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NORTHERN GOSHAWK (*ACCIPITER GENTILIS LAINGI*) POST-FLEDGING AREAS ON VANCOUVER ISLAND, BRITISH COLUMBIA

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ABSTRACT.—The area used by immature birds from the time they fledge until independence is the post-fledging area (PFA). Published estimates of PFA size (170 ha) are only available from a Northern Goshawk (*Accipiter gentilis atricapillus*) population in New Mexico and applicability of this estimate to other regions and habitat types is unknown. Our objectives were to estimate PFA size and length of the post-fledging period for Northern Goshawk (*A. g. laingi*) nests on Vancouver Island, British Columbia. We estimated PFA size from 95% adaptive kernel estimates of telemetry locations from 12 fledglings at 12 nests between 29 June and 2 September 2001–02 (N = 6, 2001; N = 6, 2002). Because our adaptive kernel estimates are based on a small number of locations, we also estimated the precision of these home range estimates using a smoothed bootstrap approach. Almost all (93%) fledgling locations were within 200 m of nests during the early fledgling-dependency period, but less than half (42.4%) of these locations were within this distance during the late fledgling-dependency period. Northern Goshawks departed from PFAs 45.9 ± 1.3 d post-fledging. Mean PFA size was 59.2 ± 16.1 ha, and the bootstrapped variance around PFA estimates ranged from 12.7–1820.8 ha. Our estimate for the mean size of one PFA per nest area for *A. g. laingi* fledglings on Vancouver Island was much smaller than the mean size estimate reported for *A. g. atricapillus* in New Mexico. However, management plans should consider nest areas and PFAs to be one functional component of Northern Goshawk breeding habitat and should include multiple alternative nest trees, each with an associated PFA.

KEY WORDS: *Northern Goshawk*; Accipiter gentilis laingi; *activity centers*; *adaptive kernel*; *bootstrapping*; *fledging-dependency period*; *immature movements*; *natal dispersal.*

ÁREAS POST-EMPLUMAMIENTO DE *ACCIPITER GENTILIS LAINGI* EN VANCOUVER ISLAND, BRITISH COLUMBIA

RESUMEN.—El área utilizada por las aves inmaduras desde que abandonan el nido hasta que alcanzan la independencia de sus padres es el área post-emplumamiento (APE). El único estimado publicado del tamaño del APE de *Accipiter gentilis* (170 ha) corresponde a una población del estado de New Mexico (subespecie *atricapillus*), y la aplicabilidad de este estimado a otras regiones y tipos de hábitats es desconocida. Nuestros objetivos fueron estimar el tamaño del APE y la longitud del período post-emplumamiento para nidos de *A. g. laingi* ubicados en Vancouver Island, British Columbia. Estimamos el tamaño del APE a partir de estimados adaptativos de los kernels del 95% de ubicaciones obtenidas mediante telemetría para 12 volantones de 12 nidos, entre el 29 de junio y el 2 de septiembre de 2001–02 (N = 6, 2001; N = 6, 2002). Debido a que nuestros estimados de los kernels están basados en un número pequeño de ubicaciones, también estimamos la precisión de los estimados del rango de hogar empleando un método de bootstrap alisado. Casi todas las ubicaciones de los volantones (93%) estuvieron a menos de 200 m de los nidos durante el período temprano de emplumamiento-dependencia, pero menos de la mitad de las ubicaciones (42.4%) tuvieron lugar a menos de 200 m durante la fase tardía de este período. Los individuos abandonaron sus APE 45.9 ± 1.3 d después de abandonar el nido. El tamaño promedio del APE fue 59.2 ± 16.1 ha, y la varianza de los estimados obtenida mediante

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el método de bootstrap estuvo entre 12.7 y 1820.8 ha. Nuestro estimado del tamaño medio de un APE por área de nidificación para los volantones de *A. g. laingi* en Vancouver Island es mucho menor que el estimado medio documentado para *A. g. atricapillus* en New Mexico. Sin embargo, los planes de manejo deben considerar que las áreas de nidificación y las APE son un componente importante del hábitat de cría de *A. gentilis,* y deben incluir múltiples árboles que puedan servir como sitios alternativos para nidificar, cada uno con su APE asociada.

[Traducción del equipo editorial]

Suitable breeding habitat for avian species consists of adequate nest sites, roost sites, post-fledging areas (PFAs), and foraging areas. PFAs represent the habitat used by fledglings prior to independence and may be especially important for species with long post-fledging-parental-care periods, such as raptors. The survival of fledglings through the post-fledging period and their first year is likely influenced by PFA quality, which may be reflected by PFA size and habitat characteristics.

Several studies have reported areas around nests to be important for fledglings during the post-fledging period, before dispersal is initiated (Bald Eagles [*Haliaeetus leucocephalus*], Wood et al. 1998; Great Tits [*Parus major*], Naef-Daenzer et al. 2001; Scarlet Macaws [*Ara macao*], Myers and Vaughan 2004). However, the PFA concept (originally referred to as the post-fledging family area; Reynolds et al. 1992) and its integration with management prescriptions (Reynolds et al. 1992) have only been applied to Northern Goshawks (*Accipiter gentilis*), a species of concern in North America (Kennedy 1997, Crocker-Bedford 1998, DeStefano 1998) and Europe (Widén 1997). Kennedy et al. (1994) estimated the size of goshawk PFAs in New Mexico to be ca. 168 ha based on movement patterns of radio-tagged fledglings and adult female core-use areas. Currently, the British Columbia (BC) government recommends managing a 200-ha PFA around designated goshawk (*A. g. laingi*) nest areas (BC Ministry of Water, Land, and Air Protection, 2004). This recommendation was a modification of the southwestern U.S. guidelines (Reynolds et al. 1992) because local data were unavailable.

