



Management and Conservation Article

Movements and Resource Selection of Fledgling Goshawks in Montane Forests of Southeastern British Columbia

WILLIAM L. HARROWER,¹ *Department of Biology, University of Victoria, 3800 Finnerty Road, Victoria, BC V8P 5CZ, Canada*

KARL W. LARSEN, *Department of Natural Resource Sciences, Thompson Rivers University, 900 McGill Road, Kamloops, BC V2C 5N3, Canada*

KARI A. STUART-SMITH, *Tembec, 220 Cranbrook Street N, Cranbrook, BC V1C 3R2, Canada*

ABSTRACT The northern goshawk (*Accipiter gentilis*) has been the subject of considerable interest because of the impact of logging on this species' nesting habitat. However, few studies have examined movements of fledgling birds around the nest prior to independence, and even fewer have described resource requirements of young birds during their postfledging period. Over 3 years, we followed 31 radiotagged goshawk fledglings from 15 nests in southeastern British Columbia, Canada. Of these birds, 26 survived to disperse. Between fledging and dispersal 95% of fledgling relocations ($n = 1,148$) were within 450 m of the nest. Fledglings primarily remained within 298 m of the nest during the first 21 days postfledging and within 525 m of the nest between 21 days postfledging and dispersal. Fledglings' movements were highly directional, with individual and sibling movements away from any particular nest tending out in one direction. Postfledging areas averaged 36.7 ha in size (median = 23.1, inter-quartile range = 20.8–39.7 ha). Fledglings strongly avoided forest <40 years old and weakly selected young forests (40–80 yr), mature forests (>80 yr), and stands with >40% canopy cover during the first 21 days and after. We suggest forest managers wishing to conserve goshawk postfledging areas in the interior montane forests of British Columbia maintain forests >40 years old with high crown closure covering an area ≥ 21 ha and preferably >40 ha. This area should contain all identified occupied and alternative nest trees in a nest area. At least half this area should be forest >80 years old and contain existing nests and potential for future nest trees.

KEY WORDS *Accipiter gentilis*, British Columbia, forestry, northern goshawk, postfledging area, radiotelemetry, resource selection.

There is a clear need for detailed management information on the movements and resource selection of the northern goshawk (*Accipiter gentilis*) during the fledgling-dependency period (Peck 2000, Kenward 2006, Squires and Kennedy 2006). In both Europe and North America, where goshawks put their nests has been the focus of considerable research because of the disturbance of goshawk nesting locations by logging (see reviews in Peck 2000, Kenward 2006, Squires and Kennedy 2006). Accumulated knowledge suggests that goshawks require older forests with closed canopies and open understories for nesting, although the size of the forest stand required to possess these attributes is still uncertain (see Penteriani 2002, Kenward 2006, Squires and Kennedy 2006). Multiscale nest-site selection studies have examined forest characteristics around the nest (i.e., approx. 500 m) to account for the needs of fledgling birds (e.g., Daw and DeStefano 2001, McGrath et al. 2003); however, few studies have specifically examined the movements of fledgling birds themselves and even fewer have described resource selection by fledglings (but see Penteriani 2002, McClaren et al. 2005, Kenward 2006, Squires and Kennedy 2006). An improved knowledge of movements and forest type selection by fledgling goshawks is required to develop logging prescriptions that maintain enough forest with the minimum suitable structure for goshawks to nest in and rear fledglings.

The stages of goshawk nesting behavior are predictable and are well-described (Squires and Reynolds 1997), and from these descriptions a specific nomenclature has developed. Goshawk nests are regularly spaced on the

landscape with suitable nesting conditions, and a single nest area and its associated male and female foraging areas combine to produce a nesting territory (Reich et al. 2004). Territory fidelity is high, ranging 75–94% annually (Detrich and Woodbridge 1994, Reynolds and Joy 2006). However, breeding pairs often build new nests each year, which results in several nests occurring in close proximity. Occupied nest sites are the nest and tree used by a breeding pair in a particular year, whereas alternative nest sites are nests and trees used in previous years by the breeding pair or their predecessors. We define a goshawk nest area by the distribution of occupied and alternative nests at any one site. Thus, the nest area includes all occupied and alternative nest sites. As with birds in general, goshawk young are termed nestlings while they occupy the nest and fledglings when they leave the nest and begin to fly. The area fledglings use while they are still dependent on their parents for food (i.e., fledgling-dependency period) is termed the postfledging area (i.e., postfledging family area in Reynolds et al. [1992]). The postfledging area surrounds the occupied nest of that year and may or may not include alternative nest sites.

Presumably, the size of the postfledging area is dictated by the fledglings' ability to fly, the forest structure available to them, and their need to remain close to the nest. As fledglings age, they can move farther from the nest (Kenward et al. 1993, 1994; Kennedy and Ward 2003; McClaren et al. 2005); however, the area they traverse does not expand indefinitely (Kenward et al. 1993, McClaren et al. 2005). Adults deliver food near the nest, and fledglings that remain in this area are assured more food. However, siblings compete for food and siblings attempt to intercept

