.

Suboptimal Rank

The Suboptimal rank highlighted areas that may support individual elements of Douglas squirrel biological requirements (foraging, shelter, or breeding) but are insufficient to sustain populations throughout their lifecycles or in high densities or abundances. This included areas with mixed stands <70 years old where a pine species is <50%, where key species at non-reproductive juvenile ages were within the top three predominant species, stands that had red alder or bigleaf maple at >50%, areas where crown closure was between 10% and 35%. It also included areas where stands younger than 70 years old had a crown cover >10% and stands over 70 years old with crown closure less than 35%.

Suboptimal areas were most prevalent out of the three subpar ranks. They were within 100% of all Territories at 6.6 km and 2.5 km, within 97% of 500 m, and within 91% of 200 m. The most common features observed in Suboptimal areas were juvenile stands and/or low crown cover, which were present at all Territories within the 2.5 km buffer. Shrubby regions were relatively common, present at 24 Territories within the 2.5 km buffer. The deciduous tree species bigleaf maple and red alder were the least common, present at six and 25 Territories respectively.

Territory 5 is representative of common features that lead an area to be ranked Suboptimal (fig. 6). It has juvenile key species and/or low crown cover areas throughout all buffer zones. Shrubby areas are also found throughout at less densities. There are discontinuous red alder stands to the north and west of the centroid at the 2.5 km buffer. Territory 5 is notably engulfed in Unsuitable areas. This is because it is within a valley inside alpine regions, which will be discussed in the Unsuitable section.

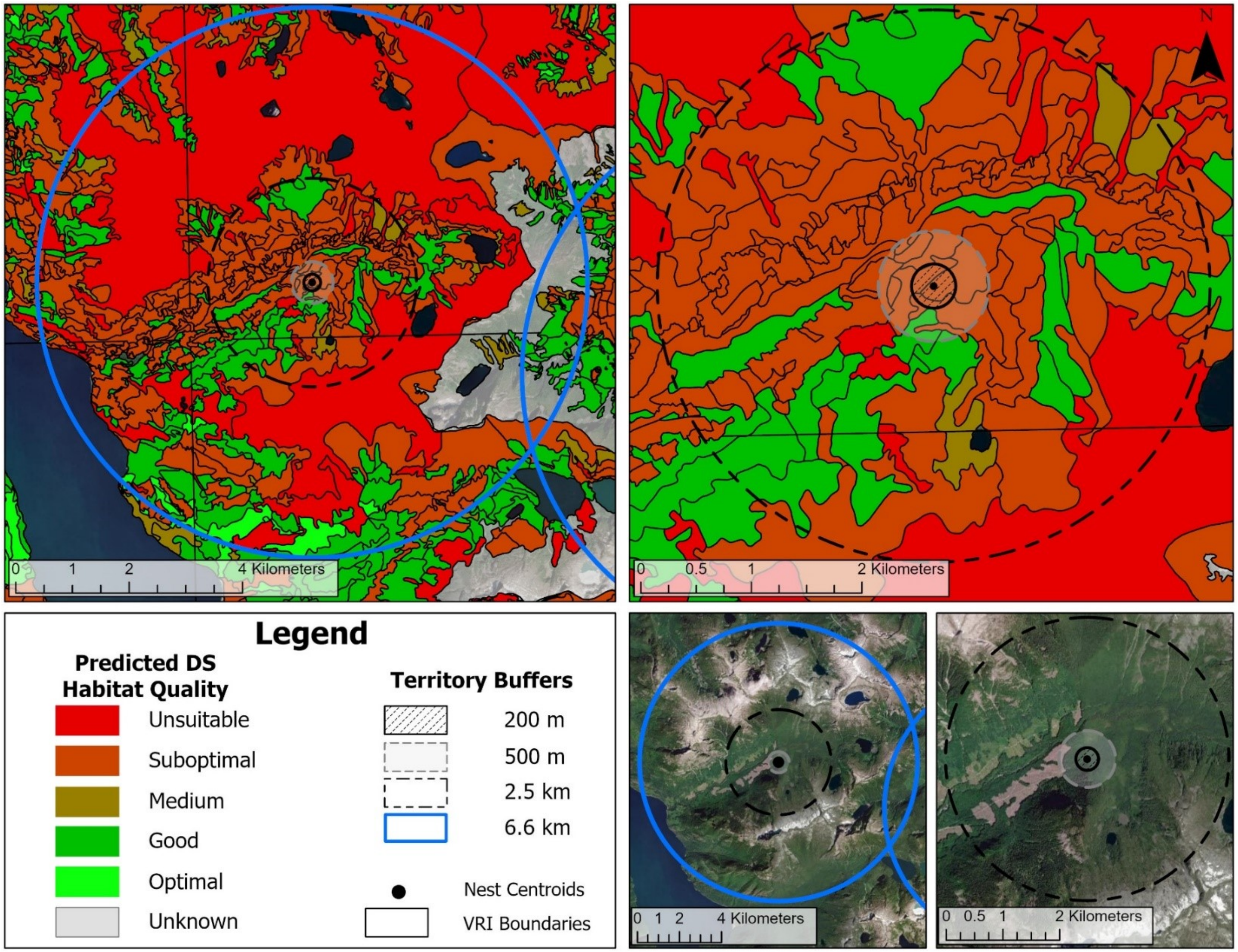

Figure 6. Predicted Douglas squirrel habitat quality in Territory 5. Ranks range from Unsuitable (red) to Optimal (Light Green) or unknown (Grey) within the 6.6 km, 2.5 km, 500 m, and 200 m territory buffers. Imagery layers are from ArcGIS Pro World Imagery base and are from 9/25/2018.

Unsuitable Rank

The Unsuitable rank highlighted areas where land features are difficult or impossible to alter (e.g., alpine regions) and those where structural features are primarily unsuitable for Douglas squirrel inhabitancy (e.g., pine forests). These areas are unlikely to support Douglas squirrels for forage, shelter, or breeding and are predicted to have no or very few Douglas squirrels (i.e., the lowest abundance of squirrels of all ranks). Territories with the most Unsuitable areas tended to be those with alpine regions within the 6.6 km buffer. This includes Territories 1, 3, and 5, which were noted above as areas that were visibly primarily Unsuitable from the gross-scale observation. Unsuitable areas were found within 100% of Territories within 6.6 km buffer, 78% within the 2.5 km buffer, 22% within the 500 m buffer, and 3% within the 200 m buffer

Finer scales provide insight on other Unsuitable parameters. Territory 1 provides a good example of what the Unsuitable rank looks like as it had the most diverse combination of structural characteristics assigned to the Unsuitable rank (fig. 7). The Unsuitable areas surrounding this centroid are mostly alpine and rocky regions. A small pine predominated forest is located south of the centroid, and the rest of the Unsuitable area is alpine or rocky. A river cuts through approximately 40% of the entire 6.6 km home range. Although bodies of water are not within the parameters used in the definition query, they are also Unsuitable for Douglas squirrels. The coastal goshawk nest centroid is located within primarily Good habitat for Douglas squirrel inhabitancy. Site 1 is furthest north of all known coastal goshawk territories and is the most isolated territory within the South Coast. It does not have overlapping territory with any other home range and the centroid of this area is 37.72 km from the nearest goshawk centroid. The combination of unsuitable alpine areas and riverine areas may contribute to why this area does not support other coastal goshawks.

