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SHORT-TERM EFFECTS OF TIMBER HARVEST AND WEATHER ON NORTHERN GOSHAWK REPRODUCTION IN NORTHERN IDAHO

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ABSTRACT.—Nesting habitat of the Northern Goshawk (*Accipiter gentilis*) in North America has been associated with the amount of mature, closed-canopy forest in the nesting area; however, few studies have experimentally tested the effects of timber harvest on goshawk reproduction. We tested the effects of clear-cutting within goshawk nesting areas on reoccupancy and nesting success for two years following treatments. We also included habitat and weather variables as potential covariates in our models. We found no treatment effects on goshawk reoccupancy, nesting success, or number of fledglings between harvested and unharvested nesting areas. Our models suggested goshawk breeding area reoccupancy was a function of the amount of potential nesting habitat available in the 170-ha area surrounding the nest; goshawks reoccupied breeding areas if they contained >39% potential nesting habitat following harvest. Nesting success was correlated with mean April precipitation and January daily temperatures. Our results suggested that, in the short term, goshawks were more likely to attempt nesting after disturbance if >39% of the 170-ha area around their nest was left in potential nesting habitat; however, our models suggested that once goshawks attempt nesting, nesting success was more likely to be a function of winter and spring weather.

KEY WORDS: Accipiter gentilis; *Northern Goshawk*; *nesting success*; *nesting habitat*; *reproduction*; *timber harvest*; *weather*.

EFECTOS DE CORTO PLAZO DE LA EXTRACCIÓN DE MADERA Y EL CLIMA SOBRE LA REPRODUCCIÓN DE *ACCIPITER GENTILIS* EN EL NORTE DE IDAHO

RESUMEN.—Se ha descrito que el hábitat de anidación de *Accipiter gentilis* en América del Norte está asociado con la cantidad de bosque maduro de dosel cerrado en el área de anidación. Sin embargo, pocos estudios han puesto a prueba experimentalmente los efectos de la extracción de madera sobre la reproducción de esta especie. Evaluamos los efectos de la tala rasa en las áreas de anidación de *A. gentilis* sobre la reocupación y el éxito de anidación en los dos años posteriores a los tratamientos. También incluimos variables del hábitat y el clima como potenciales covariables en nuestros modelos. No encontramos efectos de los tratamientos sobre la reocupación, el éxito de anidación o el número de volantones entre áreas de anidación con extracción de madera y áreas sin extracción. Nuestros modelos sugirieron que la reocupación de las áreas de cría por parte de esta especie fue una función de la cantidad de hábitat de anidación potencial disponible en un área de 170 ha alrededor del nido. Las aves volvieron a ocupar las áreas de cría si éstas contenían más del 39% del hábitat de anidación potencial tras la extracción de madera. El éxito de anidación estuvo correlacionado con el promedio de la precipitación de abril y la temperatura diaria de enero. Nuestros resultados sugirieron que, en el corto plazo, estas aves fueron más propensas a intentar anidar tras un disturbio si más del 39% de las 170 ha ubicadas alrededor de sus nidos eran dejadas como hábitat de anidación potencial. Sin embargo, nuestros modelos sugirieron que una vez que las aves intentan anidar, el éxito reproductivo dependió más probablemente de las condiciones climáticas del invierno y la primavera.

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Adverse effects of timber harvest on Northern Goshawk (*Accipiter gentilis atricapillus*) (hereafter referred to as goshawk) reproduction in North America were first reported by Crocker-Bedford (1990). Since 1990, numerous researchers have demonstrated a positive correlation between goshawk reproduction and the quantity of suitable nesting habitat at various scales (see review by Andersen et al. 2005). Most of these studies were observational, thus their results provided limited inference (Garton et al. 2005). The paucity of experiments testing the effects of timber harvest on goshawk reproduction is perplexing considering the common conclusion from many authors of correlative studies that goshawks may be sensitive to timber harvest within their nesting areas (Squires and Kennedy 2006). Only three published studies have incorporated a replicated experimental design to test the effects of timber harvest on North American goshawk reproduction (Crocker-Bedford 1990, Mahon and Doyle 2005, Patla 2005). This is significant because experiments, even with nonrandom treatments, have more power to infer cause and effect than observational studies (Garton et al. 2005). Interestingly, these three studies provided contrasting results; Mahon and Doyle (2005) reported no significant adverse effects of timber harvest on breeding area reoccupancy or nesting success in British Columbia, while Patla (2005) and Crocker-Bedford (1990) reported reduced breeding area reoccupancy and nesting success due to timber harvest in southeastern Idaho, and Arizona, respectively.

