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A DESIGN FOR MONITORING NORTHERN GOSHAWKS AT THE BIOREGIONAL SCALE

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Abstract. Information on Northern Goshawk (*Accipiter gentilis*) populations is generally obtained by studying nesting activity at local scales. Although this approach provides breeding information for specific territories, it can not be used to track changes in the abundance of goshawks over broader spatial extents. To address the need for broad-scale monitoring, the USDA Forest Service (USFS) assembled a working group to develop a design for monitoring goshawk population trends at a bioregional scale (i.e., northern Rockies or Intermountain Great Basin). The working group consisted of statisticians, wildlife biologists, and goshawk researchers within and outside of the USFS. The group was chartered to create a monitoring design to be implemented on national forest lands, but the USFS invites collaboration with other landowners and state natural resource agencies in order to provide a more complete picture of goshawk status across land ownerships. The objectives of the monitoring design are: (1) to estimate the frequency of occurrence of territorial adult goshawks within a bioregion, (2) to assess changes in frequency of occurrence over time, and (3) to determine whether changes in frequency of occurrence, if any, are associated with changes in habitat. The sample population for each bioregion is a grid of 600 ha primary sampling units (PSUs) across all potential goshawk habitats on national forest lands and on lands owned or managed by collaborating parties of each bioregional monitoring program. The sampling frame is stratified to increase efficiency under a fixed monitoring budget. The indicator used to determine the frequency of occurrence of goshawks is the proportion of PSUs with goshawk presence, based on response to broadcast acoustical surveys in a sample of PSUs. Sampled PSUs are surveyed two times (nestling and fledgling periods) to obtain one estimate of goshawk presence per breeding season. Frequency of goshawk presence within the bioregion is estimated using a maximum likelihood estimator. Changes in frequency of goshawk presence will be assessed after a minimum of 5 yr, using a logistic model with habitat parameters entered as covariates. Information from bioregional monitoring will help determine the status of goshawk populations and their habitats over a spatial extent that is meaningful for goshawk conservation.

Key Words: Accipiter gentilis, broadcast surveys, maximum likelihood estimation, monitoring, Northern Goshawk, presence-absence data.

DISEÑO PARA MONITOREAR EL GAVILÁN AZOR A ESCALA BIOREGIONAL

Resumen. La información en poblaciones de Gavilán Azor (*Accipiter gentilis*), es generalmente obtenida a través del estudio de la actividad de anidación a escalas locales. Aunque este enfoque proporciona información de reproducción para territorios específicos, no puede ser utilizada para rastrear cambios en la abundancia del gavilán sobre extensiones espaciales mas amplias. Para dirigir la necesidad de monitoreo de mayor escala, el Servicio Forestal USDA (USFS) formo un grupo, con la finalidad de desarrollar un diseño para monitorear las tendencias de las poblaciones de gavilán a escala bioregional (ej. norte de las Rocallosas o las Intermontañas de la Gran Cuenca). El grupo de trabajo consistió en estadistas, biólogos de vida silvestre y de investigadores de gavilán dentro y fuera del USFS. El grupo fue contratado para crear un diseño de monitoreo para ser implementado en tierras del sistema de bosques nacionales, pero el USFS invitó a otros propietarios de terrenos y a agencias estatales de recursos naturales, con el fin de proporcionar un cuadro más amplio del estado del gavilán, el cual incluyera los distintos tipos de tenencia de la tierra. Los objetivos del diseño de monitoreo son: (1) Estimar la frecuencia de ocurrencia de gavilanes territoriales adultos dentro de una bioregión, (2) Evaluar los cambios en la frecuencia de la ocurrencia a través de los años, y (3) determinar si los cambios en la frecuencia de ocurrencia, si los hay, están asociados con cambios en el hábitat. La muestra de la población para cada bioregión consta de una red de unidades de muestreo preliminar de 600 ha (PSUs) con todos los hábitats potenciales del gavilán, en las tierras de bosques nacionales y en tierras que pertenecen o son manejadas por partidos en colaboración, por cada programa de monitoreo bioregional. El marco de muestreo está estratificado, para incrementar la eficiencia bajo un presupuesto de monitoreo mixto. El indicador utilizado para determinar la frecuencia de ocurrencia de los gavilanes, es la proporción de PSUs con la presencia de gavilán, basado en respuesta a estudios de emisiones acústicas en una muestra de PSUs. Los PSUs muestreados son estudiados dos veces (períodos de crecimiento y volanteo, para obtener un estimado de la presencia de gavilán por temporada de reproducción. La frecuencia de la presencia del gavilán dentro de la bioregión es estimada usando un estimador de probabilidad máxima. Los cambios en la frecuencia de la presencia del gavilán serán apreciados después de un mínimo de 5 años, utilizando un modelo logístico con parámetros de hábitat introducidos como covariables. La información del monitoreo bioregional ayudará a determinar el estado de las poblaciones de gavilán y sus hábitats sobre una extensión espacial, la cual es muy importante para la conservación del gavilán.

