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Research Article

Estimating Occupancy to Monitor Northern Goshawk in the Central Rocky Mountains

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ABSTRACT Designing monitoring programs to evaluate trends in low-density wildlife species at regional scales is challenging given difficulties detecting uncommon organisms distributed in potential habitats over large spatial extents. The northern goshawk (*Accipiter gentilis*) has been petitioned for listing under the Endangered Species Act and the review of the petition indicated a need for information on population trend. To evaluate trends in goshawk populations, the U.S. Forest Service developed the Northern Goshawk Bioregional Monitoring Design to estimate goshawk occupancy over broad spatial extents. We adapted and implemented this design to approximately 30,600 km^2 of 88,128 km^2 of National Forest System lands in the Forest Service Rocky Mountain Region, including portions of Colorado, Wyoming, and South Dakota. We developed a stratified random design to monitor goshawk occupancy in sampling units, defined by primary and secondary habitat quality as well as accessibility. To define habitat quality, we examined a time series for 58 previously located nesting territories. Using logistic regression, we found that the dominant conifer species and status of aspen in postfledging zones best characterized high-quality goshawk nesting habitat. We applied model results to stratify 4,445 sampling units based on habitat quality and further stratified sampling units based on accessibility into easy and difficult access categories. We conducted field sampling during the goshawk breeding season in the summer of 2006 to estimate detection probabilities and occupancy rates. Within our sampling frame, we sampled 51 sampling units and estimated goshawk occupancy ($\hat{P}$) of 0.329 (95% CI: 0.213–0.445). Occupancy within primary strata (high quality) sampling units was 0.811 (SE = 0.113), whereas occupancy in secondary strata (lower quality) sampling units was 0.124 (SE = 0.067). Future implementation of this monitoring program can achieve 0.8 power to detect 30–40% declines in $\hat{P}$ with 140 sampling units. Our implementation of a stratified sampling design to monitor occupancy of goshawks at a region-wide scale reduced the number of sampling units in each administrative unit and focused our efforts on those areas most likely to have goshawks.

KEY WORDS *Accipiter gentilis*, aspen, lodgepole pine, management indicator species, northern goshawk, ponderosa pine, regional occupancy monitoring, spruce–fir, stratified design, trend monitoring.

Environmental monitoring programs provide information to manage natural resources, inform policy, and compile data that can be used for multiple applications (Lovett et al. 2007). In general, species monitoring requires repeated assessments of population parameters in specific areas during specific time periods (Thompson et al. 1998). Designing monitoring programs to assess abundance of low-density species, occurring over large spatial extents, is challenging given the need to establish rigorous sampling designs while accounting for imperfect detectability of targeted organisms (Kendall et al. 1992, Hayward et al. 2002, MacKenzie et al. 2002). Although monitoring cryptic, low-density species is difficult, especially at the spatial extent necessary to identify trends important to managers, it is precisely the time-series that is necessary to motivate change in management activities that may have led to declining trends. For example, the conservation needs of the Amur tiger (*Panthera tigris altaica*) would not have been understood and significant management intervention would have been unlikely without heroic efforts by Russian biologists to continue surveillance monitoring over decades across a vast region of the Russian Far East (Matyushkin et al. 1996, Smirnov and Miquelle 1999). Similarly, in North America, broad scale monitoring of bats (Weller 2008) and prairie dogs (*Cynomys* spp.; Andelt et al. 2009) represent examples of the important role surveillance monitoring can play in conservation.

Northern goshawk (*Accipiter gentilis*; hereafter, goshawk) is the largest accipiter hawk found throughout the Holarctic biogeographic region (Johnsgard 1990). In North America, goshawks occur at low densities throughout the deciduous and boreal forest regions of Canada, Alaska, and the northeastern and western United States. This species has been a charismatic focal species whose status has been frequently evaluated because of its relationship with mature forest structure and the inherent conflict with timber management. As a result, the goshawk has often been a priority species for

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land management agencies. Goshawks west of the 100th meridian were petitioned for listing under the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service [USFWS] 1997), but a review of existing habitat and population information led the USFWS to deny listing (U.S. Fish and Wildlife Service 1998). However, the USFWS noted that there was insufficient data regarding trends in goshawk populations to make strong conclusions regarding the species status (USFWS 1998; see Squires and Kennedy [2006] for a review of goshawk litigation). The U.S. Forest Service classified the goshawk as a sensitive species in 6 of 8 administrative regions of the National Forest System (NFS). As of 2004, 53 national forests in 7 regions had designated the goshawk as a management indicator species in their land and resource management plans (Woodbridge and Hargis 2006). Consequently, land managers have devoted considerable resources over many years toward surveying for and managing the goshawk and its habitat (Andersen et al. 2004, Squires and Kennedy 2006). Despite this substantial interest and investment, surprisingly little is known of the status and trend of the northern goshawk in North America.

Monitoring goshawk populations presents a challenge because they occur at low densities ($\leq$12 nesting pairs/100 km^2) and are difficult to detect (Squires and Reynolds 1997, Dewey et al. 2003, Andersen et al. 2004). Existing monitoring efforts by individual national forests have not been standardized and suffer from lack of coordination, inconsistency in terminology, and differing sampling approaches. Biological populations of goshawk span large areas (Ruggiero et al. 1994); therefore, understanding dynamics of the species requires examining patterns at spatial scales commensurate with the scale of the population. In response, the United States Forest Service developed a generic, national monitoring design to estimate the proportion of occupied sampling units over broad spatial extents (Woodbridge and Hargis 2006). The Goshawk Bioregional Monitoring Design is built on a framework of occupancy monitoring with occupancy as a surrogate of population abundance (MacKenzie 2005, MacKenzie et al. 2006). A fundamental consideration with occupancy monitoring programs relates to problems of detection. Whereas observing an organism is straightforward, failure to detect an organism could result from a failure to detect present individuals or actual absence (MacKenzie et al. 2002, MacKenzie 2005). The National Goshawk Monitoring Protocol follows the direction of MacKenzie (2005) through estimating detection probabilities from a series of 2 visits to account for the negative bias that occurs when lack of perfect detection is not considered.

We implemented the national protocol and examined implications of employing the protocol to monitor goshawk at broad scales. Our objectives were to: 1) estimate the occupancy rate and detection probabilities of the goshawk across the multi-state, bioregional spatial extent of the United States Forest Service, Rocky Mountain Region, and 2) estimate the sample size necessary to achieve acceptable power to monitor change in goshawk occupancy in the Rocky Mountain Region.