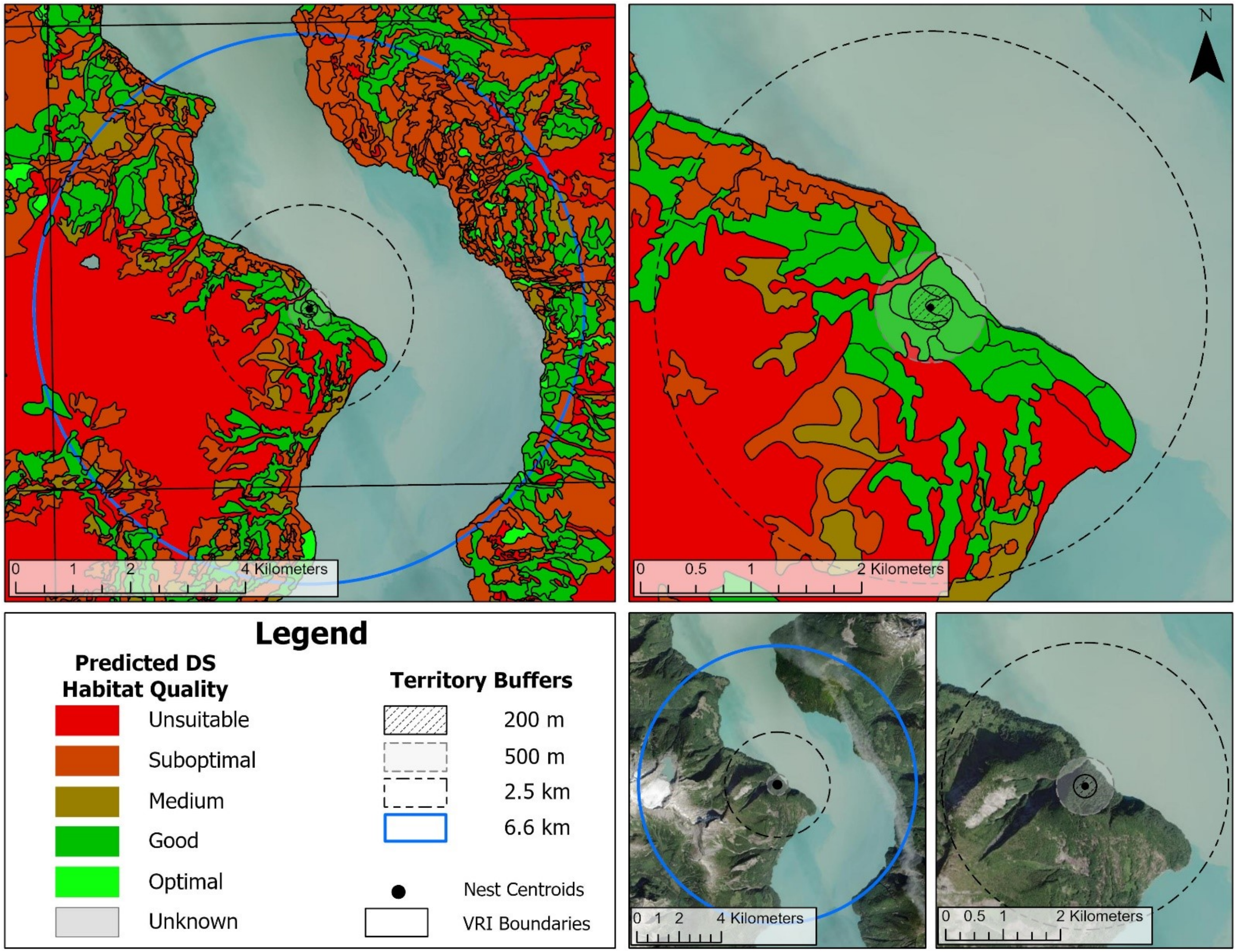

Figure 7. Territory 1's Predicted Douglas squirrel habitat quality ranging from Unsuitable (red) to Optimal (Light Green) or unknown (Grey) within the 6.6 km, 2.5 km, 500 m, and 200 m territory buffers. Imagery layers are taken from ArcGIS Pro World Imagery base map and are from 8/27/2019.

An a priori assumption made during model development was that the Medium rank would be the most common out of the three subpar ranks. In reality, the Medium rank was the least common and Suboptimal was the most prevalent. This could indicate that the model needs further refinement, or it may highlight a real phenomenon occurring in the SCCR. Supporting evidence for the latter possibility is given by looking at the harvest histories of this areas, which are provided in the VRI dataset up to 2018 and visualized as polygons surrounding historically harvested area. This allowed for visualization of where forest harvests have occurred in relation to the coastal goshawk Territories (fig. 8). This gross-scale observation shows that forestry activity since 2000 has occurred within all SCCR coastal goshawk Territories. This is not surprising as British Columbia's low to mid-elevation forests where the highest timber values are overlap with coastal goshawks (Demarchi et al. 2013).

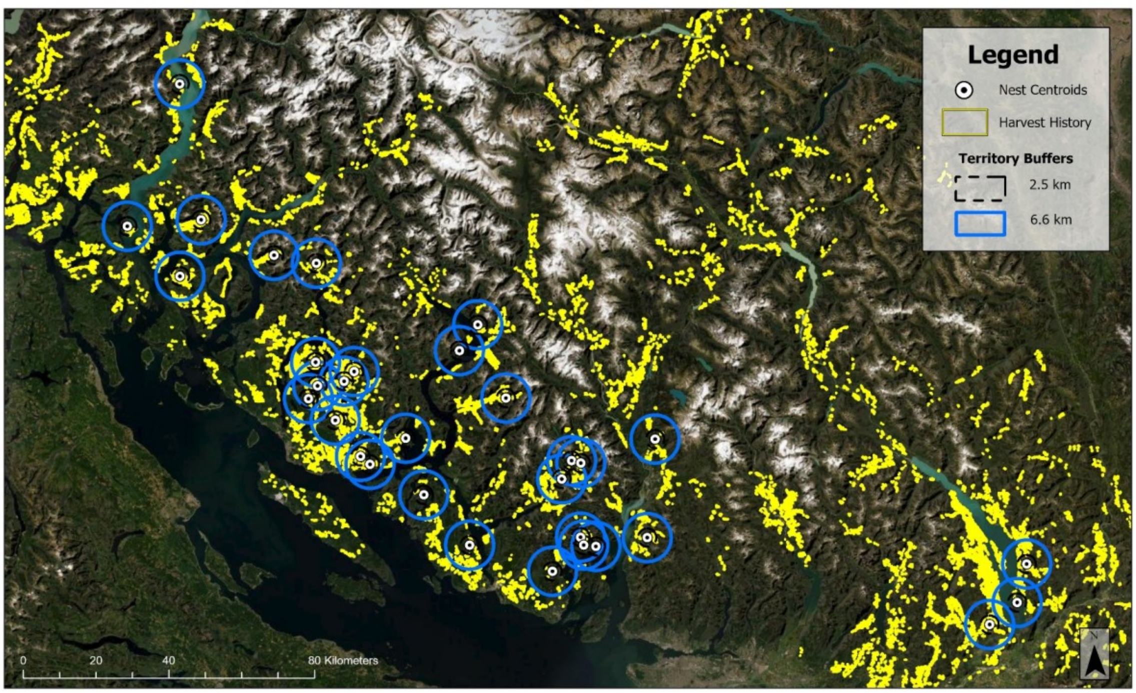

Figure 8. Areas of forest harvests since 2000 (yellow) in relation to coastal goshawk Territories (blue circles) within the SCCR.

