# Nesting Requirements of the Northern Goshawk (*Accipiter gentilis atricapillus*) in Southeastern British Columbia, Canada

**East Kootenay Northern Goshawk Project:**
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**prepared by:**

William Harrower[1], Kari Stuart-Smith[2], Karl Larsen[3], & Montana Burgess[1]

[1]High-Country Consulting 6823 Jedora Drive Brentwood Bay BC V8M 1A6, [2]Tembec Enterprises Inc PO Box 4600 Cranbrook BC V1C 4J7,
[3]Thompson Rivers University PO Box 3010 Kamloops BC V2C 5N3

## Abstract

The identification of resources animals select provides valuable insight into the factors that limit populations and control distributions. The objective of our project was to examine selection and use of resources by the northern goshawk (*Accipiter gentilis atricapillus*) during the nesting and fledging life-history stages. This work was conducted in southeastern British Columbia, Canada, from 1998 to 2007. We monitored occupancy at 48 nest areas and between 2004 and 2006 we radio-tagged and followed 34 fledgling goshawks, 20 adult females, and 6 adult males. Fledglings were tagged at 15 nest sites, female goshawks were tagged at 20 sites, and males at six of these 20 sites. At least one parent bird was tagged at each site where we tagged fledgling goshawks. We relocated birds over 1800 times during three year of monitoring program. Using Information-Theoretic techniques, we described the forest characteristics selected by adult goshawks when locating their nest sites within their breeding territories and by fledgling goshawks around the nests while they are still dependent on their parents for food. We also describe course-scale movements of adult birds during the breeding season. We found that goshawks select nesting sites with a relatively large amount of high canopy cover (>40%) forest within 200 m of the nest. The amount of high canopy cover forest remained higher than comparison points up to 1100 m from the nest, but goshawks also will select for forest openings relatively close to the nest (beyond ~ 174 m). Fledgling goshawks selected for continuous areas of forest cover, particularly areas with higher amounts of forest between 40-80 years old within 525 m distance from the nest. Presumably, goshawks selected these younger stands in order to avoid predation. Fledglings also selected areas with greater canopy cover forest and without large amounts of recently-harvested forest (<10 years of age) within 525 m of the nest. Thus, the structural characteristics of forests required by goshawks for nesting are complex, and competing characteristics are selected for at various distances from the nest. Although goshawks do require mature forest stands with high canopy cover close to the nest, a greater diversity of forest types appears to be either tolerated or even required as the distance from the nest increases. Adult female goshawks remain relatively close to the nest during to breeding season, but do make larger movements (up to ~37 km from the nest site). Alternatively, adult male goshawks spend less time near the nest, but do not range as far from the nest (~8 km max) as adult females. During the winter, goshawks that returned to breed in following years remained within 66 km of the nest. Only 30% of the adult females we tagged continued to breed for more than one year within the study area. We will continue our work on goshawks in southeastern British Columbia with the goal of extending our nest monitoring program and refining our resource selection results with the inclusion of nest area productivity data. Additionally, the results presented here as well as our future work efforts will help guide adaptive management trials aimed at determining the most effective forest management techniques for areas around goshawk nest sites.

## Acknowledgements

No project is ever accomplished by a single person, and thus we must thank the many people who helped us complete our work. Without each and all the forest workers who identified and reported nesting goshawks this work could not have been completed. Erica McClaren spent many hours providing comments and suggestions on both our field activities and our analysis. We also benefited from the blood, sweat, and tears of a number of field assistants. Karl Bachman spent years monitoring goshawk nest sites, and his incredible organizational and observational skills allowed us to return to these sites. Jon Michel, Rebecca Rozander, Debbie Bhattacharya, Barry Robinson, Jay Finstad, and Katie Langin all spent a summer on the project collecting telemetry locations, tolerating our constant push for more locations, and dealing with either a lack of sleep or an overabundance of motor homes. Richard Klafki and Melissa Hogg lent their hard work and unique touch to the project. Finally we need to thank all the Tembec planners who have written site prescriptions to accommodate both goshawks and our scientific investigations.

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## 1.0 Introduction:

The northern goshawk (*Accipiter gentilis atricapillus*) is a strong candidate for selection as one indicator of sustainable forest management in southeastern British Columbia (i.e., forest management that incorporates the protection of biodiversity and maintenance of ecological function into forest harvest plans). A major reason for this consideration is that this animal is closely associated with old and mature forests (McGrath et al**.** 2003; Patla 1997; Reynolds et al. 1992; Crocker-Bedford 1990). This situation somewhat parallels the case of the northern spotted owl in coastal forests. However, unlike spotted owls, goshawks are not restricted to coastal forests and as such may pose a greater management concern over a much greater geographic area (McGrath et al**.** 2003; DeStefano 1998). Further, the goshawk is a wide-ranging forest raptor, hunting under the forest canopy for mid-sized prey such as hare, grouse, and squirrels (Squires and Reynolds 1997). The goshawk also requires suitable, large trees in which to perch and nest. Therefore, the presence of goshawks is thought to suggest suitable 'mature' forest structure as well as abundant prey species (Reynolds et al. 1992). These and other general requirements of the goshawk are reasonably well known; however, precise data are lacking on certain critical stages in the goshawk's life history and the impacts of logging on these stages.

Although we lack information on the exact patterns and causes of how forest management impacts reproduction for most organisms, this shortcoming is especially critical when dealing with species, such as the northern goshawk, that are under consideration as indicator or focal species guiding ecosystem management (Roberge and Angelstam 2004). To effectively use this species as an indicator of sustainable forest management, we need to understand how critical life-history stages, such as selection of and behaviour in the post-fledging area (PFA) and nest area, are impacted by disturbances, such as logging. Without these data, the management actions required to maintain goshawks on the landscape cannot be completely defined. This research project attempts to fill this knowledge gap, and in doing so, the forest industry will be able to move forward with pro-active management plans.

***Northern Goshawk Status and Management***: Two subspecies of northern goshawk occur in British Columbia and their status differs dramatically. The Queens Charlotte Goshawk (ssp. *laingi*, AOU 1957 Palmer 1988) ranges across the forests of Vancouver Island, the Queen Charlotte Islands, and the coastal islands and forests of the west coast (McClaren 2004). Preliminary genetic investigations suggest that these populations are distinct from populations in the interior of both Alaska and British Columbia. The interior northern goshawk (ssp. *atricapillus*, AOU 1957 Palmer 1988) occurs through the interior forests of mainland British Columbia and its populations are contiguous with surrounding jurisdictions (McClaren 2004). Current BC management guidelines provide specific management procedures for the Queen Charlotte Goshawk since it is listed as Endangered by the British Columbia government. The Interior Goshawk was previously listed under the British Columbia Forest and Range Practices Act as Identified Wildlife; however, in 2004 it was removed from this list and thus only limited protection exists for occupied nests. This change in management strategy reflects the perceived flexibility of goshawk resource selection and the assumed stability of goshawk populations within interior forests. No current management guidelines exist for the northern goshawk in the interior forests of British Columbia. Despite the status of the Interior Goshawk, there remains considerable interest in determining the most effective methods for managing forests around goshawk nests from the forestry and oil & gas industries, the government, and academic researchers.

A number of management recommendations exist for goshawks in both British Columbia and beyond. Perhaps the most comprehensive management plan currently available for the goshawks was developed for the United States Forest Service for the forests of southwestern forests (Reynolds et al. 1992).

These recommendations require maintaining various percentages of six forest structural stages surrounding identified nests. This management plan focuses on not only protecting structural forest characteristics required by goshawks, but also suggests appropriate management for productive prey populations. In British Columbia, the guidelines for the Queen Charlotte Goshawk suggest the establishment of a 200-ha Wildlife Habitat Areas (WHAs) surrounding active nest sites. Within these areas foresters are directed to restrict road building, harvesting, and thinning. Management recommendations are also made that allow commercial harvest and thinning within a 2200-ha management area surrounding nest sites as long as forestry activities promote forest structural characteristics essential for goshawk foraging. Landscape level suggestions include: the maintenance of late structural stages across the landscape; making sure that these patches exist in a variety of sizes; allocating breeding habitat every 6-8 km; maximizing connectivity between suitable nesting, post-fledging, and foraging habitat; and maintaining suitable foraging habitats (McClaren 2004). Recent suggestions have been made including management planning on two scales (30 ha and 170 ha) surrounding identified nest areas. This may be needed to protect goshawks during the fledgling dependency period (McGrath et al. 2003) and this multi-scale approach is supported by our research (e.g., Harrower 2007). These scales may also be important in adult nest-site selection prior to breeding. At larger scales, partial cutting may benefit long-term goshawk presence by maintaining heterogeneous environments in dynamic forest ecosystems (McGrath et al. 2003; Graham et al. 1994).

***Terminology and Descriptions of Goshawk Life-history Stages:*** During the breeding season, the movements and resource selection of goshawks can be divided into a number of hierarchical levels, including nesting territories, breeding areas, nest areas, nest sites, and the post-fledging area (Figure 1). Goshawks distribution of nests on the landscape can be described using the ideal pre-emptive distribution (Fretwell and Lucas 1970, Pulliam and Danielson 1991), as the nesting territories of breeding pairs are regularly spaced across the landscape (Kruger and Lindstrom 2001, Reich et al. 2004). The components and terminology describing nesting territories can be defined by the behaviour of goshawks during the various life-history stages. Goshawks use individual *nest sites* (i.e., nest trees) in any particular year. Active nest sites are generally identified by the observation of highly aggressive birds defending their nest during the breeding season. An active nest site will normally have a number of *alternative nest sites* surrounding it and all nests will generally occur within the same forest stand. These alternative sites may have been nests using in previous years. The *nest area* encompasses all nest sites in a breeding pair's nesting territory; this area is thought to be defended by a breeding female during courtship, incubation, and the early fledgling-dependency period (Squires and Kennedy 2006). For approximately 40 days after fledging, juvenile goshawks may extensively use a portion of forest surrounding and including the nest area for learning to fly and for protection from predators. This period is termed the *fledgling-dependency period* (FDP) and during this time, fledglings are completely dependent on their parents for food (Kenward 2006, Squires and Kennedy 2006). The area traversed by fledglings during the FDP is the *post-fledging area* (PFA, Squires and Kennedy 2006). Although overlap occurs between the nest area and post-fledging area, these areas are not identical (Figure 1). We term the combined area of all possible PFAs over many years and the nest area as the *breeding area* for that individual nesting territory (Figure 1). The breeding area therefore encapsulates the entire area required to maintain successive nesting events over multiple years at a particular site. This term reflects the need, identified by McClaren et al. (2005), to manage the forests around goshawk nests for PFAs used by fledglings in multiple years, the fact that PFAs created in different years are not identical, and our requirement that PFAs be defined by the movements of fledgling birds. The breeding area is not defined by a single breeding pair and is maintained despite breeding pair turnover. Thus, birds will occupy a breeding area formally used by different, and presumably unrelated, birds. Surrounding and including the breeding area are the adult's *foraging areas*. These areas constitute the entire area traversed by the adult birds during the breeding season and are the areas where these birds hunt for food (Reynolds et al. 1992). Following from these definitions, we define a *nesting territory* as the area in which other goshawks are excluded from nesting due to the presence of a different nesting pairs.

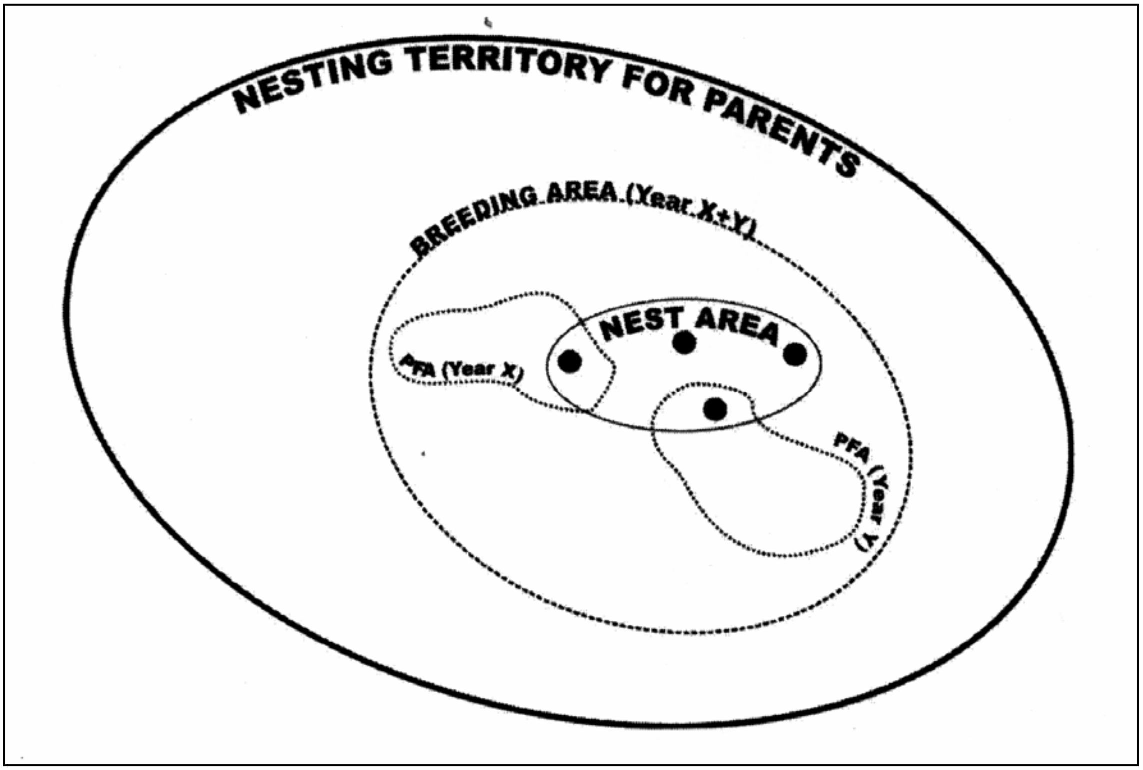


Figure 1: The use of space by different northern goshawk (*Accipiter gentilis*) life-history stages during the breeding season. Dots indicate potential nest trees used in a particular year. We define the nest area by the distribution of these trees over many years. The post-fledgling areas (PFA) for two hypothetical years (x+y) are shown along with the breeding area resulting from the nest area and all possible PFAs from many years. Adapted from Reynolds et al. 1992.