Our objective was to evaluate the applicability of PFA guidelines developed for goshawk populations in the southwestern U.S. to coastal BC, where habitat characteristics, harvest regimes, and goshawk subspecies differ. We provide the first PFA estimate for goshawks based on home-range estimates of fledglings prior to independence as well as precision estimates of PFAs, which are rarely provided in home-range analyses (Kernohan et al. 2001). Local knowledge of goshawk PFA size on Vancouver Island is crucial for adequately managing the breeding habitat of *A. g. laingi* which is federally designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as Threatened in Canada (COSEWIC, in press) and is provincially Red-listed (BC Conservation Data Centre 2005).

METHODS

Study Area. Goshawk nest areas were located on Vancouver Island, BC (Fig. 1) in forests dominated by western hemlock (*Tsuga heterophylla*) and Douglas-fir (*Pseudotsuga menziesii*), although western red cedar (*Thuja plicata*), amabalis fir (*Abies amabalis*), and red alder (*Alnus rubra*) were also abundant. Nest stands ranged in age from 45 to >250 yr. See McClaren et al. (2002, 2003) for more study area details.

Data Collection. Goshawk nests (N = 17) used in this study were located either through broadcast surveys of conspecific calls (McClaren et al. 2002, 2003), or incidentally by forest company personnel and the public, from 1994–2002. When nestlings were ca. 21 d, we climbed nest trees and lowered nestlings to the ground where they were weighed, measured, sexed, and aged by the senior author to maintain consistency in the data. Nestling gender was determined using tarsal width, recommendations provided by Kenward et al. (1993a). We aged nestlings from a photographic and behavioral key (Boal 1994) and from our estimated hatch dates. Nestlings were banded with U.S. Geological Survey bands and color-rivet bands (Acraft Sign and Nameplate Co. Ltd., Edmonton, AB Canada). With two exceptions, we fitted only the largest female nestling in each nest with a 9-g tarsal mount transmitter with a mortality switch (Advanced Technology Services, Isanti, MN U.S.A.). Males were fitted with transmitters when: (1) all nestlings were male (N = 1); and (2) the sole female nestling's transmitter battery died, and we fitted its male sibling with a new radiotransmitter. We chose the largest female to reduce potential variation in fledgling movements caused by gender differences (Byholm et al. 2003, J. Wiens unpubl. data) and to lessen possible impact of transmitter mass on survival probability. Radiotransmitters were attached to tarsi with a leather jesse (Ward and Kennedy 1996, Dewey and Kennedy 2001), so that fledglings could remove them after the 90 d transmitter battery expired. Trade name products are mentioned to provide complete descriptions of methods. The authors' institutions neither endorse these products nor intend to discriminate against products not mentioned.

Prior to collecting fledgling location data, we centered a 600 × 600-m grid on nests with young with location

