Do goshawks consider landscape factors when selecting nest areas within territories?

Abstract: I compared habitat composition and pattern between core territory areas centred on

nest areas and random plots at 2 meso-territory scales (177 ha and 400 ha) within 78 goshawk

territories in west-central British Columbia. Habitat composition and several fragmentation

metrics (patch density, largest patch index, core area, edge, contagion, and habitat diversity)

differed significantly (P<0.05) between core territory plots and random within-territory plots at

both scales. At the 177 ha scale core territory plots had, on average, 48% more mature forest

than random plots. The difference in mature forest was greater for territories with lower amounts

of mature forest (<30%), but the pattern held even for territories with >80% mature forest. Core

territory plots also had higher values for core area, contagion, and largest patch index and lower

values for patch density, edge, and habitat diversity (i.e. core territory plots were less

fragmented). Patterns were similar for the 400 ha scale, although relative differences between

core territory and random plots were smaller. This is the first study to examine the importance of

meso-scale habitat composition and pattern within goshawk territories. My results highlight the

importance of including meso-territory scale factors in habitat selection studies and habitat

suitability mapping projects (e.g. Habitat Suitability Index and Resource Selection Function

models), which have traditionally focussed on local, stand-level characteristics. My results also

support management strategies to maintain concentrations of mature forest and limit

fragmentation at meso-territory scales surrounding goshawk nest areas.

The northern goshawk (*Accipiter gentilis*; hereafter goshawk) appears to select nesting

habitat based on factors at multiple scales. Our understanding of, or at least description of,

habitat selection is good at the largest and smallest scales that goshawk habitat is typically examined at. At the population level, the location of goshawks territories (2,000-6,000 ha) appears to be largely controlled by inter-specific territoriality (Reich et al. 2005; Johnson's [1980] second-order selection) and several studies have shown a positive relationship between reproductive success and the amount of mature forest at the territory scale (Crocker-Bedford 1995, Finn et al. 2002, Greenwald et al. 2005). At the nest area scale (12-50 ha) goshawks consistently select stands of mature to old growth forests with moderate to high canopy closure (Penteriani 2002; Johnson's [1980] third-order selection).

Goshawks exhibit very strong fidelity to nest areas including continued use after failed breeding attempts and occupation by new birds if the original occupants disappear (Tomeraas 1994, Woodbridge and Detrich 1994). This strong fidelity suggests that there are benefits associated with nest area locations or conversely, limitations in other parts of the territory. Potential benefits or limitations associated with the territory and nest area scales are not evident, however. For example, the regular spacing pattern that is evident at the territory level (Reich et al. 2005) is unlikely to exert a strong spatial constraint on nest areas because territorial behaviours of goshawks are generally weak except relatively near their own nest areas (Squires and Reynolds 1997). At the nest area scale, only a relatively small area is required (12-50 ha), and numerous nesting habitat patches are usually available within the territory based on stand level habitat variables (Penteriani 2002).

One explanation for the strong selection and fidelity to nest areas is that there is selection for habitat at one or more scales between the nest area and breeding territory (e.g. 200-400 ha), which I will refer to as "core territory" here for discussion purposes. This level of selection is intermediate between the third-order and second-order levels of selection proposed by Johnson (1980). More specifically, goshawks may be locating nest areas in portions of their territory that

contain concentrations of nesting and/or foraging habitat. There are several benefits this could confer to goshawks. First, this strategy is consistent with central place foraging theory, which predicts spatial optimization of central place and territory size and shape to maximize the amount of food acquired relative to time and energetic expenditures (Schoener 1971; Pyke et al. 1977). Second, it may minimize competition and predation risk with species that are more associated with edges and more heterogeneous habitats (e.g. red-tailed hawks and corvids) (Squires and Reynolds 1997). Third, this strategy provides alternative nesting habitat in the event that all or a portion of the original nest area habitat is impacted by natural or anthropogenic disturbance (Reynolds et al. 1992).

This is the first study to examine whether goshawks locate nest areas within concentrations of high quality habitat at meso-scales within territories. Kennedy (1988) suggested that goshawks may locate nest sites within areas of high food availability, but did not provided evidence that this was actually occurring. Past goshawk nesting habitat studies have primarily examined the local habitat characteristics associated with the nest area and nest tree (see reviews by Penteriani 2002 and McGrath et al. 2003) or examined relationships between territory-scale habitat composition and reproductive success (see review by Greenwald et al. 2005). Other selection studies that have examined meso-territory scales have compared used core territory plots to random plots across the landscape (Daw and DeStefano 2001, McGrath et al. 2003), rather than comparing them to paired random plots within the same territory, which is what I do here.

The purpose of this project was to examine the influence of habitat composition and pattern at intermediate territory scales on nest area location within goshawk territories. Based on the consistent pattern that goshawks select mature and old forest for nesting and foraging (Penteriani 2002 Greenwald et al. 2005), I predicted that core territory areas surrounding nest

areas would have higher proportions of mature and old forest and that those areas will be less fragmented than other portions of the territory. To test this hypothesis I compared habitat composition and pattern between core territories centred on nest areas and similar sized plots located randomly within the remainder of the territory.