***Industrial Context of Research:*** The forest industry in British Columbia is under increasing pressure to harvest wood in a sustainable fashion. Market forces requiring forest certification and new provincial and federal regulations, geared towards the protection of biodiversity, have increased pressure on forest companies. Further, the growing number of threatened or endangered species means foresters are confronted with the overwhelming task of providing sustainable habitat for a large number of species. The use of *indicator species* has been widely touted as one means to simplify the management of multiple species and habitats on the landscape (e.g., Lambeck 1997; Simberloff 1998). In theory, maintaining viable populations of an indicator species ensures that the resource requirements for a large number of other species are met, thus alleviating the need to monitor and plan for a host of species. Further, management of the forest for the persistence of a host of focal species, each representative of a specific suit of forest values, will provide a simplified framework that encompasses many more forest values that just those protected by managing for a single indicator species (Roberge and Angelstam 2004). Tembec has developed a management plan geared at meeting their objectives of obtaining forest certification and managing forests in a sustainable fashion. This research is a component of that plan and it will feed information directly into Tembec's Criteria and Indicators Framework for Sustainable Forest Management (Tembec 2005). This framework defines key management objectives and identifies specific indicators that will be monitored in order to evaluate Tembec's performance in meeting management objectives. This information will be used to guide adaptive management plans (e.g., Walters 1986) to protect biodiversity and maintain ecological integrity on public forest lands.

## 2.0 Study Area

Our study occupies the operating areas of Tembec Enterprises Inc. in the southern Rocky Mountain Forest District of southeastern British Columbia, Canada; an area of approximately 2.6 million hectares (Figure 2). This diverse area of the province is characterized by grassland, forest, and alpine ecosystems. Large grassland and wetland river valleys (i.e., Southern Rocky Mountain Trench Ecoregion) extend though a mid-elevation forest belt to high alpine tundra and un-vegetated areas (i.e., Columbia Mountains and Highlands and Southern Rocky Mountains Ecoregions). The climate is characterized by warm dry summers and cold winters. Dry valley bottoms occur primarily due to the rain shadow effects of the Columbia Mountains on the western boarder of the region; however, as elevation increases, precipitation significantly increases resulting in forest and alpine ecosystems becoming more prominent.

Goshawks occur primarily within forested areas; therefore we restricted our investigations to these regions. Forested areas lie primarily between 800 and 2100 meters in elevation and can be classified into Ponderosa Pine (PP), Interior Douglas-fir (IDF), Interior Cedar-Hemlock (ICH), Montane Spruce (MS), and Engelmann Spruce-Subalpine Fir (ESSF) biogeoclimatic zones (Meidinger and Pojar 1991). Forests are dominated by interior Douglas-fir (*Pseudotsuga menziesii*), hybrid white spruce (*Picea glauca x engelmannii*), western larch (*Larix occidentalis*) and western red cedar (*Thuja plicata*). Engelmann spruce (*Picea engelmannii*) and sub-alpine fir (*Abies lasiocarpa*) occur at higher elevations. Extensive early seral stands of lodgepole pine (*Pinus contorta*) are common due to widespread fires, trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*) are also common. Ponderosa pine (*Pinus ponderosa*) occurs primarily at low elevations along the grassland forest interface. Our study is restricted primarily to IDF, ICH, and MS biogeoclimatic zones.

Anthropogenic disturbance of forest lands consists primarily of logging, fire suppression, and cattle grazing, these yield over 1.6 million cubic meters of wood harvested each year (BC Ministry of Forests; http://www.for.gov.bc.ca/drm/DistrictMap/about.htm). Substantial amounts of coal mining also occur locally within the Elk Valley. The annual increase in the tourism industry adds substantial development to valley bottoms. However, logging and fire suppression are still the main anthropogenic impacts on goshawk populations.

We chose this study area for a number of reasons. First, Tembec Enterprises Inc. had been identifying and monitoring goshawk breeding areas and describing the surrounding forest since 1998. Thus, a relatively large database of nest locations was available, and this information was instrumental in finding and radio-tagging an appropriate sample of fledgling birds and their parents. Second, this sample of goshawk breeding areas occurred in a region with a diverse range of forest types and a wide range of disturbance patterns. Nests in this area occur in low- to high-elevation forests, at both dry and wet sites, and with a range of disturbance patterns surrounding each nest. This sample provided us with a broad range of variation with which to investigate the patterns of resource selection by nesting goshawks. Finally, a full set of fine-scale descriptions of the forest cover immediately surrounding goshawk nest sites and up-to-date digital forest harvest information was available for us to use during our analysis.

Behavioural observations of goshawks began in 2004, although we used information from Tembec's data base to conduct a retrospective analysis of goshawk nest sites from 1998-2006. During the years of this work (1998-2006), mean monthly temperatures and precipitation values generally lay within the long-term monthly norms (Figures 3 and 4, respectively).

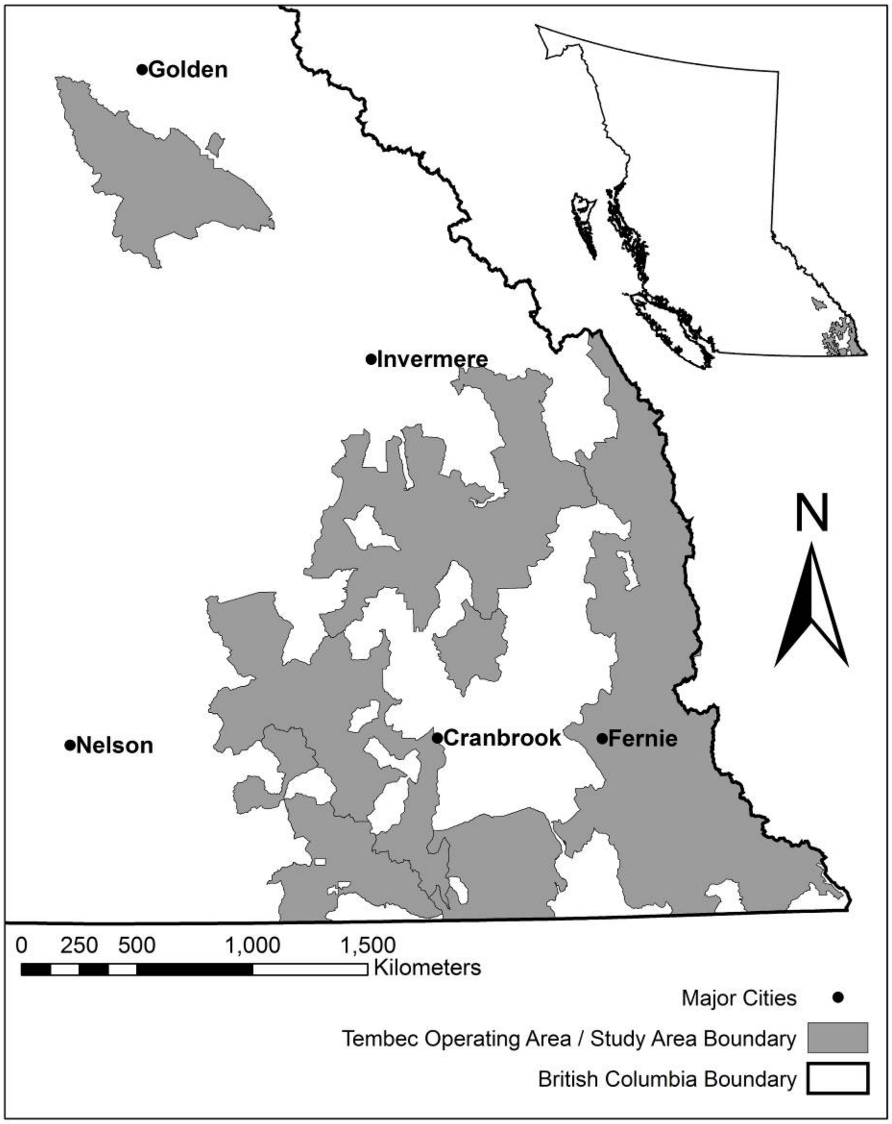


Figure 2: Study area for investigation of resource selection by goshawks in southeastern British Columbia, Canada. Observations were restricted to the forested, operating areas of Tembec Industries Inc.

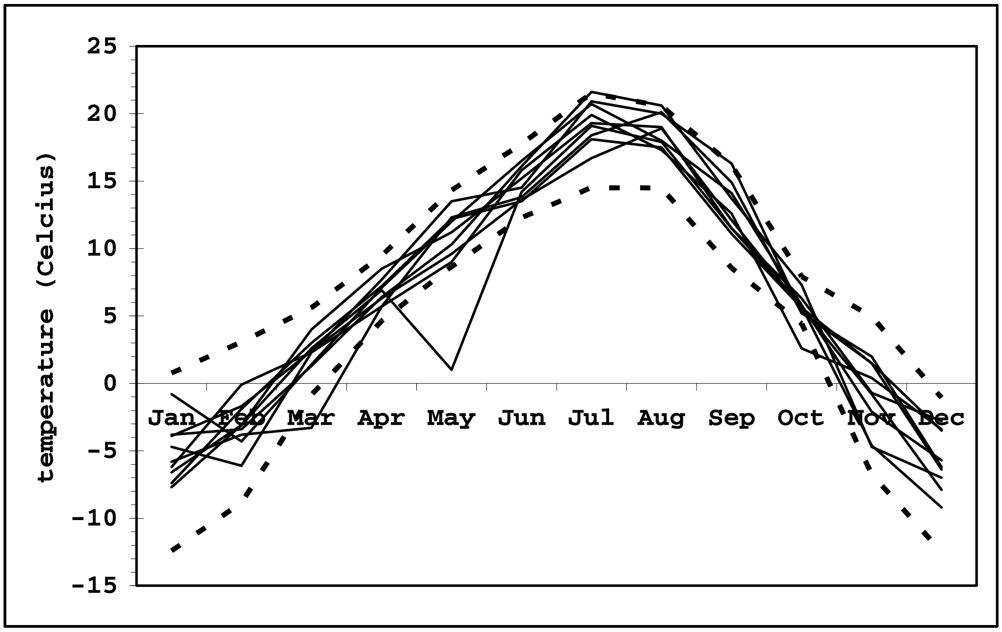


Figure 3: Mean monthly temperatures for Cranbrook City Environment Canada weather station from 1998 to 2006 (solid lines) and 95% confidence intervals for 20-year mean monthly temperatures from 1980-2000 (dashed lines).

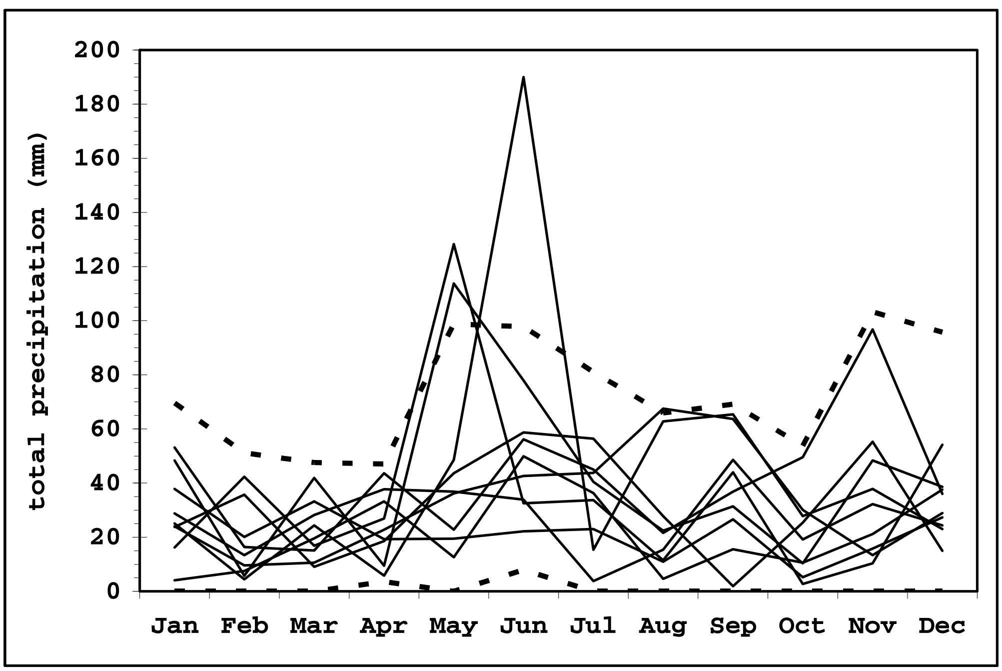


Figure 4: Total precipitation for Cranbrook City from 1998 to 2006 (solid lines) and 95% confidence intervals for 20-year mean monthly temperatures from 1980-2000 (dashed lines).

## 3.0 Objectives

This report summarizes the findings of a three-year study of goshawk movements, behaviour, and resource selection within the East Kootenay region of British Columbia. This collaborative project was performed by Tembec Inc., Thompson Rivers University, and the University of Victoria and will supplement existing Tembec survey and nest monitoring work with detailed information on the behaviour of goshawks surrounding their nests. The project was funded by the BC Ministry of Forests, Forest Science Program (FSP), the National Centers for Excellence, Sustainable Forest Management Network (NCE-SFM), the National Science and Engineering Council (NSERC), and Tembec Inc. The goal of this technical report is to outline methods and summarize the preliminary findings of this project. This report is not intended to provide a detailed description of all the results of our research; rather it is a basic summary to briefly describe the type of work performed and its success. Other documents will provide a more detailed analysis of the individual components of this project (e.g., Harrower 2007 and subsequent peer-reviewed publications). Our specific objectives of the East Kootenay Northern Goshawk Project are as follows:

***Objective 1***: To continue to monitor identified goshawk nest areas for occupancy and productivity, and to identify new nest areas when possible.