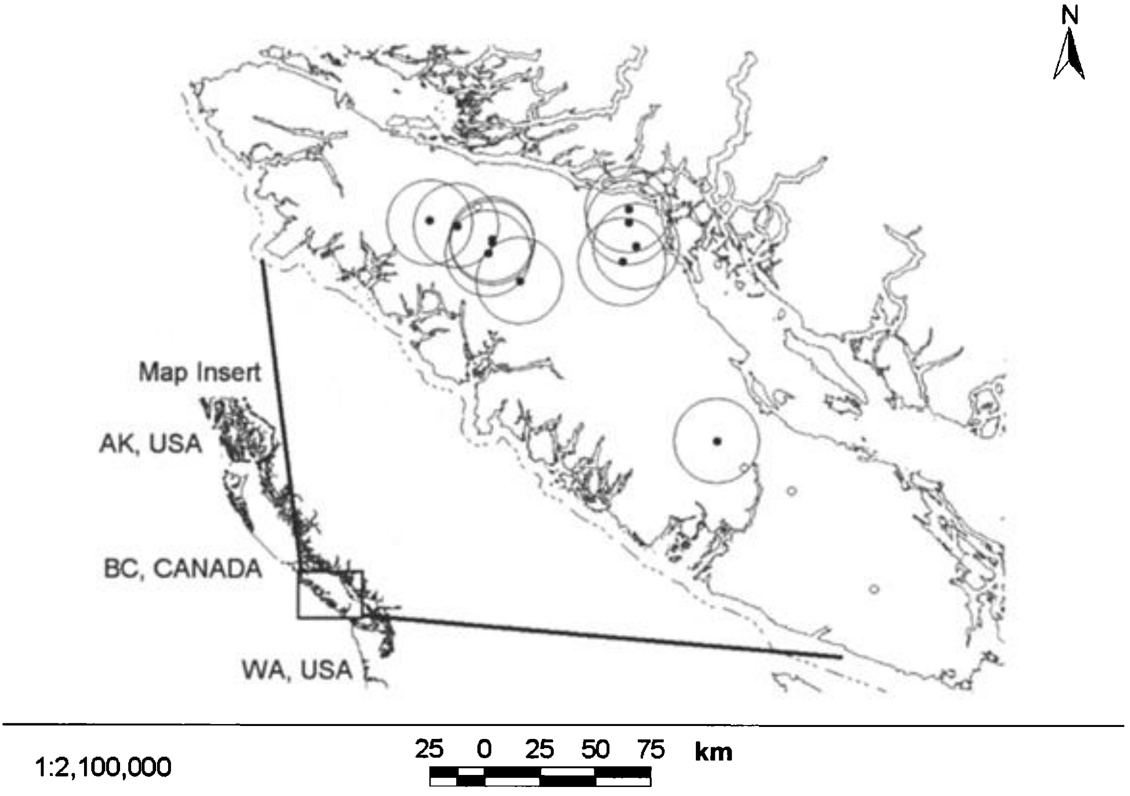

Figure 1. Northern Goshawk nest areas on Vancouver Island, British Columbia, where chicks were captured and radiotagged. Small open circles represent nests where there were insufficient radio locations ($N < 15$) to estimate post-fledgling area (PFA) size and small closed circles represent nests where there were sufficient radio locations to estimate PFA size. Larger circles around nests represent the 20 km ground search area for fledglings after they began to leave the natal area.

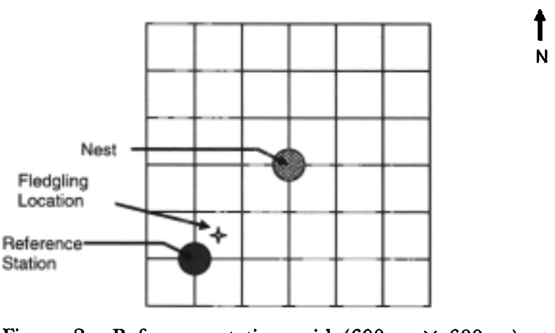

Figure 2. Reference station grid (600 m × 600 m) at Northern Goshawk nests on Vancouver Island, British Columbia, used for geo-referencing radio-tagged fledgling locations from ground-based telemetry during the 2001–02 breeding seasons. Each grid cell represents 100 m × 100 m.

reference stations at 100-m intervals (Fig. 2). After nestlings were radio-tagged, nests were visited weekly to monitor chick development, survivorship, and transmitter operation. Once tagged nestlings fledged, nest areas were visited every 1–3 d to collect fledgling location data. We rotated sampling equally among nest areas and sampling periods (<0800–1100 H, 1101–1400 H, 1401–1700 H, and >1700 H) to ensure all times of day were equally represented. Teams of two observers listened for radio signals prior to entering nest stands. Using a 3-element Yagi antenna (Telonics Inc., Mesa, AZ U.S.A.) and receiver (Models SRX-1000, SRX-400, Lotek Engineering Inc., ON, Canada), observers quietly approached fledglings on foot to obtain visual locations and to prevent influencing their movements. We verified the observed fledgling was radio-tagged by identifying color bands. At one nest site where the radio-tagged fledgling was predated 5 d prior to dispersal, we continued tracking the remaining two siblings through aural locations. We measured distance and direction of the fledgling to the closest reference grid station using a meter-marked rope and compass. When fledglings became more mobile and moved outside the 600 × 600-m grid, we either expanded the grid or used triangulation from roads to estimate fledgling locations. We estimated date of departure from natal areas as mid-way between the last visit when fledglings were verified <1.6 km from nests and when no radio signal was heard within this distance on two consecutive telemetry sessions (Kenward et al. 1993a, Kennedy and Ward 2003). Immediately after young departed from natal areas, we conducted intensive road searches for radio-tagged fledglings using a vehicle-mounted omni-directional antenna (Telonics Inc., Mesa, AZ U.S.A.), and when a signal was detected, we used triangulation to obtain a location. Road searches were conducted within a 20-km^2 area surrounding each nest (Fig. 1). We also searched a 30-km area around nests using a single aerial telemetry flight.

Location Determination. We used the survey mapping extension of Road Engineering Software (Softree Technical Systems Inc. 1998) to calculate UTM coordinates for visual fledgling locations based on the known coordinates of the nest tree location, grid reference station locations, and measured offsets from grid reference stations to fledglings. Fledgling locations derived from triangulation and their associated error ellipses were estimated using Locate II, version 1.5 (Nams 2000), based on the number of bearings, angles between bearings, and the distance from bearing locations to radio-tagged birds.