¹ E-mail: harrower@shaw.ca

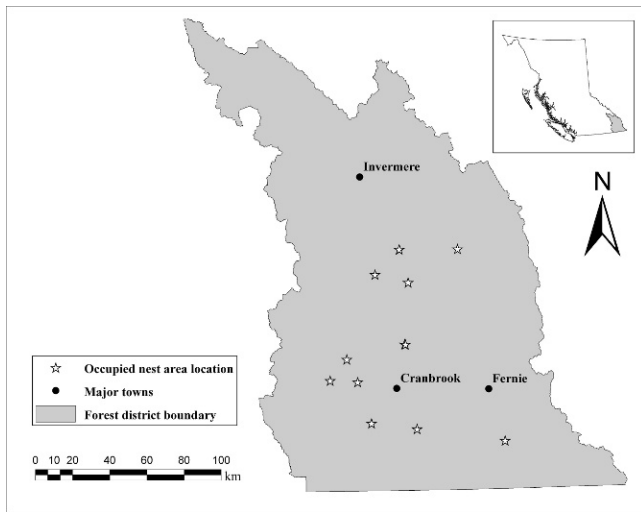


Figure 1. Study area for investigation of resource selection by fledgling goshawks in southeastern British Columbia, Canada, from 2004 to 2006. Major towns within the local Forest district boundary are shown as black dots and the locations of nest areas where fledgling goshawks were radiotagged and followed are shown by open stars. Inset shows the location of the forest district within the Province of British Columbia on the northwest shore of North America. The forest district boundary roughly follows major drainage boundaries on the northeast and west sides.

their parent's food delivery before other fledglings from the same nest. These interactions between siblings can lengthen the distance or change the direction that fledglings will travel from the nest (Kenward 2006, Squires and Kennedy 2006, Wiens et al. 2006b). Additionally, fledgling movements may be restricted by unsuitable forest types created by logging or other disturbances. Cessation of feeding by parents appears to coincide with dispersal by young goshawks (Kenward et al. 1993, Ward and Kennedy 1996, Kennedy and Ward 2003). Although the postfledging area is thought to consist of mature forest with dense canopies and small openings, it is unclear as to whether this area encompasses or is contained by the nest area (Kenward 2006, Squires and Kennedy 2006).

Our main goal was to provide information to forest managers and biologists that would aid in development of effective conservation plans and logging prescriptions for the northern goshawk in managed forests of the interior mountains of western North America. To this end, we monitored movements and selection of forest types by fledgling goshawks to quantify the size and characteristics of the postfledging area. We observed fledglings at nest sites surrounded by variable amounts of historic logging to examine the amount of forest selected by fledglings. Our specific questions were 1) how big was the postfledging area, and 2) what forest types did fledgling goshawks select for the postfledging area?

STUDY AREA

We conducted our study from 2004 to 2006 in the East Kootenay region of southeast British Columbia, Canada (Fig. 1), a mountainous area characterized by warm, dry summers and cold winters. Our work focused on the lower

to mid-elevation dry forests from 900 m to 1,600 m in elevation, dominated by Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), and lodgepole pine (*Pinus contorta*). Hybrid Engelmann and white spruce (*Picea engelmannii* × *glauca*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*) were present on moister sites. Natural (wildfire, insect outbreaks, tree diseases) and anthropogenic (timber harvesting, cattle grazing, mining, recreational development) disturbances impacted this landscape, but logging, fire suppression, and mountain pine beetle (*Dendroctonus ponderosae*) were the main factors likely impacting goshawks.

METHODS

Each spring, an annual goshawk nest-monitoring program provided locations of occupied goshawk nests (K. A. Stuart-Smith, Tembec, unpublished data). We selected nest areas to maximize the range in the amount of mature forest stands (>80 yr old) within 500 m of the occupied nest. Where possible, we selected sites with clear boundaries between mature forest and other age classes. Because a review of published literature suggested that fledglings select for mature forest, we assumed that these criteria would provide fledglings a clear contrast of suitable and unsuitable areas.

Using visual observations (Boal 1994) to monitor nests and age nestlings, we began radiotagging nestlings when they were approximately 20–25 days old. To relieve stress on both goshawks and researchers, we first lured parent goshawks into modified Dho-gaza traps, using either a captive great horned owl (*Bubo virginianus*) or a robotic replica as a lure. After we restrained adult birds, we climbed nest trees and lowered nestlings to the ground. We outfitted nestlings with a color auxiliary band (Acraft Sign and Nameplate Co. Ltd., Edmonton, AB, Canada), a United States Geological Survey silver metal band, and a 9-g, tarsal-mounted radiotransmitter equipped with a mortality sensor (Advanced Technology Services, Isanti, MN). We attached radiotags using leather jesses designed to slowly deteriorate and eventually allow birds to remove the tags (McClaren et al. 2005). We determined the sex of each nestling with tarsal width measurements (Kenward et al. 1993).

We monitored nestlings with visual and radiotelemetry observation until they dispersed from the fledgling-dependency area. We recorded fledging date as the first day that we observed a nestling perching on a tree other than the nest tree and marked the initiation of dispersal after locating the bird >1.6 km from the nest site for 2 consecutive days (Wiens et al. 2006b). After fledglings have moved this far, they rarely return to the nest (Wiens et al. 2006b). We determined locations of fledglings by homing in on radiotagged birds using radiotelemetry receivers (R-1000; Communications Specialists Inc., Orange, CA). We recorded locations in a handheld Global Positioning System (GPS) unit by averaging 100 successive locations. When possible, we used an external antenna (GPS 17-HVS GPS Sensor) to increase accuracy of locations. We made every attempt to minimize our influence on fledgling movements.

We followed 2 monitoring schedules to determine the location of fledgling birds. First, we attempted to locate all fledglings at least once per day to document their broad-scale movements. We used these data to define the postfledging area and to determine which forest types were selected by fledglings. To supplement this information, and to provide data for future investigations of fine-scale movements, we performed a series of short-term, intensive monitoring sessions at selected sites (Harrower 2007). During these focal sessions, we located fledglings hourly, from one hour before sunrise to one hour after sunset.