Information on Northern Goshawk (*Accipiter gentilis*) populations is generally obtained by tracking nesting activity at local scales. Although this approach provides breeding information for specific territories, it does not provide information on population status or trend. Local occupancy and breeding information is important to assess the effects of local management actions, but population trends must be estimated at scales that reflect the size and spatial extent of goshawk populations. Current information suggests that goshawk populations and metapopulations exist over extensive geographic areas, with genetic mixing facilitated by the species' potentially long dispersal distances and use of a broad range of forest habitats. However, insufficient information on genetics or movements prohibits the delineation of discrete biological populations.

In the absence of specific information that would enable us to delineate goshawk populations, we based the monitoring design on a bioregion concept, using geographic and ecological scales appropriate for goshawks as a surrogate for biological populations. We use the term bioregion to mean a geographically extensive area characterized by coarse-scale similarity in ecological conditions. Generally speaking, climatic, physiographic, and ecological factors are more similar within a bioregion than between bioregions. We selected the bioregion as the appropriate spatial extent for analysis of goshawk population data, after considering both smaller and larger spatial extents: individual national forests and the entire range of the goshawk.

We consider individual national forests too small for evaluating goshawk population trends, both for ecological and sampling reasons. Goshawks within a specific national forest are not isolated from goshawks on adjacent forests and other neighboring lands, so population trends for a given forest are likely not meaningful. Also, because of the inherent variability in population estimates, the sample size required to detect a significant change in abundance at the forest scale would be unaffordable for most individual forests.

The entire range of the goshawk was considered too large for aggregating and interpreting population and habitat data due to the wide variation in goshawk habitat relations across the species' range. Differences in ecological conditions between bioregions could result in different trends in goshawk populations over time. If all bioregions closely follow the bioregional survey protocol, however, it will be possible to compare trends across bioregions and assess the status of the goshawk across much of its range in the US.

The USDA Forest Service (USFS) assembled a working group to design an approach for monitoring goshawks at a bioregional scale. The working group consisted of statisticians, wildlife biologists, and goshawk researchers from within and outside of the USFS. This chapter describes the monitoring design so that each bioregion can identify interested collaborators and begin monitoring at the earliest opportunity.

The goal of bioregional monitoring is to determine the relative abundance of goshawks and their habitats, and to track broad scale changes in population status and habitat over time. The objectives are: (1) to estimate the frequency of occurrence of territorial adult goshawks within each area defined as a bioregion, (2) to assess changes in goshawk frequency of occurrence over time, and (3) to determine whether changes in frequency of occurrence, if any, are associated with changes in habitat. The targeted precision is to be within 10% of the actual frequency of goshawk occurrence with 90% confidence. The degree to which we are able to detect change in goshawk occurrence over time is unknown, but given our current understanding of detection rates and goshawk persistence at the scale of the sample unit, sample sizes are designed to detect at least a 20% change in the frequency of occurrence over a 5-yr monitoring period.

Although the design described in this chapter was originally intended for use on USFS lands, a complete picture of goshawk population status can only be obtained if monitoring is extended across all potential goshawk habitats, regardless of ownership. The USFS invites collaboration with other agencies and conservation groups to implement this monitoring design as broadly as possible.