Post-fledging Area Estimation. We used Home Ranger (version 1.5, Ursus Software, Revelstoke, BC Canada) to estimate PFA size and a smoothed bootstrap (Worton 1995) with 1000 replications to estimate variance of each PFA. Bootstrapping is a common technique for numerically estimating the precision of measurements for which sampling distributions and variances are unknown (Efron and Tibshirani 1991, Quinn and Keough 2002). Although PFAs are not equivalent to home ranges, we assumed the area used by fledglings prior to dispersal could be modeled using home-range estimation techniques. Ninety-five percent adaptive kernel estimates were used to estimate PFA size because kernel estimators were highest ranked in a recent review of the performance of home range estimators (Kernohan et al. 2001). Adaptive kernel estimates are non-parametric, indicate areas of concentrated use by fledglings (i.e., activity centers or core areas), and are more conservative than minimum convex polygon estimators because the home range boundaries are based on probability functions around bird locations rather than on linear connections between the outermost data points (Seaman et al. 1999, Kenward et al. 2001). We only included 95% of locations because we wanted to exclude exploratory or excursion behaviors that could artificially inflate PFA size (Walls and Kenward 1998, Kennedy and Ward 2003). We used the reference bandwidth (h_{ref}) smoothing parameter because it appeared to model most accurately the number of activity centers in our data. Triangulated locations with associated ellipsoid error polygons >1 km^2 were not included in PFA estimates (N = 2). We did not estimate PFA size for fledglings with <15 locations (N = 3). A minimum of 15 locations per fledgling appears small relative to the recommended minimum of 30 locations per individual for home-range estimation (Kernohan et al. 2001). However, the short post-fledging period limited our ability to collect >30 locations per fledgling that were not temporally correlated. In addition, area-observation curves (Gese et al. 1990 in Kernohan et al. 2001) suggested our sample sizes adequately represented maximum distances moved from nests during the post-fledging period, prior to departure from natal areas.

Statistical Analyses. We considered fledgling location data collected from different nest sites within the same nest area in different years to be independent (N = 2). Mean and median hatching, fledging, and departure from natal area dates were estimated with Julian days. We used the correlation procedure in SAS (SAS Institute, Inc. 1997) to examine the relationship between fledging date and the number of days until dispersal was initiated. We used a Fisher's exact test (PROC FREQ; SAS Institute, Inc. 1997) to evaluate changes in the distance fledglings were from nests at three stages of maturity during the post-fledging period. Distances were calculated as the Euclidian distance from the nest tree to the fledgling location. We categorized the distance we observed fledglings (0–99 m, 100–199 m, 200–399 m, 400–799 m, >800 m) into three time intervals (1–3 wk, 4–5 wk, and 6–7 wk post-fledging). Distance categories were as fine scale as possible given the number of locations in each category required to run the analyses. We used Wilcoxon's rank-sum tests (PROC NPAR1WAY; SAS Institute, Inc. 1997) to compare hatching, fledging, dispersal dates, and PFA size between years. We used Wilcoxon's rank-sum tests for these pair wise comparisons because small sample sizes and non-normal data may invalidate the results provided by t-tests (Ott 1993). Results were considered statistically significant at $P < 0.10$. Means and standard errors are presented unless otherwise stated. Data from all radio-tagged fledglings were included in all analyses except PFA size estimates and comparisons in which we only included data from young with sufficient locations (N = 12).

RESULTS

Forty-two goshawk nestlings from 17 nests were banded and measured. Mean age of young at banding was 20.2 ± 0.8 d. Tarsus width for male (N = 15) and female (N = 27) chicks averaged 6.1 ± 0.1 mm and 7.3 ± 0.1 mm, respectively, and means were significantly different ($t_{38} = 2.0$, $P < 0.001$).

Breeding Phenology. Median hatch date was 29 May (N = 17), median fledge date was 7 July (N = 17), and median date of departure from PFAs was 25 August (N = 15). Goshawk nestlings spent a mean of 40.4 ± 0.3 d (N = 17) in their nests before fledging and 45.9 ± 1.3 d (N = 15) in PFAs before departing from natal areas. Goshawks hatched ($S = 65.0$, $P = 0.07$) and left PFAs ($S = 24.5$, $P = 0.003$) significantly earlier in 2002 than in 2001. In 2001, individuals that fledged later spent less time within PFAs than early fledged young (Fig. 3). Thus, hatching date ($r = -0.8$, P

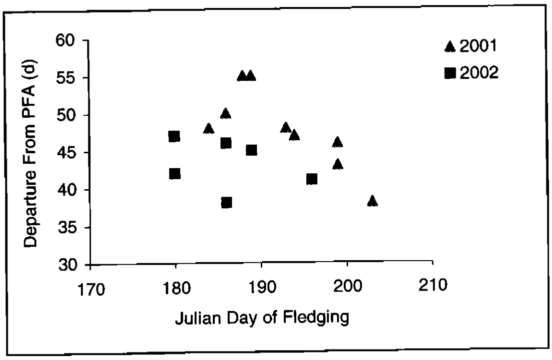

Figure 3. Relationship between fledging date and time spent within post-fledgling areas (PFAs) before dispersal initiation for Northern Goshawk fledglings on Vancouver Island, British Columbia, in 2001 and 2002.

= 0.007) and fledging date (r = −0.8, P = 0.01; Fig. 3) were negatively correlated with the amount of time young spent in PFAs before initiating dispersal. In 2002, relationships between hatching date (r = −0.3, P = 0.5) and fledging date (r = −0.3, P = 0.5; Fig. 3) with the amount of time young spent within PFAs were weak because both early and late fledged young spent nearly equal time periods within PFAs. In both years, fledgling departure from PFAs occurred over a 2-wk period (2001: 10–25 August; 2002: 20 August–2 September).