Widen (1997) reviewed a number of European studies that demonstrated a positive correlation between amount of mature forest and goshawk (*Accipiter gentilis gentilis*) reproduction. In contrast to observational studies, European studies incorporating replicated experimental designs have demonstrated minimal short-term effects of habitat loss on goshawk breeding area reoccupancy and nesting success (Penteriani and Faivre 2001, Penteriani et al. 2002). Timber harvest within goshawk nest stands in Italy and France did not affect goshawk reproduction until the original canopy cover was altered by >30% (Penteriani and Faivre 2001). Likewise, windthrow resulting in <30% loss of canopy cover within nest stands resulted in no measurable short-term effect on goshawk reproduction in France (Penteriani et al. 2002). It should be noted that the European subspecies of goshawk may be less selective of nesting habitat than *Accipiter gentilis atricapillus*, and will readily nest in small woodlots and parks in urban settings (Rutz et al. 2006).

In addition to habitat loss, other factors including weather may influence goshawk reproduction. For instance, McClaren et al. (2002) suggested that weather and prey availability influenced goshawk reproduction more than habitat characteristics. Weather can potentially affect goshawk reproduction through many mechanisms including reduced numbers of breeding pairs (Kostrzewa and Kostrzewa 1990), increased egg (Hogland 1964) and nestling (Zachel 1985) mortality, and reduced prey density and availability (Bloxton 2002); however, few researchers have examined the effects of weather on goshawk reproduction. Winter and spring weather variables significantly influenced goshawk reproductive rate over a 10-yr period in Nevada (Fairhurst and Bechard 2005). Conversely, weather variables did not affect goshawk reproduction in southeastern Idaho (Patla 2005). In Europe, increased precipitation and lower winter and spring temperatures negatively affected goshawk reproduction (Marquiss and Newton 1982, Kostrzewa and Kostrzewa 1991, Kruger and Lindstrom 2001).

Goshawk management in North America continues to be controversial (Andersen et al. 2005), partially due to contradictory study results, observational studies with weak inference, and narrowly focused studies not incorporating multiple factors potentially affecting goshawk reproduction. Few studies have examined the effects of both habitat and weather variables on goshawk reproduction and those that did had contrasting results. For instance, although Patla (2005) found no effect of weather, Kruger and Lindstrom (2001) found that models incorporating both habitat and weather best explained goshawk reproductive success in Germany.

We here present results of a study that tested if timber harvest, weather, or a combination of these two factors affected goshawk breeding area reoccupancy and nesting success in northern Idaho.

STUDY AREA

Our study occurred within an 890 000-ha region of the Clearwater Mountains in northern Idaho, bounded on the south by the Middle Fork Clearwater River and on the north by the St. Joe River. Elevations in the study area ranged from 700 to 1500 m. The climate has been characterized as inland maritime; annual precipitation ranged from 75 to 125 cm and occurred primarily during the winter and spring in the form of snow and rain, respective-

ly. Summers were warm and relatively dry with less than 2.5 cm of precipitation per month (Cooper et al. 1991). Most of the landscape consisted of mesic western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) habitat types (Cooper et al. 1991). These two habitat types are similar in productivity and vegetation composition and are differentiated primarily by the southern range of western hemlock, which terminates abruptly at the North Fork Clearwater River (Cooper et al. 1991). These habitat types are composed of stands of mixed conifers, including grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), western white pine (*Pinus monticola*), and lodgepole pine (*Pinus contorta*; Cooper et al. 1991). This region has a history of natural and anthropogenic disturbance. Prior to European settlement, large stand-replacing fires occurred on the order of every 150–400 yr within the western redcedar and western hemlock habitat types (Smith and Fischer 1997). Although burn sizes were variable, mean burn size was 196 ha (Flint 1930). Fire suppression has reduced the frequency and extent of fires more recently. The primary disturbance over the past 100 yr has been even-aged timber harvest, with a current clear-cut size of 20 to 65 ha, and a rotation age of 60 to 80 yr. These disturbances have resulted in a heterogeneous landscape, including early to late-seral forested stands (Hessburg et al. 2000).