Telemetry researchers must increasingly choose between the additional information gained by locating animals more frequently and the achievement of both the independence of each relocation and accurate relocations of animals relative to the distance they traveled (Kernohan et al. 2001, Jerde and Visscher 2005). Our preliminary observations of fledgling movements suggest that fledglings moved >30 m only once per hour (Harrower 2007), and we used this as a minimum distance a fledgling would have to travel before we considered their travel a measurable movement. We felt that 30 m achieved a valid trade-off between location or digital forest cover error and movement patterns. Furthermore, we observed that fledglings were able to traverse their entire range during any one movement, so we assumed locations collected each hour to be biologically independent and we used these locations, collected during intensive monitoring sessions, to supplement daily relocation data. Thus, we collected locations both hourly and daily and used all of these locations in our analysis. The fledgling-dependency period is a short life-history stage, and we feel the information gained by increasing the number of locations used in the analysis supports our pooling of relocation data (Kernohan et al. 2001).

We entered all locations into a Geographic Information System for analysis. We calculated Euclidean distance and bearing to the nest for each location. We estimated the 95% fixed-kernel home range sizes for each fledgling using Program HOME RANGER (version 1.5; Ursus Software, Revelstoke, BC, Canada). We calculated kernel home ranges using reference values of the smoothing parameter ($b = 0$) because this value provided the best estimate of our data and was consistent with previous studies (McClaren et al. 2005). We assume that these kernel estimates of home range size are equivalent to estimates of the postfledging area size. We obtained precision in our estimates of postfledging area size by calculating the standard error from bootstrap estimates of postfledging area size derived from 1,000 repetitions. We pooled all locations from radiotagged siblings from the same nest site in the same year because their movements were similar (see previous paragraph).

To characterize the postfledging area, we quantified selected variables at fledgling locations and compared them to randomly located comparison points. We classified locations as being either from early (<21 days postfledging) or late (≥ 21 days postfledging) period. These times correspond to 2 periods in the physical development of the birds, during which their mobility substantially changes

(McClaren et al. 2005). We chose specific radii from the nest to estimate resource availability, based on our observations of fledglings' movements; 95% of locations were within these radii before and after hard-penning of feathers. For each postfledging area, we used 200 randomly located comparison points for each period (400 total comparison points for analysis of combined early and late periods) to quantify areas available to fledglings. Thus, we compared our 1,148 fledgling locations to 6,000 comparison points for the analysis of combined early and later postfledging periods. We reclassified digital forest cover information by categorizing stands by their dominant age class and canopy closure class using data developed by the British Columbia Ministry of Forests and Range from air photo interpretation. We defined a stand as an area of forest composed of trees of uniform age or canopy cover classification. We determined age classifications for forest stands from the date of the original aerial photo interpretation, and we corrected these dates for logging and other disturbances by year with updated information on logging and road building.

For each fledgling location and comparison point, we calculated values for 4 forest types by pairing locations to digital forest cover information. We defined young forest stands as those stands 41–80 years of age, and mature forest stands as >80 years old. Initiating forest stands were those that were either burned or logged within the last 40 years or where no forest cover occurred (e.g., lakes, wetlands, grass, or other natural openings). We combined areas without forest cover with recent burns and areas that were recently logged for 2 reasons. First, most initiating stands surrounding goshawk nests were previously forested and were recently logged or burned, and second, because these areas were similar in that they both presented little tree cover for fledglings. We classified closed-canopy stands as those with canopy cover >40% estimated from aerial photo interpretation because, in our region, 40% is considered a closed-canopy stand and canopy cover rarely exceeds 80%. We conducted a multivariate analysis of explanatory variables using information-theoretic approaches and matched case-control multivariate logistic regression, a form of general linear models (Hosmer and Lemeshow 2000, Burnham and Anderson 2002, Manley et al. 2002). We conditioned all models by one random effect composed of a unique nest area-year combination (Table 1).

Our final set of candidate models had 2 constraints: the number of explanatory variables needed to be <10% of the number of observations (Peduzzi et al. 1996), and the number of candidate models needed to be less than the number of observations (i.e., $R < n$; Burnham and Anderson 2000). No 2 explanatory variables had Spearman rank correlations >0.7. These constraints and our limited sample size ($n = 15$) resulted in us only comparing models containing one explanatory variable and nest site as a random variable. We concluded that fledglings were selecting for a variable if the regression coefficient for that variable was positive and against a variable if the regression coefficient for that variable was negative. We ranked all

Table 1. Directional movements and estimated postfledging areas for northern goshawk ($n = 15$) in southeastern British Columbia, Canada, from 2004 to 2006. We pooled fledgling locations by nest area and year and the number of fledglings followed at each site is indicated along with whether we collected locations daily or hourly. We calculated postfledging area (PFA) size estimates with 95% fixed-kernel home ranges with an ad hoc estimate of the smoothing parameter, and we derived bootstrap standard error estimates from 1,000 repetitions of fixed-kernel home range estimates.

Nest area no.	Yr	No. of fledglings	No. of locations	Mean azimuth (°)	Circular variance (r^a)	Rayleigh P -value	PFA size (ha)	Bootstrap (SE)
1	2005	2 ^b	153	35	0.08	<0.001	20.2	1.17
2	2005	1 ^b	71	101	0.60	<0.001	32.5	2.36
3	2006	1	29	22	0.20	<0.001	28.3	2.67
3	2005	1 ^b	68	27	0.23	<0.001	21.3	1.48
4	2004	1	69	75	0.31	<0.001	10.3	0.75
5	2005	2 ^b	104	147	0.58	<0.001	23.1	1.46
6	2006	1	65	117	0.66	<0.001	36.3	2.85
6	2005	2 ^b	158	162	0.19	<0.001	43.2	2.28
7	2004	3 ^b	92	47	0.55	<0.001	22.8	1.51
8	2004	1 ^b	38	89	0.39	<0.001	15.3	1.52
9	2004	2	68	15	0.49	<0.001	70.9	5.71
10	2006	2	53	42	0.62	<0.001	22.6	2.07
10	2004	2 ^b	83	36	0.73	0.022	15.3	1.01
11	2006	2	51	117	0.59	<0.001	70.2	6.15
11	2004	1 ^b	46	79	0.79	0.143	50.2	4.16

^a r is a measure of angular dispersion; it has no units and varies from 0.0 to 1.0. At 1.0 all the data are concentrated in the same direction; however, when $r = 0$ the data may not be distributed uniformly in all directions (Zar 1999).