STUDY AREA

We sampled goshawk occupancy across 15 national forests managed as a group of 10 consolidated administrative units in the Rocky Mountain region (Region) of the Forest Service (Fig. 1). These forests encompassed 88,128 km^2 of Colorado, South Dakota, and Wyoming with elevations ranging from 923 m to 4,414 m and represent most goshawk habitat in this geographic area. We did not include the Nebraska National Forest in our analysis because goshawks are not known to nest on this Forest (Kennedy 2003).

Forests in northern Wyoming and the Black Hills in Wyoming and South Dakota were situated within the Central Rocky Mountains floristic province, whereas forests in southern Wyoming and Colorado were situated within the southern Rocky Mountains floristic province (Peet 2000). Although conifers dominated the forested landscape in the Region, vegetation associated with steep elevational gradients was characterized by dramatic vertical zonation (Ricketts et al. 1999, Peet 2000). The Black Hills National Forest in South Dakota and Wyoming (Fig. 1) forms a unique inclusion of ponderosa pine (*Pinus ponderosa*) within the western Great Plains (Alexander and Edminster 1981) but exhibited the least zonal development because it was lowest in elevation and had gentle topographic relief (Ricketts et al. 1999).

National forests in the northern portion of the Region were dominated by lodgepole pine (*Pinus contorta*) at mid elevations, whereas ponderosa pine dominated mid-elevation zones in the southern portion of the Region as well as in the Black Hills (Ricketts et al. 1999). Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) dominated goshawk habitat at higher elevations in Colorado and Wyoming national forests. Throughout the Region, aspen (*Populus tremuloides*) was mixed with conifer or occurred as a dominant cover type (Peet 2000). Dominant land uses across the Region included livestock grazing, timber management, and outdoor recreation.

METHODS

The National Goshawk Monitoring Protocol outlines an approach to collect occupancy data on goshawks across a broad spatial extent spanning multiple states to examine trend in goshawk occupancy over time and inform land management (Woodbridge and Hargis 2006). The protocol describes a stratified sampling design based on habitat quality and access issues that affect field implementation costs and logistics. We defined a sampling frame bounded by lands administered as national forests, stratified sampling units within those bounds based on habitat quality and accessibility, and implemented field sampling during summer of 2006.

Defining the Sampling Frame

We bounded our sampling frame to potential goshawk habitats within lands in the NFS Rocky Mountain Region. Employing a geographic information system, we created a grid of non-overlapping sampling units covering 688 ha (Woodbridge and Hargis 2006: 2–11) and placed this

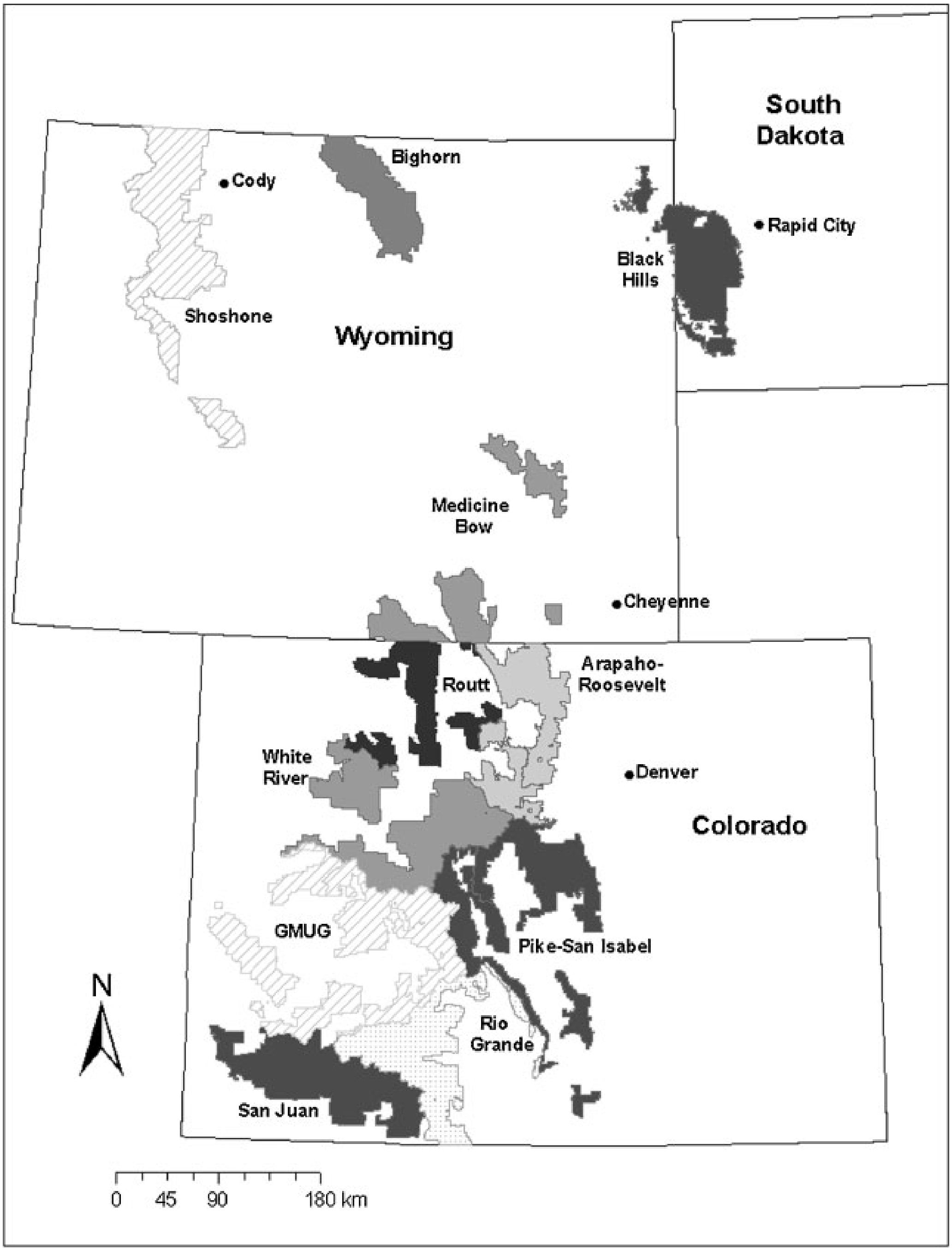

Figure 1. Geographic extent of the area to examine change in occupancy of northern goshawk comprising 15 national forests in the Rocky Mountain Region of the United States Forest Service that were managed as a group of 10 administrative units. These forests encompassed 88,128 km^2 of Colorado, South Dakota, and Wyoming, USA. For monitoring, we considered the Routt and Medicine Bow national forests separately. GMUG = Grand Mesa, Uncompahgre, and Gunnison national forests.

grid over 30,582 km^2 of NFS lands within our study area. Because of logistical issues of access, we eliminated any sampling unit that included private land. We stratified sampling units within our sampling frame according to habitat quality (primary and secondary) and accessibility (easy and difficult) considerations that affect field implementation costs and logistics.