***Objective 2:*** To determine which forest characteristics adult goshawks are use and which are selected for in a nest site within their nesting territory.

***Objective 3:*** To describe the movements of fledgling goshawks near nest sites to determine the nature and extent of the post-fledging area.

***Objective 4:*** To determine which forest characteristics fledgling goshawks use and which are selected for during the fledgling dependency period.

***Objective 5:*** To describe the size of adult goshawk foraging areas surrounding identified nest areas using coarse-scale monitoring.

## 4.0 Nest-Area Monitoring and Classification

***Identification and monitoring***: Between 1998 and 2007 occupied nests were identified by investigating reported sightings of aggressive birds during the breeding season (March through August). Most these reports came from field workers in the forest industry and are distributed across the East Kootenay. Each report was confirmed as a goshawk nest by a project biologist visiting the site and noting indications of use (nestlings, fledglings, and/or adults present, fresh green branches in the nest, whitewash streaks near the base of the nest tree, prey remains or pellets nearby), broadcasting calls (adult alarm or juvenile begging calls), and listening for a response. Nest trees were marked and their location recorded with a Garmin76 GPS device (Global Positioning System; GARMIN Corporation, Olathe, Kansas) with the aid of an external antenna (GPS 17-HVS GPS Sensor, GARMIN Corporation, Olathe, Kansas). Each nest area was revisited a minimum of twice each year and project biologists searched suitable forests within a minimum of 500-800 m from previously identified nest sites for new nest sites. Broadcast calls were played continually similar to nest identification investigations.

The activity status of both nest sites and nest areas were determined in each breeding year and classified for future analysis. We classified a nest site as *active* if a goshawk was seen incubating eggs, if nestlings were seen, or if fledglings were observed in or around the nest. Although previous studies have used the defence of a nest area or nest tree as a measure of use, goshawks may defend a nest area during the courtship and nesting periods, but not lay eggs in it (Squires and Kennedy 2006, personal observations). We included these nests in calculations of nest area size, distance between nests, and number of nests per nest area, but they were not included in the nest-tree or nest-stand selection analysis. We also classified nest areas as unused, occupied, and productive. A *productive* nest area was one with an active nest identified in an individual year. An *occupied* nest area was one where a goshawk was observed exhibiting nesting (i.e., not foraging) behaviour at the site, but that incubation, nestlings, and/or fledglings were not observed. We assume that reproduction did not occur at these sites, but these areas were selected for nesting by at least a single member of the breeding pair. This behaviour suggests that a breeding pair excludes the areas available to produce young in that year, despite the area being selected for breeding. At sites where we had radio-tagged both members of the breeding pair, we often observed only a single bird during investigations of occupied sites. Unused nest areas are those that were monitoring in that breeding year and there was no sign of goshawk activity observed. The nest monitoring program has been extremely successful, and has identified 125 nest trees at 48 nest areas by 2007 (Figure 5).

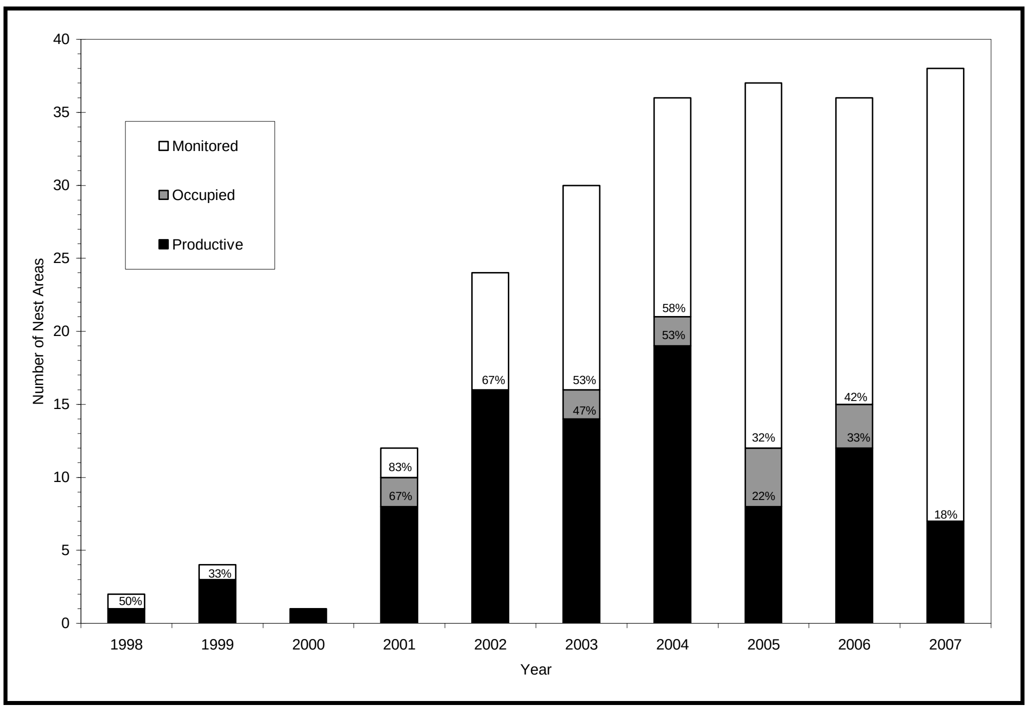


Figure 5: Number of goshawk nest areas (n=48) and their activity status found between 1998 and 2007 in southeastern British Columbia. The white bars represent the total number of nest areas monitored (under study) in a given year; the grey bars represent the nest areas occupied (goshawks observed) in the specified year; the black bars represent the number of nest areas considered productive (incubated eggs or produced nestling/fledglings) during a year. The percentages of occupied and productive nest areas of the total monitored nest areas for each year are shown above the respective bars.

***Characterization of Forest Types and Proximate Variables***: We quantified selected variables in order to describe the characteristics of both the nest site, nest area, and the post-fledgling area. We then compared them to randomly located comparison points assigned separately for each life-history stage. Nest sites were evaluated in relation to comparison points measured at ground plots located within 200 m of the nest site; nest stands were evaluated in relation to comparison points located with 5 km of the nest site. To measure resource variables (Table 1 and 2), we reclassified digital forest cover information by categorizing stands by their dominant tree species and age class using data developed by the BC Ministry of Forests and Range from air photo interpretation. We defined a *stand* as an area of forest that is composed of trees with relatively uniform composition and of similar age. Age classifications for stands that had not been harvested were projected age classes from the date of aerial photo interpretation and corrected for forest harvest by year.

Our classification of forest types was based on break points that we considered relevant to goshawks. For each location or comparison point, we calculated the distance to the nearest permanent road and distance to nearest harvested forest stand <10 years old. Young forest stands were defined as those stands between 41 and 80 years of age and mature stands were >80 years old. Non-forested stands were those that were either logged within the last 10 years or where no forest occurred (e.g., wetland or other opening). We classified high-canopy-cover stands as those canopy cover >40% estimated from aerial photo interpretation as this was the mean canopy cover present in my study area. Larch, Douglas-fir, and pine stands were those with *Larix* sp., *Pseudotsuga menziesii*, or *Pinus contorta* as the leading tree species, respectively. Seven tree species classes were defined. These are Mixed Pine (Lodgepole pine leading by <80% canopy cover), Spruce-Balsam (Spruce or Sub-alpine fir leading), Larch (western larch leading), Pine (lodgepole pine leading and >80% of canopy cover), Deciduous (a deciduous tree species leading), Fir (Douglas-fir leading), other (a tree species other than those listed is leading), and non-forest (the polygon is not forested). A 30-m pixel size was used to determine all stand measurements and a 10-m pixel size was used to measure proximity variables.

Table 1: Summary of variables used to describe the characteristics of goshawk nest trees, nest stands, and randomly selected areas within 200 m of the nest tree in southeastern British Columbia, Canada.

| Variable | Description and/or Method of measurement |
|---|---|
| Nest Tree Diameter (cm) | Diameter at breast height measured in cm |
| Nest Tree Elevation (m) | TRIM[1] DEM[2] from 30 m raster |
| Nest Tree Slope (degrees) | TRIM[1] DEM from 30 m raster |
| Nest Tree Aspect (degrees) | TRIM[1] DEM from 30 m raster |
| Nest Tree Canopy Cover (%) | Average value of 4 measurements of spherical densitometer |
| Tree 2-10m Canopy Cover (%) | Visual estimate from 3.99 m fixed radius plot |
| Tree <2m Canopy Cover (%) | Visual estimate from 3.99 m fixed radius plot |
| Small Tree (<10 m) Canopy Cover (%) | Visual estimate from 3.99 m fixed radius plot |
| Shrub Canopy Cover (%) | Visual estimate from 5.64 m fixed radius plot |
| Veteran Tree Height (m) | Height in meters of the trees that are older and taller than the trees comprising the main tree canopy and are remnant from the stand that occupied the site prior to a major disturbance (i.e., stand initiating event) |
| Dominant Tree Height (m) | Height in meters of the trees in the nest stand that are more vigorous than the trees comprising the main tree canopy |
| Main Canopy Tree Height (m) | Height in meters of the trees that comprise the largest amount of the tree canopy |
| Sub-canopy Tree Height (m) | Height in meters of trees over 10 m but that do not reach the main tree canopy, these trees may form a secondary canopy in multi-layered stands |

[1] TRIM = British Columbia Terrain Resource Inventory Mapping
[2] DEM = Digital Elevation Model

Table 2: Summary of variables used to describe the characteristics of goshawk nest trees and nest-stand level comparison plots within 5 km of the nest tree in southeastern British Columbia, Canada.

| Variable | Description and/or method of Measurement |
|---|---|
| Distance to Road (m) | Euclidean distance in meters measured to the nearest permanent road, including forestry roads |
| Distance to Water (m) | Euclidean distance in meters measured to either the nearest mapped wetland, lake, or permanent stream |
| Distance to Harvest (m) | Euclidean distance in meters measured to the nearest harvested forest stand logged since 1971 (i.e., <36 years old) |
| % of Young Forest[1,2] | Percentage of the area in each of four circular buffers[1] with 41-80 year old stands |
| % of Mature Forest[1,2] | Percentage of the area in each of four circular buffers[1] with >80 year old stands |
| % of Larch Forest[1] | Percentage of the area in each of four circular buffers[1] with larch as the leading tree in the stand |
| % of Doug-fir Forest[1] | Percentage of the area in each of four circular buffers[1] with Douglas-fir as the leading tree in the stand |
| % of Canopy Cover >40% | Percentage of the area in each of four circular buffers[1] with stand canopy cover >40% |
| Average Stand Area ($m^2$) | Average area in square meters of all stands within circular buffer, stands are defined by each unique combination of age[2] and species[3] classification |
| Total Edge Length (m) | Total length of the edge in meters of all stands within circular buffer, stands are defined by each unique combination of age[2] and species[3] classification |

[1] Four circular buffers used to define explanatory variables (200 m, 500 m, 800 m, 1100 m)
[2] Three age classes defined: Initiation (0-40 years), Young (41-80 years), and Mature (80+ years)
[3] Seven species classes defined: Mixed Pine (Lodgepole pine leading by <80% canopy cover), Spruce-Balsam (Spruce or Sub-alpine fir leading), Larch (western larch leading), Pine (lodgepole pine leading and >80% of canopy cover), Deciduous (a deciduous tree species leading), Fir (Douglas-fir leading), other (a tree species other than those listed is leading), and non-forest (the polygon is not forested).

## 5.0 Nest-Site and Nest-Stand Selection

***Study design and methods***: Two types of nest site selection were identified following Johnson (1980): nest-site and nest-stand levels and more detailed methods and results can be found elsewhere (Harrower 2007). We defined *nest-site selection* as selection of a tree within a circle with a radius of 200 m (12.6 ha) in order to represent the typical size of a goshawk nest stand. To assess how the characteristics of the nest tree differed from the characteristics of trees available for nesting within the stand, we employed a used versus unused design (Sampling Protocol C, Design III: Manley et al. 2002). The forest characteristics at each nest tree (used) and at seven comparison trees (unused) situated at random distances (1-200 m) and random bearings ($1^o$-$360^o$) from the nest tree were described by Tembec personnel and we used these data in our analysis. We defined *nest-stand selection* as the selection of a nest tree within a nesting territory (i.e., comparison points selected within 5 km). Forest cover variables were measured at nest trees (used) and 10 comparison points (unused) placed randomly within 5 km of the nest tree (Sampling Protocol C, Design III: Manley et al. 2002). We chose a distance of 5 km to represent the minimum distance between the geographic centres of nest areas and thus approximate nesting territory size. The geographic centre of nest areas was determined by calculating the weighted mean of the Euclidean distance between nest area centres. We used a conservative estimate of nesting territory size based on our minimum-observed inter-nest-area distance (mean = 4.67 km, SE = 4.49, n = 35).

We quantified characteristics of the nest tree and nest stand, and, when possible, compared them to the analogous data collected from nest-site comparison plots. Combinations of variable and fixed radius plots were used to characterize the area around both nest trees and comparison points (Table 3). We measured a series of stand- and patch-level variables to determine the differences between nest trees and comparison points in order to assess nest-stand level selection (Table 4). We identified four grains of measurement for explanatory variables that were perceived relevant to goshawks when they were selecting a nest location. These grains were: (1) the nest stand and primary area used prior to hard-penning of fledgling feathers (a 200-m radius buffer, 13-ha [Reynolds et al. 1992 and personal observations]), (2) a standard conservative post-fledging area (a 500-m radius buffer; 79-ha [Woodbridge and Detrich 1994]), (3) the initial post-fledging area estimate (a 800-m radius buffer; 201-ha [Kennedy et al. 1994 and personal observations]), and (4) roughly the largest area observed between alternative nests (1100-m radius buffer; 380-ha).