Study Area

I examined 78 goshawk territories from 2 different forest types in west-central British Columbia, Canada, with approximately equal numbers of nest areas in each. The first study area is within the Interior Cedar Hemlock (ICH) and Coastal Western Hemlock (CWH) biogeoclimatic zones (Banner et al. 1993) in the Kispiox Forest District (N55^o 25', W127^o 45'N; Fig. 1). This area is along the eastern side of the Coast Mountain Range and consists of mountain ranges bisected by broad glaciated valleys with an elevation range of 200 – 2500 m. The climate is transitional between cool, wet coastal conditions and drier interior conditions with greater seasonal temperature variation. The average annual precipitation varies from 600 - 1200 mm (Banner et al. 1993). Forests within the ICH and CWH (hereafter ICH) are predominantly old growth (>200 years) coniferous stands dominated by western hemlock (*Tsuga heterophylla*), and including subalpine fir (*Abies lasiocarpa*), western redcedar (*Thuja plicata*), and Roche spruce (*Picea sitchensis* x *glauca*). Zonal ecosystems consist of hemlock forests with moderate-high canopy closure, sparse shrub and herb layers and a thick feathermoss carpet.

The second study area is 200 km to the southeast in the Sub-Boreal Spruce (SBS) biogeoclimatic zone (Banner et al. 1993) in the Lakes and Morice Forest Districts (N54^o 25', W126^o 00'; Fig. 1). It occurs on the interior Nechako Plateau with elevations of 500 – 1000 m. The climate is continental and is characterized by greater seasonal temperature extremes, with cold, snowy winters and relatively warm, moist, short summers. Annual precipitation is 440 - 650 mm (Banner et al. 1993). Forests in the SBS have been subject to frequent fires (average

fire interval <150 years) and zonal sites are frequently dominated by mature seral stands of lodgepole pine (*Pinus contorta*) with subalpine fir, hybrid white spruce (*Picea glauca* x *engelmannii*), and trembling aspen (*Populus tremuloides*). The shrub and forb layers are usually sparse, though variable, and are generally more developed than in the ICH.

In both study areas approximately 50% of the forested land base is mature forest, 25% is young forest, and 25% is in shrub/herb stage. Forestry roads and clearcuts are present in all portions of both study areas and the latter account for the majority of area in the shrub/herb stage. Stands in both study areas are typically even-aged resulting with clearcutting and stand-replacing fires as the dominant disturbance types (vs partial-cutting/selective logging and natural gap-phase dynamics that result in uneven-age stands).

Minimum goshawk densities of approximately 4 pairs per 100 km^2 were similar between the ICH and SBS based on inventory work in core portions of each study area (Mahon and Doyle 2005). Potential avian competitors for nest sites and habitat occurred at low densities and included red-tailed hawks (*Buteo jamaicensis*), which were found in open areas, barred owls (*Strix varia*), mostly in the ICH, great gray owls (*Strix nebulosa*), mostly in the SBS, and great horned owls (*Bubo virginianus*), which occurred within riparian and mixed forest habitats at lower elevations throughout the region. Prey biomass during the breeding seasons consisted predominantly of red squirrels (*Tamiasciurus hudsonicus*) in both study areas, with secondary prey dominated by medium sized passerines, grouse (*Bonasa umbellus*, *Falcipennis canadensis* and *Dendragapus obscurus*, and snowshoe hares (*Lepus americanus*) (T. Mahon and F. Doyle, unpublished data).

Methods

I used a matched-case design to compare the composition and pattern of habitat surrounding the nest area to equal sized random plots outside of the nest area but still within the

same territory. This design focuses on within-territory differences to account for differences in overall habitat amount and pattern at the territory level. My sample of 78 goshawk territories were located between 1995 and 2003 through a combination of systematic call playback surveys (Kennedy and Stahlecker 1993) and incidental discoveries by forest workers. An incubating female occupied each goshawk territory for at least 2 years during this period.

I classified habitat into 7 classes using 1:20,000 scale British Columbia Ministry of Forests Forest Cover map data, which was available over all of my study areas. The Forest Cover (FC) data is a polygon coverage mapped at 1:20,000 scales from 1:15,000 – 1:18,000 air photos. Minimum polygon sizes are 2.0 ha for forested polygons and 0.5 ha for non-forested polygons. The FC database includes numerous habitat attributes including forest composition, stand age, stand height, canopy closure, site index, disturbance type and disturbance year. My habitat classes represent broad seral stage classes and are based primarily on stand age: 1) Herb, 2) Shrub, 3) Pole/Sapling, 4) Young Forest, and 5) Mature Forest/Old Growth (after *Structural Stages* in BC Ministry of Environment, Lands and Parks, and BC Ministry of Forests 1998), plus two non-forested types: 6) Non-Forested (e.g. wetlands, alpine) and 7) Not Suitable (e.g. water, urban, rock, glacier). A description of the characteristics of each habitat type, including their general suitability as nesting and foraging habitat for goshawks, is provided in Table 1. For analysis purposes I converted the polygon-based habitat map to a 100m-cell raster coverage.

I estimated average breeding average breeding territory size in this study to be 2300 ha based on average spacing distances of 5412 m between 23 adjacent nest area pairs, and assuming circular, non-overlapping territories. Although the true size and shape of territories are expected to vary in response to a number of factors including habitat, prey and intra-species interactions, Lemkuhl and Raphael (1993) concluded that circles can provide reasonably unbiased territory estimates for raptors based on telemetry tracking. In addition, telemetry data for 10 territories in

this study indicated that home ranges were roughly circular and were centred on the nest areas (T. Mahon, unpublished data).