^b Includes relocations obtained both hourly and daily.

single-variable models using the change in Akaike's Information Criterion for small sample size from most parsimonious model. We assessed how well a model discriminated by assessing the area under the receiver operator characteristic curve (AUC). We assessed model calibration by determining whether the 95% confidence interval of the odds ratios encompassed 1.0, indicating poor calibration. Calibration is an assessment of how well the data fit a statistical model and discrimination assesses a model's ability to determine whether an outcome is positive ($x = 1$) or not ($x = 0$). Area under the curve values range from 0.5 to 1. Values >0.7 are considered acceptable, those between 0.8 and 0.9 are considered excellent, and those >0.9 are rarely observed.

We report the results of 2 other types of tests. We tested for significance between 2 general linear models, one with a response variable and intercept and an intercept-only model, to determine whether size of the estimated postfledging area or the maximum distance moved by fledglings was influenced by the proportion of mature or initiating forest surrounding the nest. We used the F -statistic in place of a chi-square statistic in our significance tests to account for any overdispersion of our data. We tested all angular data for deviations from uniformity with the Rayleigh Test for circular uniformity (Zar 1999) and we assessed angular dispersion using the index r that ranges from 0.0 to 1.0, where 1.0 indicates data highly concentrated in one direction (Zar 1999). We performed all geographic analyses in ARCGIS ArcEditor 9.2 and statistical analyses in R 2.4.1 (R version 2.11.1; <www.r-project.org>, accessed 17 Jun 2010).

RESULTS

We observed 34 nestlings at 17 occupied goshawk nests over the 3 years of investigation. Eight birds died prior to dispersal: 3 as nestlings and 5 as fledglings. Nestlings were

removed from the nest by either mammalian or avian predators and we found remains or transmitters near the nest on all 3 occasions. One fledgling died of malnutrition and 4 fledglings were killed by avian predators but not plucked, eaten, or otherwise disturbed. Yearly survival of marked fledglings was 70% in 2004, 100% in 2005, and 79% in 2006. From the 15 nests at 11 nest areas where fledglings survived to disperse, 31 goshawks fledged and 26 survived to disperse from the natal area. We marked, followed, and analyzed movements of these 26 birds. Fledglings dispersed 33–48 days after leaving the nest.

We recorded locations of fledglings 1,148 times with an average of 44 locations/fledgling (SE = 1.4, range = 24–81) and 77 locations/postfledging area (SE = 9.7, range = 29–158, $n = 15$). Of the fledglings' locations, 95% were within 450 m of the nest ($\bar{x} = 168$, median = 126, SE = 4.3, $n = 1,148$; Fig. 2). Within the first 21 days after fledging, 95% of locations were within 298 m of the nest ($\bar{x} = 120$, median = 94, SE = 3.7, $n = 713$). Locations recorded after 21 days postfledging, but while fledglings were still dependent on their parents, were within 525 m of the nest 95% of the time ($\bar{x} = 246$, median = 201, SE = 8.2, $n = 435$). Although we located fledglings farther from the nest following completion of feather development, all of the birds returned frequently to the area immediately surrounding the nest during this period. We determined the azimuth of each fledgling's location from the nest tree and compared the mean azimuth among siblings at sites with >1 fledgling. There was 88.48% overlap in siblings' fixed-kernel home ranges (SE = 5.83, range = 77.08–97.69%, $n = 10$). Our estimates of postfledging area sizes (Table 1) ranged 10.3–70.9 ha ($\bar{x} = 36.7$ ha, median = 23.1, SE = 6.58, $n = 15$). Individuals were able to traverse their entire range between relocations, which confirmed our assumption of independence between locations.

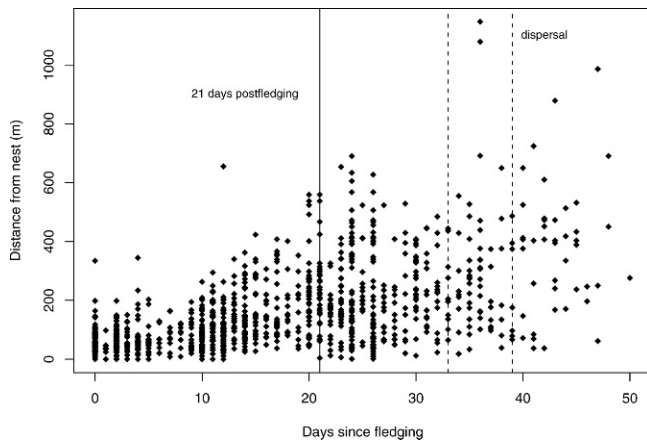


Figure 2. Distance of fledgling goshawk relocations ($n = 1,148$) from the nest, in southeastern British Columbia, Canada, as a function of days postfledging. Relocations were made during the fledgling-dependency periods from 2004 to 2006 at 15 different nests. Fledglings were outfitted with radiotransmitters and relocated at least once each day until they dispersed from the nest area. We considered a nestling goshawk fledged when we located it in a tree other than the nest tree or located it on the ground.