METHODS

We conducted an experiment with nonrandom treatments to test the effects of timber harvest within the nest area, which is the immediate area surrounding a nest used by breeding goshawks (Andersen et al. 2005) and was defined as 12 ha by Reynolds et al. (1992). We defined the breeding area as a 170-ha circle surrounding known nesting areas with multiple alternate nests (Woodbridge and Detrich 1994; Carroll et al. 2006; see spatial analysis section for further definition of breeding area). Our definition of breeding area was similar to that of Andersen et al. (2005) in that a breeding area contains one or more nesting areas used by goshawks in the present, past, or both.

Breeding Area Surveys. Goshawk nests ($N = 21$) were initially located opportunistically ($N = 16$) and through dawn and call playback surveys ($N = 5$) from 2001 to 2003. All breeding areas included in the study were occupied and successfully fledged young the year prior to treatment and were monitored for reoccupancy and nest success during each of the following two years. Although we noted occupancy and nest success in the year before treatment, such data were not included in our analyses because nests were found opportunistically throughout the breeding season (courtship, incubation, and nestling phases) and thus reproductive data may have been biased toward successful nests in that year. Each breeding area was visited a minimum of three times in each subsequent year: once during the courtship (10 Mar to 10 Apr) or incubation period (10 Apr to 10 May), once during the nestling period (10 May to 20 Jun), and once during the post-fledging period (20 Jun to 15 Aug). This level of sampling was necessary to achieve a high detection rate (Boyce et al. 2005). We conducted predawn surveys during the courtship period (Penteriani 1999), and stand searches (Boyce et al. 2005) and call-playback surveys (Kennedy and Stahlecker 1993) during the incubation through fledging periods. We considered breeding areas reoccupied when ≥1 adult was observed near a stick nest during the nesting period (15 Mar to 30 Jun), and when ≥1 of the following conditions occurred: (1) a goshawk was observed incubating or brooding on a nest, (2) eggs or young were observed in a nest, (3) freshly molted feathers were found ≤50 m of a nest, or (4) a nest contained green twigs and fresh downy feathers (Andersen et al. 2005). We monitored reoccupied nests weekly either from the ground using binoculars or by climbing the nest tree to document the fate of the nestlings. We considered nests successful if ≥1 nestling was observed in a nest within 1 wk of the estimated fledging date, or if fledglings were observed in the nesting area after June 15, which is when goshawks begin fledging in our study area (B. Moser unpubl. data).

Harvest Treatments. All nest areas had a ≥70% overstory tree canopy closure and an overstory tree DBH of >31 cm (vegetation structural stages 4, 5, or 6; Reynolds et al. 1992). Because these goshawk nest stand conditions were similar to those described by Hayward and Escano (1989) for this region, we defined this cover type as potential nesting habitat. We chose nest areas for harvest ($N = 11$) based primarily on logistical constraints such as existing harvest contracts. All timber harvests were clear-cuts, with 85–95% of tree volume removed from the stand and remaining trees distributed primarily in a randomly dispersed fashion. All timber harvest occurred after the nesting season once the adults and fledglings had left the nest area. Mean

Table 1. Characteristics of goshawk breeding areas, northern Idaho, 2001 to 2005.