***Nest-site descriptions***: We analysed data from 36 goshawk nest areas that were located between 1998 and 2005, and females were observed incubating eggs in nests at 65 individual trees at these nest areas. Nests were primarily in Douglas-fir (*Pseudotsuga menziesii*, 48%) and western larch (*Larix* spp., 32%). Other nests were located in lodgepole pine (*Pinus contorta*, 8.0%), spruce (*Picea* spp., 6%), and deciduous (4%) trees. The majority of nests were in trees that comprised the main tree canopy (62%), but additional nests were located in large old trees that reached above the main tree canopy (29%), and trees greater than 10 m in height yet still below the main canopy (9%). Generally, a nest was located 1/3-1/2 of the way up the tree, usually on the first major branch whorl, and was always against the trunk of the tree. Nest trees occurred in six different biogeoclimatic subzones (31% dry moist, Interior Douglas-fir; 31% dry cool, Montane Spruce; 17% moist warm Interior Cedar-Hemlock; 15% moist cool, Interior Cedar-Hemlock; 6% dry cool, Engelmann Spruce-Sub-alpine Fir), and occurred in 8 different stand types (25% mature larch; 20% mature Douglas-fir; 23% mature spruce-balsam; 12% young mixed-pine or other stand type; 3% mature, pure-pine or deciduous; and 2% mature, mixed-pine). Neither nests nor comparison points were located on any particular aspect relative to those available on the landscape (used mean = $94.2^o$, p-value 0.4312; unused mean = $88.0^o$, p-value = .2451).

The average distance between nest trees within the 36 nest areas was 203.6 m (SE = 19.91, n = 96).

Table 3: Mean values, standard errors (SE), and ranges of values for descriptions of the characteristics of goshawk nest trees and nest-tree level comparison plots within 200 m of the nest trees in southeastern British Columbia, Canada.

| Variable (n) | Nest Plots | | | Comparison Plots | | |
|---|---|---|---|---|---|---|
| | mean | SE | range | mean | SE | range |
| Nest Tree Diameter (cm, n = 65) | 49.5 | 1.99 | 17.0-91.0 | - | - | - |
| Nest Height (m, n = 65) | 14.6 | 0.51 | 7.1-25.0 | - | - | - |
| Nest Tree Elevation (m, n = 65) | 1283 | 23.3 | 865-1680 | - | - | - |
| Nest Tree Slope (%, n = 65,650) | 18.0 | 1.00 | 1.9-34.5 | - | - | - |
| Stand Canopy Cover (%, n = 63, 466) | 89.7 | 1.98 | 15.0-99.7 | 81.1 | 0.89 | 3.0-100.0 |
| Tree 2-10m Canopy Cover (%, n = 63, 466) | 6.4 | 0.89 | 0.0-27.0 | 7.0 | 0.40 | 0.0-75.0 |
| Tree <2m Canopy Cover (%, n=63, 466) | 2.3 | 0.48 | 0.0-20.0 | 2.7 | 0.32 | 0.0-70.0 |
| Small Tree Canopy Cover (%, n = 63, 466) | 8.7 | 1.2 | 0.0-40.0 | 9.7 | 0.64 | 0.0-100.0 |
| Shrub Canopy Cover (%, n = 63, 466) | 12.2 | 1.8 | 0.0-75.0 | 14.7 | 0.79 | 0.0-95.0 |
| Veteran Tree Canopy Height (%, n = 17, 95) | 33.8 | 1.61 | 22.5-44.9 | 33.3 | 0.66 | 19.1-47.3 |
| Dominant Tree Canopy Height (n = 61, 430) | 27.9 | 0.81 | 18.1-42.0 | 26.8 | 0.31 | 15.3-85.2 |
| Main Tree Canopy Height (n = 48, 369) | 22.8 | 0.75 | 10.2-37.0 | 20.5 | 0.22 | 11.3-35.0 |
| Sub-canopy Tree Height (n = 33, 236) | 15.0 | 0.55 | 10.0-21.8 | 14.3 | 0.18 | 10.0-24.0 |

Table 4: Mean values, standard errors (SE), and ranges of values for descriptions of the characteristics of goshawk nest trees and nest-stand level comparison plots within 5 km of the nest trees in southeastern British Columbia, Canada.

| Variable | Grain (m) | Nest Points (n = 65) | | | Comparison Points (n = 715) | | |
|---|---|---|---|---|---|---|---|
| | | Mean | SE | range | mean | SE | range |
| Dist to Road (m) | NA | 170.4*** | 24.87 | 18.2-1509.0 | 486.1 | 24.90 | 0.3-4062.0 |
| Dist to Water (m) | NA | 249.3** | 23.77 | 6.7-1058.0 | 198.6 | 7.26 | 0.0-1181.0 |
| Dist to Harvest[1] (m) | NA | 384.5*** | 68.05 | 0.0-3876.0 | 791.6 | 33.4 | 0.00-4007.0 |
| % of young | 200 | 14.3 | 3.02 | 0-100 | 18.7 | 1.14 | 0-90 |
| | 500 | 15.3 | 2.28 | 0-100 | 18.4 | 0.97 | 0-70 |
| | 800 | 16.8 | 2.32 | 0-100 | 18.0 | 0.88 | 0-70 |
| | 1100 | 17.8 | 2.30 | 0-90 | 18.0 | 0.82 | 0-70 |
| % of mature | 200 | 54.8* | 4.06 | 0-100 | 47.3 | 1.34 | 0-1.0 |
| | 500 | 50.2** | 2.80 | 0-100 | 43.9 | 1.07 | 0-80 |
| | 800 | 48.1** | 2.45 | 0-100 | 42.9 | 0.94 | 0-80 |
| | 1100 | 45.3 | 2.35 | 0-100 | 42.3 | 0.85 | 0-80 |
| % of larch leading | 200 | 29.5 | 3.29 | 0-100 | 30.6 | 1.20 | 0-100 |
| | 500 | 31.1 | 2.18 | 0-100 | 34.5 | 1.01 | 0-80 |
| | 800 | 31.9* | 2.01 | 0-100 | 36.0 | 0.88 | 0-80 |
| | 1100 | 6.6** | 0.98 | 0-50 | 4.5 | 0.27 | 0-20 |
| % of Douglas-fir leading | 200 | 19.6 | 3.09 | 0-100 | 21.3 | 1.21 | 0-90 |
| | 500 | 22.6 | 3.03 | 0-90 | 19.6 | 0.98 | 0-80 |
| | 800 | 22.5** | 3.04 | 0-90 | 18.7 | 0.88 | 0-70 |
| | 1100 | 21.3* | 2.88 | 0-80 | 18.4 | 0.82 | 0-70 |
| % of high-canopy-cover[2] | 200 | 74.5*** | 3.38 | 0-100 | 55.0 | 1.31 | 0-100 |
| | 500 | 65.0*** | 2.82 | 0-100 | 52.4 | 1.08 | 0-100 |
| | 800 | 60.8*** | 2.52 | 0-100 | 51.5 | 0.95 | 0-90 |
| | 1100 | 58.2** | 2.26 | 0-100 | 51.0 | 0.85 | 0-90 |
| Average Stand Area (ha) | 200 | 4.04*** | 0.342 | 0.97-13.00 | 5.20 | 0.140 | 0.63-13.00 |
| | 500 | 7.41*** | 0.432 | 1.78-15.70 | 16.00 | 0.706 | 0.68-78.52 |
| | 800 | 9.91*** | 0.594 | 2.01-22.34 | 24.04 | 1.520 | 1.26-200.00 |
| | 1100 | 11.61*** | 0.645 | 2.77-25.00 | 28.11 | 2.382 | 2.13-380.00 |
| Total Edge Length (km) | 200 | 45.75* | 3.985 | 8.54-140.00 | 40.15 | 1.099 | 4.07-140.00 |
| | 500 | 75.50** | 4.351 | 27.10-151.82 | 61.57 | 1.223 | 7.02-157.34 |
| | 800 | 97.78*** | 4.294 | 50.53-180.00 | 82.78 | 1.425 | 7.02-220.00 |
| | 1100 | 125.22*** | 4.906 | 58.38-200.00 | 104.96 | 1.752 | 7.60-270.00 |

Significance Levels (Wald) = *** <0.001, ** <0.05, *<0.10

[1]harvested stands are those logged within the last 36 years

[2]high-canopy-cover is all stands with canopy cover >40%

***Nest-Site Selection***: We assessed the multivariate selection of explanatory variables using Information-Theoretic (IT) approaches (Burnham and Anderson 2002) and matched case-control multivariate logistic regression (Hosmer and Lemeshow 2000). We estimated the best plausible approximation of the information in our data, by assessing the relative Kullback-Leibler distance between multiple competing models (Burnham and Anderson 2002). We were able to assess the relative importance of only those variables we assumed to be important to goshawks *a priori*. Unlike standard logistic regression, matched case-control logistic regression allows the pairing of used sites with comparison points. This pairing controls for the random effect between strata (nest-areas in this case) and reduces some autocorrelation problems typical of spatial and temporal data (Whittington et al. 2005; Hosmer and Lemeshow 2000). A matched case-control logistic model's interpretation is identical to standard logistic regression and, because the number of controls per case reduces error, we were better able to sample our unused areas by using multiple control points per case (Whittington et al. 2005, Manley et al. 2002, Hosmer and Lemeshow 2000).

We selected variables for inclusion in our candidate set of models by examining the collinearity between explanatory variables. For pairs of variables with Spearman rank correlations >0.7, we selected the variable that explained the greatest amount of variation in the data for inclusion in our candidate set (i.e., variable with the lowest $AIC_c$ score: Burnham and Anderson 2002). For the nest-stand selection investigation, we removed variables that were deemed uninformative by examining the Wald statistic of the single variable statistical model and removing variables with a p-value <0.10. We developed our final set of candidate models for nest-site and nest-stand levels within two operating constraints: the number of explanatory variables needed to be 1/10 the number of observations (Peduzzi et al. 1996), and the number of candidate models (R) was required to be less than the number of observations (R<n [Burnham and Anderson 2000]).

We ranked candidate models in order of decreasing parsimony using Akaike's Information Criterion for small samples ($AIC_c$). Final models were developed using a model-averaging approach for all variables from models with a <4 AIC-unit change from the most parsimonious candidate. Since we employed a used versus unused design, we assessed model fit by calculating the area under the receiver operating characteristic (ROC) curve (Boyce et al. 2002, Hosmer and Lemeshow 2000). All geographic analysis and data collection were performed in ARCGIS, ArcEditor 9.1 (Environmental Systems Research Institute, Redlands CA) and statistical analyses performed in R v.2.4.1 (R Core Development Team 2007).

We examined all combinations of the remaining variables at the nest-site level and each model received substantial support (Table 5), but when the models were averaged, the variables representing the canopy cover surrounding the nest tree had the strongest influence (Table 6). However, an examination of model fit provided an ROC score of 0.56, suggesting the model had no discriminatory power (Hosmer and Lemeshow 2000) and thus does not provide any information about selection.

Table 5: Model negative log-likelihood (-loglik), number of parameters (K), Akaike's information criterion for small sample sizes ($AIC_c$), the change in Akaike's information criterion for small sample size from most parsimonious model ($\Delta AIC_c$), and Akaike's weight ($\omega$) for the final candidate set of models used to examine nest-tree selection by goshawks in southeastern British Columbia, Canada.

| Model | -loglik | K | $AIC_c$ | $\Delta AIC_c$ | $\omega$ |
|---|---|---|---|---|---|
| Stand canopy cover | 122.74 | 2 | 249.68 | 0.0000 | 0.5077 |
| Stand canopy cover + shrub canopy cover | 122.37 | 3 | 251.14 | 1.4644 | 0.2441 |
| Stand canopy cover + small tree canopy cover | 122.74 | 3 | 251.88 | 2.1989 | 0.1691 |
| Stand canopy cover + small tree canopy cover + shrub canopy cover | 122.37 | 4 | 253.41 | 3.7313 | 0.0786 |

Table 6: Model-averaged regression coefficients ($\beta$), standard errors (SE), Wald statistics ($\beta$/SE) and relative importance of explanatory variables (ω+). Selection based on $\Delta AIC_c$<4, and models are ordered by their decreasing explanatory strength ($\omega$+). ROC = 0.5621.

| Variable | $\beta$ | SE | Wald | $\omega$+ |
|---|---|---|---|---|
| Stand canopy cover | 4.7921e-02 | 1.4588e-02 | 3.28489 | 0.9995 |
| Shrub canopy cover | -8.9139e-03 | 1.4078e-02 | -0.63318 | 0.3227 |
| Small tree canopy cover | -6.1493e-04 | 1.4299e-02 | -0.04301 | 0.2477 |

$\omega$+ indicated the sum of ω in the previous table

***Nest-Stand Selection***: Of all the variables we examined at the nest-stand level, 22 were significant at the Wald <0.10 level (Table 4). Variables measured across different spatial grains were highly correlated. For each explanatory variable, we chose the spatial grain that explained the most variation in our data (i.e., had the lowest $AIC_c$ value). Thus, the final variables included in our candidate set of models were percentages of the following forest attributes: mature forest stands at 800 m, larch leading stands at 800 m, Douglas-fir leading stands at 800 m, stands with canopy covers >40% at 200 m, the average stand sizes within 500 m, and the total length of stand edges within 1100 m. The distance to the nearest water features, permanent roads, and recently harvested stand measurements were all included in the final set of candidate variables. To ensure we had ≥10 data points for each explanatory variable, we developed a set of plausible candidate models, each with <7 parameters (6 explanatory variables and 1 conditional requirement). In this set we included as many combinations of variable types as possible (i.e., stand type, canopy cover, age class, distance to landscape feature, and patch characteristics) and tested each variable individually. Our final candidate set included 64 different models.

