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EFFECTS OF TIMBER HARVESTING NEAR NEST SITES ON THE REPRODUCTIVE SUCCESS OF NORTHERN GOSHAWKS (*ACCIPITER GENTILIS*)

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ABSTRACT.—We assessed the effects of timber harvesting near nest sites on the reproductive success of the Northern Goshawk (*Accipiter gentilis*). Harvest trials were implemented at 27 of 79 known nest areas, and the median post-treatment monitoring period was 3 yr (range = 1–7). We used a mean nest area size of 24 ha, based on the average number and spacing of nests within nest areas, to assess the impact of harvesting. Harvesting trials consisted of clearcutting, with the amount of nest area harvested ranging from 5–95%. From 1996–2002, we found no significant difference in nest area reoccupation frequencies or fledging rates of goshawks between treatment areas and control areas ($P > 0.10$). Even treatment areas with >50% of the nest-area stand removed ($N = 7$) did not exhibit reduced reoccupation or fledging rates. These results are preliminary, pending longer post-treatment monitoring to address high annual variation and a potential lag effect that may be exhibited by the goshawks. If these results are consistent over a longer period, they may support de-emphasis of management and research effort at the nest-area scale and greater emphasis at the territory and landscape scales to examine correlations between timber harvesting and territory abandonment and population declines reported in other studies.

KEY WORDS: *Northern Goshawk;* Accipiter gentilis; *timber harvesting; nest area; reproductive success; adaptive management; British Columbia.*

EFECTO DE LA COSECHA DE MADERA CERCA DE LOS SITIOS DE NIDIFICACIÓN SOBRE EL ÉXITO REPRODUCTIVO DE *ACCIPITER GENTILIS*

RESUMEN.—Determinamos el efecto de la cosecha de madera realizada cerca de los nidos sobre el éxito reproductivo de *Accipiter gentilis.* Los tratamientos de cosecha fueron implementados en 27 de 79 áreas de nidificación conocidas, y la mediana del periodo de observación post-tratamiento fue de 3 años (rango = 1–7). Para determinar el impacto de la cosecha de madera, utilizamos un área de nidificación promedio de 24 ha basándonos en el número y espaciamiento promedio de nidos dentro de las áreas de nidificación. Los tratamientos de cosecha consistieron en tala rasa y variaron entre un 5% y un 95% de área cosechada del área de nidificación. Entre 1996 y 2002, no encontramos diferencias significativas en las frecuencias de reocupación de sitios de nidificación o en las tasas de emplumamiento de los halcones entre las áreas de los tratamientos y las áreas control ($P > 0.10$). Incluso los tratamientos en que se removió >50% del bosque del área de nidificación ($N = 7$) no exhibieron tasas reducidas de re-ocupación o de emplumamiento. Estos resultados son preliminares hasta que se obtengan resultados de un monitoreo post-tratamiento más largo para dar cuenta de la alta variabilidad anual y posibles efectos retardados que puedan estar exhibiendo los halcones. Si estos resultados son constantes a lo largo de un periodo de tiempo mayor, éstos pueden apoyar una disminución del énfasis de los esfuerzos de manejo e investigación a la escala de sitio de nidificación y un aumento del énfasis a las escalas de territorio y de paisaje para examinar las correlaciones entre la cosecha de madera y el abandono de los territorios y disminuciones poblacionales que se han descrito en otros estudios.

The Northern Goshawk (*Accipiter gentilis*) is widely recognized as a species sensitive to timber harvest (Squires and Reynolds 1997). In 1995, British Columbia established the Forest Practices Code, which strengthened management requirements for non-timber resources and included a variety of coarse- and fine-filter management strategies for

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wildlife under the Identified Wildlife Management Strategy (IWMS; BC Ministry of Environment and BC Ministry of Forests 1999). The Northern Goshawk was identified as a focal species in the IWMS, and habitat-management guidelines were developed that included protection of nest areas, maintenance of a high proportion of mature and old forest in the post-fledging area, and for the threatened *A. g. laingi,* broad seral stage targets for the foraging area (BC Ministry of Environment and BC Ministry of Forests 1999). However, conflicting policy limited the number of goshawk territories that IWMS guidelines were applied to. For forest managers, the question became whether alternative management strategies that were less conservative than the IWMS guidelines could still maintain goshawk nest-area habitat requirements and reproductive success. We have attempted to answer that question within an adaptive management framework by monitoring the response of goshawk reproductive success to timber-harvesting trials at nest areas.