BREEDING AREA	TREATMENT	HARVEST UNIT SIZE (ha)	HABITAT TYPE	ELEVATION (m)
Dent	Harvested	65	*Thuja plicata*	700
Fisher Creek	Harvested	23	*Thuja plicata*	1013
Harvard	Harvested	74	*Thuja plicata*	916
Hume Creek	Harvested	65	*Thuja plicata*	970
Carlin Creek	Harvested	36	*Tsuga heterophylla*	992
Davies Creek	Harvested	52	*Tsuga heterophylla*	1057
Evans Creek	Harvested	53	*Thuja plicata*	928
Olson Creek	Harvested	21	*Tsuga heterophylla*	1164
Thompson Creek	Harvested	20	*Thuja plicata*	774
Reeds Creek	Harvested	16	*Tsuga heterophylla*	1324
Hangman Creek	Harvested	34	*Tsuga heterophylla*	1041
Alder Creek	Unharvested	0	*Tsuga heterophylla*	1082
Aldermand Ridge	Unharvested	0	*Thuja plicata*	974
Calder	Unharvested	0	*Tsuga heterophylla*	1074
Crocker Creek	Unharvested	0	*Thuja plicata*	941
Deer Creek	Unharvested	0	*Thuja plicata*	1055
Glenwood	Unharvested	0	*Thuja plicata*	1001
Grandad	Unharvested	0	*Thuja plicata*	732
Hugus Creek	Unharvested	0	*Tsuga heterophylla*	1053
Mica Creek	Unharvested	0	*Tsuga heterophylla*	1233
Washington Creek	Unharvested	0	*Thuja plicata*	1175

(SD) clear-cut size was 42 (21) ha (Table 1). In some cases, small groups of trees were retained; however, we did not find nests in these remaining groups of trees during our study. Each clear-cut encompassed all or part of the original nesting area that was used the first year goshawks were found nesting. In all cases, the original nest area was converted to a clearcut so that it no longer was expected to contain potential nesting habitat around the previous years' nest; however, at least 20% of the breeding area was left in potential nesting habitat adjacent to the original nest area. Because goshawks have three to eight nest trees ≤0.8 km apart in a breeding area and they alternate use of nests among years (Woodbridge and Detrich 1994), it is possible that alternate nests were retained in potential nesting habitat adjacent to the harvest unit. We did not sample for alternate nest trees in the breeding areas, so we do not know how many were harvested or how many might have been retained. Timber harvest was conducted during 2001 ($N = 1$), 2002 ($N = 3$), and 2003 ($N = 7$). We began monitoring a similar number of untreated control breeding areas in each year: 2001 ($N = 2$), 2002 ($N = 3$), and 2003 ($N = 5$). Control breeding areas in our study were defined as those that did not have any type of timber harvest scheduled for the duration of our study.

Weather Variables. We collected weather data for each breeding area from the closest weather station that was at or near the same elevation as the center of the breeding area. Distances from weather stations to breeding area centers ranged from 10 to 22 km. Data were downloaded from the National Weather Service (http://www.insideidaho.org/asp/liststations.asp) for 2001 to 2005. We included daily mean precipitation and daily mean maximum temperature from January through May (Table 2) because other researchers found them to be important factors affecting goshawk reproduction (e.g., Fairhurst and Bechard 2005). This time period represents the time immediately preceding the breeding season through the nestling-rearing stage, which is when goshawk reproduction is likely to be most affected by extreme precipitation and temperatures (Reynolds et al. 2006).

Spatial Analyses. Carroll et al. (2006) recently studied 565 goshawk nest locations and found that goshawk nest-site occurrence was best predicted using habitat variables in the 170-ha area around the nest. This area has been referred to as the post-fledging area due to its use by young goshawks soon after fledging (Kennedy et al. 1994). It may also correlate to the defended portion of a goshawk's territory (Reynolds et al. 1992) as well as a cluster

Table 2. Habitat and weather variables used to develop classification tree models to predict goshawk breeding area reoccupancy and nesting success, northern Idaho, 2001 to 2005.

VARIABLE	DESCRIPTION	REOCCUPANCY	NESTING SUCCESS
Treatment	Timber harvest versus no harvest	X	X
Year postharvest	Time following timber harvest	X	X
Preharvest habitat	Percentage of breeding area in potential nesting habitat before timber harvest	X	
Postharvest habitat	Percentage of breeding area in potential nesting habitat after timber harvest	X	X
January precip	January mean daily precipitation	X	X
February precip	February mean daily precipitation	X	X
March precip	March mean daily precipitation	X	X
April precip	April mean daily precipitation		X
May precip	May mean daily precipitation		X
Jan max temp	January mean daily maximum temperature	X	X
Feb max temp	February mean daily maximum temperature	X	X
Mar max temp	March mean daily maximum temperature	X	X
Apr max temp	April mean daily maximum temperature		X
May max temp	May mean daily maximum temperature		X

of nesting areas (Andersen et al. 2005). Thus, our unit of analysis was a 170-ha circle centered on ≥1 more known nests used by a pair of breeding goshawks and referred to here as the breeding area.