Fledgling goshawks avoided areas of initiating forest (Table 2). During the entire fledgling-dependency period, we were 72 times less likely to find a bird in initiating forest than in other forest type (Table 3). Fledglings positively selected areas of closed-canopy forest (>40% closure), young forests (41–80 yr old), and mature forests (>80 yr), although selection for these areas was not as strong as their avoidance of initiating forest (<40 yr old). The model using the proportion of initiating forest to examine selection during the entire dependency period had the greatest discrimination ($AUC = 0.709$) of all models we examined (Table 2) and although odds ratio 95% confidence interval of all models did not encompass 1.0, these intervals were large for all models except the initiating forest model (Table 3).

Models describing resource selection during the late and early fledgling-dependency periods did not perform as well as those for the entire fledgling dependency period, although fledglings still avoided initiating forest stands.

During the early dependency period, fledglings appeared to strongly avoid initiating forest; however, this model discriminated poorly (Table 2), had a large error in parameter estimates, and an upper 95% confidence interval could not be calculated for the odds ratio of this model (Table 3). Poor performance of this model was primarily because there were so few points in initiating forest stands during the early dependency period. Despite this model's poor discrimination it was still the best model of the candidate set at describing the location of fledglings. During the late dependency period, fledgling movements were less associated with specific stand ages, and birds used closed-canopy stands more extensively. Fledglings were 6 times more likely to be found in closed-canopy forest than open-canopy forest and 93 times more likely to be found in areas that were not initiating forest than in initiating forest stands. Discrimination of models was poor during the late fledgling-dependency period. All models discriminated poorly (approx. 0.5–0.6; Table 2). Much of the explanatory information for the late dependency-period candidate model set was contained in the 2 best calibrated models: those describing selection for closed-canopy forest and against initiating forest stands.

Availability of forest types to fledglings was different during the early and late fledgling-dependency periods. We measured availability within radii defined by fledgling movements. There was generally a lower proportion of initiating forest within 298 m of the nest than within 525 m of the nest. The median proportion of initiating forest within 298 m of the nest was 10% (range = 0–64%, $\bar{x} = 22\%$, $SE = 6.4$), whereas the median proportion of initiating forest within 525 m of the nest was 26% (range = 0–64%, $\bar{x} = 27\%$, $SE = 6.1$). The median proportion of mature forest within 298 m of the nest was 29% (range = 5–100%, $\bar{x} = 68\%$, $SE = 8.3$) and within 525 m was 66% (range = 29–97%, $\bar{x} = 62\%$, $SE = 6.5$). We reported median values because mean values were highly influenced by large percentages of initiating or mature forest at individual locations. There was no relationship between the size of the postfledging area and the amount of mature

Table 2. Conditional logistic regression models we used to assess fledgling goshawk selection during the entire fledgling-dependency period (FDP) and early and late FDPs in southeastern British Columbia, Canada, from 2004 to 2006. We used negative log-likelihood (Log-lik), number of parameters (K), Akaike's Information Criterion for small sample sizes (AIC_c), the change in AIC_c from most parsimonious model (ΔAIC_c), and Akaike weight (w_i) for plausible models to examine resource selection by fledgling goshawks. Models are ranked by AIC_c , and the area under the receiver operator characteristic curve (AUC) values are given. We developed all models using the number of locations and 200 randomly located comparison points for early and late FDPs or 400 randomly located comparison points for the entire FDP.

Period	Model	Log-lik	K	AIC_c	ΔAIC_c	w_i	AUC
Entire FDP	Initiating forest	-4.356	2	13.156	0.000	0.974	0.709
	Young forest	-9.014	2	22.472	9.317	0.009	0.493
	Closed-canopy forest	-8.916	2	22.277	9.121	0.010	0.504
	Mature forest	-9.301	2	23.047	9.891	0.007	0.622
Early FDP	Initiating forest	-4.159	2	12.762	0.000	0.978	0.671
	Young forest	-8.835	2	22.115	9.353	0.009	0.493
	Mature forest	-9.079	2	22.602	9.840	0.007	0.613
	Closed-canopy forest	-9.329	2	23.101	10.339	0.006	0.520
Late FDP	Closed-canopy forest	-8.509	2	21.462	0.000	0.389	0.558
	Initiating forest	-8.562	2	21.569	0.107	0.369	0.656
	Young forest	-9.388	2	23.220	1.758	0.161	0.462
	Mature forest	-10.073	2	24.590	3.128	0.081	0.578

Table 3. Model performance characteristics for all 12 conditional logistic regression models showing beta coefficients (Coeff.), standard errors, estimates of odds ratio (Odds) and the 95% confidence intervals of the odds ratios (Lower 95% CI, and Upper 95% CI) from conditional logistic regression models we used to assess fledgling goshawk selection during the entire fledgling-dependency period (FDP) and early and late FDPs in southeastern British Columbia, Canada, from 2004 to 2006.