To identify sampling units of potential goshawk habitat on which we would focus our field survey, we refined our sampling frame by eliminating lands that represented non-goshawk nesting habitat within the NFS Rocky Mountain Region based primarily on tree size class, tree cover, and tree species criteria. Our criteria included any sampling units: 1) composed of an inadequate amount and structural class of forested vegetation, 2) composed of inadequate forested cover, and 3) dominated by forested vegetation not used by goshawks. We removed sampling units that met ≥ 1 of these criteria for non-habitat from the sampling frame. We defined non-habitat criteria empirically based on the statistical distribution of vegetation characteristics around the center nests in 58 monitored goshawk territories from the NFS Rocky Mountain Region (see below). To evaluate habitat we characterized vegetation within a 172 ha circular area around each nest site, approximating a postfledgling zone (Reynolds et al. 1992), which was equivalent to the area within one quadrant of a sampling unit and allowed for evaluation of the suitability of sampling units within the sampling frame. Throughout our analyses we used 30 m pixel size and employed a majority rule of smaller pixels within larger quadrants to make spatial interpretations.

First, we evaluated tree size and found that the 172 ha postfledgling zone areas were dominated by trees that were sapling-pole to mature size class or greater (2.5 cm to ≥23.0 cm dbh). Thus, we eliminated sampling units if ≥1 quadrant did not meet this criterion. We used these structural stage data because they are the standard forest classification data for the U.S. Forest Service, Rocky Mountain Region; however we recognize that different classifications will work well in other landscapes. Second, we evaluated the extent of forest cover within a 688 ha square area (Woodbridge and Hargis 2006) around the central territory nest from our sample of 58 territories (Fig. 2). We eliminated sampling units with <50.3% forested cover, the value 2 standard deviations below the pooled mean. We selected this value because, for normally distributed data, approximately 95% of all observations lie within 2 standard deviations from the mean (Fowler et al. 1998). We recognized that likely some of the sampling units with <50% forested cover may have been occupied by goshawks depending on suitability of habitat within adjacent sampling units; however, our goal in applying this criterion was to narrow our sampling frame to the potential pool of sampling units where goshawks were most likely found.

By evaluating dominant cover (>50%) in quadrants, we removed sampling units dominated by forest or woodland types that were unlikely to be used by goshawks during the breeding season and that did not have ≥1 quadrant dominated by suitable forest types. We accordingly removed sampling units dominated by bristlecone pine (*P. aristata*), limber pine (*P. flexilis*), or two-needle pinyon pine (*P. edulis*)-juniper (*Juniperus* spp.) woodland because those forest types provide inadequate nesting structure to goshawks (Crocker-Bedford 1990, Graham et al. 1999, Kennedy 2003). Note that this dominant cover criterion eliminated few potential sampling units from the sampling frame because these cover types were not common on NFS lands in the Rocky Mountain Region.

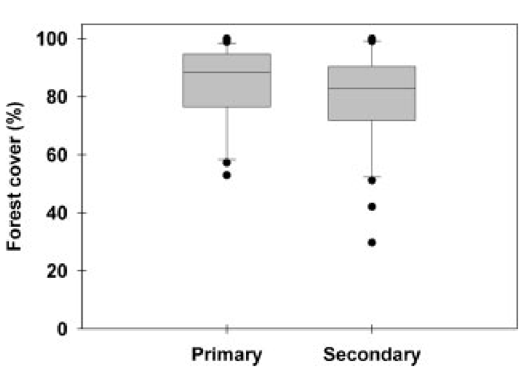

Figure 2. Distribution of forest cover percentages in 688 ha square areas placed around center nests of 58 northern goshawk territories categorized as secondary or primary from 1998 to 2004, United States Forest Service, Rocky Mountain Region, USA. Boxes include the interquartile range (25th–75th percentile) in forest cover around center nests; horizontal lines inside boxes are median forest cover; lower and upper whiskers are forest cover around center nests extending to 1.5 times the interquartile range; points above and below whiskers are outliers in forest cover around goshawk nests.

Defining Strata

We defined strata based on both habitat quality and accessibility issues that affect the cost of surveying. To delineate habitat-based strata, we developed a simple model of goshawk habitat quality based on nest-monitoring histories from the 58 goshawk territories. We classified territories as either primary or secondary based on nest occupancy history from 1998 to 2004. Primary territories ($n = 21$), assumed to be those in higher quality habitat, were those where nesting attempts were successful or attempted in ≥50% of the years they were monitored (≥3 years) or were active in 3 consecutive years. We classified all others as secondary ($n = 37$).

Modeling to define primary and secondary habitat.— We measured characteristics in a 172 ha circle around the central nest in each of the 58 monitored goshawk territories to define goshawk habitat features. Topographic variables we computed from a 30 m digital elevation model included average slope (%) and aspect (classified as cool [315–135°] or warm [136–314°]). We classified vegetation within each 172 ha circle based on existing Forest Service vegetation classification. Vegetation variables included dominant conifer species based on the species with greatest cover, percent cover of dominant conifer, percent total tree cover, and percent aspen cover. We explored occurrence of water, percentage canopy cover, and dominant structural stage; however, we found little explanatory ability with these data to distinguish between primary and secondary goshawk habitat, so we did not include these variables in modeling.