We mapped goshawk nests in ArcView 3.2 (ESRI 2000) and placed a 170-ha circle around each nest found the year before any timber harvest was conducted (year 0). We delineated potential nesting habitat within each nest area using Landsat 7 satellite imagery with 90 m resolution to define cover types. Potential nesting habitat was defined as forest with >70% overstory tree canopy closure containing dominant and subdominant trees ≥31 cm DBH. This classification corresponds with Reynolds et al. (1992) vegetation structural stages 4 to 6. We ground-truthed all nest areas to assess cover-type classification accuracy by systematically placing 48 plots in a 30-ha circle around nests and measuring trees per ha on variable radius plots using a 20 basal area factor prism and a densiometer to measure overstory tree canopy closure. Classification accuracy of Landsat 7 satellite imagery for potential nesting habitat was 91%.

Univariate Analyses. We treated breeding area reoccupancy and nesting success as binary outcomes, and calculated mean (SD) number of young fledged for each of the two years following timber harvest. We estimated median distance between occupied nests within a breeding area from the year prior to harvest to the year following harvest. We used the median rather than the mean because the data were not normally distributed, and the median is a better measure of central tendency for skewed data (Zar 1999). We used a median test to test for differences in distance moved between nests for each treatment. Fisher's exact tests were used to test for differences in reoccupancy and nesting success between treatments. Two-sample *t*-tests were used to test for differences in number of fledglings and distance moved between treatments. We also tested for differences in the amount of potential nesting habitat remaining in breeding areas between occupied and unoccupied, and successful versus unsuccessful breeding areas. We used Satterthwaite's method to estimate degrees of freedom for unbalanced designs with unequal variances (Snedecor and Cochran 1980). We used Statistix 8 (Analytical Software 2003) for all univariate tests. We considered the results of all statistical tests significantly different when $P \leq 0.10$.

Modeling. We modeled breeding area reoccupancy and nesting success for two years as a function of both habitat and weather variables (Table 2). Data from the 21 goshawk breeding areas were pooled across two years for a total of 42 cases used for modeling. A variable was included in the models to account for variation associated with time since harvest.

We used classification trees using CART 5.0 (Salford Systems 2002) to model goshawk breeding area reoccupancy and nesting success. We evaluated model fit based on correct classification rates using

Table 3. Goshawk reoccupancy, nesting success, and mean (SD) number of fledglings for one and two years following timber harvest, northern Idaho, 2001 to 2005.

TREATMENT	YEAR	REOCCUPANCY (%)	NESTING SUCCESS (%)	FLEDGLINGS PER NESTING ATTEMPT[1,3]	FLEDGLINGS PER SUCCESSFUL NEST[2,3]
Harvested	1	91	64	1.0 (0.9)	1.6 (0.5)
	2	73	36	1.2 (1.3)	2.3 (0.6)
Unharvested	1	80	60	1.3 (1.2)	2.2 (0.4)
	2	80	30	0.5 (0.8)	1.7 (0.6)

[1] Includes all nests where there was evidence that eggs were laid.
[2] Includes all nests that fledged at least one chick.
[3] No difference in number of young fledged between treatments (Satterthwaite's *t*-tests ($P > 0.305$).

the original data. We evaluated predictive ability of each model using 10-fold cross-validation on the original data.