I compared core territories and random areas within territories using 2 intermediate territory scales: 177 ha and 400 ha. The 177 ha scale approximates the post-fledging family area described by Kennedy et al. (1994) and Reynolds et al. (1992) and has been commonly used in goshawk habitat studies (Daw and DeStefano 2001, Finn et al. 2002, McGrath et al. 2003). I selected the 400 ha sample scale on the bases of it being approximately twice the size of the post-fledging area. While breeding activities are less likely to be relevant at this larger scale, factors related to foraging may be more important. I assessed the relative importance of these 2 scales by testing a separate model for each scale (see statistical analysis below), and comparing the overall significance of each model and the relative difference in effect size of the predictor variables between core and random samples. I used separate random circles rather than the nested concentric circles or rings often used in other studies (e.g. McGrath et al. 2003) because of potential sampling biases associated with using sample units of different size and shape. For example, a ring will cover a broader extent and intersect more habitat patches than a circle of the same area.

The core territory plots were located over the geometric centroid of the nest areas based on the average X and Y coordinates of all of the known nest sites for a given nest area (n= 1 to 7). Four random plots were located in each territory to provide a representative sample of the remaining territory. The centroids of the random plots were constrained to distances between 1200 m and 2706 m out from the centre of the nest area. Random plots were further constrained to a maximum 10% overlap with each other and the nest area plot, and the requirement of at least 30 ha of mature forest, representing an available nest area patch (Fig. 2). Without this latter constraint the random sample would not be truly available to the goshawks. If either of these 2

constraints was not met for a random sample it was discarded and a replacement sample was drawn.

For each core territory and random sample I measured habitat composition (class level), 5 class-level fragmentation metrics, and 7 landscape-level fragmentation metrics using FRAGSTATS v3.3 (McGarigal et al. 2002). The fragmentation metrics included 2 area/density metrics, Patch Density (PD) and Largest Patch Index (LPI), 2 core area metrics, Total Core Area (TCA) and Area-weighted Mean Core Area (CORE_AM), 1 contrast metric, Contrast-Weighted Edge Density (CWED), 2 contagion/juxtaposition metrics, Contagion (CONTAG) and Percentage of Like Adjacencies (PLADJ), 1 connectivity metric, Patch Cohesion Index (COHESION), and 1 diversity index, Simpson's Diversity Index (SIDI). Descriptions of each metric are provided in Table 2. Few studies have assessed the relationships between goshawks and habitat pattern (but see Finn et al. 2002 and McGrath et al 2003) and no studies have shown strong functional relationships between habitat pattern and either fitness or habitat selection. Given this context, my use of these fragmentation metrics was more exploratory in nature than driven by their known relevance to goshawk biology. My working hypothesis was that goshawks would select areas with higher levels of mature forest, more interior forest, greater connectivity, lower levels habitat contrast, and lower amounts of edge. I selected the above list of metrics on the basis that they appeared useful for describing this broad type of habitat pattern.

Statistical Analysis – For each territory I tabulated the differences in habitat composition and fragmentation metrics between core territories and random plots and tallied the number of territories exhibiting the same direction of difference (i.e., sign) as the average. I also conducted univariate paired *t*-test for each variable as a data reduction process to help select variables to include in my multivariate analysis (Hosmer and Lemeshow 1989). To test for overall differences between core territories and random territory plots I used matched-case conditional

logistic regression in STATA (StataCorp 2005) and classified used core area plots as "1" and the

unused random plots as "0". The matched-case design is analogous to a paired-plot design and

controls for among territory variation. For my multivariate model I planned to include mature

forest and all fragmentation metrics that met a colinearity constraint of having Pearson's

correlation coefficients <0.6 (Riitter et al. 1995) and which had P-values of <0.20 from the

paired *t*-tests. I only included Mature Forest as a habitat type in the full model because, 1)

goshawk habitat relationships are only consistent for mature forest (Penteriani 2002, Greenwald

et al. 2005), 2) most other habitat type were not present, or occurred in very low proportions in

several of the territories, and 3) due to inherent colinearity associated with compositional data

(Aitchison 2003). To address the unit sum constraint associated with compositional data I

transformed habitat type proportions using the log ratio transformation before using them in

statistical tests (Aitchison 2003).

Results

Habitat composition and several fragmentation metrics (patch density, largest patch

index, core area, edge, contagion, and habitat diversity) differed significantly (*P*<0.05) between

nest area plots and random within-territory plots at both the 177 ha and 400 ha scales (Tables 3

and 4). At the 177 ha scale nest area plots had, on average, 48% more Mature Forest than

random plots. The amount of Mature Forest was greater in core territories than random plots at

88% of the 78 territories. The difference in habitat composition was generally greater for

territories with lower amounts of mature forest (<30%), but the pattern held even for territories

with >80% mature forest (Fig. 3). The greatest differences between core territories and random

plots occurred for CORE_AM, at both the landscape level and the class level for Mature Forest

(59% and 103%, respectively). The smallest differences occurred for the Percentage of Like

Adjacencies (PLADJ, 4.8%) and Patch Cohesion Index (COHESION, 6.5%). Nest area plots

also had higher values for core area, contagion, and largest patch index and lower values for patch density, edge, and habitat diversity.

Patterns were similar for the 400 ha scale, although relative differences between nest area and random plots were generally smaller (Table 4). For example, at 400 ha the core area plots had 31% more Mature Forest than random plots, compared to a 48% difference at the 177 ha scale. The direction (i.e. sign) of the relative differences was the same for all composition and fragmentation variables at both scales, as were the variables that showed the largest and smallest differences between core territories and random plots.