A closer look shows that forestry history does correspond with Suboptimal areas and, to a smaller degree, Unsuitable areas (fig. 9). Aside from one Suboptimal polygon associated with insufficient crown closure, all other instances of Suboptimal or Unsuitable rankings that were not within areas previously logged were predominated by red alder or pine.

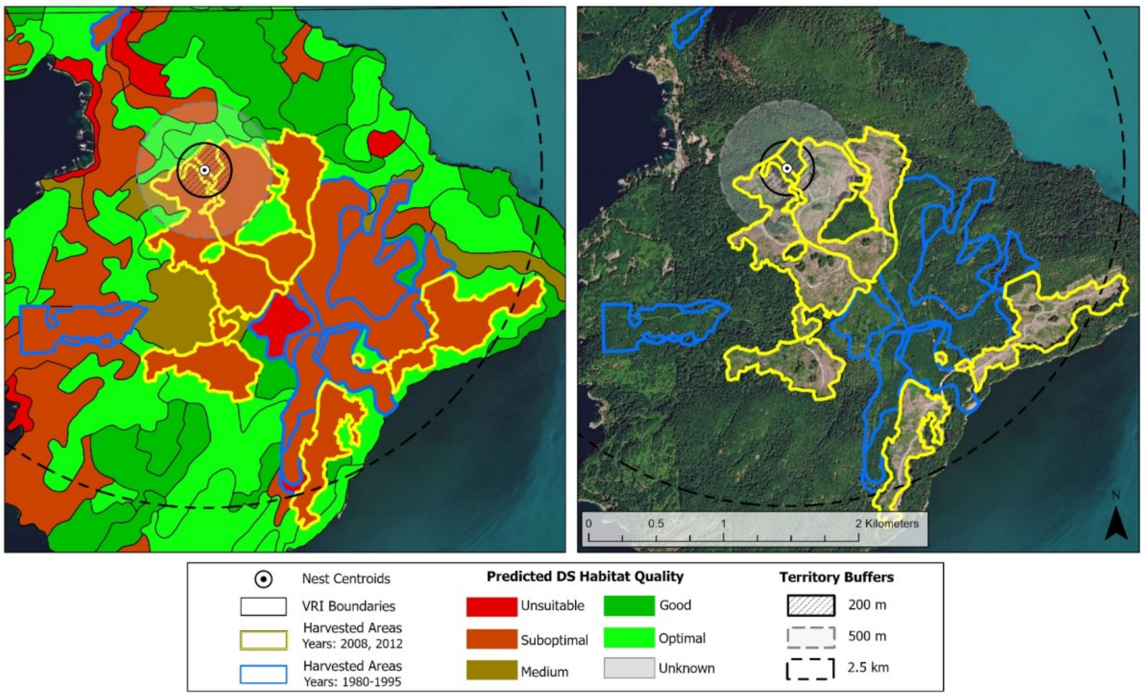

Figure 9. Comparison between the Suboptimal and Unsuitable ranked polygons and the harvested areas within the 2.5 km buffer of Territory 2. Imagery layers are taken from ArcGIS Pro World Imagery base map and are from 8/27/2019

The fragmentation occurring within coastal goshawk breeding and foraging home ranges may be impacting breeding pairs by reducing viable breeding and foraging habitat, and pairs may be staying within these areas because of high site fidelity (Parks Canada 2018). It should not be assumed that this subspecies stays within the circular buffers assigned to delineate different conceptual aspects of their territories – it is possible that they may be foraging mainly within Good and Optimal regions and have enough contiguous forest to make this possible. Alternatively, it may highlight areas where Douglas squirrel is less common and where another key prey species is found.

Recommendations for Restoration

The model can highlight areas where specific strategies of restoration may be employed to increase predicted suitability for Douglas squirrel and thus their predicted abundances. For example, low crown cover was a common issue throughout all three subpar ranks and across many Territories. Selective thinning can be a useful strategy in these circumstances as it has been observed to accelerate second growth biocomplexity while retaining the old-growth characteristics existing in forests (Carey 2001). Thinning can stimulate cone production and provide more sunlight and nutrients to remaining trees, providing more foraging opportunity in areas where stand ages are low (Puritch 1997). Removing pine, red alder, or bigleaf maple to provide room for key species expansion may have resounding impacts on animal species that rely on these trees for forage, so these decisions must be made holistically and after understanding the biological composition of the area. However, selective thinning of these species may allow for key species present to overtake predominance.

Restoration methods like reintroducing key tree species may be used to recover foraging habitat lost through forestry harvests. Numerous studies have shown that Douglas squirrel populations increase with supplementary feeding (Sullivan and Sullivan 1982, Sullivan 1990, Ransome and Sullivan 2003). This may be a way to increase abundances within coastal goshawk areas, but it is not a sustainable alternative to manipulating these areas via restoration or silviculture methods. However, this strategy could be used to protect establishing saplings from Douglas squirrels during any planting as Douglas squirrels will focus on the food source that requires the least amount of energy expended (Sullivan and Sullivan 1982, OECD 2010).

Any restoration decisions must be influenced by coastal goshawk biology and selection preferences. Although both species are both found within forests with old-growth characteristics, this does not mean that optimal habitat for Douglas squirrel is the same as optimal habitat for the coastal goshawk. There will be differences in habitat requirements and the requirements for goshawks need to be made priority, even if restorative actions were able to increase Douglas squirrel abundance in an area. For example, optimal crown cover is likely different for the coastal goshawk as they select for relatively closed canopies (>50-75%) whereas Douglas squirrels are benefited by closer crown cover (Steele 1999, McClaren et al. 2015). It may be that areas ranked as Good for Douglas squirrels should be prioritized in some cases if Optimal stands have overly high crown cover.

Restorative efforts targeting Unsuitable areas may be difficult, particularly those located where land features do not provide the basic requirements necessary to support the vegetative structural characteristics for Douglas squirrel forage and shelter (e.g., alpine areas). However, similar principles for restoration activity will apply for the parameters around tree species, ages, and crown cover across the three subpar ranks.

Model Limitations and Future Research

Models are increasingly important for ecological restoration and wildlife population recovery, but we need to verify that the parameters used in them are as reliable as possible before we can try to apply them to real-world ecosystems. This model requires further refinement before it should be used to guide coastal goshawk recovery decisions. Some limitations are inherent given the scope and data availability, whereas others can be addressed and improved upon by further research.

Coastal goshawk data

The coordinate locations of nest centroids were collected during coastal goshawk surveys done in 2018. Although it is unlikely that it has changed drastically as goshawks have high site fidelity, the most up-to-date location data should be used in the model to reduce human error and provide the most accurate representation of the region possible. Additionally, this data does not show if there are multiple nests within a breeding area, information that could further inform management practices. Although coastal goshawks only use one nest per breeding season, they may use different nests within a breeding area year-to-year (McClaren et al. 2015).