RESULTS

Univariate Analyses. We found no differences in breeding area reoccupancy or nesting success between harvested and unharvested breeding areas in year 1 or 2 following treatment (Fisher's exact test, $P > 0.293$; Table 3). Number of young fledged was similar between harvested and unharvested areas in year 1 ($t = -0.66$, df = 17, $P = 0.519$) and year 2 ($t = 1.10$, df = 15, $P = 0.305$) following treatment (Table 3). We found no difference in median distance between occupied nests in year 1 to year 2 ($P = 1.000$). Median distance between nests was 107 m in harvested and 90 m in unharvested breeding areas. The mean amount of potential nesting habitat remaining after timber harvest was not different for reoccupied versus unoccupied breeding areas in year 1 ($t = -2.25$, df = 3, $P = 0.113$) or year 2 ($t = -1.49$, df = 5, $P = 0.198$) following treatment (Table 4). Mean potential nesting habitat remaining after timber harvest was not different for successful versus unsuccessful nests in year 1 ($t = -1.06$, df = 18, $P = 0.304$) or year 2 ($t = 0.16$, df = 13, $P = 0.875$) following treatment.

Modeling. Potential nesting habitat postharvest was the only significant predictor of breeding area reoccupancy (Fig. 1). The classification tree predicted a goshawk breeding area to be reoccupied when it contained >39% potential nesting habitat. Correct classification rates for both the learning and cross-validated data were 89% for reoccupied breeding areas and 63% for unoccupied breeding areas with an overall correct classification rate of 83%.

The nesting success model included April mean daily precipitation and January mean maximum daily temperature, in that order of importance, as predictors of nesting success (Fig. 2). The model predicted goshawk nests to be unsuccessful if: (1) April mean daily precipitation was >0.3 cm or (2) April mean daily precipitation was <0.3 cm and January maximum daily temperature was <0.7 C. The model predicted a successful nest if April mean daily precipitation was <0.3 cm and January maximum daily temperature was >0.7 C. The model fit the learning data with a correct classification of 75% for unsuccessful nests and 78% for successful nests with an overall correct classification rate of 76%. The cross-validated model correctly classified 67% of successful nests and 63% of unsuccessful nests with an overall correct classification rate of 64%.

DISCUSSION

We found that goshawks reoccupied breeding areas that were altered by timber harvest and they did not move any further to alternate nests in subsequent years than birds in unharvested breeding areas, suggesting that the harvest within nesting areas was not enough to cause goshawks to abandon breeding areas. Furthermore, goshawk nesting success and number of fledglings produced in subsequent years was not affected by timber harvesting. Our findings were similar to those of Mahon and Doyle (2005) in British Columbia, Penteriani and Faivre (2001) in Italy, and Penteriani et al. (2002) in France, who found that habitat modification within goshawk nest areas did not adversely affect goshawk breeding area reoccupancy or nesting success. Our findings contradicted those of Crocker-Bedford (1990) and Patla (2005), who found that goshawks in breeding areas subjected to some type of timber harvest exhibited lower reoccupancy and nest-success rates. However, Crocker-Bedford (1990) studied the effects of extensive timber har-

Table 4. Mean (SD) proportion of 170-ha goshawk breeding areas in suitable nesting habitat before and after timber harvest, northern Idaho, 2001 to 2005.

YEAR AND NESTING STATUS	PROPORTION PREHARVEST NESTING HABITAT[1]	PROPORTION POSTHARVEST NESTING HABITAT[1]
Year 1		
Occupied (N = 18)	0.70 (0.17)	0.57 (0.16)
Unoccupied (N = 3)	0.50 (0.15)	0.35 (0.15)
Successful (N = 13)	0.71 (0.20)	0.56 (0.19)
Unsuccessful (N = 7)	0.61 (0.13)	0.50 (0.15)
Year 2		
Occupied (N = 16)	0.68 (0.19)	0.58 (0.19)
Unoccupied (N = 3)	0.59 (0.19)	0.43 (0.18)
Successful (N = 7)	0.67 (0.21)	0.54 (0.21)
Unsuccessful (N = 4)	0.66 (0.19)	0.55 (0.21)
Year 1 and 2		
Occupied (N = 34)	0.69 (0.18)	0.57 (0.17)
Unoccupied (N = 8)	0.55 (0.17)	0.39 (0.16)
Successful (N = 20)	0.69 (0.20)	0.55 (0.19)
Unsuccessful (N = 22)	0.63 (0.16)	0.53 (0.18)

[1] Potential nesting habitat was defined as ≥70% overstory tree canopy closure and an overstory tree DBH of >31 cm.