Patterns of difference were also similar between the ICH and SBS study areas. The relative difference in Mature Forest between core territories and random plots was 44% in the ICH and 51% in the SBS. As with the 2 scales, the variables that showed the largest and smallest differences between core territories and random plots, and the direction (i.e. sign) of the relative differences, were the same for all composition and fragmentation variables at both study areas.

At both the 177 ha and 400 ha scales the amount of Mature Forest and the 13 fragmentation variables showed a high degree of colinearity. Seventy eight of the 91 pair-wise comparison's of Pearson's correlation coefficients were >0.6 and all were >0.4. Further, all of the variables had correlations >0.6 with at least 4 other variables in the correlation matrix. Given the strong degree of autocorrelation among the variables I decided it was inappropriate to include them in a multivariate analysis. I did test for differences in Mature Forest between core territories and random plots using the conditional logistic regression model as a method of verifying the paired t-test results, and the model was significant at both the 177 and 400 ha scales (both P values < 0.001). I choose Mature Forest as the most appropriate variable to use because

the importance of mature forest to goshawks is well documented whereas the importance of the various fragmentation metrics to goshawks is generally not understood.

Discussion

This is the first study to demonstrate within-territory selection by goshawks for meso-scale core territories surrounding nest areas. Previous studies of goshawk nesting habitat can be generalized into 2 types: primarily descriptive studies (Reynolds et al. 1982, Hall 1984, Kennedy 1988, and Hayward and Escano 1989) and selection studies that compared used nest areas to random plots within the overall study area (Squires and Ruggiero 1996, Penteriani and Faivre 1997, Daw and DeStefano 2001, McGrath et al. 2003). Both types of studies have been conducted at various scales from the nest tree to 177 ha. Although the habitat variables examined and the observed patterns of use and selection often varied among studies, some consistent patterns of habitat use and selection are evident (see review by Penteriani 2002). At the smaller nest site and nest area scales (1-50 ha) goshawks tend to locate their nests in the largest trees in the stand, below or within the lower canopy, and within mature stands with dense canopy closure and open subcanopy flyways. At larger scales (50-177 ha) goshawks consistently select areas with higher proportions of mature forest than random areas across the landscape (Daw and DeStefano 2001, McGrath et al. 2003). My study adds to this body of knowledge by demonstrating that selection for meso-scale areas with higher proportions of mature forest also occurs within goshawk territories.

The degree of within-territory selection was strongest when the amount of mature forest at the territory level was relatively low (e.g. <30%) but was still evident even when the amount of mature forest present in the territory was greater than 80% (Fig. 3). This suggests that selection of core areas within territories may be primarily relative in nature, rather than being dependent on an absolute value (at least for the range of Mature Forest within my study). If

selection was based on an absolute amount of mature forest I would have expected the pattern in Fig. 3 to break down at some level, with approximately equal numbers of territories above and below the zero difference line.

Few studies have assessed the influence of habitat pattern on selection of habitat by goshawks. In their recent monograph comparing areas surrounding nest sites to random sites across their study areas McGrath et al. (2003) evaluated 2 CWED metrics (1 defined by forest height and 1 by canopy closure), mean nearest neighbour distance, Simpson's evenness index, and Contagion at 5 nested scales ranging from 30-170 ha. Of these, Simpson's evenness index was consistently higher at goshawk sites than random sites. This is consistent with my observation of lower Simpson's diversity index values at core territories than random plots (Simpson's evenness index is the Simpson's diversity index for a site divided by the maximum Simpson's diversity index for the sample [McGarigal et al. 2002]). For contagion, they found higher values for random plots, which is the opposite of what I found in this study. The reason for this difference is unclear, but may be due to overriding selection for mature forest and differences in distribution and pattern of mature forest between our 2 studies. Neither of the 2 CWED variables nor the mean nearest neighbour distances differed among goshawk sites and random sites.

Finn et al. (2002) also used pattern metrics (11 variables) to compare conditions between 12 goshawk territories that were occupied at least once over a 3-year period and 18 historic goshawk territories that were not occupied during the same period. The patterns they observed between used and unused territories at a 170 ha sampling scale were very similar to what I observed between core territories and random plots. They found that the proportion of late seral forest, patch core size, and late-seral core size were greater at used territories and that patch density, edge density, patch richness, and contrast were lower at used territories. Additional

studies examining the influence of fragmentation metrics on habitat use by goshawks are required to identify general patterns of selection for these variables, in the same way that numerous studies of site and stand scale habitat variables have identify general patterns of selection for those variables (Penteriani 2002).

The mechanisms underlying the strong pattern of selection I observed for higher proportions of mature forest in core territories are not clear. Given the strong selection that goshawks exhibit for mature forest for both nesting (Penteriani 2002) and foraging habitat (Greenwald et al. 2005), both factors likely contribute. In relation to nesting, Reynolds et al. (1992) suggested that it may be important to have alternative nesting habitat available in the event that all or a portion of the original nest area is impacted. Within my study area goshawks avoided locating nests within 100m of edges (T. Mahon, unpublished data), which is consistent with my observations in this study of avoidance of CWED and selection of CORE_AM at meso-scales surrounding nest areas. Locating nest sites within more contiguous patches of mature forest and away from edges may minimize competition and predation risk with species that are more associated with edges and more heterogeneous habitats (e.g. red-tailed hawks and corvids) (Squires and Reynolds 1997). In terms of foraging, goshawks consistently select mature forest where prey is most accessible, even when prey may be more abundant in other habitat types (Reynolds et al. 1992, Beier and Drennan 1997, Good 1998, Stephens 2001, Drennan and Beier 2003, Greenwald et al. 2005). Locating the nest area within a concentration of mature forest is consistent with central-place foraging theory to maximize the amount of food acquired relative to time and energetic expenditures (Schoener 1971; Pyke et al. 1977).