Fledgling Location Data. We collected 236 radio-telemetry locations from 15 radio-tagged goshawk fledglings. Most of these were visual locations (93.2% N = 220). Triangulated locations (6.8%; N = 16) had a mean error ellipse of 0.029 ± 0.009 km^2, equivalent to a circle around each location with a mean radius of 96.1 m. Ninety-three percent of fledgling locations were within 200 m of nests ($\bar{x}$ = 107.8 ± 8.9 m, N = 105) during the first 3 wk post-fledging, but only 42.4% of locations were within this distance ($\bar{x}$ = 261 ± 17.5 m, N = 131) during the remaining 4 wk post-fledging (Fig. 4). As fledglings matured, we generally located them farther from nests (2001: χ^2 = 52.5, P < 0.001; 2002: χ^2 = 32.4, P < 0.001). However, we observed fledglings returning to nest trees throughout the post-fledging period, so fledglings did not continue to expand their PFA size indefinitely until they departed from natal areas. Maximum movements were observed in the 2 wk after fledglings completed feather growth and subsequent feather hardening, ca. 70–75 d of age (Fig. 4). We were

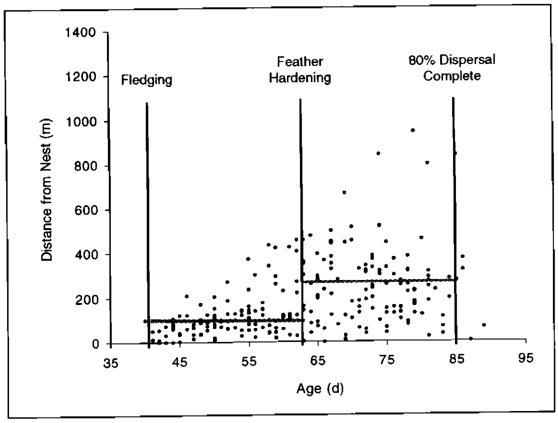

Figure 4. Distance of Northern Goshawk fledglings (N = 15) from nests during the post-fledging period on Vancouver Island, British Columbia, 29 June–2 September, 2001–02. Vertical lines represent median fledge date and estimated median feather-hardening date. Horizontal grey bars represent mean distances fledglings were observed from nests pre-feather hardening and post-feather hardening.

only able to relocate one fledgling 27 d after it left the PFA, and it was 82 km from its natal site.

We gathered 17.8 ± 0.6 (range = 15–22) locations per fledgling from the 12 fledglings for which we had sufficient locations (N > 15) to estimate PFA size (Table 1). We did not include locations from one male fledgling because he was sick and remained near the same perch tree until he was recovered dead 3 wk post-fledging. Overall, mean PFA size was 59.2 ± 16.1 ha (N = 12), and the range was 14.5–229.7 ha (Table 1). Variance around PFA estimates based on the bootstrap samples ranged from 12.7–1820.7 ha (Table 1). PFA size did not significantly differ (S = 39.0, P = 1.0) between 2001 (71.1 ± 32.3 ha) and 2002 (47.4 ± 6.8 ha), although small sample sizes may have reduced our power to detect annual differences.

The size and shape of PFAs varied among fledglings, and one fledgling used >1 activity centers. In 75% of PFAs, fledgling activity centers included nest trees. The three fledglings with PFAs that did not include nest trees had activity centers that were ca. 100 m, 150 m, and 300 m from nest trees.

Fledgling Fate. Brood reduction occurred at a minimum of seven nests prior to banding. At least three nestlings died post-banding, but pre-fledging. In 2001, 100% of radio-tagged fledglings survived through the post-fledging period (Table 2).

Table 1. Post-fledging area estimates for Northern Goshawk nests ($N = 12$) on Vancouver Island, British Columbia, 29 June–2 September 2001–02.

Nest Area					
Name	Year	PFA Size (ha)	Bootstrap Min., Max.	Percent Visual Locations	N
Great Central Lake	2001	54.3	50.8, 173.8	69	17
Klaklakama No. 7	2001	229.7	182.7, 1820.8	53	20
Loon Lake	2001	34.7	26.4, 275.9	100	18
Paterson	2001	53.4	39.0, 446.3	95	21
Roberts Lake	2001	14.5	12.7, 101.0	95	23
Toad No. 2	2001	40.0	36.4, 107.6	100	20
Sutton	2002	26.7	24.5, 103.0	100	15
John Road	2002	77.8	36.2, 1120.0	100	17
Klaklakama No. 3	2002	46.6	32.0, 272.5	100	19
Toad No. 3	2002	47.9	23.4, 547.8	100	16
Surprise Lake	2002	40.9	34.0, 259.5	100	16
Pye Lake	2002	44.4	23.7, 372.1	100	17

However, in 2002, 37.5% (N = 8) of radio-tagged fledglings, and at least one untagged fledgling, died prior to leaving the natal area. We experienced one premature battery failure, and one fledgling removed its transmitter prior to initiating dispersal.