British Columbia's Vegetation Resource Inventory

Some inventories were taken between the 1970s-2010s and are likely not reflective of the region's current structural composition. Some regions do not have inventory data and cannot be included in the model evaluation as they lack the information necessary to be included within the prey ranks. Re-inventorying areas with outdated records or no records should be done at least within parts of coastal goshawk Territories. In the meantime, comparing the VRI's data to the most recent satellite imagery available can help confirm larger discrepancies that are noticeable from visual desktop analysis (e.g., areas that appear to have forestry impacts but are not marked as Suboptimal or Unsuitable; fig. 10). These rank anomalies should be acknowledged and used to refine the definition queries that rank Douglas squirrel's predicted abundance.

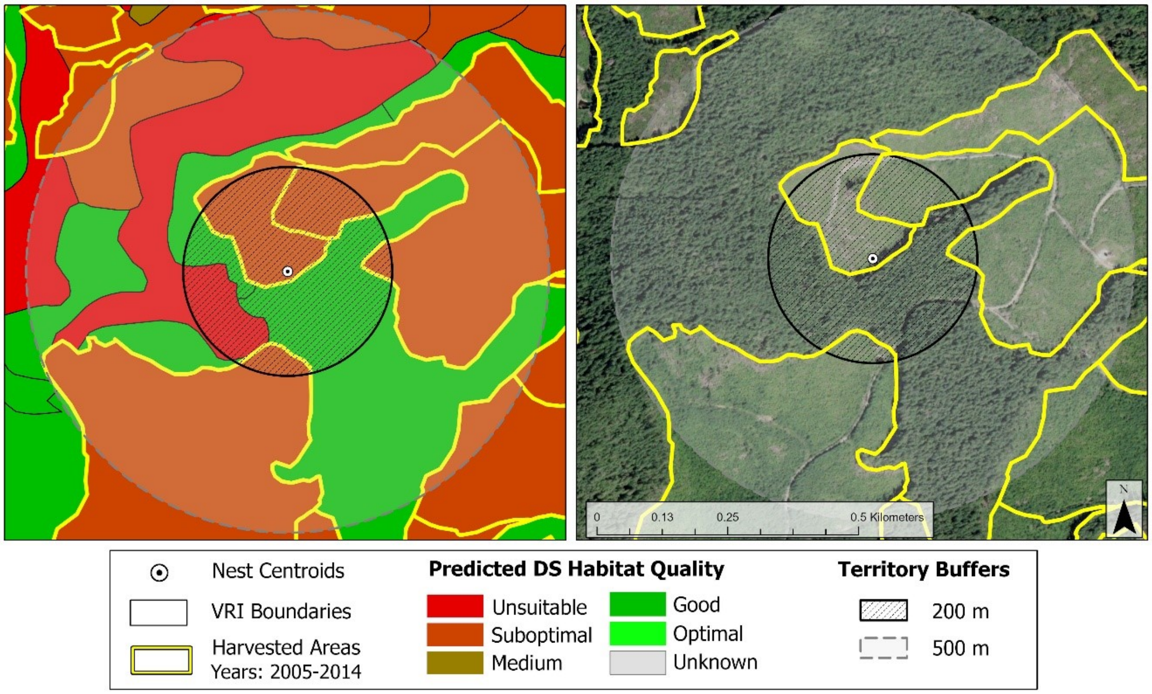

Figure 10. Comparison of ranks associated with predicted Douglas squirrel habitat quality to satellite imagery of the same area. Unsuitable areas have higher tree coverage and densities than Suboptimal areas harvested between 2005-2014. Imagery layers are taken from ArcGIS Pro World Imagery base map and are from 8/27/2019

Douglas squirrel biology

The parameters used to develop the different ranks representing Douglas squirrel predicted habitat quality (and thus predicted prey abundance) were shaped by trends and conclusions from the available scientific literature. However, Douglas squirrels likely exist within a variety of different conditions, and it is likely that not all of them are considered here. Further research regarding Douglas squirrel biology, behaviours, and territory preferences may further refine the parameters used in the model. As more is understood about Douglas squirrel biological requirements, the model should be updated accordingly and use the most up-to-date information available.

Future iterations of this model should include tree species preference exhibited by the Douglas squirrel once more is understood about their preferences within these areas of the SCCR. Studies have noted apparent selective preferences seed number and cone weight and hardness, and a study focusing on a population at Manning Provincial Park noted observations of tree species-specific preferences: squirrels harvested Pacific silver fir cones within their territory first, then moved on to Douglas-fir and Engelmann spruce concurrently, and then harvested from western hemlock once those sources were exhausted (Elliot 1988, Smith 1970). Engelmann spruce and to a lesser degree Pacific silver fir trees are less common in forests around the SCCR nest sites, so if tree species-specific preference exists in the Douglas squirrel populations around these areas it is currently poorly known and may inform model refinement if researched.

A study should be done to confirm the reliability of the model and ranks before it is used to guide real-world decisions. Monitoring and comparing Douglas squirrels found within select areas that the model currently shows as representative of low predicted prey abundance and high predicted abundance areas could show how accurate the model is and is a necessary step before application.

Prey dynamics

At this time, the selection preferences of coastal goshawk prey are known primarily through one prey ecology study, which looked at a small timeframe and noted that they were unable to identify over half of the avian samples observed (Case 2021). Although the Douglas squirrel appears to be the main food source for the SCCR coastal goshawk population, it would be irresponsible to assume that this is the only important prey species. Even if this species is the most consumed, Douglas squirrel populations and abundances fluctuate with conifer cone crop cycles and as a result may not be the most abundant and available prey species every year. Additionally, current diet research occurs during the breeding season (Parks Canada 2018). Further research should investigate strengthening the knowledge of prey in this region across years and seasons. These species should be included in this model by following the methods used to parameterize the Douglas squirrel. Their biological limiting factors and requirements should be understood and be assigned to structural surrogate features that can be geospatially analyzed and ranked through available data. These ranks should be confirmed through monitoring and conducting field surveys at rank-representative areas.

Another study comparing reproductive output and model ranks would further help determine the reliability of the model and strengthen our understanding of how prey availability, distribution, and potentially species options influence breeding success. This should be done after confirming the reliability of the model through surveying areas for Douglas squirrels, as well as after determining other key prey species and creating structural surrogate layers representing their biological requirements in the model.

Conclusion

As of 2019, British Columbia has begun working with Indigenous partners and interested parties to incorporate traditional ecological knowledge and more sustainable practices into forest management. The recent commitment to short-term forestry deferrals will protect select old-growth forests throughout British Columbia temporarily as they consider new management strategies. During this time, decision makers and leaders should think beyond the old-growth definitions that focus on age and economic value and consider the wider implications old-growth forests have for culture, species, and global biodiversity.

However, deferrals alone are not enough to save at-risk flora and fauna. Developing, implementing, and adaptively managing species recovery plans will need to remain a priority. Most species will not experience the temporary protections offered by the old-growth forestry deferrals: out of the 11.1 million ha of old-growth forests remaining in British Columbia, the deferrals are proposed to only protect 2.6 million ha of these stands. No SCCR coastal goshawk territory will fall within these areas (Government of British Columbia 2021a, 2021b). Old-growth stands will continue to be logged throughout the coastal goshawk's provincial range and other old-growth dependent species will continue to be impacted by ongoing forestry.