We used binary logistic regression (Proc Logistic; SAS Institute 2003) to classify goshawk nesting habitat by contrasting characteristics at primary and secondary territories. Models included a global model, which incorporated aspect, aspen cover, dominant conifer cover, dominant conifer species, mean elevation (m), mean percent slope, and total tree cover; 7 single-variable models; 4 prey species richness models based on simple vegetation associations known to compose habitats used by goshawk prey in the Rocky Mountain Region, which we developed based on ideas described in Reynolds et al. (2006); and a null model. We assessed strength of evidence for each model with Akaike's Information Criterion for small samples (AIC_c; Burnham and Anderson 2002). We selected the model with the lowest AIC_c value as the best-fitting model, and we used the difference (Δ_i,) between AIC_c for the best model and AIC_c for the ith candidate model to identify models competing with the best model. Akaike weights (w_i) allowed us to assess the weight of evidence in favor of each model (Burnham and Anderson 2002). We ranked the relative importance of variables by summing w_i across all of the models in which they occurred (Burnham and Anderson 2002). To examine the discriminating ability of our best logistic regression model we evaluated the area under the receiver operating curve, which in our case provided a measure of the best model's ability to discriminate between habitat characteristics at primary nests (Hosmer and Lemeshow 2000).

We performed a 5-fold cross-validation to evaluate goodness-of-fit for our best goshawk primary nesting habitat selection model (Boyce et al. 2002) by dividing primary and secondary nest observations randomly into 5 cross-validation groups. To evaluate model performance we compared predicted primary habitat against actual primary goshawk habitat, with the predicted probabilities grouped into bins (Boyce et al. 2002). We used Spearman's rank correlation (PROC CORR; SAS Institute 2003) to compare cross-validated prediction ratios with ratios of observed primary goshawk habitat.

Classifying habitat strata.– Evaluation of goshawk territories demonstrated that dominance of pine was most important for identifying primary nesting territories (see Results Section). We also designated sampling units dominated by large diameter (≥23 cm) aspen trees as primary habitats because: 1) the percent aspen cover around the 58 territories was the second most important variable explaining primary goshawk nesting habitat (see Results Section), 2) studies in north-central Colorado (Shuster 1980) and northern Nevada (Younk and Bechard 1994) found large diameter aspen (21–50 cm) were the preferred tree species selected by goshawks for nesting, and 3) forests dominated by aspen were not well represented in our sample of 58 nesting territories.

Therefore, we designated primary habitats as sampling units dominated by ponderosa and lodgepole pines as well as aspen. We placed sampling units in the primary strata if 3 or 4 of the 172 ha quadrants forming the sampling unit were dominated by pines or aspen. We marked all other sampling units as secondary habitat. In cases where 2 quadrants were primary habitat, we evaluated total cover within the sampling unit and assigned stratum classification based on which class (primary or secondary) was most (>50%) of the cover classification within the sampling unit. We found secondary habitats to be dominated by Engelmann spruce, blue spruce (*P. pungens*), white fir (*A. concolor*), subalpine fir, and Douglas-fir (*Pseudotsuga menziesii*).

Classifying accessibility strata.– We further stratified all sampling units based on predicted survey costs using 2 criteria: distance from an administrative office and the distance of the site from the road. We defined sampling units >48.3 km (30 mi) from a Forest Service office, or sampling units <48.3 km from a Forest Service office but >1.6 km (1 mi) from a road, as difficult. We classified all others as easy access. Stratification by habitat and accessibility resulted in 4 strata: 1) primary habitat, easy access; 2) primary habitat, difficult access; 3) secondary habitat, easy access; and 4) secondary habitat, difficult access.

Allocating the Sample and Monitoring

Within each national forest we individually labeled each sampling unit by strata and totaled the sampling units in each stratum by forest and across the Region. We randomly selected sampling units within each stratum on each national forest and numbered them in the random selection order until all sampling units were numbered. We ensured geographic dispersion of sampling units by allocating sampling units to strata within individual national forests based on proportion of the total regional sampling units occurring within each national forest stratum.

We used an interactive spreadsheet developed by the United States Forest Service (J. Baldwin, U.S. Forest Service, Pacific Southwest Research Station, personal communication) to distribute samples among strata incorporating the budget planned for field implementation (Woodbridge and Hargis 2006). The spreadsheet estimated the expected number of visits (s_i) to each sampling unit as: $s_i = 2 - P_i d_1(i)(1 - r_i)$, where P_i is the proportion of sampling units with occupancy in stratum i, $d_1(i)$ is the probability of detection when a sampling unit has occupancy during the first visit in stratum i, and r_i is the probability of a second visit, given the first visit results in occupancy in stratum i (J. Baldwin, personal communication). The spreadsheet apportioned the number of sites visited in stratum i with optimal allocation: $n_i \cong C((N_i\sigma_i/\sqrt{c_i})/(\sum_{j=1}^{4} N_j\sigma_j\sqrt{c_j}))$, where C is the total desired cost of the monitoring program and $c_i = s_i \cdot v_i$ is the expected cost per sampling unit, where v_i is average cost per visit to a sampling unit in stratum i. The proportion of sampling units optimally allocated to a stratum depends on the expected cost per sampling unit (more cost means fewer units sampled), the number of sampling units in the stratum (more units in a stratum means more units are sampled), and variation among sampling units (strata with larger variances require larger samples); the optimal sample size is proportional to $((N_i\sigma_i)/\sqrt{c_i})$.

To sample goshawk occupancy, we delineated a 600.7 ha sample plot nested within each 688 ha sampling unit (Fig. 3A). We used the sample plot size selected by Woodbridge and Hargis (2006) based on a comparison of spacing between goshawk territories in 3 distinct geographic regions. A beneficial effect of the 600.7 ha sample plot within the 688 ha sampling unit is that goshawks in adjacent sampling units should be outside of the 150 m zone of auditory detection (Woodbridge and Hargis 2006), thus restricting our calling efforts to goshawks within the sampling unit.