From our final candidate set, six different variables were included in plausible models ($\Delta AIC_c$ <4, Table 7 and 8) and these two models received considerable support ($\omega$+=0.8833, Table 8). Only one additional variable (% mature forest within 800 m) was included in models that received any support ($\Delta AIC_c$ <10) and it was included in only one model that received little support ($\omega$=0.0150). Goshawks selected nest sites with relatively more areas with stands composed of >40% canopy cover within 200 m of the nest, for locations with relatively more stand edges within 1100 m, and locations with smaller average stand sizes within 500 m of the nests. Goshawks preferred to nest farther from water features, but closer to forest roads and recently-harvested forest stands (<36 years). The final model received an ROC score of 0.8311 suggesting that this model has excellent discriminatory power (Hosmer and Lemeshow 2000).

Table 7: Model negative log-likelihood (-loglik), number of parameters (K), Akaike's information criterion for small sample sizes ($AIC_c$), the change in Akaike's information criterion for small sample size from most parsimonious model ($\Delta AIC_c$), and Akaike's weight ($\omega$) for plausible models used to examine nest-stand level selection by goshawks in southeastern British Columbia, Canada. Selection was based on ΔAICc <10

| Model | -loglik | K | $AIC_c$ | $\Delta AIC_c$ | $\omega$ |
|---|---|---|---|---|---|
| dist.rd[1]+dist.water[2]+dist.cut[3]+cc.200[4]+ area.500[5]+edge.1100[6] | 104.23 | 7 | 224.43 | 0.0000 | 0.4857 |
| dist.rd+dist.water+cc.200+ area.500+edge.1100 | 105.61 | 6 | 224.67 | 0.2430 | 0.3976 |
| cc.200 | 107.73 | 2 | 228.90 | 4.4743 | 0.0495 |
| dist.cut | 109.34 | 2 | 229.69 | 5.2648 | 0.0334 |
| dist.water | 108.54 | 2 | 230.53 | 6.0970 | 0.0220 |
| dist.rd+dist.water+dist.cut+ ma.800[7]+edge.1100 | 110.13 | 6 | 231.29 | 6.8573 | 0.0150 |

[1]distance to nearest road, [2]distance to nearest water, [3]distance to recently harvested forest stand, [4] % canopy cover >40% within 200 m, [5]average patch area within 500 m, [6]total edge length within 1100 m, [7] % of mature forest within 800 m.

Table 8: Model-averaged regression coefficients ($\beta$), standard errors (SE), Wald statistics ($\beta$/SE) and relative importance of explanatory variables ($\omega$+). Selection based on ΔAICc<4 and models are ordered by their explanatory strength ($\omega$+). ROC = 0.8311

| Variable | $\beta$ | SE | Wald | $\omega$+ |
|---|---|---|---|---|
| % of cc.200[1] | 0.0272 | 0.0075 | 3.63239 | 0.9328 |
| distance to nearest water | 2.5582e-03 | 8.8523e-04 | 2.91676 | 0.9203 |
| distance to nearest road | -3.2108e-03 | 8.8820e-04 | -3.61495 | 0.8983 |
| length of edge.1100[2] | 1.2794e-05 | 6.9184e-06 | 1.84938 | 0.8983 |
| average patch area.500[3] | -1.3467e-05 | 4.3848e-06 | -3.07185 | 0.8833 |
| distance to harvested forest stand | -5.5737e-04 | 8.1224e-04 | -0.68621 | 0.5341 |

ω+ indicated the sum of ω in the previous table
[1]high canopy cover within 200 m, [2]total amount of stand edge within 1100, [3]average patch size within 500 m

## 6.0 Capture and Radio-Tagging

We chose sites to mark goshawks from the occupied nests identified during nest-area monitoring. We chose to radio-tag birds at nest areas offering a range of amounts mature forest stands (>80 years old) within 500 m of the nest. Not all nest areas have continuous mature forest surrounding the nest, and we, therefore, attempted to select sites with clear boundaries between young (41-80 years) and mature (>80 years) forest (Table 2). These selection criteria provided a clear contrast to fledglings between suitable and unsuitable areas. We restricted the nests at which we marked birds to a number of biogeoclimatic zones. Birds were marked within Interior Douglas Fir (IDF), Montane Spruce (MS), and Interior Cedar Hemlock (ICH) zones in order to reduce variability in forest structure due to altitudinal changes in ecosystem type. Sites also were chosen based on the distribution of nests within the study area in order to reduce travel time between nests and increase the number of nests we were able to sample.

We monitored potential nest sites during late May and early June in order to determine the exact numbers and ages of nestlings. From 2003 to 2006, we captured and radio-tagged fledgling and adult goshawks. Nestlings were observed using binoculars and spotting scopes over a minimum of two days in order to target the age of the nestlings and determine the most effective date of capture for both adult and fledgling birds. We attempted to capture and radio-tag goshawk nestlings when they were between 20 and 25 days old. Nestlings were aged using visual observation of feather development following Boal (1994). When appropriate capture dates were determined, we approached nest sites and attempted to capture both adult goshawks and all nestlings.

Before climbing trees to capture nestling goshawks, we attempted to capture the adult birds. The adult female goshawks were netted by prompting the birds to fly into a modified Dho-gaza trap, using as a lure either a captive tame Great Horned Owl (*Bubo virginianus*), or a robotic replica. Adult birds were measured (weight, tarsus width, wing cord, talon length, beak length, moult status, etc.), radio-tagged, and samples taken for DNA analysis and West Nile virus monitoring. The adult females were outfitted with an 18-g backpack style radio-transmitter (Biotrack Limited, Dorset UK, Model# TW51 with mortality switches) and banded with USFW Service and colour auxiliary bands (Acraft Sign and Nameplate Co. Ltd. Edmonton, AB, Canada). These transmitters were designed to provide 1.5-years (male) to 2.5-years (female) of continuous monitoring.

Following the capture of adult birds, we climbed nest trees in order to obtain nestlings. We marked all siblings at a nest in order to determine annual nest area production (number of nestlings produced, corrected for post-fledging mortality), and to determine if large differences exist between the movements of siblings. Nestlings were processed in a similar manner to adult birds; however, they were outfitted with 8.5g, tarsal mount, VHF radio transmitters (Advanced Telemetry Systems, Isanti MN USA, Model# A5040 with mortality switches) and returned to the nest. These transmitters were attached so that the transmitter would fall away from the tarsus after approximately six months. All birds were banded with United States Fish and Wildlife (USFW) and colour auxiliary bands (Acraft Sign and Name Plate Company, Edmonton AB, Canada) to facilitate the remote determination of the sex of birds we observed during field activities and the return of birds that left the study area. We determined the sex of birds we handled using tarsal width measurements, following Kenward et al. (1993).

## 7.0 Monitoring Radio-Tagged Birds

We began monitoring both juvenile and adult birds immediately following capture and before nestlings fledged. All fledgling relocations were obtained by homing in on the birds location using radio-telemetry receivers (Communications Specialists Inc. R-1000, Orange, California) until the bird was sighted. The location was recorded in a handheld GPS unit (Garmin 76GPS or 72GPS, Global Positioning System, GARMIN Corporation, Olathe, Kansas) by averaging 100 successive locations and until the variance reached some minimal target of under 15 m. When possible, an external antenna (GPS 17-HVS GPS Sensor; GARMIN Corporation, Olathe, Kansas, USA) was used to increase the accuracy of locations. All attempts were made to minimize the disturbance to fledglings. Many locations were recorded by marking the location of the bird and determining the coordinates at a later time.

Two monitoring schedules were followed to determine the location of fledgling birds. First, we attempted to locate all fledglings at least once per day in order to document their broad-scale movements within the PFA. These data were used to define the PFA and to determine which forest characteristics the fledglings were selecting. To supplement this information and to provide data for future investigations of the fine-scale movements of fledglings (Harrower unpublished data); we performed a series of short-term, intensive monitoring sessions at selected sites. During these daily sessions, fledglings were located hourly. We documented movements from one hour before and one hour after sunrise and sunset.

Preliminary observations of fledgling movements suggested that they made a movement >30 m no more than once per hour. Therefore, we used this as the minimum distance for achieving a valid trade-off between location and/or forest cover error and movement patterns (Jerde and Visscher 2005). Additionally, we observed that fledglings were able to traverse the entire PFA available to them during any one movement. Thus, hourly locations were assumed to be biologically independent, and we used the locations collected during the intensive monitoring sessions to supplement the other non-focal data. Although this rationale is subject to debate, the information gained by increasing the number of locations used in the analysis, for a life-history stage of limited duration, supports a more liberal approach to statistical independence (Kernahan et al. 2001).

Nestlings were monitored from nestling to juvenile stages in order to determine both fledge date and dispersal date. We recorded *fledge date* as the first day that a nestling was observed perching on a tree other than the nest tree, and marked the *dispersal date* as the day prior to locating the bird farther than 1.6 km from the nest site on two consecutive days (Weins 2004). Following dispersal from the nest area we attempted to located juvenile animals by ground telemetry. This was largely unsuccessful; therefore, we attempted aerial telemetry locations in conjunction with aerial telemetry locations for the seasonal movements of adult birds. However, due to the extensive dispersal movements of juvenile birds (Weins 2004), operating times of tarsal mount transmitters, and the limited resources for aerial flights, no information was collected on the natal dispersal movements of juvenile birds.

Adult goshawks were relocated opportunistically throughout both the nesting and fledging-dependency periods (June-August) and their locations determined through standard triangulation techniques of >3 strong bearings (Kenward 2001). Bearings were plotted on 1:20 000 topographic forest cover maps and the most probable location determined. Following assessment of the blind re-location of stationary transmitters, and through the estimation of the quality of plotted bearings, we estimated the average telemetry error to be 316 m (SE = 52.3, n = 22), which is an error estimate we feel adequately placed birds within forest stands. Our goal in the location of adult birds was simply to document their general location as we did not intend to analyze their fine-scale movements or fine-scale resource selection.

Adult birds were also located using aerial telemetry during winter months (October through March). Locations were attempted monthly in an effort to document the broad-scale seasonal movements of adult birds. A Cessna 182 airplane was used to search for the radio transmitter signals and to locate each goshawk. We used a scanning telemetry receiver (Communications Specialists Incorporated, Orange CA USA, Model #R-1000) set to a 2-second scan interval to pick up radio signals from transmitters. Our standard search path covered the Rocky Mountain Trench and associated side drainages from approximately Fairmont Hot Springs Resort south to the United States-Canada border. We also searched the southeast corner of the Rocky Mountain Forest District, east to the Alberta-British Columbia border; including the Elk Valley and Flat Head regions of southeastern British Columbia. This search area encompassed the majority of the southern half of the Rocky Mountain

Forest District and covered a large area surrounding the nests of marked goshawks. We are confident we located each bird that did not make significant movements away from the study area.

All locations were entered into a Geographic Information System (GIS) for subsequent data collection and analysis. The Euclidean distance and bearing to the nest was calculated for each location. We documented the extent of juvenile and adult movements away from the nest tree during the post-fledging period. We estimated the 95% fixed kernel home range sizes for each fledgling using program HOME RANGER (version 1.5, Ursus Software, Revelstoke, BC Canada). Kernel home ranges were calculated using an *ad hoc* estimation of the smoothing parameter and error rates were obtained from bootstrap estimates derived from 1000 repetitions. Because a different nest could be used in the same nest area in different years, forest structure within 500 m of active nest trees could differ between years due to logging, and sibling fledglings exhibited a high degree of overlap in their movements. We pooled all locations from radio-tagged siblings in the same year.

## 8.0 Fledgling Movements

***Phenology:*** We estimated the hatching date of juveniles from sampled nests by counting back from the estimated ages of nestlings. The mean hatching dates were 25 May, 2004, 29 May, 2005, and 30 May 2006, with the earliest hatchings on 20 May, 2004, 17 May, 2005, and 26 May, 2006 and the latest on 1 June, 2004, 13 June, 2005, and 3 June, 2006 (Table 9). Between 1 and 3 chicks were hatched at each nest. On average, nestlings remained in the nest for 40.6 days (36 to 45 days) in 2004, 41.1 days (36 to 45 days) in 2005, and 40.6 days (38 to 43 days) in 2006. Surviving fledglings left the nest area when they were between 72 and 87 days old (mean = 79.6 days) in 2004. In 2005 they dispersed when there were between 72 and 93 days old (mean = 80.9 days), and in 2006 they were between 64 and 83 days old (mean = 74.4 days). From these dates we calculated the average length of the post-fledging period to be 39.1 days (33 to 48 days) in 2004, 39.8 days (29 to 48 days) in 2005, and 34.1 days (26 to 40 days) in 2006.