The potential contributions and inherent limitations of bioregional monitoring must be clearly recognized. Currently no monitoring program in place throughout the range of the Northern Goshawk provides information on population trends or broad-scale changes in habitat, and the bioregional monitoring design fills this gap in a way that is practical and cost effective. However, this design is not structured to investigate the effects of management treatments. We suggest ways to seek potential correlations between observed population trends and environmental factors, but any correlations cannot be assumed to be causative. Bioregional monitoring is not research and should not be viewed as a substitute. Trends obtained through bioregional monitoring could, however, be used to motivate research and to provide justification for funding such research.

PLANNING AND DESIGN

We recommend that each bioregion identify a bioregional coordinator to oversee the goshawk monitoring program, because the success of the program rests on having a central entity to carry out the necessary planning activities, ensure that data are collected in a consistent and rigorous way, conduct data analysis, prepare annual reports, and administer the budget. The bioregional coordinator will communicate frequently with other bioregional coordinators to promote consistency across bioregions in all aspects of design, data collection, and analysis. The coordinator can be affiliated with any agency, research facility, or university.

Description of the Indicator

The selected indicator of goshawk frequency of occurrence is P, the proportion of primary sampling units (PSUs) (Levy and Lemeshow 1999) with goshawk presence, which is estimated ($\hat{P}$) using a sample of PSUs. Each PSU is approximately 600 ha and the sampling frame is a grid of PSUs laid over all potential goshawk habitat on all lands of collaborators in the bioregion. Goshawk presence is estimated for each sampled PSU based on whether at least one detection is made within the PSU using the field protocol described in the data collection section below. The data are binary because each PSU survey can have one of two possible outcomes—presence or absence.

If $\hat{P}$ is expressed as a simple summary proportion of PSUs with observed presence, it will tend to underestimate the true P because of surveys where absence was observed even though a goshawk was present. To reduce this bias, many of the PSUs are visited twice to allow the estimation of the detection probability (the conditional probability that presence will be observed given that the PSU has actual presence). The detection probability is used as a multiplicative adjustment to the simple summary proportion , thereby reducing the negative bias of $\hat{P}$ (MacKenzie et al. 2002, 2003).

Delineation of Bioregions

To aid in delineating bioregional boundaries, we evaluated current information on goshawk distribution, dispersal and movement patterns. An assessment of the distribution of known goshawk territories in the western US (USDI Fish and Wildlife Service 1998a) suggests that populations and metapopulations exist over extensive geographic areas, encompassing a broad range of forest habitats. Natal dispersal distances of 101 km (B. Woodbridge, unpubl. data), and 60–106 km (Wiens 2004) have been reported in the western US, although shorter distances have been reported (14.4–32.0 km; Reynolds and Joy 1998). These likely are underestimations because survey efforts in mark-recapture studies are typically limited to specific study areas, whereas birds dispersing outside of the study area are unlikely to be detected. In northern Arizona, >80% of juveniles radio marked over 4 yr dispersed beyond the 15,000 km^2 principal aircraft monitoring area around the natal territories (Wiens 2004). This high potential for movement suggests that monitoring for population trend should occur over spatial extents of several thousand square kilometers.

We delineated 10 bioregions (Table 1, Fig. 1) by overlaying the geographic range of the Northern Goshawk (Squires and Reynolds 1997) with the Forest Service National Hierarchical Framework of Ecological Units (Bailey 1980, McNab and Avers 1994). In the absence of data on any differences in goshawk abundance between geographic areas, the boundaries of each bioregion were established by simply aggregating neighboring polygons of similar adjacent ecological provinces. If a relatively small polygon of one ecological province was completely or nearly enclosed within a larger polygon of a different ecological province, it was included in the bioregion of the larger polygon (Fig. 2). Boundaries

Table 1. Bioregions for monitoring Northern Goshawks.