We surveyed goshawks within each sampling unit using broadcast acoustical methods with call stations placed to ensure complete coverage within the sampling unit (Woodbridge and Hargis 2006; Fig. 3B). We conducted nestling phase surveys from mid-June through mid-July and fledgling phase surveys from mid-July to late August 2006. We placed 120 call stations spaced 200 m apart in each sampling unit along 10 transects spaced 250 m apart (Fig. 3B). To reduce the time spent locating goshawks, survey crews began their work in a quadrant of each selected sampling unit associated with the highest

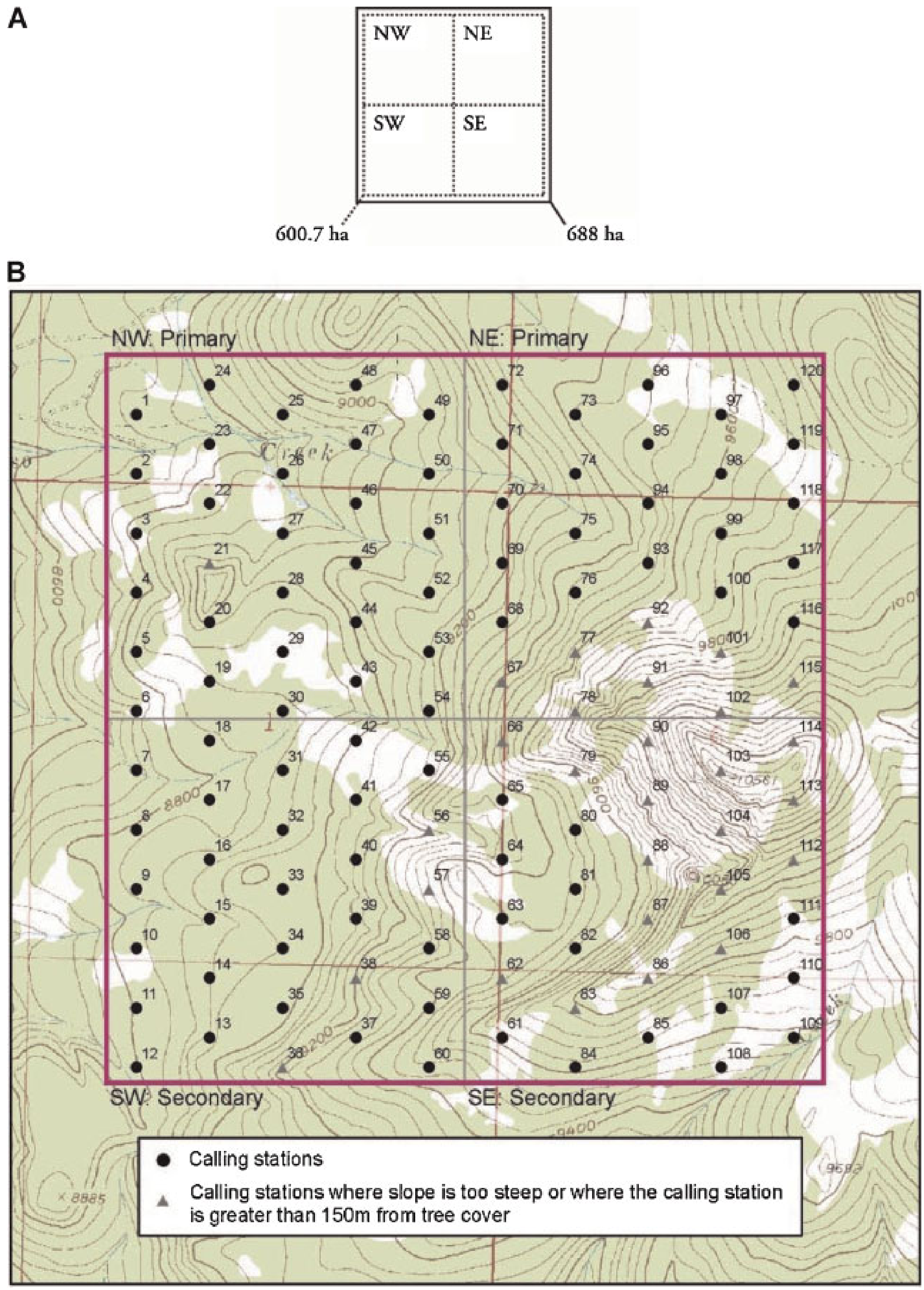

Figure 3. Sampling unit and sample plots we used to estimate northern goshawk occupancy, United States Forest Service, Rocky Mountain Region, USA, 2006. A: A 600.7-ha sample plot nested within a 688-ha sampling unit divided into 4 quadrants. B: 120 call stations placed in each 600.7-ha sample plot.

quality habitat based on classification as either primary or secondary habitat quality (Fig. 3B). We did not visit call stations when steep slopes (>36%) reduced safety or tree cover was not present within 100 m of the station.

Estimating Detection Probabilities and Occupancy of Goshawks in Sampling Units

The parameter of interest in monitoring goshawks is (P) the proportion of sampling units among all strata in the Rocky Mountain Region that have goshawk occupancy (Woodbridge and Hargis 2006). We defined occupancy as direct detections of adult or juvenile goshawks, such as visual observations, aural detections, or detection of freshly molted feathers (Woodbridge and Hargis 2006). We did not consider observation of other sign including whitewash, prey remains, plucking posts, or inactive nests (Woodbridge and Hargis 2006). We calculated separate estimates of P for each of 4 strata and a global estimate for the Region. We allowed detection probabilities to vary by strata and for each visit. We did not model other factors affecting detectability because protocols were standardized to reduce variability in detection probabilities among observers and detection probabilities were high. For our regional estimate, we combined the easy and difficult access strata to provide separate estimates of occupancy within sampling units stratified as primary or secondary as well as an overall estimate of occupancy within the sampling frame. We focused on these occupancy estimates because we included the accessibility factor for cost considerations, whereas our biological interest was in occupancy in primary versus secondary habitats. Data we used to estimate P were binary (occupied or not occupied) and we assumed the outcome of each visit within a sample unit was independent. We used a maximum likelihood estimator ($\hat{P}_i$) described in MacKenzie et al. (2002) and Woodbridge and Hargis (2006). We emphasize that in many instances the maximum likelihood asymptotic variance associated with this estimator is an underestimate of the true variance.

Estimating Adequate Sample Sizes to Detect Goshawk Occupancy

We used the previously mentioned interactive spreadsheet to estimate sample sizes necessary to provide estimates of change in goshawk occupancy in suitable habitat. We incorporated sampling unit occupancy rates and detection probabilities from field data collected during our summer 2006 study. Because the fledgling detection probability in the secondary stratum was not estimable, we substituted the detection probability for the secondary stratum nestling phase (0.646, SE = 0.280).

We computed estimates of cost per sampling unit based on 2006 field surveyor salary costs, project overhead and indirect costs, lodging, and vehicles to survey primary and secondary sampling units to protocol. We surveyed each sampling unit for goshawk occupancy a maximum of 2 times (MacKenzie et al. 2002), with first visits corresponding to the nestling phase and second visits to the fledgling phase. We estimated first-visit ($d_1(i)$) and second-visit ($d_2(i)$) detection probabilities according to methods described in MacKenzie et al. (2002). We set a value of 0.50 for the proportion of sites we visited after we detected goshawks in the first visit (r_i); revisiting a high proportion of sites with occupancy during the first visit reduces variation and the number of sample locations necessary to reach a given level of precision (J. Baldwin, personal communication).