The development of new forest management frameworks that use ecological knowledge can provide us with an opportunity to promote the recovery of land and species. It should not be taken as an alternative to further the research and update the strategies used to recover lost ecosystem function and wildlife populations. A predicted prey abundance model provides a new approach to recovering the coastal goshawk by focusing on restoring prey areas, many of which have been lost by forestry. This preliminary research will create the foundation for work that can help recover and sustain the costal goshawk (and potentially other at-risk species) through educated ecosystem-focused application.

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Appendix A. Broad Strategies for the Provincial and Federal Recovery Plans: Meeting Population and Distribution Objectives

Table 2. Objective 1: To manage and, where necessary, conserve and recover habitat that meets the needs of the Northern Goshawk *A. gentilis laingi* through its annual cycle (Parks Canada 2018).

Threat(s) assessed	Broad strategy	Priority	Recommended approaches to meet recovery objectives	Action	Conservation Region	Timeline
Habitat loss and fragmentation – nesting.	Habitat protection.	High	Protect known nest trees and PFAs.	Pursue available tools for protection on public and private lands.	All	1999-2012
Habitat loss and fragmentation – nesting and foraging.	Science-based guidelines for habitat management; stewardship.	High	Manage nesting and foraging habitat that is required but cannot be included in Wildlife Habitat Areas (WHAs) for required forest attributes & human disturbance impacts.	Develop science-based guidelines (incl. stand structure, seral stage distribution, human disturbance, access planning) for nesting and foraging habitat.	All	2008
Habitat loss and fragmentation – foraging.	Habitat management; stewardship.	High	Develop land use designations for *A. gentilis laingi* foraging areas.	Develop and implement general wildlife measures to ensure sufficient *A. gentilis laingi* foraging habitat outside WHAs is conserved.	All	2008-2017

Table 2 cont.

Threat(s) assessed	Broad strategy	Priority	Recommended approaches to meet recovery objectives	Action	Conservation Region	Timeline
Habitat loss and fragmentation – nesting and foraging; prey diversity and availability.	Research; habitat management guidelines.	High	Recover sufficient habitat to support population goals	Research, develop and implement silvicultural techniques to promote stand attributes for the recovery, maintenance, and diversity of prey populations.	All	1991-ongoing
Habitat loss and fragmentation – foraging; introduced species; prey diversity and availability.	Research; habitat management guidelines; stewardship; outreach.	High	Manage introduced species to minimize habitat impact.	Develop and implement management plans for introduced species (e.g., deer) that are affecting foraging habitat and prey of *A. gentilis laingi*.	HG	2008-ongoing
Habitat loss and fragmentation – nesting and foraging; prey diversity and availability; introduced species; human disturbance	Stewardship; outreach.	Med	Engage public and private landowners, and resource managers in conserving habitat for *A. gentilis laingi.*	Develop and implement outreach and education strategies for these groups.	All	1995-ongoing

Table 2 cont.

Threat(s) assessed	**Broad strategy**	**Priority**	**Recommended approaches to meet recovery objectives**	**Action**	**Conservation Region**	**Timeline**
Habitat loss and fragmentation.	Monitoring; adaptive management.	High	Assess the effectiveness of habitat management actions to protect habitat of *A. gentilis laingi*.	Conduct effectiveness monitoring as required.	All.	1995-ongion
Research; habitat management guidelines/	Research; habitat management guidelines.	Low	Consider habitat management over decadal time scales.	Predict change in habitat attributes and distribution related to climate cycles and climate change scenarios, using climate modelling exercises.	All.	2012-2017

Table 3. Objective 2: To conserve and, where necessary, recover a well-distributed and viable population of Northern Goshawk *A. gentilis laingi* within coastal B.C. (Parks Canada 2018)

Threat(s) assessed	Broad strategy	Priority	Recommended approaches to meet recovery objectives	Action	Conservation Region	Timeline
Genetic isolation.	Research; population management guidelines.	High	Define population and distribution objectives for each conservation region	Use spatially explicit population modelling for each conservation region Continue to collect and analyze genetic samples.	All	2007-2009
Habitat loss and fragmentation-nesting and foraging; genetic isolation	Implement habitat management guidelines to manage populations; inventory; monitoring	High	Manage populations by conservation region to meet defined population and distribution objectives.	Use habitat conservation and management strategies defined under objective 1 to conserve and recover populations. Conduct inventory and monitoring as required.	All	1999-ongoing. 1995-ongoing
Introduced species; prey diversity and availability.	Introduced species guidelines.	High	Manage introduced species to minimize population impacts.	Develop and implement management plan for introduced species interactions affecting *A. gentilis laingi* indirectly prey diversity and availability) and directly (predation).	HG	2008-ongoing

Table 3 cont.

Threat(s) assessed	Broad strategy	Priority	Recommended approaches to meet recovery objectives	Action	Conservation Region	Timeline
Prey diversity and availability.	Monitoring; research.	Med	Assess and monitor prey abundance and diversity.	Determine primary prey species for *A. gentilis laingi.*	NC, SC	2008-2009
				Monitor prey populations and assess impacts of forest harvest techniques on prey.	All	1994-ongoing
Persecution	Stewardship; outreach; research.	Low	Assess threat to *A. gentilis laingi* from persecution and reduce if required.	Evaluate degree of risk to *A. gentilis laingi* posed by persecution.	All	2006-2012
				Address persecution issues through outreach and education strategies, if required.		
Disease	Monitoring; research.	Low	Monitor for presence of West Nile Virus and other potential diseases.	Design and implement monitoring program for WNV (model potential impacts).	All	2015-2017
Competition, depredation.	Monitoring; research.	Low	Monitor populations of edge-adapted predators and competitors.	Design and implement a monitoring program for edge-adapted competitors and predators (e.g., red-tailed hawks, great horned owls, barred owls).	All	2010-2012

Table 4. Additional recommended approaches proposed by the Federal Goshawk Recovery Plan (Parks Canada 2018).

Approach / Strategy	Description of Management and Research Approaches	Outcome / Deliverables	Priority
Discover or manage habitat for additional home ranges to meet population and distribution objectives.	Option 1 – Discover additional home ranges through the use of surveys for home ranges. Option 2 – Manage suitable habitat at a landscape level to ensure long term viability of a sufficient number of home ranges.	A sufficient number of home ranges are discovered or managed to meet population and distribution objectives.	Urgent
Develop approaches to mitigate human induced mortality.	Human induced mortality is a significant issue in at least one region (where landowners are protecting chickens; B. Wijdeven, pers. comm.). Assist landowners to implement non-lethal measures, where appropriate.	Reduced human induced mortality.	Urgent
Genetic analysis.	Conduct additional genetic analyses to confirm the range of the *laingi* subspecies.	Revised range boundaries for *laingi* subspecies.	Necessary
Refine population and distribution objectives.	The population and distribution objectives require adjustment due to the inclusion of the transition zone in the federal recovery strategy. The historic capability of each region needs to be determined for the long-term objective.	Revised population and distribution objectives that account for inclusion of the transition zone and clarify how many home ranges are required in each region.	Necessary
Refine Steventon (2012 a, b) Population Viability Analysis (PVA).	Additional work is required to refine the PVA and reduce its level of uncertainty, as well as include the effects of gene flow to areas outside of Canada.	Refinements to both short- and long-term population and distribution objectives.	Beneficial