Discussion

Post-fledging Period Behavior. Goshawk fledglings on Vancouver Island exhibited similar movement patterns during the post-fledging period to goshawks in Sweden (Kenward et al. 1993a) and New Mexico (Kennedy et al. 1994, Kennedy and Ward 2003). Within the first 3 wk post-fledging, fledglings remained within 200–300 m ($\bar{x}$ = 107.8 ± 8.9 m, N = 105) of nests, and they were often on the ground or in the lower canopy. Immediately after this period, fledglings experienced a behavioral transition in which they were frequently located farther from nests ($\bar{x}$ = 261 ± 17.5 m, N = 131); they were adept fliers and perched in the upper canopy, often in treetops. These changes in fledgling behavior correspond with completion of primary and retrix feather growth and subsequent feather hardening (Kenward et al. 1993a). Interestingly, goshawks did not continue to expand their PFA size indefinitely until departing from nest areas. Instead, the farthest distance we observed fledglings from nests during the post-fledging period peaked within 1–2 wk after they completed feather growth and approximately 10 d prior to departing PFAs. Kenward et al. (1993a) and Minguez et al. (2001) described a similar pattern for goshawks in Sweden and for Bonelli's Eagles (*Hieraaetus fasciatus*) in Spain, respectively. Such a pattern illustrates the importance of collecting fledgling locations uniformly throughout the post-fledging period when trying to characterize fledgling movement patterns.

In 2001, hatch and fledge dates were negatively correlated with the amount of time young spent within PFAs. Similar negative relationships between hatch date and age when dispersal was initiated were reported for goshawks in Sweden (Kenward et al. 1993b) and Finland (Byholm et al. 2003). However, in 2002 goshawks initiated breeding earlier on Vancouver Island than in 2001, and fledglings spent similar amounts of time within PFAs, regardless of their hatch and fledge dates. In several bird species, an early onset of breeding often indicates higher food availability within the nest area, which results in higher fledgling mass and survival (Dewey and Kennedy 2001, Naef-Daenzer et al. 2001, Aparicio and Bonal 2002). Because we did not manipulate any proximate factors that may have influenced the length of the post-fledging period, we can only speculate on what influenced the timing of fledgling departure from natal areas and length of post-fledging periods in our study. Food availability within home ranges, predator and competitor abundance, and weather are all possible influential factors (Kenward et al. 1993a, Dewey and Kennedy 2001, Byholm et al. 2003). We found no evidence that parental aggression caused fledglings to disperse on Vancouver Island, which supports

Table 2. Fate of radio-tagged Northern Goshawk fledglings 29 June–11 September 2001–02 during post-fledgling area (PFA) estimation on Vancouver Island, British Columbia.

FLEDGLING		DATE LAST OBS.	
ID	YEAR TAGGED	(BIRD AGE IN d)	FATE
China	2001	27-Aug-01 (84)	Departed from PFA
Cous	2001	22-Aug-01 (88)	Departed from PFA
Great Central Lake	2001	27-Aug-01 (79)	Departed from PFA
Mesachie	2001	16-Aug-01 (89)	Departed from PFA
Klaklakama No. 7	2001	24-Aug-01 (94)	Departed from PFA
Loon Lake No. 3	2001	24-Aug-01 (88)	Departed from PFA
Paterson	2001	25-Aug-01 (82)	Departed from PFA
Roberts Lake	2001	25-Aug-01 (97)	Departed from PFA
Toad No. 2	2001	24-Aug-01 (90)	Departed from PFA
Claud Elliot	2002	29-Jul-02 (63)	Dead (unknown cause)
Toad No. 3	2002	05-Aug-02 (77)	Dead (predated)
John Road a[a]	2002	03-Aug-02 (75)	Battery failed
John Road b	2002	11-Sep-02 (114)	Mortality switch on
Loon Lake No. 3	2002	14-July-02 (41)	Dead (unknown cause)
Sutton	2002	10-Aug-02 (79)	Departed from PFA
Klaklakama No. 3	2002	19-Aug-02 (87)	Departed from PFA
Pye Lake	2002	21-Aug-02 (87)	Departed from PFA
Surprise Lake	2002	23-Aug-02 (83)	Departed from PFA

[a] Two individuals were radiotagged at this nest because the first radiotransmitter battery died. We captured and radiotagged its sibling after a failed attempt to recapture the originally tagged individual.

experimental results provided by Kenward et al. (1993a).

Although the onset of fledgling dispersal varied by approximately 10 d between 2001 and 2002, fledglings departed natal areas abruptly between 80–96 d of age in both years. This seems to be a common pattern for goshawks (Kenward et al. 1993a, Dewey and Kennedy 2001) and for many other raptors (Spotted Owls [*Strix occidentalis*]: Willey and van Riper 2000; Bonelli's Eagles: Minguez et al. 2001). In contrast, Walls and Kenward (1998) reported a bimodal pattern of departure from natal areas for Common Buzzards (*Buteo buteo*) and Kennedy and Ward (2003) observed supplementally-fed goshawk fledglings returning to natal areas after they initiated dispersal. We were unable to evaluate movement patterns for radio-tagged goshawks during their first year of life because our transmitter batteries expired when young were ca. 110 d of age. However, we searched for fledglings within 30 km of nest areas after they initiated dispersal, and our inability to locate them suggested fledglings moved >30 km after departing PFAs. Initial departure distances were probably moderated by local food availability, whereby fledglings within food-rich areas moved shorter distances after leaving natal areas than fledglings from food-poor areas (Kenward et al. 1993b, Kennedy and Ward 2003).