Table 9: Summary of hatching dates of northern goshawk nestlings (n = 34) from sampled nests. The mean, standard error, and range of days as nestlings (Hatch-Fledge), the age at dispersal (Hatch-Dispersal) and number of days as fledglings (Fledge-Dispersal) are indicated.

| Year | Hatching Date | Hatch-Fledge (days) | Hatch-Dispersal (days) | Fledge-Dispersal (days) |
|---|---|---|---|---|
| 2004 | 25/05/2004 (±0.9), 20/05/2004 - 01/06/2004 | 40.6 (±0.6), 36-45 | 79.6 (±1.5), 72-87 | 39.1 (±1.6), 33-48 |
| 2005 | 29/05/2005 (±2.5), 17/05/2005 - 13/06/2005 | 41.1 (±1.1), 36-45 | 80.9 (±2.6), 72-93 | 39.8 (±1.9), 29-48 |
| 2006 | 30/05/2006 (±1.1), 26/05/2006 - 03/06/2006 | 40.6 (±0.8), 38-43 | 74.4 (±3.0), 64-83 | 34.1 (±2.2), 26-40 |

***Fledgling Survival***: During the breeding seasons of 2004, 2005, and 2006, we radio-tagged 34 fledgling goshawks, 20 adult female and 4 adult male goshawks at 23 nest sites in 15 nest areas (Table 10). Nestlings were tagged at 15 nest sites in 10 nest areas. Twenty-eight of these nestlings survived to disperse from the PFA. Of the eight nestlings that did not survive, four were preyed upon by either an avian or mammalian predator prior to fledging, and two were killed by avian predators after fledging and were not eaten, plucked, or otherwise disturbed. One female fledging and one male fledgling starved to death. The female had two female siblings and died during a mid-summer snow storm, while the male had one female and one male sibling. Only 2 of the 17 (11.8%) nests did not produce fledglings after adult females were seen incubating eggs. At both of these sites a single nestling hatched, and then was killed by a mammalian predator prior to fledging.

Table 10: Summary of capture, mortality, and location results for the radio-tagging of 58 northern goshawks at 23 nest sites during the 2004, 2005, and 2006 summer seasons. The letter "F" represents a female bird and the letter "M" represents a male bird. We were only able to determine the cause of death of juvenile birds.

| Nest Area | Year | Juveniles Tagged | Adults Tagged | Juvenile Location | Adult Locations | Mortalities |
|---|---|---|---|---|---|---|
| GN-BD | 2004 | 0 | 1F | 0 | 6 | |
| | 2005 | 0 | 1F 1M | 0 | 33 | |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-BL | 2004 | 0 | 0 | 0 | 0 | |
| | 2005 | 0 | 1F | 0 | 6 | |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-BT | 2004 | 0 | 0 | 0 | 0 | |
| | 2005 | 2F | 1F | 153 | 16 | |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-CO | 2004 | 0 | 0 | 0 | 0 | |
| | 2005 | 1F | 1F | 71 | 12 | |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-GC | 2004 | 0 | 0 | 0 | 0 | |
| | 2005 | 1F | 1F | 68 | 19 | |
| | 2006 | 1F 1M | 1F 1M | 65 | 44 | One male juvenile |
| GN-JC | 2004 | 1F 1M | 1F | 69 | 27 | |
| | 2005 | 1F | 1F | 0 | 27 | One adult, one juvenile |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-KS | 2004 | 1F | 1F | 0 | 35 | One juvenile |
| | 2005 | 1F 1M | 1F | 104 | 35 | |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-MD | 2004 | 0 | 0 | 0 | 0 | |
| | 2005 | 1F 1M | 1F | 158 | 29 | |
| | 2006 | 1F 2M | 1F | 105 | 29 | One male juvenile |
| GN-NW | 2004 | 0 | 1F | 0 | 8 | |
| | 2005 | 1M | 1F 1M | 0 | 28 | One male adult, one juvenile |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-RM | 2004 | 3M | 1F | 92 | 24 | One adult |
| | 2005 | 0 | 0 | 0 | 0 | |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-RO | 2004 | 2F | 1F 1M | 38 | 48 | One female adult, one juvenile |
| | 2005 | 0 | 0 | 0 | 0 | |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-SE | 2004 | 1M | 1F | 0 | 7 | One adult, one juvenile |
| | 2005 | 0 | 0 | 0 | 0 | |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-SW | 2004 | 3F | 1F | 68 | 28 | One female juvenile |
| | 2005 | 0 | 0 | 0 | 0 | |
| | 2006 | 0 | 0 | 0 | 0 | |
| GN-TP | 2004 | 2F | 1F | 83 | 17 | One adult |
| | 2005 | 0 | 0 | 0 | 0 | |
| | 2006 | 2M | 1F | 103 | 19 | |
| GN-WB | 2004 | 1M | 1F 1M | 46 | 79 | Two adults |
| | 2005 | 0 | 0 | 0 | 0 | |
| | 2006 | 2M | 1F1M | 114 | 35 | |

***Distance and Direction of Fledgling Movements from the Nest:*** We recorded the location of fledglings 1148 times with an average of 44 locations/fledgling (SE = 1.4, range = 24-81) and 77 locations/PFA (SE = 1.7, range = 29-158). Ninety-five percent of the fledglings' locations were within 450 m of the nest (mean = 168, median = 126, SE = 4.3, n = 1148). Within the first 21-days after fledging (when feather growth and hardening was not completed), 95% of locations were within 298 m of the nest (mean = 120, median = 94, SE = 3.7, n = 713). Locations recorded 21-days post-fledging, but while the fledglings were still in the FDP, were within 525 m of the nest 95% of the time (mean = 246, median = 201, SE = 8.2, n = 435). Although we located fledglings farther from the nest following the completion of feather development, all of the birds returned frequently to the area surrounding the nest site (Figure 6). This behaviour was highly variable between sites and individuals, but fledglings did spend considerable time close to the nest tree. We determined the azimuth of each fledgling's location from the nest tree, and compared the mean azimuth between siblings at sites with more that one fledgling. No differences were observed between siblings, we thus pooled all locations from each nest area (88.48%, SE = 5.83, range = 77.08-97.69%, n = 10).

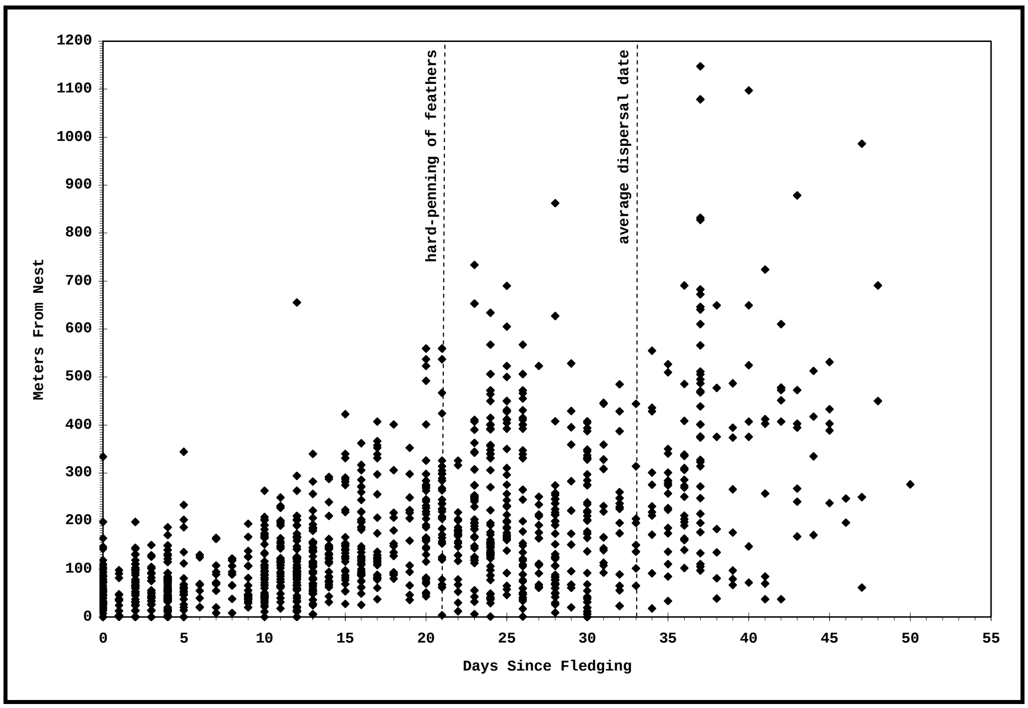


Figure 6: Distribution of the movements of fledgling goshawks away from the nest during the 2004, 2005, and 2006 post-fledging periods (n = 1337). Hard-penning of flight feathers occurs at approximately 21 days and allows for greater mobility of fledglings. This date was used to examine differences in movements between early and late post-fledgling periods. The average date of dispersal for monitored fledglings was 38 days.

We used Rayleigh's general unimodal test to determine if the movements were directional (Zar 1999), and used the Watson test and Q-Q plots to see if the fledgling movements fit the von Misses distribution (the circular distribution is analogous to the normal distribution). All geographic analysis and data collection were performed in ARCGIS, ArcEditor 9.1 (Environmental Systems Research Institute, Redlands CA) and statistical analyses performed in R 2.4.1 (R Core Development Team 2007). Fledglings' movements from the nest were directional at all nest areas except for one (Table 11, Figure 7).

Table 11: Summary of the directional movements of fledgling goshawks observed from 2004 to 2006 at nest trees located in southeastern British Columbia, Canada. Fledgling locations were pooled by nest area and year. The only non-significant movement away from the nest tree was at WB4_2004 ($p = 0.14$). All other p-values were <0.001 except TP2_2006 ($p = 0.0220$).

| Nest Tree | Mean Azimuth (deg) | Circular Variance | Number of Locations |
|---|---|---|---|
| BT4_2005 | 35 | 0.086 | 153 |
| CO3_2005 | 101 | 0.605 | 71 |
| GC1_2006 | 22 | 0.205 | 29 |
| GC2_2005 | 27 | 0.227 | 68 |
| JC2_2004 | 75 | 0.309 | 69 |
| KS6_2005 | 147 | 0.585 | 104 |
| MD1_2005 | 117 | 0.659 | 158 |
| MD2_2006 | 162 | 0.192 | 65 |
| RM4_2004 | 47 | 0.553 | 92 |
| RO2_2004 | 889 | 0.389 | 38 |
| SW3_2004 | 15 | 0.488 | 68 |
| TP2_2004 | 42 | 0.617 | 83 |
| TP2_2006 | 36 | 0.732 | 53 |
| WB1_2006 | 117 | 0.594 | 51 |
| WB4_2004 | 79 | 0.794 | 46 |

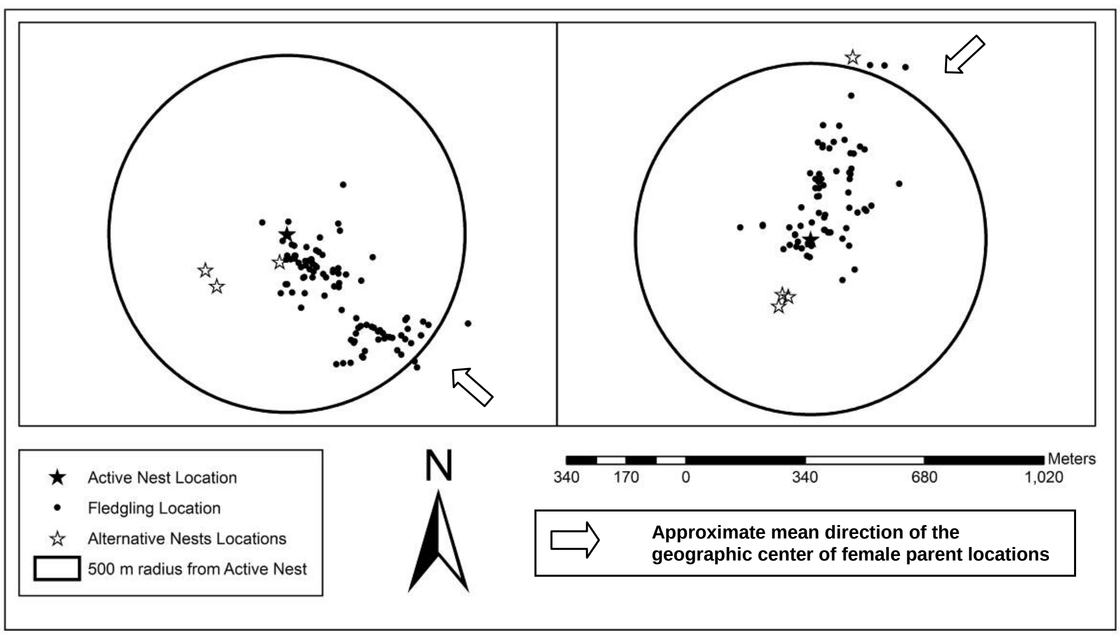


Figure 7: Two representative northern goshawk nest areas traversed by fledglings in southeastern British Columbia, Canada. Post-fledging areas are offset towards the geographic center of their mother's breeding season locations and do not necessarily encompass alternative nest sites.

***Fledgling Home Range Analysis:*** An average number of 77 locations per site (SE = 9.7, range = 29-158, n = 15) was used to estimate 95% fixed kernel PFA sizes (Table 12), which ranged from 10.3 ha to 70.9 ha (mean = 36.7 ha, SE = 6.58, n = 15). Since all locations were used to calculate PFA size, we estimated the degree of independence between points using Swihart and Slade's Independence Index (Kernahan et al. 2001). The values of this index ranged from 0.00 to 2.56 across nest areas, suggesting a low autocorrelation between points, and supporting my previous observation that individuals were able to traverse their entire range between relocations.