Appendix B. Distribution of Engelmann Spruce and Subalpine Fir Across the SCCR

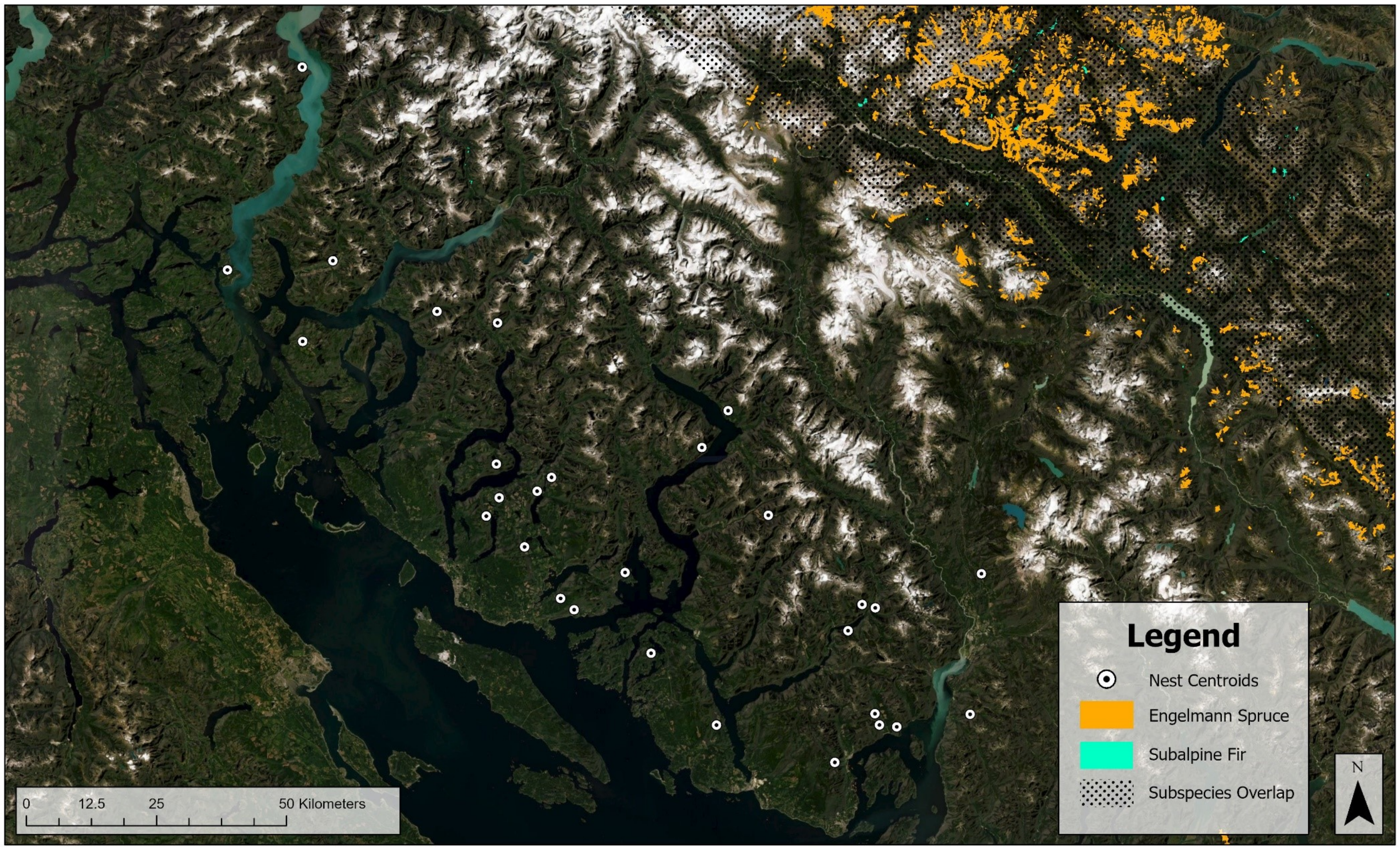

Figure 11. Distribution of forests that contain Engelmann spruce (orange) and Subalpine fir (blue) in relation to the nest centroids (white marker) in the SCCR.

Appendix C. Rank Codes

To understand the definition queries in this appendix it is important to know the names used to represent tree species. Refer to Table 6.

Table 5. Names of tree species used in developing the parameters for Douglas squirrel

Tree Species	VRI Reference Name
Pacific silver fir (*A. amabilis*)	Ba
Grand fir (*A. grandis*)	Bg
Douglas-fir (*P. menziesii*)	Fd, Fdc
Sitka spruce (*P. sitchensiis*)	Ss
Western hemlock (*T. heterophylla*)	Hw
Western redcedar (*T. plicata*)	Cw
Red alder (*Alnus rubra*)	Dr
Bigleaf maple (*Acer macrophyllum*)	Mb
Lodgepole pine (*P. contorta*)	Pl
Western white pine (*P. monticola*)	Pw
Ponderosa Pine (*P. ponderosa*)	Py

Rank Specifics and SQL Code

Unknown: No data has been collected.

```
BCLCS_LV_1 = 'U'
```

- Describes areas with no vegetation resource inventory.

Unsuitable: Does not support Douglas squirrels for forage, shelter, or breeding.

```
(LBL_SPECIS = 'Pw' Or LBL_SPECIS = 'Py' Or LBL_SPECIS = 'Pl' Or LBL_SPECIS LIKE 'Pw%' Or LBL_SPECIS LIKE 'Py%' Or LBL_SPECIS LIKE 'Pl%') Or (CR_CLOSURE <= 10 And CR_CLOSURE >= 1) Or (BCLCS_LV_1 = 'N' And BCLCS_LV_2 NOT IN ('W')) Or BCLCS_LV_3 = 'A' Or BCLCS_LV_4 = 'RO' Or BCLCS_LV_4 = 'EL' Or BCLCS_LV_4 = 'HE' Or BCLCS_LV_4 = 'BY' Or BCLCS_LV_4 = 'BM' Or BCLCS_LV_4 = 'BL' Or BCLCS_LV_4 = 'SI'
```