Post-fledging Area Size. Most fledglings included nest trees within their activity centers throughout the post-fledging period. Similar patterns reported by Ward and Kennedy (1996: goshawks), Wood et al. (1998: Bald Eagles), and Belthoff and Ritchison (1989: Eastern Screech-Owls [*Otus asio*]) suggest that nest trees are important throughout the post-fledging period for raptors. Some goshawk management guidelines recommend reduced disturbance levels around goshawk nests until young fledge (e.g., BC Ministry of Water, Land, and Air Protection 2004). However, the vulnerability of young during the early fledging-dependency period (Wiens 2004) and their continued use of the nest site throughout the post-fledging period, suggests there should be strict adherence to disturbance recommendations until young leave PFAs. Disturbance near nest areas during the post-fledging period may interfere with adult prey deliveries to young and development of juvenile hunting and flight skills (Kenward et al. 1993a, Kennedy et al. 1994, Wood et al. 1998).

Our study reports the first published estimate of goshawk PFAs based on home-range estimates derived almost entirely from visual locations, with no location error. Our estimated mean PFA size of 59.2 ha is smaller than that reported by Kennedy et al. (1994). Kennedy et al. (1994) based their PFA size estimate on adult female core use areas which were corroborated with fledgling location data, rather than calculating PFA size directly from fledgling locations. Also, reanalysis of fledgling location data from Kennedy et al.'s (1994) study indicated the non-visual observations of fledglings frequently had a 500-m radius error (Kennedy and Ward 2003). Similarly, fledgling distances provided by Kenward et al. (1993a) were likely inflated because their telemetry locations were accurate within only 100 m. Our PFA estimates may have been slightly inflated because they included one fledgling (Klaklakama No. 7) from which 47% of locations were collected using triangulation with an associated 104.4-m radius error (Table 1). However, our second largest PFA estimate was for a fledgling (John Road) for which 100% of locations were visuals.

Additionally, post-fledging movement patterns may be influenced by fledgling gender (Byholm et al. 2003, J. Wiens unpubl. data) and by landscape habitat characteristics surrounding nests. Our PFA estimates may be smaller than those reported by Kennedy et al. (1994) because all but one PFA estimate were for females that, in one northern Arizona study, were smaller than male PFAs (J. Wiens unpubl. data). PFA size on Vancouver Island may also be smaller than in New Mexico because the definitive forest edges of nest stands in coastal forest ecosystems may act as barriers to fledgling movements more than the less defined ecotones that occur between southwestern forest types (Siders and Kennedy 1996).

Because PFA size can only be estimated from location data, providing variance estimates for these and other types of home range data is extremely informative, but rarely done (Worton 1995, Kernohan et al. 2001). Our variance estimates of the PFA estimates include the 169 ± 129 ha PFA size reported by Kennedy et al. (1994) and the distances (100–1000 m) that Kenward et al. (1993a) observed fledglings from nests. Our PFA estimate was closer to the minimum bootstrapped estimate than the maximum bootstrapped estimate because a greater proportion of our location data were closer to nests. Few fledgling locations far from nests created more variability in the maximum bootstrapped estimate, although maximum estimates provide important information (F. Hovey pers. comm.).

Home-range estimates also vary depending on the techniques used to collect location data and on the home-range estimation program used to calculate home range size (Lawson and Rodgers 1997, Seaman et al. 1999, Kenward et al. 2001). For example, Kennedy et al. (1994) used a harmonic mean estimator to calculate female core use areas, whereas we used an adaptive kernel estimate. Therefore, comparison of PFA size estimates among studies that use different data collection and size estimation techniques is difficult.

Management Implications. Most goshawk management guidelines in North America are based on Reynolds et al. (1992), which suggest managing for three hierarchical levels of goshawk home ranges: (1) nest area, (2) PFA, and (3) foraging area. However, Reynolds et al. (1992) also recommended managing for alternative nests within goshawk nest areas and they assumed that all alternative nests were within PFAs. Therefore, the biological functionality of a nest area independent of a PFA is questionable, and managing these habitat components in isolation may reduce the effectiveness of management plans. Recent studies comparing habitat characteristics around goshawk nests to random sites (areas assumed not to contain goshawk nests) at multiple spatial scales concluded that goshawk habitat could be discriminated from random sites by a larger proportion of large-diameter, late-seral, closed-canopy forests (Ethier 1999) at scales between 83 ha (McGrath et al. 2003) and 170 ha (Daw and DeStefano 2001). Additionally, Finn et al. (2002) reported occupied historic goshawk nests had a greater proportion of late-seral forest with high canopy closure, less stand initiation cover, and reduced landscape heterogeneity at 177 ha and 1886 ha scales, than at similar scales around unoccupied historic nests. These studies suggest goshawk PFAs may be characterized by unique habitat characteristics at spatial scales within the size range we have reported for PFAs as well as the size range reported by Kennedy et al. (1994).