Few previous studies have monitored the response of goshawks to timber harvest near occupied nest areas within an experimental framework. Crocker-Bedford (1990) measured the effects of timber harvest on goshawk reproduction by examining the success of 16–200 ha reserves in maintaining goshawk occupation in nest areas surrounded by large partial-cut units (1000–5000 ha). Only 25% of 12 treatment territories were reoccupied at least once over a 3-yr period, compared to 79% of 19 control areas that were reoccupied (Crocker-Bedford 1990). Woodbridge and Detrich (1994) observed a correlation between nest area (nest stand cluster) size and occupancy, with occupancy frequencies at stand clusters <20 ha, 40–60 ha, and >60 ha of <50%, 75–80%, and nearly 100%, respectively. In that study, timber harvesting was one factor that affected nest-stand cluster size, but it was not explicitly isolated from other factors potentially affecting stand patterns and sizes. Patla (1997) found that occupancy was higher at nest areas prior to timber harvesting (79%) than after (47%), and that post-harvest areas with >50% occupancy had higher percent mature forest cover than nest areas with <50% occupancy. Penteriani and Faivre (2001) found that goshawk reproductive productivity did not differ between shelterwood harvested and untreated nest stands.

Our study differs from previous work that evaluated the effects of timber management on goshawk nest area reoccupancy and productivity for several reasons: (1) we monitored a larger sample of territories than previously studied (27 treatment areas and 52 controls); (2) our study was replicated in two forest types with ca. equal sample sizes in each area; (3) we examined a range of treatment levels (amount of nest area removed by clearcutting), and were able to control those levels experimentally; and (4) we compared responses pre- and post-treatment, as well as post-treatment responses to controls. Here we summarize the results of this ongoing study from 1996–2002.

STUDY AREA AND METHODS

We replicated this study in two different forest types in west-central British Columbia, Canada, with approximately equal numbers of nest areas in each. The first study area was within the Interior Cedar Hemlock (ICH) and Coastal Western Hemlock (CWH) biogeoclimatic zones (Banner et al. 1993) in the Kispiox Forest District (55°25′N, 127°45′W). This area (ICH/CWH) 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 mean annual precipitation varies from 600–1200 mm (Banner et al. 1993), with rain occurring on half the days during the goshawk breeding seasons we monitored. Forests within the ICH and CWH are predominantly old growth (>200 yr), coniferous stands dominated by western hemlock (*Tsuga heterophylla*), and included subalpine fir (*Abies lasiocarpa*), western redcedar (*Thuja plicata*), and Roche spruce (*Picea sitchensis* × *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°25′N, 126°00′W). It occurs on the interior Nechako Plateau, with elevations of 500–1000 m. The climate in the SBS is primarily continental and is characterized by greater seasonal temperature extremes than in the coast mountain range, with cold, snowy winters and relatively warm, moist, short summers. Annual precipitation is 440–650 mm (Banner et al. 1993), with rain occurring on less than 20% of the days during the breeding seasons we monitored. Forests in the SBS have been subject to frequent fires (mean fire interval <150 yr), and zonal sites are frequently dominated by mature seral stands of lodgepole pine (*Pinus contorta*) with subalpine fir, hybrid white spruce (*Picea glauca* × *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, ca. 55% of the forested land base is mature forest, 25% is young forest, and 20% is in a 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. Minimum goshawk densities of ca. four pairs per 100 km^2 are similar between the ICH and SBS based on inventory work in core portions of each study area (T. Mahon and F. Doyle unpubl. data). Potential avian competitors for nest sites and habitat occur at low densities and included Red-tailed Hawks (*Buteo jamaicensis*), which are 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 occur within riparian and mixed forest habitats at lower elevations throughout the region.

Nest Area Size and Habitat Characteristics. The estimated size of goshawk nest areas in the literature ranges from 8 ha (Reynolds 1983) to 50 ha (McCarthy et al. 1989). We calculated a theoretical "typical" nest-area size in our study based on the mean number of nest sites and the mean spacing distance among nest sites for 21 nest areas located early in the study and applied a 200 m buffer around the nests. The 200 m buffer was based on observed distance of nest sites from forest edges, concentrated sign (plucking perches, "white wash" [fecal deposits], and roosts), juvenile movements during the early post-fledging period, and nest defense behaviors displayed by adult birds, which are recognized as key features that determine the boundaries of goshawk nest areas (Reynolds et al. 1992, Squires and Reynolds 1997). Using our observed mean of three nests per nest area, mean spacing of 188 m between nest trees, and a 200 m buffer resulted in a nest-area size of 24 ha.