Management Implications

The strong pattern of selection I observed for goshawk nest areas at 177 ha and 400 ha has important implications for nesting habitat selection studies, habitat suitability mapping, and

management. Previous research on goshawk nesting habitat has focussed on site and stand scale characteristics, such as stand age and height, canopy closure, and topography (Penteriani 2002). My results highlight the importance of also examining habitat composition and pattern at meso-territory scales in future habitat studies. Additional studies examining relationships between fragmentation metrics and goshawk nesting and foraging habitat to identify consistent patterns of selection.

The same issue of scale applies to goshawk nesting habitat models (e.g. Habitat Suitability Index models [US Fish and Wildlife 1981] and Resource Selection Functions [Manly et al. 2002]), which are often used as management tools, and which often only incorporate stand-scale habitat variables. Goshawks are often included as a focal species or mature forest indicator in land use planning processes and habitat supply is included as a forecast variable for assessing the outcomes of different management scenarios. In British Columbia several regional planning processes have incorporated goshawk habitat supply analysis but none of them incorporated habitat characteristics at scales larger than the stand-level (BC Ministry of Sustainable Resource Management 2004, Coast Information Team 2004, Mahon et al. 2003). Incorporating selection for higher proportions of mature forest at meso-territory scales into habitat models may be important for accurately predicting true habitat suitability. Specifically, incorporating meso-territory scale condition would improve the specificity of models by differentiating among stands with similar suitability based solely on stand characteristics. Without this consideration, habitat models may overestimate the amount of suitable habitat and have weaker predictive ability in a spatial context. Incorporating meso-territory scale condition may also result in different interpretations of management scenarios, such as dispersed vs. aggregated timber harvesting patterns.

The importance of conserving mature forest at the post-fledging area scale (170 ha) has been highlighted in previous management guidelines (Reynolds et al. 1992, BC Ministry of Environment and BC Ministry of Forests 1999). However, several recent studies of post-fledging areas indicate that the average size of areas used by juvenile goshawks is usually smaller than the 170 ha originally estimated by Kennedy et al. (1994). This could lead to the de-emphasis of management at the PFA scale or a reduction in size of the management unit. In northeast Nevada, Shipman (1998) observed mean PFA sizes of 12ha (n=7). In southeast Alaska 7 PFAs averaged 26ha (Iverson et al. 1996). On Vancouver Island McClaren et al. (2005) reported mean PFA size of 59ha (n = 12) and in my study areas mean PFA size was 20 ha (n = 34; Mahon and Doyle, In Prep.). Results from this study show a strong pattern of selection for mature forest in 177 ha and 400 ha core territories surrounding the nest area and support strategies to maintain mature forest and limit fragmentation at these scales.

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Table 1. Characteristics of the 7 habitat types used in this study and their suitability as goshawk nesting and foraging habitat.

Habitat Type	Stand Age (years)	Stand Height (m)	Description / General suitability to goshawks
Herb	0-15	0 - 2	Early successional stage dominated by herbs resulting from recent clearcuts and burns. Forage and cover for goshawk prey limited.
Shrub	15-40	2 - 6	Early successional stage dominated by shrubs and regenerating coniferous trees. Grouse and hares may be abundant but availability to goshawks is limited due to thick cover.
Pole-Sapling	41-60	6 - 15	Mid seral stage in which conifer trees have overtopped shrub and herb layers. Stands are typically densely stocked; self thinning not yet evident. Low prey abundance and availability to goshawks. Requirements for nesting generally not available.
Young Forest	61-120	10 - 25	Self thinning has become evident. Prey abundance still low due to low productivity in the herb and shrub layers (although squirrels may be increasing); prey more available due to stand thinning. Minimum requirement for nesting generally available (branches adequate to support nests with subcanopy flyways through stands).
Mature Forest/ Old Growth	>120	>16	Trees from the last disturbance have matured; stand thinning largely complete. Herb and shrub layers have redeveloped, often including understory tree regeneration. Squirrels at highest abundance; prey availability generally best for goshawks at this stage. Nesting habitat at optimal conditions.
Non-Forested	N.A.	N.A.	Alpine, alpine parkland, wetlands, meadows. Prey generally low, but variable; less preferred habitats for hunting.
Not Suitable	N.A.	N.A.	Ice, rock, water, urban

Table 2. Description of fragmentation metrics calculated from Fragstats 3.3 (MacGarigal et al. 2002) for each core area and random plot within 78 goshawks territories in west-central British Columbia.