Mean PFA size estimates on Vancouver Island were smaller than the 200-ha area currently recommended for managing the area around goshawk nests in coastal BC (BC Ministry of Water, Land, and Air Protection 2004). However, our results represent only one nest, and therefore, one PFA per nest area, within a given year. We monitored fledglings from two different nest sites within two nest areas in 2001 and 2002, and there was minimal overlap between PFAs in different years. This suggests that each alternative nest site may have a unique PFA. Therefore, a more meaningful approach to managing goshawk breeding home ranges is to manage for areas that include multiple nests and associated PFAs. Our bootstrapping results suggest this PFA size is highly variable and likely depends upon methods used to estimate PFA size as well as environmental factors such as topography, habitat characteristics around nests, prey availability, and fledgling gender (Dewey and Kennedy 2001, Byholm et al. 2003, Kennedy and Ward 2003, J. Wiens, unpubl. data).

We developed a simplistic graphical depiction of how our information could be applied to develop management scenarios for *A. g. laingi* nest areas throughout coastal BC (Fig. 5). This figure is based on Vancouver Island data with a mean number of 3.0 ± 0.2 (N = 34 nest areas) alternative nests/nest area and a mean distance of 274 ± 37.2 m (N = 65) between alternative nest trees (E. McClaren unpubl. data). The total area to be managed would vary by nest area and depends on the juxtaposition of alternative nests and PFAs (Fig. 5). For example, Figures 5a and 5b depict areas that are 104.8 ha and 96.3 ha in size, respectively. In areas where the inter-alternate distance is larger (inter-alternate distances > 1.0 km are not uncommon; Dewey et al. 2003, Squires and Kennedy in press), the total management area would be larger. In the absence of fledgling radiotelemetry data and information on fledgling habitat selection patterns, multiple PFAs within one goshawk home range should be managed to create an area that maintains connectivity among alternative nests and to adjacent stands of similar habitat (i.e., reduce stand isolation) to minimize possible edge effects, facilitate food transfers from adults, and provide dispersal corridors.

Although our results suggested the area used by goshawk fledglings on Vancouver Island, and possibly elsewhere, was smaller than estimated in New Mexico (Kennedy et al. 1994), PFA habitat was not the only habitat necessary for goshawks to successfully reproduce. Prey availability in habitats outside of, but in proximity to, PFAs was also essential for adults to rear young (Reynolds et al. 1992, Kennedy and Ward 2003, Wiens 2004). For example, Bloxton (2002) reported radio-tagged adult goshawks in the Olympic Peninsula, WA, to concentrate their foraging efforts within 5 km of occupied nests during the breeding season. Current goshawk management guidelines in BC (BC Ministry of Water, Land and Air Protection 2004) do not include explicitly managing for goshawk foraging areas, and the effect of not managing goshawk foraging areas in landscapes actively managed for timber harvest is unknown.

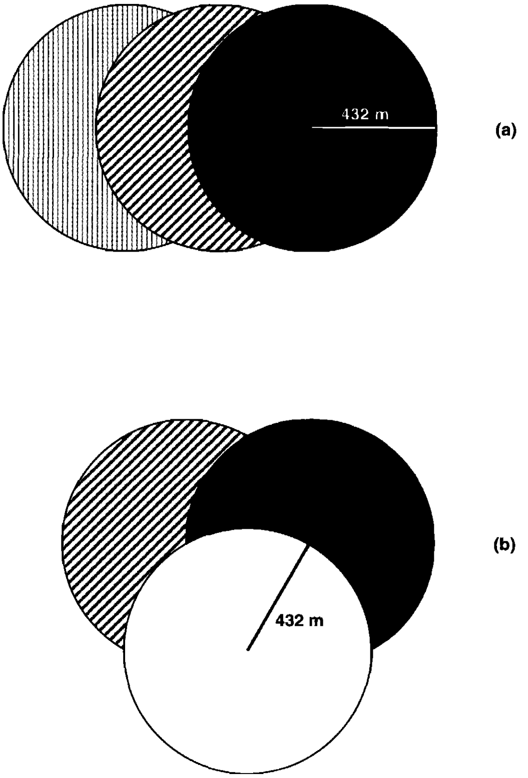

Figure 5. Conceptual representation of managing three alternative Northern Goshawk nests and their associated post- fledgling areas (PFAs). Two possible configurations, (a) all nests adjacent or (b) two adjacent and one below, are shown with 274 m as the mean distance between alternative nests and a mean PFA size of 59 ha on Vancouver Island, British Columbia. The diagram is drawn to scale.

Research Recommendations. In future PFA studies, we recommend increasing the minimum number of locations/fledgling to a minimum of 30 to improve the precision of PFA estimates (Kernohan et al. 2001). Goshawk post-fledging periods are extremely short, and the timeframe for data collection is limited. Obtaining reasonable samples of locations will require collecting either daily locations after young fledge or collecting multiple locations per sample day and relaxing guidelines around independence of locations. A sampling regime that spaces location data collection evenly throughout the duration of the study, enabling a reasonable amount of time for animals to relocate, may be more important than concerns about autocorrelation of data (Kernohan et al. 2001). Additionally, PFA size and habitat studies should be conducted across a diversity of ecosystems, so that management recommendations may be fine-tuned to reflect similarities and differences across broad geographic areas. This information may assist with designating suitable PFAs around nests when it is not feasible to collect radiotelemetry data.

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