To test the appropriateness of this theoretical nest area size, we overlaid a 24-ha circle on each of the 79 known nest areas in 2002 to assess how many nest sites were encompassed within the 24-ha circular area. On the basis that only 4% of the nest sites fell outside of the 24-ha circles, we accepted that this size was the appropriate size to use.

Nest area stands in the ICH/CWH were dominated by western hemlock and typically had larger diameter and taller trees than in the SBS, which were dominated by lodgepole pine, but otherwise habitat characteristics were similar between study areas. Most nest areas were in mature (>100 yr) or old growth (>240 yr) stands with relatively closed primary canopies (45–65%) and open subcanopy flyways, on mesic sites. We observed no evidence of nest area selection with respect to slope or aspect in either study area, except for avoidance of very steep slopes (>45%). In most cases, nest areas were located in contiguous mature forest matrix, and in all cases suitable alternative nest area stands were available within 800 m of the original nest area. Forest composition, stand age, stand height, and canopy closure did not differ between treatment and control nest areas within each study area ($P > 0.10$).

Experimental Design. We employed an adaptive management framework in this study to integrate our research into operational timber harvesting and to maximize the utility of research outcomes to forest managers. This approach involved four key steps: (1) defining an area of scientific uncertainty; (2) developing and implementing management trials as real world experiments to test that uncertainty; (3) evaluating the outcomes of the trials; and (4) adjusting management guidelines on the basis of the knowledge gained (Morrison et al. 1998) The key uncertainty we investigated was how much goshawk nest area habitat can be removed via clearcutting before nest area reoccupation and productivity are impacted.

Design of harvesting trials included operational factors identified by forest licensees, as well as experimental factors associated with our study. In this context, these trials were not tightly controlled experiments because we could not completely control aspects of the timber harvesting relating to pattern and overall size. However, the resultant harvesting trials do provide a range of scenarios with respect to our primary treatment variable (amount of nest area harvested). Timber harvesting consisted of clearcuts with patch retention. Patch retention areas did not have any harvesting within them and were generally located to provide a mature forest buffer (25–200 m) around known goshawk nest trees. Other mature forest patches were occasionally retained in goshawk nest areas, including 20–60 m wide riparian buffers and 0.1–4.0 ha upland "wildlife tree patches." Within the clearcut areas, all merchantable trees were removed and in-block retention, if any, was limited to sporadic deciduous trees, scattered advanced regeneration, and occasional snags that were topped at 2 m. Timber harvesting was conducted outside of the breeding season to minimize the confounding effect of logging disturbance (Toyne 1997).

We quantified two response variables related to reproductive success. Our primary variable was the rate of nest area reoccupation into the incubation period, which represents the evaluation of nest areas by goshawks and their commitment to use them. Importantly, we present reoccupation rates, opposed to occupation rates. This was necessary because we found new nest areas each year and added them to the study. Therefore, the sample of nest areas used to calculate reoccupation rates in year X is the sample of nest areas that were known at the end of year X−1.

We tested for overall differences in reoccupation rates between treatments and controls using a chi-square analysis and pooled data from study areas and years. To assess the effect of treatment level (amount of nest area harvested), we also summarized the reoccupation rates separately for treatment areas that had >50% of the nest area stand removed and which we had monitored for at least 2 yr post-treatment.

We also examined nest productivity—the number of fledglings produced per nesting attempt—as a response variable. Nest productivity must be interpreted with caution, because once a commitment is made to nest in an area, overall fledging rates are more likely dependent on breeding season food supply than nest area habitat (Doyle 2000). An exception to this would be if timber harvesting led to higher nestling depredation rates. To address this issue, we evaluated the cause of nestling mortalities whenever possible. Similar to reoccupation rates, mean annual fledging rates were summarized excluding new nest areas found for that year. We tested for overall differences in fledging rates between treatments and controls using a *t*-test, again pooling data from study areas and years.

Nest-area Monitoring. We used a combination of telemetry and nest area searches at areas without tagged birds

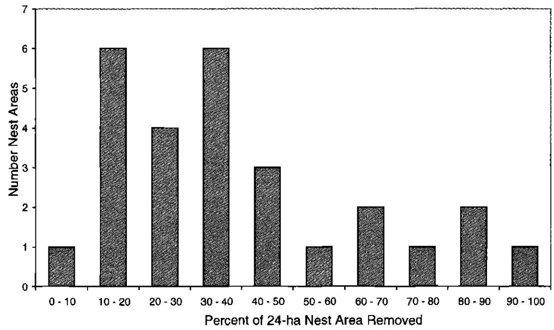

Figure 1. Distribution of treatment levels (amount of nest area clearcut) for harvesting trials at 27 Northern Goshawk nest areas in west-central British Columbia 1996–2002.