Fragmentation Metric	Description
Patch Density (PD)	The number of patches within the landscape or of the corresponding patch type (NP) divided by total landscape area, multiplied by 10,000 and 100 (to convert to 100 ha). (assessed at class and landscape levels)
Largest Patch Index (LPI)	The percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance. (assessed at landscape level only)
Area-Weighted Mean Area (AREA_AM)	The average area-weighted area per patch for the landscape or for the corresponding patch type (assessed at class and landscape levels)
Area-Weighted Mean Core Area (CORE_AM)	The average area-weighted core area per patch for the landscape or for the corresponding patch type (assessed at class and landscape levels)
Contrast-Weighted Edge Density (CWED)	The sum of the lengths of each edge segment in the landscape multiplied by the corresponding contrast weight for the corresponding 2 habitat types, divided by total landscape area. (landscape-level only; contrast weights between each habitat type are provided in Appendix 1).
Contagion (CONTAG)	A measure of the proportional abundance of each habitat type and their interspersion and juxtaposition in the landscape. (assessed at landscape level only)
Percentage of Like Adjacencies (PLADJ)	Measures the degree of aggregation of cells (versus patches for CONTAG) for the focal class type. (assessed at class and landscape levels)
Patch Cohesion Index (COHESION)	Measures the connectedness of the corresponding class type. (assessed at class level only)
Simpson's Diversity Index (SIDI)	The probability that any pixels selected at random would be different class types. (assessed at landscape level only)

Table 3. Habitat composition and pattern characteristics for core territory plots, centred on nest areas, and random within-territory plots for 78 goshawk territories in west-central British Columbia (177 ha scale).

Variable[1]	Random Plots		Core Area Plots		Relative Difference[2]	Territories (%)[3]	P-value
	Mean	SE	Mean	SE			
Habitat Type							
Herb	12.26	1.27	5.95	0.91	-51.4%	75.6%	<0.001
Shrub	10.35	1.18	6.19	1.10	-40.3%	73.1%	<0.001
Pole-Sapling	8.40	1.41	4.64	1.18	-45.1%	87.2%	<0.001
Young Forest	14.30	1.74	8.98	1.72	-37.2%	84.6%	0.003
Mature Forest	46.81	2.26	69.29	2.75	48.0%	88.5%	<0.001
Non-Forest	5.05	0.97	3.07	0.79	-39.2%	79.5%	0.027
Not Suitable	2.51	0.38	1.88	0.49	-25.0%	78.2%	0.111
Class Level Fragmentation Metrics							
PD	1.52	0.07	1.02	0.08	-32.9%	82.1%	<0.001
AREA_AM	72.62	4.19	117.83	5.21	62.3%	88.5%	<0.001
CORE_AM	36.18	3.07	73.27	4.39	102.5%	84.6%	<0.001
PLADJ	76.13	1.22	86.46	0.84	13.6%	88.5%	<0.001
COHESION	91.47	1.03	97.43	0.45	6.5%	92.3%	<0.001
Landscape Level Fragmentation Metrics							
PD	5.29	0.22	4.09	0.23	-22.6%	76.9%	<0.001
LPI	56.33	1.56	70.44	2.29	24.9%	78.2%	<0.001
AREA_AM	75.84	2.89	101.81	4.74	34.0%	76.9%	<0.001
CORE_AM	13.76	2.35	62.24	4.22	59.3%	74.4%	<0.001
CWED	38.94	1.05	20.11	1.28	-22.6%	71.8%	<0.001
CONTAG	26.01	1.10	58.43	1.94	19.0%	73.1%	<0.001
PLADJ	49.08	0.68	83.32	0.75	4.8%	75.6%	<0.001
SIDI	0.51	0.01	0.39	0.02	-24.1%	69.2%	<0.001

[1] For a description of the fragmentation metrics refer to Table 2.
[2] Relative difference = mean difference of core territories and random plots divided by mean random value.
[3] Proportion of territories (n=78) that differ in the same direction (i.e. sign) as the average difference.

Table 4. Habitat composition and pattern characteristics for core area plots centred on nest areas
        and random, within-territory plots for 78 goshawk territories in west-central British
        Columbia (400 ha scale).

Variable[1]	Random Plots Mean	Random Plots SE	Core Area Plots Mean	Core Area Plots SE	Relative Difference[2]	Territories (%)[3]	P-value
Habitat Type							
Herb	13.52	1.28	8.95	1.01	-33.7%	70.5%	<0.001
Shrub	10.00	1.07	7.48	1.13	-25.2%	67.9%	0.010
Pole-Sapling	7.33	1.13	5.32	1.24	-27.7%	76.9%	0.006
Young Forest	13.12	1.53	10.17	1.67	-22.5%	75.6%	0.030
Mature Forest	47.72	2.18	62.37	2.49	30.7%	80.8%	<0.001
Non-Forest	4.37	0.85	3.56	0.68	-18.5%	66.7%	0.055
Not Suitable	3.95	0.72	2.15	0.50	-45.7%	79.5%	0.001
Class Level Fragmentation Metrics							
PD	1.00	0.06	0.70	0.06	-30.3%	75.6%	<0.001
AREA_AM	156.43	9.71	226.79	11.69	44.8%	78.2%	<0.001
CORE_AM	87.51	7.35	144.97	9.61	65.3%	80.8%	<0.001
PLADJ	81.52	0.70	85.92	1.30	5.4%	85.9%	<0.001
COHESION	95.19	0.36	96.45	1.29	1.3%	83.3%	0.302
Landscape Level Fragmentation Metrics							
PD	3.84	0.17	3.51	0.19	-8.5%	61.5%	0.005
LPI	52.78	1.61	61.68	2.26	16.9%	73.1%	<0.001
AREA_AM	152.16	6.74	184.36	9.92	21.2%	69.2%	<0.001
TCA	173.30	4.88	195.20	6.63	12.6%	73.1%	<0.001
CORE_AM	88.03	5.63	116.07	8.60	31.9%	67.9%	<0.001
CWED	26.24	0.97	23.05	1.18	-12.1%	66.7%	0.002
CONTAG	51.47	1.01	55.91	1.55	8.6%	67.9%	0.002
PLADJ	81.79	0.58	83.85	0.63	2.5%	70.5%	<0.001
IJI	61.63	1.06	60.63	1.78	-1.7%	56.4%	0.585
COHESION	95.21	0.21	95.87	0.22	0.7%	67.9%	0.168
SIDI	0.54	0.01	0.48	0.02	-11.5%	66.7%	<0.001
MSIDI	0.84	0.03	0.71	0.04	-15.3%	67.9%	<0.001