Table 12: Estimated post-fledging areas for northern goshawk (n = 15) in southeastern British Columbia, Canada, calculated with 95% fixed kernel home ranges with an *ad hoc* estimate of the smoothing parameter, using program HOME RANGER.

| Nest Tree | 95% Fixed Kernel (ha) | Bootstrap (SE) | Bootstrap Range (Max, Min) | Number of Locations |
|---|---|---|---|---|
| BT4_2005 | 20.23 | 1.166 | 23.05, 30.13 | 153 |
| CO3_2005 | 32.45 | 2.359 | 32.10, 47.28 | 71 |
| GC1_2006 | 28.32 | 2.669 | 25.30, 43.70 | 29 |
| GC2_2005 | 21.31 | 1.481 | 19.25, 29.36 | 68 |
| JC2_2004 | 10.31 | 0.753 | 10.44, 14.82 | 69 |
| KS6_2005 | 23.12 | 1.460 | 25.18, 35.21 | 104 |
| MD2_2006 | 36.29 | 2.851 | 35.62, 53.18 | 65 |
| MD1_2005 | 43.15 | 2.279 | 42.49, 60.31 | 158 |
| RM4_2004 | 22.77 | 1.506 | 22.05, 31.66 | 92 |
| RO2_2004 | 15.28 | 1.523 | 14.23, 23.69 | 38 |
| SW3_2004 | 70.88 | 5.714 | 69.65, 103.99 | 68 |
| TP2_2006 | 22.64 | 2.071 | 23.06, 37.95 | 53 |
| TP2_2004 | 15.30 | 1.007 | 14.24, 20.36 | 83 |
| WB1_2006 | 70.16 | 6.148 | 73.41, 107.39 | 51 |
| WB4_2004 | 50.19 | 4.158 | 43.72, 69.76 | 46 |

## 9.0 Fledgling Resource Selection:

***Study Design and Methods:*** We quantified selected variables in order to describe the characteristics of the PFA, and compared them to randomly located comparison points, during both the early (<21-days post-fledging) and late (≥21-days post-fledging) period. These scales were chosen because they represented the areas available to fledglings during different life-history stages (pre- and post-hard-penning of feathers). The specific radii from the nest we chose to estimate resource availability was based on our observations of fledglings' movements. We used five randomly chosen comparison points for each telemetry location, and assessed all locations collected during either the early or late time periods during analyses. To measure resource variables (Table 2), digital forest cover information was reclassified by categorizing stands by their dominant tree species and age class using data developed by the BC Ministry of Forests and Range from air photo interpretation. We defined a *stand* as an area of forest that is composed of trees of relatively uniform tree composition and age. Age classifications for stands that had not been harvested were projected age classes from the date of aerial photo interpretation and corrected for forest harvest by year (Table 2).

For each location or comparison point, we calculated the distance to the nearest permanent road and distance to nearest harvested forest stand <36 years old. We included these in our models as linear, rather than quadratic terms, as linear predictors better fit our data, and thus we are assuming a linear response of goshawks to these proximity measurements. Young forest stands were defined as those stands between 41- and 80-years of age and mature stands were >80 years old. Non-forested stands were those that were either logged within the last 10 years or where no forest occurs (e.g., wetland or other opening). We classified high canopy cover stands as those canopy cover >40% estimated from aerial photo interpretation as this was the mean canopy cover present in our study area. Larch, Douglas-fir, and pine stands were those with *Larix* sp., *Pseudotsuga menziesii*, or *Pinus contorta* as the leading tree species, respectively.

We conducted a multivariate analysis of explanatory variables using Information-Theoretic (IT) approaches (Burnham and Anderson 2002) and matched case-control multivariate logistic regression (Hosmer and Lemeshow 2000). We selected variables for inclusion in the set of candidate models by examining the collinearity between explanatory variables. For pairs of variables with Spearman rank correlations >0.7, we selected the variable that explained the greatest amount of variation in the data for inclusion into our set of candidate models. We developed my final set of candidate models for each FDP time period while working within two constraints: the number of explanatory variables needed to be <1/10 the number of observations (Peduzzi et al. 1996), and the number of candidate models needed to be less than the number of observations (R<n; Burnham and Anderson 2000). We ranked candidate models in order of decreasing parsimony using Akaike's Information Criterion for small samples ($AIC_c$). Final models were developed using a model-averaging approach for all variables, from models with a <4 AIC-unit change from the most parsimonious candidate. We assessed model fit by calculating the area under the receiver operating characteristic (ROC) curve (Hosmer and Lemeshow 2000).

***Selection of Forest Types:*** We examined nine attributes of PFAs (Table 13); however, areas with a high percentage of non-forest area were strongly avoided, and thus were removed from the overall analysis. The percentage of non-forested area was by far the greatest predictor of PFA location, receiving the largest amount of support when compared to other candidate models (AIC$\omega$ = 0.9769). From the remaining variables, five plausible variables were identified and model averaging was used to produce a predictive equation from locations collected during the entire fledgling dependency period (Tables 14 and15). When selection during the early FDP was examined (298 m from the nest), the area of non-forest (AIC$\omega$ = 0.6079) and the distance to nearest harvested forest stand (AIC$\omega$=0.3217) were the only plausible variables. The received a combined support of 92.9% over all other models. During the late FDP (525 m from the nest) the area of non-forest (AIC$\omega$ = 0.8235) and area of forest with canopy cover greater than 40% (AIC$\omega$ = 0.1541) were the only plausible variables combining to receive 97.8% of the support over other models. Fledglings avoided areas of non-forest while selecting for areas with high canopy cover.

Table 13: Summary of average measurements for each explanatory variable used in resource selection analysis to determine selection by northern goshawk fledglings in southeastern British Columbia, Canada. Available areas were defined as the entire area within a 525 m radius of the nest.

| Variable | post-fledging area (n = 11) | | | available area (n = 11) | | |
|---|---|---|---|---|---|---|
| | mean | SE | range | mean | SE | range |
| % larch stands | 39.54 | 11.486 | 0-95 | 32.07 | 8.485 | 0-78 |
| % Douglas-fir stands | 22.44 | 11.157 | 0-100 | 25.29 | 9.748 | 0-90 |
| % pine stands | 22.11 | 9.134 | 0-84 | 15.82 | 6.387 | 0-62 |
| % >40 canopy cover stands | 88.81* | 05.425 | 39-100 | 78.37 | 5.035 | 51-100 |
| % young stands | 38.53 | 12.675 | 0-97 | 26.74 | 9.799 | 0-88 |
| % mature stands | 54.68 | 13.107 | 3-100 | 51.73 | 10.334 | 8-94 |
| % non-forest stands | 6.66 | 2.370 | 0-24 | 21.26 | 4.889 | 3-51 |
| distance to road (m) | 191.2 | 26.60 | 103.0-396.0 | 199.3 | 31.67 | 75.8-369.1 |
| distance to harvest <10 years (m) | 295.3 | 108.32 | 38.7-1161.9 | 272.8 | 110.04 | 28.0-1178.9 |

Significance Levels (Wald) = *** <0.001, ** <0.05, *<0.10

Table 14: Model negative log-likelihood (-loglik), number of parameters (K), Akaike's information criterion for small sample sizes ($AIC_c$), the change in Akaike's information criterion for small sample size from most parsimonious model ($\Delta AIC_c$), and Akaike's weight ($\omega$) for plausible models used to examine resource selection by fledgling goshawks during the entire dependency period in southeastern British Columbia, Canada. Plausible variables have $\Delta AIC_c$<4.

| Model | -loglik | K | $AIC_c$ | $\Delta AIC_c$ | $AIC\omega$ |
|---|---|---|---|---|---|
| % young stands | 4.7118 | 2 | 13.6173 | 0.0000 | 0.3796 |
| % >40 canopy cover stands | 5.2173 | 2 | 14.6281 | 1.0108 | 0.2290 |
| distance to harvest | 5.7430 | 2 | 15.6796 | 2.0623 | 0.1354 |
| % larch stands | 6.0872 | 2 | 16.3679 | 2.7507 | 0.0959 |
| % pine stands | 6.3110 | 2 | 16.8154 | 3.1982 | 0.0767 |
| % fir stands | 7.1008 | 2 | 18.3952 | 4.7780 | 0.0348 |
| % mature stands | 7.4104 | 2 | 19.0145 | 5.3973 | 0.0255 |
| distance to road | 7.5138 | 2 | 19.2211 | 5.6039 | 0.0230 |

Table 15: Model coefficients ($\beta$), standard errors (SE), Wald statistics ($\beta$/SE) and relative importance of explanatory variables ($\omega$) of plausible variables from the analysis of resource selection by fledgling goshawks during the entire dependency period in southeastern British Columbia, Canada. Plausible variables include all variables with $\Delta AIC_c$<4 and models are ordered by their explanatory strength ($\omega$). ROC = 0.7335

| Variable | $\beta$ | SE | Wald | $AIC\omega$ |
|---|---|---|---|---|
| % young stands | 0.1660 | 0.12700 | 1.3070 | 0.4141 |
| % >40 canopy cover stands | 0.1060 | 0.06490 | 1.6333 | 0.2498 |
| distance to cut | 0.0510 | 0.03890 | 1.3111 | 0.1477 |
| % larch stands | 0.8650 | 0.06010 | 1.4393 | 0.1047 |
| % pine stands | 0.9780 | 0.08340 | 1.1727 | 0.0836 |

## 10.0 Adult Goshawk Survival and Movements

We captured and radio-tagged 20 adult female goshawks and six adult male goshawks from 2004-2006 and many birds either permanently left our study area or died during the course of our investigations. Of the adult female goshawks we radio-tagged, six birds were found dead and eight birds either permanently left our study area or had their transmitter fail and were not re-sighted. We searched for missing birds extensively during both fall and spring aerial telemetry flights and are confident that when we could not relocate birds that all functioning transmitters were not within ~200 km of their previous nest site. If we assume that the birds we could not relocate left their breeding territory and did not breed again, 70% (30% confirmed dead) of the adult females we marked were removed from the East Kootenay breeding pool. We also were not able to relocate a number of breeding males between years. Two of six radio-tagged males were located dead and we lost one bird. Thus, although sample sizes are small only 30% of the adult females and 50% of the adult males we marked and that reproduced in year one returned to either defend their previous nest area of reproduced for the life time of the study with the many birds only breeding in a single year. No marked fledglings were observed breeding within our study area as of the 2007 breeding season, and no adult birds were observed nesting at a nest area other than in the one they were marked. Additionally, no birds marked outside the study area were observed.

Each bird was relocated throughout the year (Table 16). Each bird was captured at its breeding site and fledglings were tagged at many sites. We obtained a total of 502 locations on adult birds with an average of 19.3 locations per bird (18.7 loc/bird for females, and 21.3 loc/bird for males). We classified the behaviour of goshawks into three seasons. Breeding season locations were collected between the beginning of March and the day fledglings dispersed from the nest area (generally mid August). At sites where all fledglings died during the nestling or early fledgling phases, we removed adult locations from breeding season analyses. Non-breeding locations were those collected for birds between March and August but where adult goshawks did not have a productive nest during that year. Winter locations were collected between the beginning of September and the end of February. Breeding season locations accounted for 78.1% of all locations. We gathered 285 locations on breeding females (15.8/bird), and 107 locations on breeding males (21.4/bird). These locations were not equally distributed at all sites. We were able to obtain between 5 and 29 locations on each breeding females and between 17 and 27 locations for breeding males. However, at some sites were unable to locate birds consistently.

We calculated the average and maximum distance to the currently (breeding locations) or previously (non-breeding or winter locations) and the 100% Mean Convex Polygon for each bird were we felt we obtained an adequate number of relocations (Table 16). Breeding female movements were highly variable with birds making extensive movements away from the nest later in the season. However, they generally remained close to the nest site in the early breeding season (Figure 8). Breeding females ranged up to 37.4 km from the nest site, but the average distance from the active nest was 3.1 km (SE = 0.4, n = 18). Breeding males generally spent less time near the nest (Figure 9), but remained closer to nests when they did move. Adult breeding males ranged up to 7.8 km from the nest, but the average distance to the nest was 2.0 km (SE = 0.4, n = 5). Conversely, non-breeding females ranged up to 65.9 km from nest sites (n = 6), while adult males ranged 6.2 km (n = 2) when they either returned to the previous years nest area or lost all their young early in the season. During the winter season and for birds that remained in the study area, female goshawks were relocated up to 66.5 km from the nest (n=16) and adult males ranged up to 13.7 km (n=3) from the previous years nest. The average 100% mean convex polygon size for adult female goshawks was 7844.8 ha (SE = 2821.6, n = 10) and ranged from 391.7 ha to 29150.5 ha. Adult male goshawk, 100% mean convex polygons were 1553.8 ha and 2044.8 ha. These estimates provide an estimated average polygon size of 3598.6 ha (SE = 18.6, n = 2) for breeding male goshawks. These female mean convex polygons are extremely variable and may suffer from a limited number of locations documenting the furthest extent of movements of some birds. However, we only calculated MCP polygons for birds that we were able to located consistently and thus the variability in these estimates presumably arises from the distribution of foraging areas within the females range for differences of behaviour between birds. For example, at GN-WB mean convex polygons for the two individual females we observed at this site varied between 392 ha and 29151 ha. Although the forest cover available to these two birds did not change substantially between years and the primary foraging areas were still intact, each bird traversed dramatically different areas.

Winter monitoring consisted primarily of fall and spring aerial telemetry flights to determine if adult goshawks had died or left the study area. We did not concentrate on the relocation of non-breeding birds or relocate adult birds consistently in winter. Attempts were made to relocate 12 adult goshawks on six monthly telemetry flights during the winter of 2004-2005. Four of these birds (2 females and 2 males) were not relocated on a regular basis. As describe above, one adult female goshawk died in early winter (late December). Additionally, three birds (2 females and 2 male) left our study area in late fall. Our first flight (October 2004) was successful in locating all 12 birds except the two adult male goshawks. Due to inclement weather, our next flight was not until December 2004. At this time all birds were located except two adult females, and the two adult males missing from the previous attempt. The only goshawk of these four located again was a single adult male. He was located on March 2005, our final flight, and may have been returning to his nest area. During the winters of 2005-2006 and 2006-2007, our winter monitoring efforts were reduced from the first season and consisted of two flights (one fall and one spring) performed to located birds we were unable to find through ground investigations. Re-occupancy and survival data are provided above. A total of 48 relocations were made during the winter season. Forty-five of these relocations were of adult females and three were adult males. On average, adult females were relocated 7.3 km (SE = 11.4) from the previous years nest and they ranged up to 66.5 km from their nest site. Adult males averaged 8.9 km (SE = 11.1) from the previous years nest and ranged up to 13.7 km from this site.