vest treatments (>1000 ha) on goshawk reproduction. Although our study involved more intensive timber harvest, it was in a much smaller area than reported by Crocker-Bedford (1990). The differences in timber harvest treatments between our study area and Crocker-Bedford's (1990) study area may also explain the differences in our results. For instance, the timber harvest treatments in Crocker-Bedford's (1990) study were conducted across large areas (1000 to 5000 ha), which may be more likely to negatively affect goshawk reproduction by affecting the quality of foraging habitat. Subsequent unpublished analyses suggested timber harvest within goshawk foraging areas had adverse effects on goshawk reproduction (C. Crocker-Bedford pers. comm.). Mean goshawk home ranges in our study area were 5146 ha for males and 3859 ha for females (Moser 2007). The amount of area harvested within each breeding area was a relatively small proportion of the entire home range, which may explain why we found no significant differences in reproduction between harvested and unharvested goshawk breeding areas.

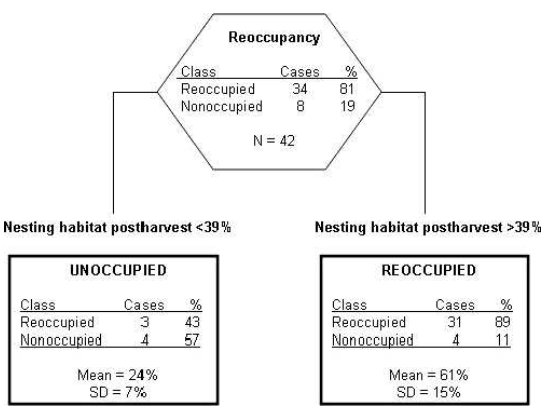

Figure 1. Classification tree for predicting goshawk breeding area reoccupancy. Reoccupancy is predicted by the amount of potential nesting habitat remaining within the 170-ha breeding area after timber harvest. The mean (SD) amount of nesting habitat remaining postharvest is given for the cases in each node.

Breeding area reoccupancy in our study appeared to be related to the amount of potential nesting habitat in the breeding area. Although our timber harvest treatments had no direct effect on goshawk reproduction, our model suggested that goshawk breeding areas that had <39% potential nesting habitat were more likely to be unoccupied.

Our findings that winter and spring weather affected goshawk reproduction were similar to those of Fairhurst and Bechard (2005) in Nevada, Keane et al. (2006) in California, and many researchers in Europe (Marquiss and Newton 1982, Kostrzewa and Kostrzewa 1991, Kruger and Lindstrom 2001). In addition, McClaren et al. (2002) suggested that weather and prey availability may have influenced goshawk reproduction more than habitat characteristics. Our findings contradict those of Patla (2005)