Period	Model	Coeff.	SE	Odds	Lower 95% CI	Upper 95% CI
Entire FDP	Initiating forest	-32.42	25.30	0.723	<0.001	<0.001
	Young forest	8.77	7.50	1.092	3.354	627,814
	Closed-canopy forest	5.65	3.79	1.058	6.424	12,581
	Mature forest	4.07	3.00	1.041	2.915	1,176
Early FDP	Initiating forest	-201.98	60,577	0.133	0.000	n/a
	Young forest	9.13	8.87	1.096	1.297	65,659,969
	Mature forest	4.13	2.83	1.042	3.669	1,053
	Closed-canopy forest	4.66	3.74	1.048	2.509	4,447
Late FDP	Closed-canopy forest	6.11	3.90	1.063	9.116	22,247
	Initiating forest	-6.20	3.81	0.940	<0.001	0.092
	Young forest	7.28	6.07	1.076	3.354	627,814
	Mature forest	1.86	2.36	1.019	0.607	68.03

forest ($F_{1,14} = 2.156$, P -value = 0.166) or initiating area ($F_{1,14} = 3.76$, P -value = 0.07) within 525 m of the nest. Neither did we detect a relationship between the maximum distance moved by fledglings and the proportion of mature forest ($F_{1,14} = 1.559$, P -value = 0.23) or initiating area ($F_{1,14} = 4.5$, P -value = 0.53) within 525 m.

Fledglings generally traveled out from the nest in one direction and their movements were often concentrated along this vector. Fledgling movements were offset in one direction from the nest (Table 1) at all nest areas except nest area 11 in 2004 (Table 1). All tests for circular uniformity also were highly significant (i.e., P -value < 0.001) except for nest area 10 in 2004 (Table 1; P -value = 0.02), suggesting our data fit the vonMisses distribution (a circular analog to the normal distribution). Fledgling location data from most nest sites were concentrated away from the nest in one direction, according to r values (Table 1). A notable

exception is nest area 1 in 2005 where data were not concentrated, but were highly directional. Three other sites had a low concentration of points (i.e., $r < 0.3$; Table 1), but again fledgling movements at these sites were directional. At both sites where directionality was not highly significant (i.e., Rayleigh Test for significance P -value < 0.001) locations were concentrated (i.e., $r > 0.7$). In some nest areas, distribution of forest types resulted in a restriction of movements to narrow patches of forest (e.g., Fig. 3). However, in many cases fledglings had ample suitable forest available and they did not use it (e.g., Fig. 3).

DISCUSSION

Fledglings in our area moved shorter distances than those reported elsewhere. Kenward et al. (1993) reported that fledglings in Sweden always were within 1,000 m of the nest, with most locations within 800 m; 91% of observations

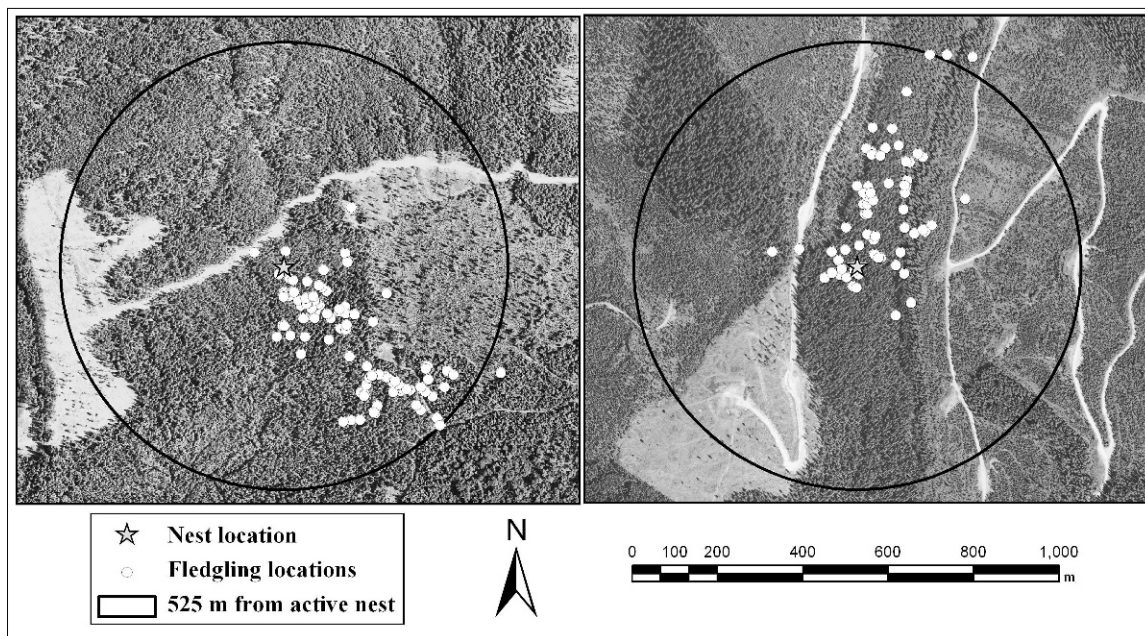


Figure 3. Two representative northern goshawk nest areas used by fledglings in southeastern British Columbia, Canada. Fledgling relocations are shown as open circles and were obtained in 2005. A 525-m-radius circle surrounds each year's occupied nest site (open stars). We overlaid graphics on digital aerial photos. In both examples, fledglings avoided recent logging but only used the available older forest in the example with the largest amount of logging.

by Kennedy et al. (1994) in New Mexico, USA, were within 800 m of the nest, and 99% of observations by McClaren et al. (2005) on Vancouver Island also were within 800 m. We observed few locations >800 m from the nest and 95% of our locations were within 450 m. Possible reasons why fledglings in our study may have remained closer to the nest than fledglings studied elsewhere include an abundance of food at the nest tree provided by their parents (Kennedy and Ward 2003) and the distribution of initiating forest, which may have restricted their movements. We observed a direct correlation between fledgling age and an increase in fledgling movements away from the nest similar to those reported in other locations (Kenward et al. 1993, McClaren et al. 2005). However, even after obtaining full flight capability (i.e., late fledgling-dependency period), fledglings remained attracted to the nest site, presumably because the nest is a central location to obtain food and protection from their parents.