to monitor annual reoccupation and fledging rates at treatment and control nest areas. Initially, we attempted to radio-tag an individual at every treatment area and at a subsample of the control areas. However, as the study progressed, we determined that nest-area searches were sufficient to document reoccupation. Due to the extra time and cost associated with radio-tagging, and the potential negative impacts of radio-tagging to goshawks (Reynolds et al. 2004), we reduced our annual sample of nest areas with tagged birds to ca. 10% and only tagged birds at treatment areas. Adult goshawks were captured and tagged during the nestling period and early post-fledging period using box traps baited with Rock Pigeons (*Columba livia*; Kenward and Marcstrom 1983) or mist nets around a tethered pigeon or owl decoy. Tail-mounted radios were used instead of backpacks, so that we did not have to recapture the birds to remove the tags. Tagged birds were monitored the following breeding season using ground-based telemetry tracking to determine their breeding status and location.

For nest areas without tagged birds, we conducted intensive ground searches within ca. 1 km of the original nest area to ascertain the occupancy of each nest area. This involved surveying all known nests within a nest area, and if none of the known nests were occupied, intensively searching for new nests and other signs of use such as presence of goshawks, "white-wash," and plucking perches. If no occupied nest was found using visual searches, we conducted systematic call playback surveys (Kennedy and Stahlecker 1993) using a 300 × 300 m grid to elicit responses from goshawks in the vicinity. Nest area searching was conducted during the courtship, incubation, and post-fledging periods. All occupied nests were monitored biweekly to determine their success and fledging rates.

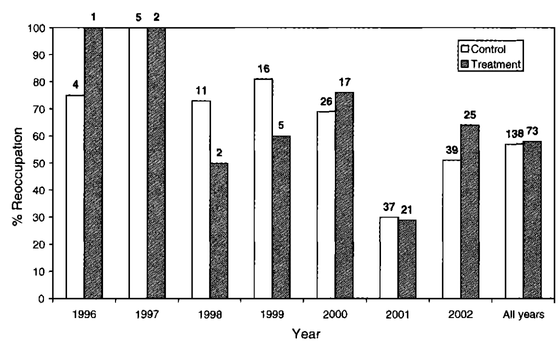

Figure 2. Annual reoccupation rates at Northern Goshawk nest areas at treatment sites, where timber harvest occurred, and control areas in west-central British Columbia, 1996–2002. Values above the bars equal number of nest areas available for reoccupation.

RESULTS

Of the 79 nest areas located in the two study areas, harvesting trials were implemented at 27 areas (13 ICH/CWH, 14 SBS). The treatment levels (amount of nest area clearcut) ranged from 5–95% (Fig. 1). The median time since timber harvest at treatment nest areas was 3 yr (range = 1–7).

We found no difference in reoccupation rates of nest areas between treatment and control areas (χ^2 = 0.021, P = 0.89). We combined data from the two study areas for analysis because they showed a similar pattern of response with reoccupation rates for treatments and controls of 54% and 53% in the ICH/CWH, and 61% and 63% in the SBS. The total reoccupation rates from 1996–2002 were 58% at treatment areas (N = 73 potential breeding attempts) and 57% at controls (N = 138; Fig. 2). We found consistent patterns of reoccupation rates between treatment and controls across years, with greater variation among years than between treatments and controls.

Seven nest areas had >50% of the nest area stand removed. Goshawks returned and bred successfully at all seven of these nest areas in at least one year post-treatment. For the years 2000–02 combined (the post-treatment period for these seven treatments), the reoccupation rates were 62% at treatment areas compared to 50% at controls.

The mean number of chicks fledged per nesting attempt did not differ between treatments (1.63 ± 1.05 [SD], N = 44) and controls (1.31 ± 1.13, N = 73; t = 0.306, P = 0.77). The mean nest productivity by study area was 1.54 ± 0.70 (N = 22) for treatments and 1.29 ± 1.03 (N = 35) for controls in the ICH/CWH and 1.67 ± 1.16 (N = 22) for treatments and 1.43 ± 1.06 (N = 38) for controls in the SBS.

DISCUSSION

All nest areas we monitored for ≥2 yr showed evidence of multiyear use and strong nest-area fidelity. Further, occupancy has been maintained at several nest areas where at least one of the original occupants has died or disappeared. This is consistent with other studies that have observed high fidelity even after the nest area is modified (Reynolds 1983, Woodbridge and Detrich 1994, Patla 1997). The implication of this behavior is that fidelity to nest areas may override response to reduced suitability and result in a lag effect before goshawks relocate to more suitable habitat.