[1] For a description of the fragmentation metrics refer to Table 2.
[2] Relative difference = mean difference of core territories and random plots divided by mean random value.
[3] Proportion of territories (n=78) that differ in the same direction (i.e. sign) as the average difference.
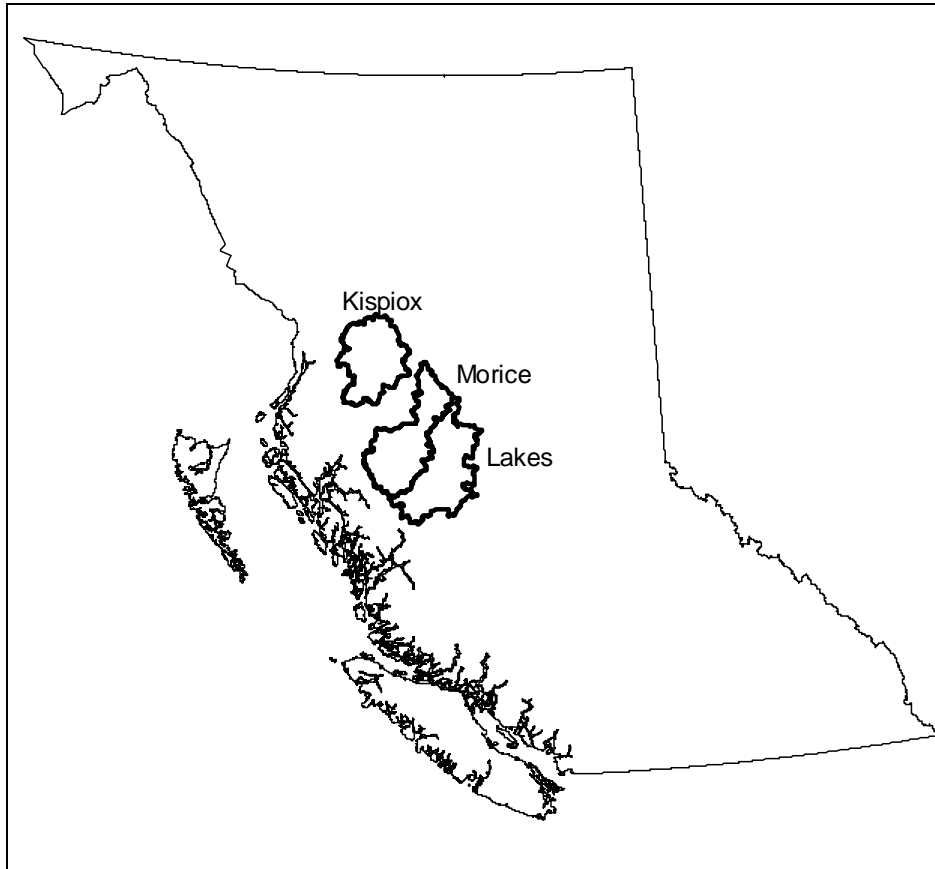
Fig. 1. Location of study areas in British Columbia. The Kispiox is predominantly within the Interior-Cedar-Hemlock Biogeoclimatic zone; the Lakes and Morice are predominantly within the Sub-boreal Spruce (Banner et al. 1993).
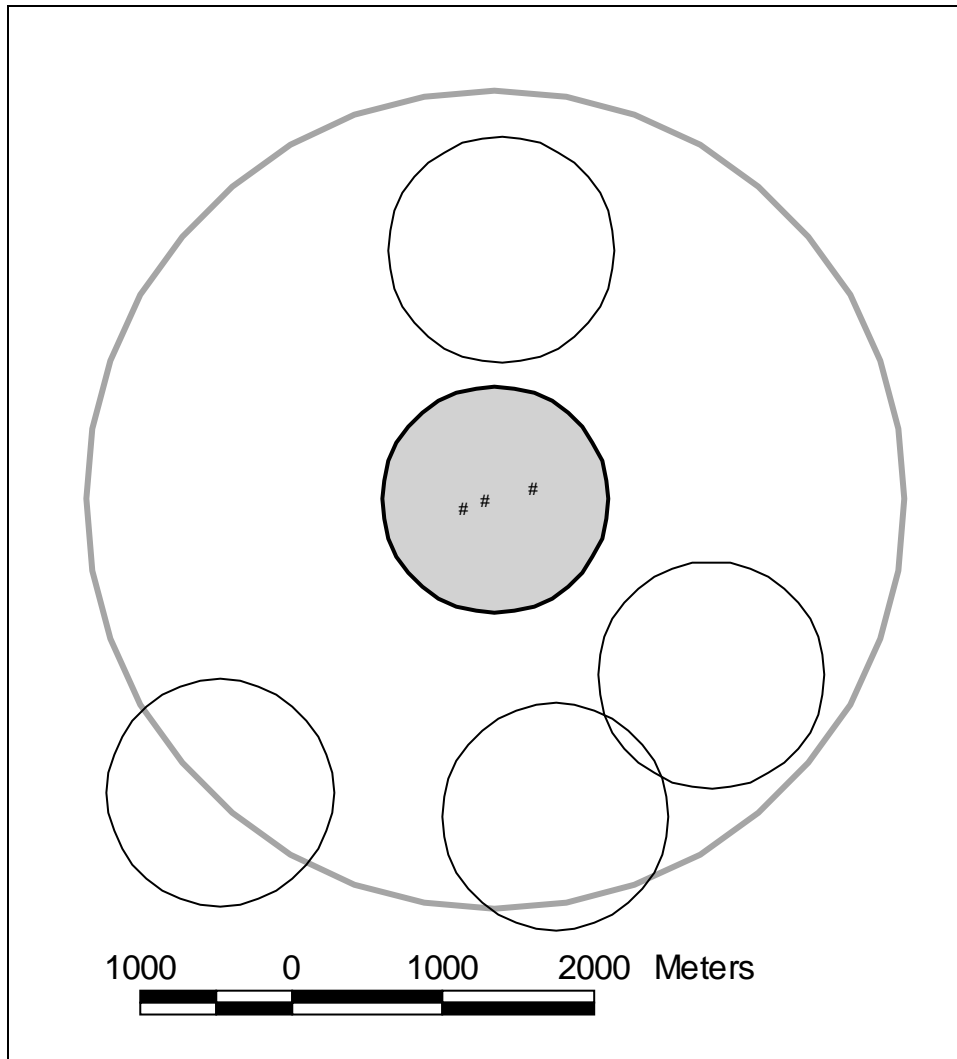