Suboptimal: Areas that may support individual elements of Douglas squirrel biological requirements (foraging, shelter, or breeding) but are insufficient to sustain populations throughout their life histories or in high densities and abundances.

```
((LBL_SPECIS LIKE '%Pw' Or LBL_SPECIS LIKE '%Pl' Or LBL_SPECIS LIKE '%Py') And PROJ_AGE_1 < 70) Or (LBL_SPECIS = 'Ba' And PROJ_AGE_1 < 40) Or (LBL_SPECIS = 'Bg' And PROJ_AGE_1 < 40) Or (LBL_SPECIS = 'Fd' And PROJ_AGE_1 < 20) Or (LBL_SPECIS = 'Fdc' And PROJ_AGE_1 < 20) Or (LBL_SPECIS = 'Ss' And PROJ_AGE_1 < 20) Or (LBL_SPECIS = 'Cw' And PROJ_AGE_1 < 20) Or (LBL_SPECIS = 'Hw' And PROJ_AGE_1 < 25) Or (SPEC_CD_1 = 'DR' And SPEC_PCT_1 >= 50) Or (SPEC_CD_1 = 'MB' And SPEC_PCT_1 >= 50) Or (LBL_SPECIS LIKE '%Ba%' And PROJ_AGE_1 < 40) Or (LBL_SPECIS LIKE '%Bg%' And PROJ_AGE_1 < 40) Or (LBL_SPECIS LIKE '%Fd%' And PROJ_AGE_1 < 20) Or (LBL_SPECIS LIKE '%Fdc%' And PROJ_AGE_1 < 20) Or (LBL_SPECIS LIKE '%Ss%' And PROJ_AGE_1 < 20) Or (LBL_SPECIS LIKE '%Cw%' And PROJ_AGE_1 < 20) Or (LBL_SPECIS LIKE '%Hw%' And PROJ_AGE_1 < 25) Or (CR_CLOSURE < 35 And CR_CLOSURE > 10) Or (PROJ_AGE_1 < 70 And CR_CLOSURE > 10) Or (PROJ_AGE_1 >= 70 And CR_CLOSURE < 35) Or BCLCS_LV_4 = 'ST' Or BCLCS_LV_4 = 'SL'
```

Medium: Areas that can support multiple elements of Douglas squirrel biological requirements (foraging, shelter, and/or breeding) but can be manipulated to support higher densities and abundances.

```
(((LBL_SPECIS = 'Ba' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 40) Or (LBL_SPECIS = 'Bg' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 40) Or (LBL_SPECIS = 'Fd' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 20) Or (LBL_SPECIS = 'Fdc' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 20) Or (LBL_SPECIS = 'Ss' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 20) Or (LBL_SPECIS = 'Cw' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 20) Or (LBL_SPECIS = 'Hw' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 25)) Or (LBL_SPECIS LIKE '%Ba%' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 40) Or (LBL_SPECIS LIKE '%Bg%' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 40) Or (LBL_SPECIS LIKE '%Fd%' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 20) Or (LBL_SPECIS LIKE '%Fdc%' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 20) Or (LBL_SPECIS LIKE '%Ss%' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 20) Or (LBL_SPECIS LIKE '%Cw%' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 20) Or (LBL_SPECIS LIKE '%Hw%' And PROJ_AGE_1 < 70 And PROJ_AGE_1 >= 25)) Or (LBL_SPECIS = 'Dr%' Or LBL_SPECIS = 'Mb%') Or (LBL_SPECIS LIKE 'Dr%' Or LBL_SPECIS LIKE 'Mb%') Or (CR_CLOSURE < 50 And CR_CLOSURE >= 35)
```

Good: Areas that are expected to provide foraging, shelter, and breeding habitat for Douglas squirrels year-round. Some restoration or silviculture may increase suitability and provide structural characteristics that can support greater densities of squirrels.

```
((LBL_SPECIS = 'Ba' Or LBL_SPECIS = 'Bg' Or LBL_SPECIS = 'Fd' Or LBL_SPECIS = 'Fdc' Or LBL_SPECIS = 'Ss' Or LBL_SPECIS = 'Hw' Or LBL_SPECIS = 'Cw') Or ((LBL_SPECIS LIKE 'Bg%' Or LBL_SPECIS LIKE 'Fd%' Or LBL_SPECIS LIKE 'Fdc%' Or LBL_SPECIS LIKE 'Ss%' Or LBL_SPECIS LIKE 'Hw%' Or LBL_SPECIS LIKE 'Cw%') And PROJ_AGE_1 >= 70 And PROJ_AGE_1 < 100 And CR_CLOSURE >= 50 And CR_CLOSURE < 70)) Or (CR_CLOSURE >= 50 And CR_CLOSURE < 70) Or (PROJ_AGE_1 >= 70 And PROJ_AGE_1 < 100) Or (PROJ_AGE_1 <= 100 And CR_CLOSURE >= 70) Or (PROJ_AGE_1 >= 100 And CR_CLOSURE >= 70)
```

Optimal: Areas expected to provide the most optimal foraging, shelter, and breeding habitat for Douglas squirrels year-round.

```
(LBL_SPECIS = 'Ba' Or LBL_SPECIS = 'Bg' Or LBL_SPECIS = 'Fd' Or LBL_SPECIS = 'Fdc' Or LBL_SPECIS = 'Ss' Or LBL_SPECIS = 'Hw' Or LBL_SPECIS = 'Cw') Or ((LBL_SPECIS LIKE 'Ba' OR LBL_SPECIS LIKE 'Bg%' Or LBL_SPECIS LIKE 'Fd%' Or LBL_SPECIS LIKE 'Fdc%' Or LBL_SPECIS LIKE 'Ss%' Or LBL_SPECIS LIKE 'Hw%' Or LBL_SPECIS LIKE 'Cw%') And PROJ_AGE_1 >= 100 And CR_CLOSURE >= 70)
```