Table 16: Summary of adult northern goshawk breeding season movements for birds radio-tagged in 2004, 2005, and 2006 in southeastern British Columbia. Relocations were obtained with standard triangulation relocation techniques and were collected between March and mid-August. Mean and maximum distances from the nest are given along with 100% mean convex polygon size and number of relocations obtained. Breeding females are coded GF-XX and males GM-XX.

| Bird ID | Nest Area | Mean Distance to Nest (m) | SE of Mean Distance | Max. Distance Moved (m) | 100% MCP (Ha) | Number of Locations |
|---|---|---|---|---|---|---|
| GF-01 | GN-WB | 1381.8 | 272.5 | 4901.4 | 391.7 | 24 |
| GF-02 | GN-TP | 1735.7 | 743.9 | 9370.8 | 2387.3 | 14 |
| GF-04 | GN-SE | 767.0 | 151.1 | 1139.1 | n/a | 6 |
| GF-05 | GN-SW | 869.1 | 317.7 | 4478.2 | n/a | 15 |
| GF-06 | GN-KS | 3327.4 | 1079.4 | 32096.4 | 9774.9 | 29 |
| GF-07 | GN-NW | 1077.6 | 493.3 | 2966.9 | n/a | 7 |
| GF-08 | GN-JC | 2749.8 | 1117.3 | 24904.9 | 10140.9 | 22 |
| GF-09 | GN-BD | 2035.4 | 1109.7 | 6181.1 | n/a | 5 |
| GF-10 | GN-RM | 3649.3 | 1649.3 | 23052.8 | 8719.4 | 18 |
| GF-11 | GN-RO | 3302.1 | 1201.9 | 24463.5 | 19764.8 | 22 |
| GF-12 | GN-BT | 1717.0 | 298.4 | 3891.1 | n/a | 11 |
| GF-13 | GN-MD | 1727.6 | 253.3 | 5326.1 | 1481.2 | 28 |
| GF-15 | GN-GC | 2314.7 | 498.6 | 6133.6 | 966.5 | 19 |
| GF-16 | GN-BL | 36435.7 | 283.7 | 37400.9 | n/a | 5 |
| GF-17 | GN-CO | 2103.4 | 1448.6 | 15070.2 | n/a | 10 |
| GF-18 | GN-BD | 1471.4 | 368.3 | 4986.1 | n/a | 12 |
| GF-19 | GN-TP | 4169.0 | 1125.6 | 15277.6 | 7591.0 | 19 |
| GF-20 | GN-WB | 4460.3 | 1841.3 | 34192.2 | 29150.5 | 19 |
| GM-01 | GN-WB | 1932.5 | 331.7 | 6177.8 | 1553.8 | 27 |
| GM-02 | GN-RO | 1577.7 | 195.9 | 2887.9 | n/a | 20 |
| GM-04 | GN-BD | 1332.5 | 123.8 | 2332.8 | n/a | 18 |
| GM-05 | GN-GC | 2081.8 | 421.0 | 7817.3 | n/a | 25 |
| GM-06 | GN-WB | 2897.1 | 377.9 | 5044.3 | 2044.8 | 17 |
| **Female Total** | | **3102.5** | **371.2** | **37400.9** | **7844.8 (SE = 2821.6)** | **285** |
| **Male Total** | | **1953.4** | **153.4** | **7817.3** | **3598.6 (SE = 18.6)** | **107** |

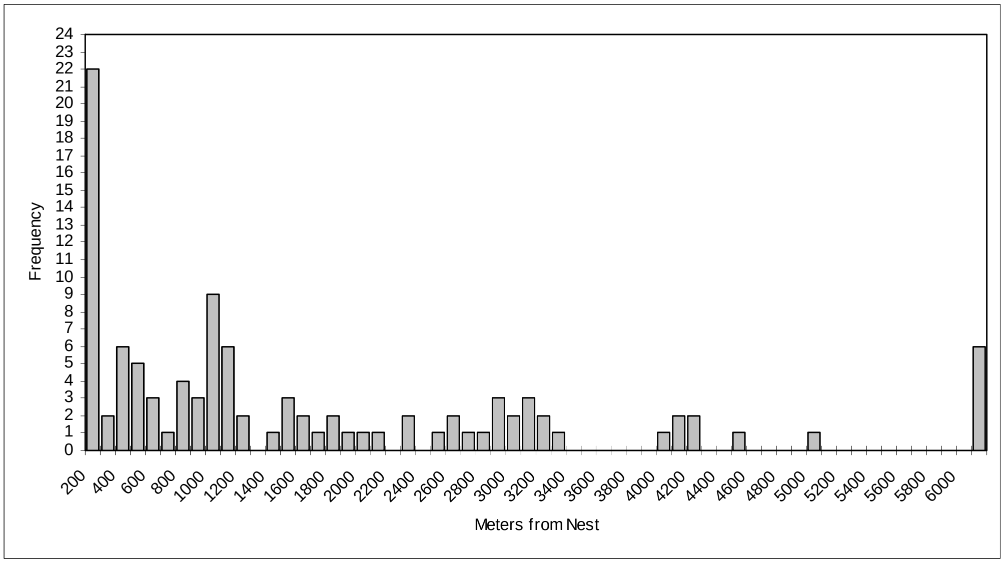


Figure 8: Histogram of adult female goshawk movements away from the nest site during the breeding season in southeastern British Columbia. Relocations were obtained with standard triangulation relocation techniques and were collected between March and mid-August. Adult females spend the majority of their breeding season near the nest site, but do make larger movements away from the nest than males

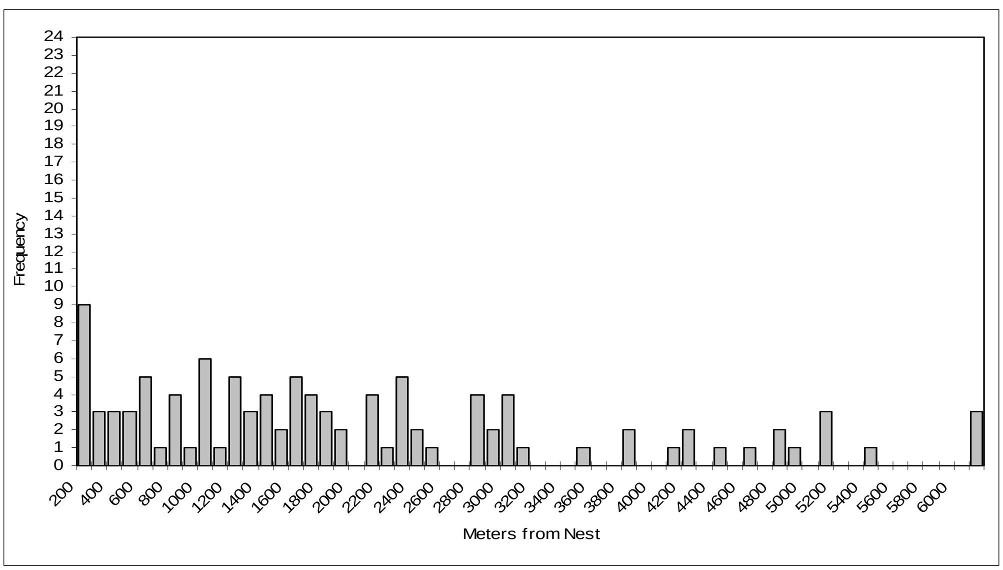


Figure 9: Histogram of adult male goshawk movements away from the nest site during the breeding season in southeastern British Columbia. Relocations were obtained with standard triangulation relocation techniques and were collected between March and mid-August. Adult male movements away from the nest are distributed more evenly than those of adult females.

## 11.0 Conclusions and Future Research Directions:

The major findings from our investigations of goshawk resource selection are: (1) adult goshawks select habitat features at multiple scales, up to at least 1100 m from the nest area, (2) a core area of 200 m exists around the nest sites where a high proportion of forest with canopy closure >40% exists, (3) beyond 200 m from the nest, forest cover is less homogenous, and selection for variability in patch area and edge habitat is seen, (4) fledgling goshawks, in addition to selecting for forests with high canopy closure, select for forests between 40 and 80 years old, a characteristic not detected in analysis of adult nest-stand selection. These results help quantify the spatial scale at which resources are required, and raise important questions as to the nature of what resources are required beyond 200 m from the nests. However, these results, like any other resource selection investigations, are subject to interpretation and constraint by the terminology and approaches used to define units of measurement and describe the areas available to animals. The results we present in this report are by necessity preliminary, and we are proceeding with a reanalysis based on peer-reviews of our work. Final results will be submitted to scientific journals for publication.

The scale at which availability is defined and the type and grain of resource variables examined interact to allow an adequate quantification of selection (Weins 1989); our definitions of extent and grain allow us to better document goshawk resource selection. We defined availability at two spatial extents (nest-site and nest-stand) and found that the strength of selection differed between them. Models for predicting nest location performed poorly at the nest-tree level, but adequately described selection at the nest-stand level. Despite using variables that were thought to best describe goshawk nest-tree location within a stand (high overhead cover and low understory cover) our model was no better than random (Hosmer and Lemeshow 2000) at predicting the location of a nest tree within 200 m of the nest. Nest-stand-level models had better discrimination than nest-site-level models and thus showed an excellent ability (Hosmer and Lemeshow 2000) to predict the location of nests within goshawk territories. The strongest variable in both these models was overhead canopy cover. Although these metrics are not identical (each was measured in a manner suitable to its spatial scale of reference), they both represent the amount of cover available around the nest. Our results suggest that canopy cover, an important correlate with nest location, provides information about the location of the nest only at a particular spatial scale, the nest-stand level.

Our results suggest that goshawk breeding requirements are more plastic than originally proposed, and that large areas of mature forest may not be required to preserve nesting locations; however, appropriate forest management techniques are still required to maintain goshawk population numbers. Goshawks have long been proposed as a flagship species (Lambeck 1997, Simberloff 1998) for the protection of old-growth forest in North America. Moreover, European studies suggest that goshawks will nest in small isolated woodlands (Kenward 2006, Rutz et al. 2006), and breeding populations have even become re-established in seven European cities (Rutz et al. 2006). However, these populations have access to suitable nesting sites, abundant prey populations, and areas with limited disturbance (e.g., prosecution and predation [Rutz et al. 2006]). These are all forest conditions that can presumably be provided by sustainable forest management techniques. For example, removing substantial amounts of forest cover can shift the availability of suitable nesting locations in favour of red-tailed hawks (*Buteo jamaicensis*), a competitor of the goshawk (La Sorte et al. 2004). This situation may be analogous to that of interactions between the common buzzard (*Buteo buteo*) and the goshawk in the United Kingdom (Kenward 2006). Thus, the management of forests beyond the 200 m of the nest is essential in maintaining viable prey populations, foraging areas, and reducing competition for goshawks; additionally, these techniques may benefit other forest species (Carroll et al. 2006). However, the conditions of the landscape beyond the nest area that are required by goshawks are poorly understood (Anderson et al. 2005, Kenward 2006, Squires and Kennedy 2006) and may be essential in determining population productivity (Kenward 2006). Thus, future research should be focused on landscape conditions and nest productivity metrics other than nest occupancy.

We have provided detailed descriptions of the forest characteristics selected by fledgling goshawks when locating their PFAs. Our observations of fledgling mortality and our PFA size estimates are similar to those reported elsewhere (Weins 2004, McClaren et al. 2005, Mahon and Doyle 2003). However, our descriptions of the offset of the PFA from the nest site and the selection of young forest provide valuable new information, which can contribute towards a better understanding of the function of the PFA and its relationship to the nest site and nest area. A discrepancy exists between the forest characteristics selected by adult goshawks when they are selecting their nest sites and the forest characteristics selected by fledglings when they are selecting their PFA. However, the selection of young forests by fledglings, a variable presumably not identified by their parents, is not surprising. Fledgling goshawks are highly susceptible to predation and thus require escape cover during the FDP. However, this insight, when combined with our nest-site selection results, suggests that the forest composition and shape of the PFA required may be more complex than previously thought. Management guidelines currently focus on protecting high-canopy-cover forest within 200 m of the nest. Beyond this distance, both our nest-site selection results and our PFA selection results suggest that the area beyond 200 m may be important in nesting and may require more complex, and possibly more active (i.e., silvicultural prescriptions and/or logging) management. Additionally, the location of the PFA may not be completely governed by the forest characteristics surrounding the nest. Further investigations into factors influencing the specific movements of fledglings are required to understand the function of the PFA and how inter-familiar interactions influence PFA location.

To extend our work on the factors influencing the nesting requirements of goshawks in southeastern British Columbia we suggest the following investigations:

(1) apply and validate the results of both nesting and fledgling selection models and test if the application of the fledgling model can increase the ability to distinguish occupied sites;
(2) examine how measures of nest site productivity, such as number of young fledged or dispersed, and surrogates of nest area productivity, such as number of years occupied, are influenced by the composition of the forest in both breeding territories and foraging areas; and
(3) continue to examine how the movements of fledgling birds, and thus the placement of the PFA, are influenced by interactions among fledglings and their parents, and fledglings and their siblings.

Some discrepancies exist in both the research directions taken in Europe and those in North America (Kenward 2006), but the observations made by researchers on these two continents seem more similar as new information becomes integrated into local research efforts and into a global understanding of this species' requirements. Human use of forests has resulted in widespread and dramatic change in the composition, structure, and distribution of forests in both Europe and in eastern North America. Research and conservation efforts in western North America have attempted to document and monitor goshawks in order to maintain populations, therefore avoiding the population declines, extirpation, and re-colonization cycles seen in large parts of this species' range. However, without knowledge of the specific resources that limit goshawk populations, observational and mensural studies will fail to document essential requirements of this species. These studies are essential as they provide the natural history framework within which applied ecologists can develop effective questions to test our assumptions of nesting requirements. It is from these foundations that questions concerning the spatial extent and grain of resource selection can be examined and thus resource limitations identified.

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