Fig. 2. Habitat sampling design. The shaded circle in the centre is the 177 ha core area sample
with the known nest sites indicated by the dots. The 4 hollow circles are the random
territory samples and the largest circle is the 2300 ha breeding territory boundary.
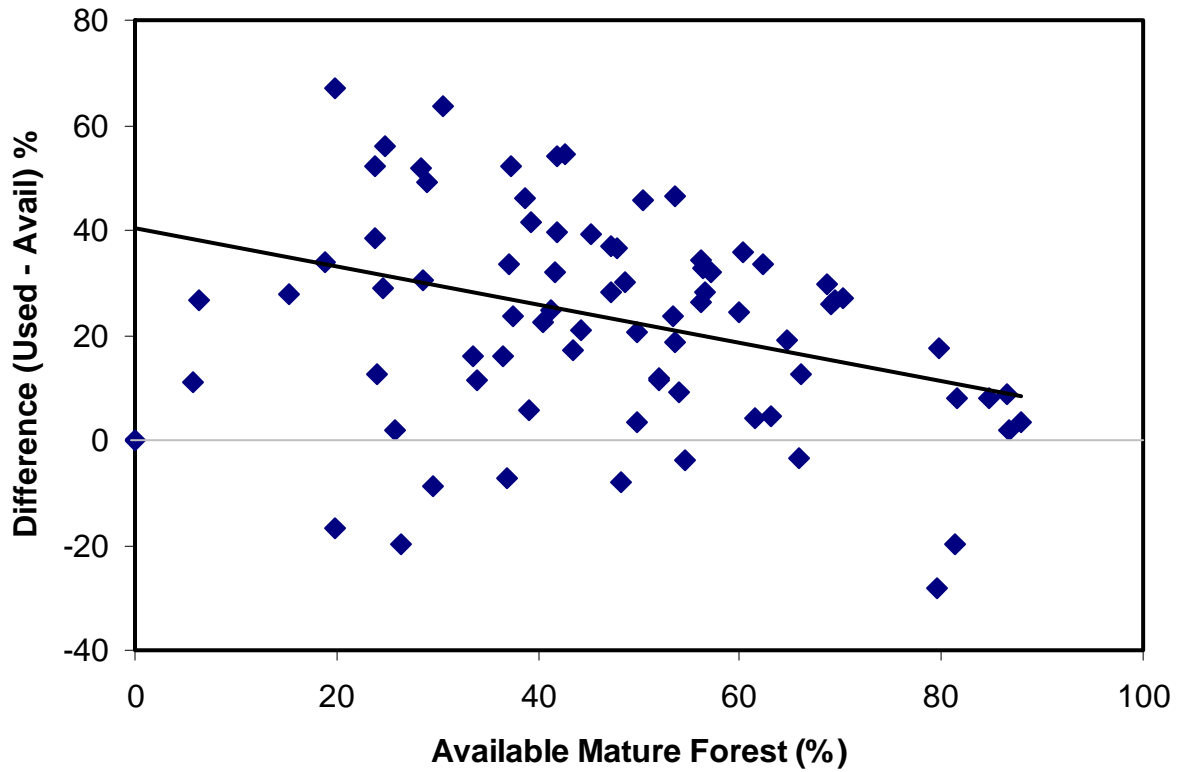
Fig. 3. Relative difference in the amount of mature forest between 177 ha core territory plots centred on nest areas and random plots within the same territories for 78 goshawk territories in west-central British Columbia. Available mature forest was estimated using four random plots within a territory. Used refers to the core territory plot. Plot size was 177 ha.