Another major implication of the nest-area fidelity exhibited by goshawks relates to forest management. Effectively, nest-area fidelity is so strong in our study areas that nest areas can be considered spatially-fixed resources for forest management purposes. Once a nest area is located and protected, forest managers can proceed with harvesting in other parts of the territory, as estimated by territory spacing data, with low risk of impacting another nest area. Where goshawk nest area protection is a management objective, this provides forest licensees with a strong incentive to locate and to maintain nest areas because it reduces potential constraints within the remainder of the territory. Failing to adequately protect a nest area may result in the goshawks relocating to another stand scheduled for timber harvesting, which was the case with two of three relocations we observed in 2003. Management strategies to maintain alternate nesting habitat, post-fledging area habitat, and suitable foraging habitat would still be desirable at the territory scale, but those strategies are typically more flexible, at least in a spatial context, than protection measures for the nest area.

In addition to nest-area fidelity, inaccuracy in our estimate of nest-area size or variability in sizes could also affect the interpretation of our results. For example, if our estimates were too large, and included area outside of the true nest area, then the actual treatment impact would be less than reported. We estimated the "typical" nest-area size in our study areas based on mean number of nest sites, spacing between nest sites, evidence of occupation, and defensive behavior around nest sites. These characteristics were variable among nest areas, which probably corresponded to different nest-area sizes. We considered estimating the size of each nest area individually, but decided that would be even more problematic and biased than our systematic approach. Because of the uncertainty associated with nest-area size and its relationship to estimated treatment level, we did not focus our analysis on treatment level beyond two classes: all treatment areas and nest areas where >50% of the stand have been clearcut.

Despite nest-area fidelity by goshawks and potential lag effects, our study supports the findings of other research (Penteriani and Faivre 2001) that indicated goshawks tolerated modification of nest area stands, or relocated to new stands, without decreased reproductive output (assuming that alternative nest area habitat was available and distributed within the landscape appropriate to goshawk territory spacing). In Italy and France, Penteriani and Faivre (2001) reported a similar response by goshawks to shelterwood harvesting. They found that breeding frequency and the number of young produced per breeding pair did not differ between logged and unlogged stands. They also reported that where timber harvesting exceeded 30% of the nest stand, goshawks often relocated to the neighboring mature stands, but that overall reproductive success was not affected.

Several independent studies in Fennoscandia have shown that goshawk populations declined by 50–60% from the 1950–80s (Widén 1997). Widén (1997) examined several factors most often associated with declining raptor populations, including pesticides, persecution, prey populations, and nesting and foraging habitat loss associated with forest development. Of these factors, only decreases in the amount and patch size of mature forest at the foraging habitat scale showed a clear correlation with the decline in goshawk populations.

North American studies that suggested decreased nesting productivity in response to timber harvesting (Crocker-Bedford 1990, Patla 1997) were limited by their study design or by issues regarding scale of analysis relative to scale of harvesting. In Idaho, Patla (1997) compared reproductive success pre- and post-treatment, but not post-treatment areas to controls. Pre- and post-treatment comparisons in the absence of controls depend on the assumption that other factors affecting reproductive success are similar over the entire monitoring period, or at least have a minor effect relative to the treatment effect being studied. However, the reproductive success of goshawks is known to vary considerably from year to year depending on prey abundances (Doyle and Smith 1994) and weather (Younk and Bechard 1994).

Crocker-Bedford (1990) examined 16–200 ha nest area reserves surrounded by large partial cuts in Arizona and found much lower occupancy in the logged territories than at controls. However, the timber harvesting being evaluated was carried out over 1000–5000 ha units, which would have influenced both nesting and foraging area suitability. Crocker-Bedford (1995) later reanalyzed reoccupation rates and nestling production with respect to amount of harvesting that had occurred at the home-range scale of 2290 ha and found an inverse correlation between the reproductive success variables and harvesting.

To address high annual variation and a potential lag effect in responses by the goshawks, we will continue this study through 2005. If our longer-term results are consistent with Penteriani and Faivre (2001) and continue to show no decreased reproductive success by goshawks at nest areas modified by timber harvesting, it would support Widén's (1997) theory that habitat changes at the foraging area scale are the primary factor affecting goshawk populations. Notwithstanding the need for additional manipulative studies at the nest-area scale, we recommend that research on goshawks needs to shift from descriptive nest-area scale studies, which are numerous, to territory and landscape scale studies, which are few. Specifically, research should attempt to examine habitat requirements at the territory and landscape scale that can be incorporated into forest management strategies, such as seral-stage and patch-size distributions.

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