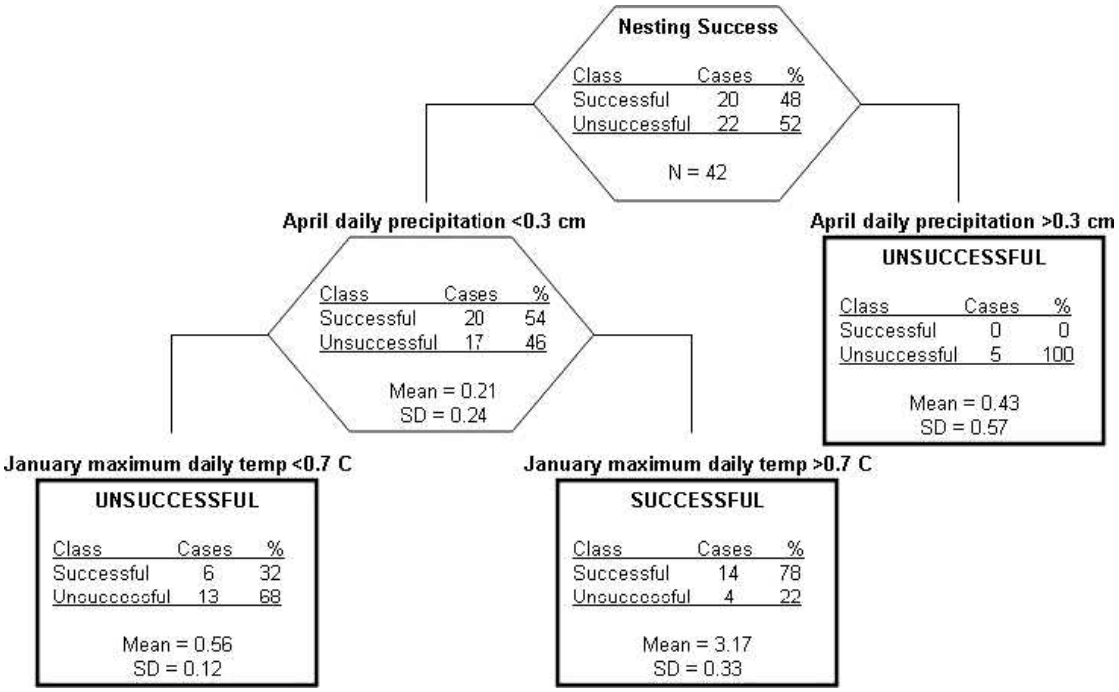

Figure 2. Classification tree for predicting goshawk nesting success. Nest success is predicted by a combination of April daily precipitation and January maximum daily temperature. The mean (SD) for each significant explanatory variable is given for the cases in each node.

who found no effects of weather on goshawk reproduction; however, her study examined the effects of drought rather than cold, wet winter and spring weather. The influence of weather on goshawk reproduction may be better understood if departures from long-term averages are used as explanatory weather variables in models.

It is clear from the large number of observational studies examining goshawk nesting habitat that goshawks prefer to nest in relatively closed-canopy forests and that they generally select larger stands of this cover type when available (Andersen et al. 2005). What is not conclusive is how sensitive goshawks are to habitat modification within their nesting or breeding area. Of interest is the apparent discrepancy between studies in higher-productivity forests (e.g., northern Idaho, British Columbia, France, and Italy) and those in lower-productivity forests (e.g., southeastern Idaho, Arizona; Bazilevich 1994). Perhaps higher-productivity forests have more abundant prey following harvest activities than lower-productivity forests (Huston 1994, Kondoh 2001), which may offset negative effects of disturbance on goshawk reproductive success.

We hypothesize that a combination of factors is responsible for both the temporal and spatial variability that we observed in goshawk reproduction. As long as goshawks have a suitable amount of nesting habitat within their breeding area, we hypothesize that weather may be one of the primary factors related to reproductive success. Cold, wet weather may directly affect goshawk reproduction by reducing breeding activity (Newton 1979) and nesting success (Kruger and Lindstrom 2001). In addition, adverse weather could presumably affect hunting success and prey densities and availability (Bloxton 2002).

Current forest management guidelines developed for the southwestern United States recommend no commercial timber harvest within a 12-ha goshawk nesting area and at least 60% of the 170-ha area surrounding the nest in equal portions of vegetation structural stages 4 to 6 (Reynolds et al. 1992). Because no published guidelines based on empirical data exist for mesic forests in the northern Rocky Mountain region, management principles from the southwestern guidelines have often been applied. However, based on our results, we recommend that timber harvest can be implemented with-

in goshawk nest areas in our study area after the post-fledging dependency period, which ends ca.15 August, with no short-term adverse effects on subsequent year's reproduction, provided that >39% of the 170-ha breeding area is left in vegetation structural stages 4, 5, or 6 (DBH >31 cm) with a canopy closure >70%. Our recommendations are similar to those of Desimone and DeStefano (2005) who studied long-term occupancy of goshawk breeding areas in south-central Oregon and suggested leaving >40% of mid- to late-aged, closed-canopy forest in the 170-ha area around goshawk nests.

Because breeding goshawks may exhibit a delayed response to changes in prey densities (Tornberg et al. 2005), we recommend long-term monitoring of this species in areas of forest management. Further, because many factors may interact at various spatial and temporal scales to affect goshawk reproduction (Reynolds et al. 2006), we suggest that future studies should consider the effects of other interacting factors such as prey availability, weather, predation, competition, and disease.

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