Our estimated average postfledging area size (36.7 ± 6.6 ha, $n = 15$) was smaller than those reported by the only other published study that followed fledglings and estimated postfledging areas with similar methods (59.2 ± 16.1 ha, $n = 12$; McClaren et al. 2005). Fledglings may have remained closer to the nest in our study area because of high food availability or because they were restricted by available forest cover. Fledglings leave the postfledging area when their parents stop feeding them, and the timing of this event can be changed through supplemental feeding (Kenward et al. 1993, Kennedy and Ward 2003). Fledgling movements also have been shown to be influenced by supplemental feeding (Kennedy and Ward 2003). We do not have the data to test whether food availability influenced fledgling movements in our area.

Fledgling goshawks we observed avoided initiating forest, primarily areas that were recently logged. We presume that fledglings avoided these stands because they provided little tree cover. During the early fledgling-dependency period, fledglings remained close to the nest where availability of forest types was dependent on the location of the nest. Goshawk nest areas have previously been estimated at approximately 12 ha (approx. 200-m radius; Reynolds et al. 1992). The nest area roughly coincides with the area used by fledglings during the early fledgling-dependency period and fledglings can easily receive food and protection from their parents in this area. However, during the late fledgling-dependency period, fledglings are more mobile and tend to travel beyond their parents' nest area. During the late fledgling-dependency period, fledglings selected closed-canopy stands but still did not use initiating forest stands. We thought fledglings may move into younger, denser forest stands to avoid predation from other hawks or owls, but our data did not show strong selection for young forest stands. The relative strength of selection between forest types was not as strong during the late fledgling-dependency period, suggesting the birds used a wider range of forest types as they grew older and more mobile. We assumed that we would see strong selection by fledglings for mature forest; however, our data show a weak (if any) relationship to forests >80 years old. Fledglings appeared to use any age of forest >40 years

old with canopy cover >40%. Thus, fledgling goshawks may be more tolerant of forest type than previously thought and simply do not use areas with little or no tree cover.

Our results represent only a snapshot of the potential multiyear movements of fledglings around a nest area. The amount of forest used by fledglings differed between the early and late fledgling-dependency periods in our study but could also differ among years at individual sites. Changes in forest composition, prey distribution, or identity of the parental birds may influence the direction and magnitude of multiyear movements from the nest. At 4 locations we followed fledglings from different nests, occupied in different years, and located within the same nest area. Although nest sites were different and logging had occurred close to the nests in 3 cases, there were limited differences in the azimuth that fledgling movements were offset from the nest. Our sampling strategy was not designed to determine differences in movements between years at individual sites and we hesitate to predict similar movements over many years.

An obvious constraint of our study was that we could only follow fledglings from nest sites where adult birds had successfully nested. We observed goshawk fledglings surviving to disperse from postfledging areas as small as 10 ha, and fledgling survival was high in both our study (70–100% from fledgling to dispersal each yr) and others. Wiens et al. (2006a) followed 81 fledglings and found that mean annual survival of fledglings ranged between 0.81 (95% CI = 0.60–0.93) to 1.00 (95% CI = 0.95–1.00) and observed that fledgling survival was strongly related to prey abundance. Thus, if fledglings survived to disperse from a nest area we must assume that the minimum necessary forest conditions for survival, growth, and dispersal were met; however, we cannot assume that our study revealed the entire range of forest conditions that would be sufficient for fledglings to survive to dispersal. Nonetheless, the range of nest area attributes included in our study is still noteworthy.

MANAGEMENT IMPLICATIONS

Given differences in selection of forest types we observed between the early and late postfledging period, we suggest managing goshawk nest areas at 2 scales: the early postfledging period (in our study roughly 300 m from the nest) and late postfledging period (roughly 500 m from the nest). Given that fledgling goshawks in our study used postfledging areas of 10–70 ha and avoided initiating forest, we suggest that the total postfledging area managed should be ≥ 21 –40 ha (the inter-quartile range of our postfledging area estimates). We encourage managers to manage for variability in size, rather than consistently managing the minimum end of this range. The postfledging area should not include any forest <40 years old or areas devoid of forest cover (i.e., lakes, wetlands, large grassy areas). Within 300 m of the nest, the focus should be on maintaining a high proportion of mature forest (>80 yr) with high canopy closure, whereas at greater distances from the nest more young forest (40–80 yr) with higher canopy closure should be included. Although variability was high and selection by fledglings weak, we recorded a mean of 66–68% mature

forest within 300 m and 500 m of the nest. Although this may reflect selection by adults rather than fledglings, it does suggest that $\geq 50\%$ of these areas should consist of mature forest.

The general concepts behind our recommendations should apply to the interior montane forests of British Columbia, although the exact ages defining stand types and percentages denoting closed-canopy stands will likely differ among regions. Ideally, experimental manipulation of the size and composition of reserves around goshawk nests should be conducted in various locations to determine appropriate management areas and guidelines. Fledgling goshawks we observed avoided initiating forest and were more tolerant of 40–80-year-old forest than previously thought. This new information should help guide logging prescriptions around goshawk nests and within goshawk nest areas.

ACKNOWLEDGMENTS

We thank the forest professionals of the East Kootenays for providing sightings of goshawks and goshawk nests. Our field staff of I. Adams, K. Bachmann, D. Bhattacharya, J. Finstad, R. Klafki, J. Michel, B. Robinson, and R. Rozander were all essential for locating and monitoring nests, radiotagging birds, and monitoring fledglings. We thank E. McClaren of the British Columbia Ministry of Environment for lending her experience with goshawk capture and radiotagging, for providing valuable information about goshawks, and for acting as a sounding board for our research ideas. T. Mahon provided valuable advice and assisted in securing financial support. C. Carlyle provided valuable suggestions throughout the project and comments on this manuscript. Our robotic owl was constructed by R. Hill of Realistic Taxidermy and K. McIsaac and his students in the Computer Automated Systems Technician program at Thompson Rivers University. This project was funded by the Canadian National Science and Engineering Research Council, the BC Ministry of Forests, Forest Science Program, the National Centers of Excellence–Sustainable Forest Management Network, grants and assistance from the University of Victoria, and administrative and logistical support from Tembec and Thompson Rivers University.