Appendix D. Territory Location Key

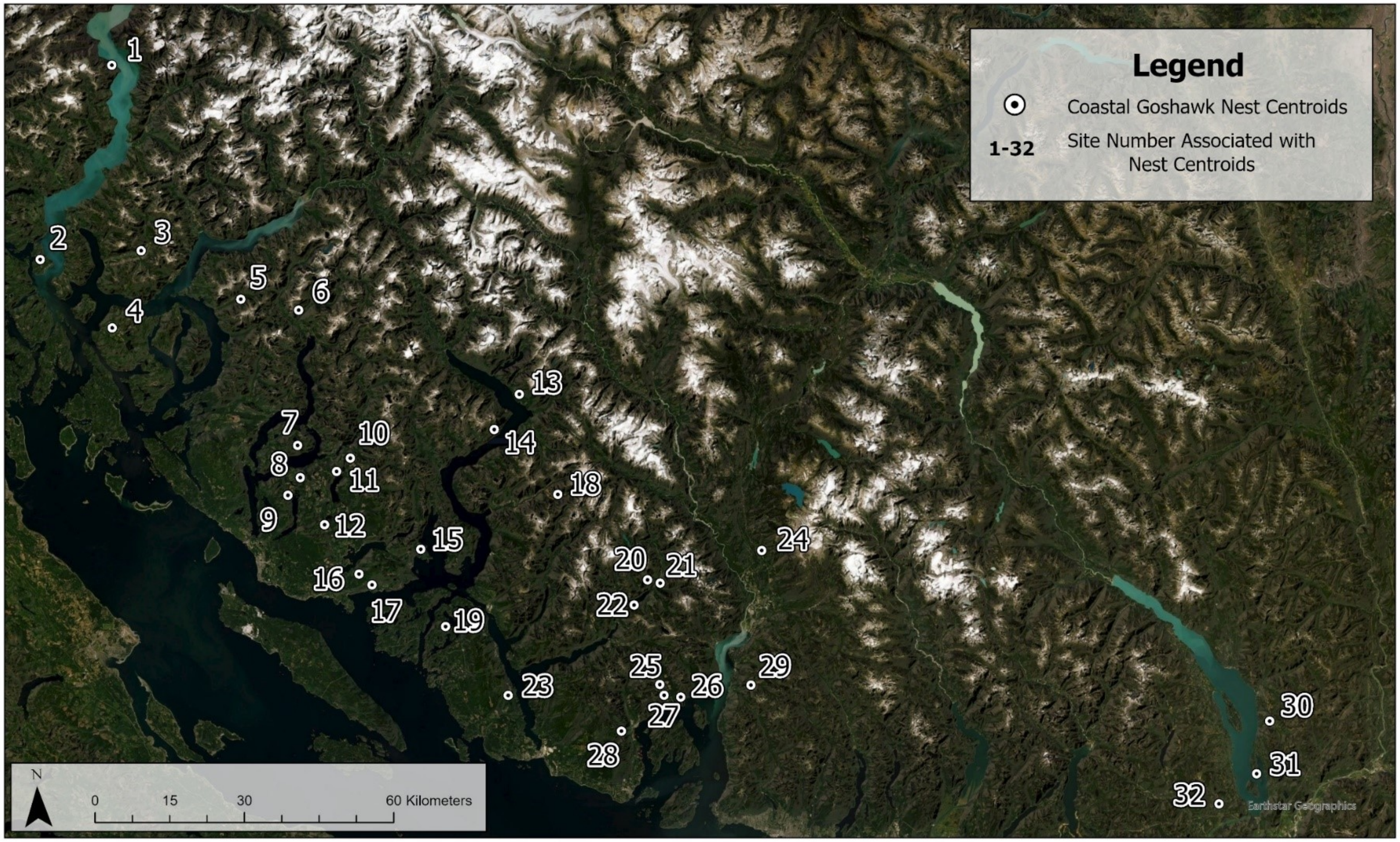

Figure 12. Territory numbers assigned to goshawk centroid (black and white markers) across the SCCR.

Appendix E. Site-specific parameters associated with Unsuitable, Suboptimal, and Medium ranks.

Table 6. Specific parameters associated with Unsuitable, Suboptimal, and Medium ranks found within 2.5 km, 500 m, and 200 m at all Territories. A = alpine; R = rocky; P = pine; J = juvenile; CC = crown cover; Dr = red alder; Mb = bigleaf maple; S = shrubby.

Territory		Unsuitable	Suboptimal	Medium
1	2.5 km	A, R, P, CC	J, CC, Dr, Mb	1
	500 m	A, R, P	-	-
	200 m		-	-
2	2.5 km	R, P, CC, EL, HE	J, CC, Dr, S	2
	500 m	-	J, CC, Dr	Dr
	200 m	-	J, CC	-
3	2.5 km	A, R	J, CC, Dr, S	3
	500 m	-	J, CC, S	-
	200 m	-	J, CC	-
4	2.5 km	R, P, CC, HE	J, CC, S	4
	500 m	CC	J, CC	-
	200 m	CC	J, CC	-
5	2.5 km	A, R, CC	J, CC, Dr, S	5
	500 m	-	J, CC, S	-
	200 m	-	J, CC, S	-
6	2.5 km	-	J, CC, S	6
	500 m	-	J, S	-
	200 m	-	J, S	-
7	2.5 km	-	J, CC, Dr, S	7
	500 m	-	J, CC, S	-
	200 m	-	J, SS	-

Table 6 cont.

Site		Unsuitable	Suboptimal	Medium
8	2.5 km	-	J, CC, S	CC
	500 m	-	S	-
	200 m	-	-	-
9	2.5 km	P, CC	J, CC, Dr, S	CC
	500 m	-	J, Dr	CC
	200 m			CC
10	2.5 km	-	J, CC, Dr, S	CC
	500 m	-	J, CC	-
	200 m	-	J, CC	-
11	2.5 km	-	J, CC, Dr, S	-
	500 m	-	J, CC, S	-
	200 m	-	J, CC, S	-
12	2.5 km	CC	J, CC, Dr, S	CC
	500 m	-	J, S	-
	200 m	-	S	-
13	2.5 km	A, R, CC	J, CC, Dr	CC
	500 m	-	J, CC	-
	200 m	-	J, CC	-
14	2.5 km	R, CC, P	J, CC, Dr, S	CC
	500 m	CC, P	J, CC	CC
	200 m	-	J	CC
15	2.5 km	-	J, CC, Dr	-
	500 m	-	J, CC	-
	200 m	-	CC	-
16	2.5 km	-	J, CC, Dr	CC
	500 m	-	J, CC	-
	200 m	-	J	-

Table 6 cont.

Site		Unsuitable	Suboptimal	Medium
17	2.5 km	CC, EL, HE	J, CC, Dr, Mb, S	17
	500 m	CC	J, CC, Dr. S	-
	200 m	-	S	-
18	2.5 km	CC, A, HE	J, CC	18
	500 m	-	J, CC, S	-
	200 m	-	J, CC	-
19	2.5 km	CC – actually h2o	J, CC, Dr	19
	500 m	-	CC	-
	200 m	-	CC	-
20	2.5 km	A, CC, HE	J, CC, Dr, Mb, S	20
	500 m	-	J, CC, Dr, Mb	-
	200 m	-	J	-
21	2.5 km	A, CC, HE	J, CC, Dr, S	21
	500 m	-	J, CC	-
	200 m	-	J, CC	-
22	2.5 km	CC, HE	J, CC, S	22
	500 m	-	J, CC	-
	200 m	-	J, CC	-
23	2.5 km	CC	J, CC, Dr	23
	500 m	-	J, CC	-
	200 m	-	CC	-
24	2.5 km	CC, EL, BY	J, CC, S	24
	500 m	CC	J, CC	-
	200 m	-	J	-
25	2.5 km	CC, HE	J, CC, Dr, S	25
	500 m	-	J, CC, S	-
	200 m	-	J, CC, S	-

Table 6 cont.

Site		Unsuitable	Suboptimal	Medium
26	2.5 km	CC, HE	J, CC, Dr, S	26
	500 m	-	J, CC	CC
	200 m	-	J	CC
27	2.5 km	CC, HE	J, CC, Dr, S	27
	500 m	-	J, CC	-
	200 m	-	J	-
28	2.5 km	CC, El, HE	J, CC, S	28
	500 m	J, CC	J, CC	-
	200 m	-	J, CC	-
29	2.5 km	CC, Dr, HE, BY	J, CC, Dr, S	29
	500 m	CC, Dr	J, CC, S	-
	200 m	-	J, CC	-
30	2.5 km	CC, HE, BY	J, CC, Dr, S	30
	500 m	-	J, CC	-
	200 m	-	J, CC	-
31	2.5 km	CC, HE	J, CC, Dr, Mb, S	31
	500 m	-	J, CC	CC
	200 m	-	J, CC	-
32	2.5 km	CC, P	J, CC, Dr, Mb, S	32
	500 m	-	J, CC	Mb
	200 m	-	J	CC

Unsuitable
2.5 km: 25/32 = 78%
500 m: 7/32 = 21.8 = 22%
200m = 1/32 = 3%

Suboptimal
2.5 km: 32/32 = 100%
500 m: 31/32 = 96.8 = 97%
200 m: 90.6 = 91%

Medium
2.5 km: 27/32 = 84%
500 m: 6/32 = 18.7 = 19%
200 m: 2/32 = 6 %