To estimate detection probabilities some sampling units where goshawks are observed on the first visit must be visited $\geq$2 times (MacKenzie et al. 2002). We visited a second time half of the sampling units with occupancy on the first visit. We randomly selected half of the sampling units within each stratum for re-visits. We visited all sampling units without occupancy on the first visit a second time.

Power Analysis to Evaluate Sample Effort to Monitor Goshawk Change

We used an approximate power analysis based on a 1-tailed, t-test framework (Proc Power; SAS Institute 2003) to evaluate power for 6 cost-based sampling scenarios ($50,000–$500,000) to detect declines in occupancy of goshawks in sampling units across the Rocky Mountain Region of the United States Forest Service. Our goal was to examine sample sizes and costs necessary to achieve 0.8 power to detect declines across our sampling frame. We based effect sizes in our power analysis on mean differences between estimated mean occupancy of goshawks in sampling units in 2006 ($\hat{P} = 0.329$) and a second time period (e.g., 3 years later). The mean difference characterized the effect on power of incremental amounts of change in $\hat{P}$ from 5% to 40%. Standard deviations and sample sizes from our 2006 field study represented input for the power analysis run using the interactive spreadsheet (J. Baldwin, personal communication).

Our evaluation of sample size and power employed an α (probability of Type-I error rate) of 20% ($\alpha = 0.20$). Allowing a Type-I error rate of 20% represents a reasonable compromise in rare species monitoring (Kendall et al. 1992, Beier and Cunningham 1996) because of the relative importance of Type I (concluding there is a decline when in reality a decline has not occurred) versus Type II (concluding that a decline has not occurred when in reality there has been a decline) error rates to avoid delaying conservation measures.

RESULTS

From our geographic information system-based evaluation of potential goshawk nesting habitat we identified 4,445 sampling units on NFS lands in the Rocky Mountain Region. The secondary-easy to access stratum dominated the Region (1,909 [43%]), followed by secondary-difficult to access (1,208 [27%]), primary-easy to access (1,086 [24%]), and primary-difficult to access (242 [6%]). Shoshone National Forest had the highest number of sampling units (801), with 77% in secondary habitat. The fewest sampling units (105) were in the Black Hills National Forest, with 99% in primary habitat.

Elevation, slope, percent aspen cover, percent cover by dominant conifer species, and total tree cover did not differ among known goshawk territories classified as primary or secondary habitat based on nesting histories (Table 1). We

Table 1. Habitat characteristics of 58 goshawk nesting territories with consistent monitoring from 1998 to 2004, United States Forest Service, Rocky Mountain Region, USA. We measured characteristics in 172 ha circles centered on the center nests of 21 primary and 37 secondary nesting territories. We classified territories as either primary or secondary based on nest occupancy history from 1998 to 2004. Primary territories were those where nesting attempts were successful or attempted in $\geq$50% of the years we monitored them ($\geq$3 years) or active in 3 consecutive years. We classified all others as secondary.

	Territory classification			
	Primary		Secondary	
Habitat characteristic	$\bar{x}$	SE	$\bar{x}$	SE
Topography				
Elevation (m)	2,706	57	2,743	44
Slope (%)	20	2	18	1
Vegetation				
Aspen cover (%)	13	3	17	3
Dominant conifer cover (%)	62	5	59	4
Total tree cover (%)	87	3	85	3

found similar percentages of 172 ha circles around monitored nests to be dominated by cool ($\bar{x} = 62\%$, SE = 8%) or warm ($\bar{x} = 59\%$, SE = 11%) aspects. Habitat around primary nests was primarily pine forest ($\bar{x} = 86\%$ cover, SE = 6%), whereas a smaller percentage of habitat around secondary nests was dominated by pine ($\bar{x} = 57\%$, SE = 11%). Spruce–fir was more dominant in habitats around secondary nests ($\bar{x} = 43\%$, SE = 11%) than around primary nests ($\bar{x} = 14\%$, SE = 6%).

The logistic regression model best explaining habitat around primary goshawk territories was the dominant conifer species model (Table 2). No other model was competitive with this best model ($\Delta AIC_c \geq 2$) and dominant conifer species was also included in 5 of the top 6 candidate models (Table 2). The receiver operating curve for our best model (0.65) indicated this model was effective in discriminating between primary habitats based on dominance of conifer species around nests (Hosmer and Lemeshow 2000). In addition, given our simple case, a Fisher's exact test between the proportion of primary nests surrounded by pine versus spruce–fir also provided a measure of discrimination ($P = 0.040$). Weights for the 2 most important explanatory variables supporting our model were dominant conifer species (0.72) and percentage aspen cover (0.34); relative importance for other variables evaluated across models was ≤ 0.09. Odds of primary nesting territories being dominated by pine were 4.6 times (95% CI: 1.1–18.3) greater than primary nesting territories being dominated by spruce–fir. Our cross-validation analysis indicated the best model performed moderately to predict primary goshawk nesting habitat ($r_s = 0.43$, $P = 0.219$, $n = 10$).

Survey crews visited 51 and 43 sampling units during the nestling and fledgling phases, respectively (Table 3). We detected more goshawks in primary compared to secondary sampling units during both survey phases. Across survey phases and strata, we visually detected 86% (25 of 29 total detections) of detected goshawks (Table 3).

Goshawk occupancy in 688 ha sampling units for the 4 habitat–access strata were 0.836 (SE = 0.114) for primary-easy; 0.603 (SE = 0.303) for primary-difficult; 0.167 (SE = 0.088) for secondary-easy; and not estimable in secondary-difficult. Goshawk detection probabilities in primary strata were 0.697 (SE = 0.127) and 0.740 (SE = 0.159) during nestling and fledgling phases, respectively.

Table 2. Model fit statistics for primary nesting habitat selection of northern goshawk ($n = 58$), in the United States Forest Service, Rocky Mountain Region, 1998–2004. We based models on habitat characteristics at 21 primary and 37 secondary nesting territories monitored from 1998 to 2004 and are listed according to the model that best fit the data and ranked by the difference (ΔAIC_c) between the model with the lowest Akaike's Information Criterion for small samples (AIC_c) and the AIC_c for the current model. We also present the number of parameters (K), value of the maximized log-likelihood function (log[L]), and Akaike's weight (w_i) for each model.