LITERATURE CITED

- Boal, C. W. 1994. A photographic and behavioural guide to aging nestling northern goshawks. *Studies in Avian Biology* 16:32–40.
- Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer, New York, New York, USA.
- Daw, S. K., and S. DeStefano. 2001. Forest characteristics of northern goshawk nest stands and post-fledging areas in Oregon. *Journal of Wildlife Management* 65:59–65.
- Detrich, P. J., and B. Woodbridge. 1994. Territory fidelity, mate fidelity, and movements of color-marked northern goshawks in the southern cascades of California. *Studies in Avian Biology* 16:130–132.
- Harrower, W. L. 2007. Nesting requirements of the northern goshawk (*Accipiter gentilis atricapillus*) in southeastern British Columbia. Thesis, University of Victoria, Victoria, British Columbia, Canada.
- Hosmer, D. W., and S. Lemeshow. 2000. Applied logistic regression. Wiley, New York, New York, USA.
- Jerde, C. L., and D. R. Visscher. 2005. GPS measurement error influences on movement model parameterization. *Ecological Applications* 15:806–810.
- Kennedy, P. L., and J. M. Ward. 2003. Effects of experimental food supplementation on movements of juvenile northern goshawks (*Accipiter gentilis atricapillus*). *Oecologia* 134:284–291.
- Kennedy, P. L., J. M. Ward, G. A. Rinker, and J. A. Gessaman. 1994. Post-fledging areas in northern goshawk home ranges. *Studies in Avian Biology* 16:75–82.
- Kenward, R. E. 2006. The goshawk. T & A D Poyser, London, United Kingdom.
- Kenward, R. E., V. Marcström, and M. Karlbom. 1993. Post-nestling behaviour in goshawks, *Accipiter gentilis* I: the causes of dispersal. *Animal Behaviour* 46:365–370.
- Kernohan, B. J., R. A. Gitzen, and J. J. Millsbaugh. 2001. Analysis of animal space use and movements. Pages 125–166 in J. J. Millsbaugh and J. M. Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California, USA.
- Manley, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals. Kluwer Academic, Boston, Massachusetts, USA.
- McClaren, E. L., P. L. Kennedy, and D. D. Doyle. 2005. Northern goshawk (*Accipiter gentilis laingi*) post-fledging areas on Vancouver Island, British Columbia. *Journal of Raptor Research* 39:253–263.
- McGrath, M. T., S. DeStephano, R. A. Riggs, L. L. Irwin, and G. J. Roloff. 2003. Spatially explicit influences on northern goshawk nesting habitat in the interior Pacific Northwest. *Wildlife Monographs* 154.
- Peck, J. 2000. Seeing the forest through the eyes of a hawk: an evaluation of recent efforts to protect northern goshawk populations in southwestern forests. *Natural Resources Journal* 40:125–156.
- Peduzzi, P., J. Concato, E. Kemper, T. R. Holford, and A. R. Feinstein. 1996. A simulation study of the number of events per variable in logistic regression analysis. *Journal of Clinical Epidemiology* 49:1373–1379.
- Penteriani, V. 2002. Goshawk nesting habitat in Europe and North America: a review. *Ornis Fennica* 79:149–163.
- Reich, R. M. S., S. M. Joy, and R. T. Reynolds. 2004. Predicting the location of Northern Goshawk nests: modeling the spatial dependency between nest locations and forest structure. *Ecological Modeling* 176:109–133.
- Reynolds, R. T., R. T. Graham, M. H. Reiser, R. L. Bassett, P. L. Kennedy, A. B. Boyce, G. Goodwin, R. Smith, and E. L. Fisher. 1992. Management recommendations for the northern goshawk in the southwestern United States. U.S. Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experimental Station, Gen. Tech. Rep. RM-217, Ft. Collins, Colorado, USA.
- Reynolds, R. T., and S. M. Joy. 2006. Demography of northern goshawks in northern Arizona, 1991–1996. *Studies in Avian Biology* 13:63–74.
- Squires, J. R., and P. L. Kennedy. 2006. Northern goshawk ecology: an assessment of current knowledge and information needs for conservation and management. *Studies in Avian Biology* 31:8–62.
- Squires, J. R., and R. T. Reynolds. 1997. Northern goshawk (*Accipiter gentilis*). Account 298 in A. Poole and F. Gill, editors. The birds of North America. The Academy of Natural Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington, D.C., USA.
- Ward, J. M., and P. L. Kennedy. 1996. Effects of supplemental food on size and survival of juvenile northern goshawks. *Auk* 113:200–208.
- Wiens, J. D., B. R. Noon, and R. T. Reynolds. 2006a. Post-fledging survival of northern goshawks: the importance of prey abundance, weather, and dispersal. *Ecological Application* 16:406–418.
- Wiens, J. D., R. T. Reynolds, and B. R. Noon. 2006b. Juvenile movement and natal dispersal of northern goshawks in Arizona. *Condor* 108:253–269.
- Zar, J. H. 1999. Biostatistical analysis. Fourth edition. Prentice-Hall, Upper Saddle River, New Jersey, USA.

Associate Editor: Bechard.