Model[a]	Log(L)	K	AIC_c	ΔAIC_c	w_i
DCS	−35.20	2	74.627	0.000	0.422
Aspen + DCS	−35.17	3	76.781	2.154	0.144
Null	−37.97	1	78.005	3.378	0.078
Aspen + DCS + tree cover	−34.97	4	78.693	4.066	0.055
Aspen + DCS + DCC	−35.12	4	79.003	4.376	0.047
Aspen + DCS + aspect	−35.17	4	79.086	4.459	0.045
Slope	−37.45	2	79.108	4.481	0.045
Aspen	−37.48	2	79.181	4.554	0.043
DCC	−37.80	2	79.814	5.187	0.032
Elevation	−37.83	2	79.883	5.256	0.030
Tree cover	−37.88	2	79.983	5.356	0.029
Aspect	−37.95	2	80.118	5.491	0.027
Global	−33.29	8	85.516	10.889	0.002

[a] Explanatory variables in 172 ha circles surrounding each nest are: aspect = majority categories of cool (135–315°) and warm (136–314°) aspect in each circle; aspen = % cover of aspen in circles; constant = model with no explanatory variables; DCC = % cover of the most dominant conifer cover type; DCS = dominant conifer cover species; elevation = mean elevation (m) in circles; global = the model including all explanatory variables; slope = mean % slope in circles; and total tree cover = % tree cover in circles.

Table 3. Sampling statistics of 51 sampling units we sampled in primary and secondary strata to estimate detection and occupancy probabilities for northern goshawk, United States Forest Service, Rocky Mountain Region, 2006. We conducted nestling phase surveys from mid-June through mid-July and fledgling phase surveys we conducted from mid-July to late August 2006.

	Nestling phase		Fledgling phase	
Sampling parameters	Primary	Secondary	Primary	Secondary
Surveys				
Sampling units visited	25	26	18	25
Call stations visited	1,629	1,588	1,063	1,497
Detections				
Goshawk detections	14	2	10	3
Aural (A) detections	2	0	1	1
Visual (V) detections	3	1	7	1
Both A and V detections	9	1	2	1

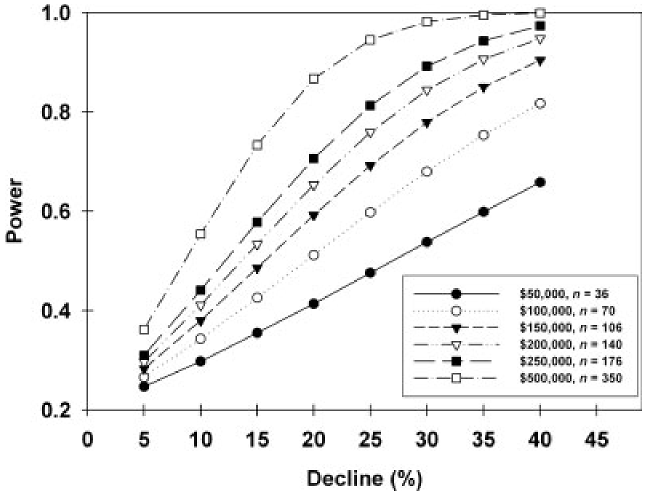

Figure 4. Power to detect declines of 5–40% in occupancy of goshawks in 688 ha sampling units, United States Forest Service, Rocky Mountain Region, USA. We based this analysis on declines from our Region-wide occupancy estimate of $\hat{P} = 0.329$ in 2006.

Detection probability was 0.646 (SE $=$ 0.280) for secondary strata during the nestling phase. Detection was not estimable for the fledgling phase in secondary strata. Estimated occupancy of primary habitat by goshawks Region-wide was 0.811 (SE $=$ 0.113), whereas occupancy in secondary strata was 0.124 (SE $=$ 0.067). In summer 2006, overall occupancy of goshawks in the 4,445 sampling units forming the Rocky Mountain Region sampling frame was $\hat{p} = 0.329$ (95% CI: 0.213–0.445).

Using parameter estimates from our study, we were able to estimate an optimal sample size allocation among the strata at 5 hypothetical budget levels. Sample sizes per cost of sampling effort (based on 2006 values) were 36 for $50,000, 70 for $100,000, 106 for $150,000, 140 for $200,000, 176 for $250,000, and 350 for $500,000 (Fig. 4). Based on parameter estimates from our study, we can achieve 0.8 power to detect 20% declines in $\hat{P}$ between 2 monitoring periods (e.g., 3 years later) only after sampling $n = 350$ sampling units (Fig. 4). However, 0.8 power to detect declines of 30–40% could likely be achieved at a sampling intensity of $n = 140$ ($200,000), indicating sufficient power to detect declines in $\hat{P}$ in the sampling frame at less conservative levels (Fig. 4).

DISCUSSION

Our region-wide modeling approach incorporated greater heterogeneity of goshawk habitat than fine-scale approaches such as those at the scale of individual national forests (Joy et al. 2003). Our approach ensured a level of geographic dispersion in line with the distribution of habitat across the Region. In our application, sampling units dominated by pines–aspen or spruce–fir provided an effective approach to stratify sampling units by habitat quality and substantially increase efficiency (and therefore lower cost) of the survey.

Paradigm Shift in Monitoring Northern Goshawk

Past efforts to monitor goshawk in the United States Forest Service, Rocky Mountain Region have occurred haphazardly on portions of individual national forests and were based largely on observing the status of known goshawk territories located through convenience sampling. This approach suffered from several important shortcomings related to sampling design. First, monitoring goshawks on individual national forests results in a mismatch between the spatial scale of the sample and the biological population. Based on characteristics of natural history (Squires and Reynolds 1997), recorded movement patterns (Squires and Ruggiero 1995), and principles of population biology (Ruggiero et al. 1994, Wells and Richmond 1995), a biological population of goshawks likely occurs at the scale of a bioregion or several bioregions. Therefore, monitoring an individual forest examines trend from a small portion of the biological population. Second, because monitoring was not standardized across the Region and data not recorded in a common repository, analysis of the data was difficult. Finally, and maybe most importantly, monitoring of a set of opportunistically located known territories, without a systematic approach to examining unoccupied territories, will result in a system guaranteed to demonstrate a downward trend, as territories become unoccupied over time (Reynolds et al. 2005). A related issue is that variation in annual nesting rates will influence detectability (Reynolds et al. 2005). Therefore, to the extent that occupancy monitoring provides an adequate estimate of detection probability, this method should perform well compared to nest monitoring. Our adaptation of the national monitoring design addresses each of these shortcomings of past efforts to monitor goshawk in the United States. The scale of monitoring, across most of a Forest Service region, is a spatial extent more in line with the extent of the biological population. To address the second problem, the national design provides the mechanism for coordinated field sampling, coordinated data recording, and evaluation of the precision of estimates based on defined costs. Most important, addressing the third problem, we based our sample on a well-defined survey sampling approach (Scheaffer et al. 1996) with particular attention to defining the sampling frame and casting a sample with good geographic dispersion. Stratification based on survey costs explicitly addresses the logistical constraint of accessing remote areas while maintaining the ability to make inferences across a larger area.

We did not design our test of the implementation of the National Goshawk Monitoring Protocol to address the potential consequences of variation in the floater population (subadult or non-territorial individuals) within the population (Squires and Reynolds 1997) on detection or occupancy rates. Techniques to detect goshawks have been developed for breeders, suggesting a great need to develop methods to detect non-breeders during the breeding season (Kennedy 2003). As with other species it is difficult to both design a sampling protocol and test that protocol regarding the influence of non-breeding animals on trend detection. If implemented rigorously, nest monitoring can provide useful information on vital rates (i.e., survival and reproduction). However, in most instances, the necessary information on nesting success, fledgling survival, and other demographic parameters is not collected during nest monitoring because repeat observations are necessary.

Goshawk Status and Future Surveys

We narrowed our sampling frame and field of inference to sampling units containing only lands administered by the NFS, which resulted in elimination of many potential sampling units along the boundaries of the national forests. Eliminated sites were typically lower elevational sites dominated by vegetation considered primary goshawk habitat. For some national forests, such as the Black Hills, application of this criterion eliminated most of the pool of potential sampling units for that Forest. A multi-agency partnership that includes other land ownerships could be considered when planning a bioregional survey, thus allowing greater inferential utility of the data collected.

Our implementation of the National Goshawk Monitoring Protocol (Woodbridge and Hargis 2006) demonstrates the logistical feasibility and management benefits of monitoring goshawks at a broad spatial scale commensurate with the scale of the biological population. It also provides some initial insight into the status of goshawk in the Rocky Mountain Region employing targeted monitoring (an approach to monitoring species valued highly by on-the-ground managers charged with conserving multiple species across large areas; Holthausen et al. 2005). Others have referred to this form of monitoring as surveillance monitoring and suggested it represents an inefficient expenditure of funds. However, given the indirect costs associated with failing to comply with laws and regulations and the benefits of detecting trends across broad spatial scales, this form of monitoring is seen as quite effective by resource managers (Holthausen et al. 2005, Woodbridge and Hargis 2006).

The advantages of a stratified sampling design at the Region-wide scale include increasing the inferential power of the monitoring protocol while reducing the number of sampling units in secondary habitat and more difficult to access areas. Our results demonstrate the substantial differences in occupancy across strata. Our findings also provide important information to support surveys conducted for individual forest management actions. Our study clearly illustrates that goshawks are likely to be found in primary habitats. In addition, the detection probabilities we determined from the broadcast-acoustical survey method for goshawks in the Rocky Mountain Region in both the nestling and fledgling periods are critical in understanding the findings of project-level species surveys. This is of particular importance for understanding the results of single effort project surveys, in that 25–35% of the time goshawks are likely present even though surveys failed to detect them.

Our results provide surprising evidence regarding the status of goshawk in the Rocky Mountain Region. We estimated occupancy of >80% of sampling units supporting primary habitat (29.9% [9,137 km^2] of our sampling frame) throughout the Region. Clearly goshawks are well distributed and common, in suitable habitat, within the Region. Furthermore, a simple habitat model effectively discriminated between primary and secondary habitat, providing an effective broad-scale stratification approach. Resulting differences in observed occupancy between primary and secondary habitat illustrates important patterns of habitat use at the scale of the Region—goshawk occurred largely in lodgepole pine, ponderosa pine, and aspen habitats and were rare in other forest types.

Our evaluation of power focused on the trade-off of cost relative to precision indicated that the most efficient sampling design would require a $200,000 budget to survey 140 sampling units across the Region (budget includes administrative costs, data recording, and all logistical expenses based on 2006 costs). Achieving our target precision to sample sufficiently to detect a 20% decline in goshawk occupancy would require substantial resources. We based our evaluation of power on extensive data collected over 1 year. Our evaluation indicated that, as sampling intensity increased, there was a gradual shift from linear to asymptotic responses that began around 100 samples, suggesting that the power to detect a range of declines in goshawk occupancy was enhanced at higher sampling intensities, but cost/benefit of sampling began to decline around 175 samples. Future monitoring will allow for incorporation of annual variability and sensitivity of model parameters incorporated into power analysis.

MANAGEMENT IMPLICATIONS

Monitoring provides a foundation for informing conservation and management actions. Goshawk monitoring will allow for evaluation of conservation targets and the consequences associated with a range of habitat changes including bark beetle (*Dendroctonus* spp.) outbreaks, forest management, and vegetation responses to climate change. The benefits of implementing broad-scale monitoring are especially apparent in light of recent major natural forest disturbance events in the central Rocky Mountains. Stand-replacing fire changed the structure and composition of large areas of Colorado, Wyoming, and South Dakota during the past several years and similar disturbances can be expected during the next decade. In addition, bark beetle epidemics have killed most mature lodgepole pines in stands covering >10,117 km^2 in central Colorado during the past 8 years (B. Howell and J. Ross, U.S. Forest Service, Rocky Mountain Region, personal communication) and the extent of the disturbance is expected to continue to expand over the next 3 years. Response of goshawk to these and future broad-scale disturbances would not be easily detected through haphazard monitoring on portions of individual national forests. However, monitoring throughout the entire Region with an approach that is scalable to individual forests will provide managers an understanding of goshawk trends at a scale commensurate with the scale of disturbance. Given the territorial behavior of goshawks, adults may continue to use stands severely impacted by beetles for several years as long as the stand maintains adequate nesting structure and prey abundance (Graham et al. 1999). As stands begin to fall apart, goshawk prevalence in beetle-killed areas may decline if adequate nesting and foraging habitat does not remain, which may result in population decline or a geographic redistribution of goshawks to secondary habitats that could only be detected with broad-scale monitoring.

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