Goshawk bioregion	Area (km^2)
West Coast	121,590
Cascade Sierra	1,181,072
Central Rocky Mountains	317,891
Colorado Plateau and southwest mountains	514,700
Great Lakes	490,500
Intermountain Great Basin	620,861
Northern Rockies-Blue Mountains	480,028
Northeast and central Appalachian Mountains	517,225
Coastal Alaska	173,700
Interior Alaskan forests	697,545

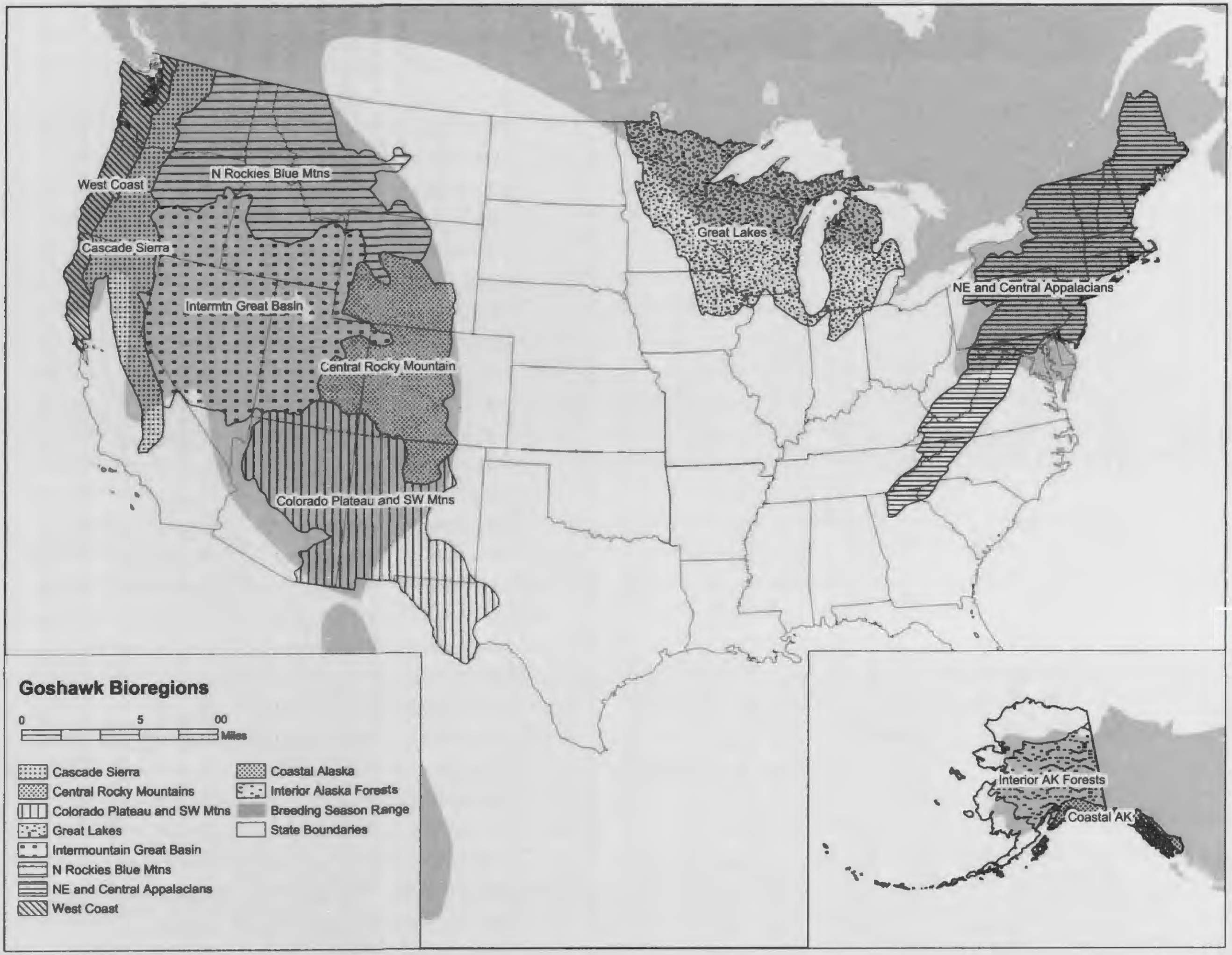

FIGURE 1. Bioregions for monitoring Northern Goshawks.

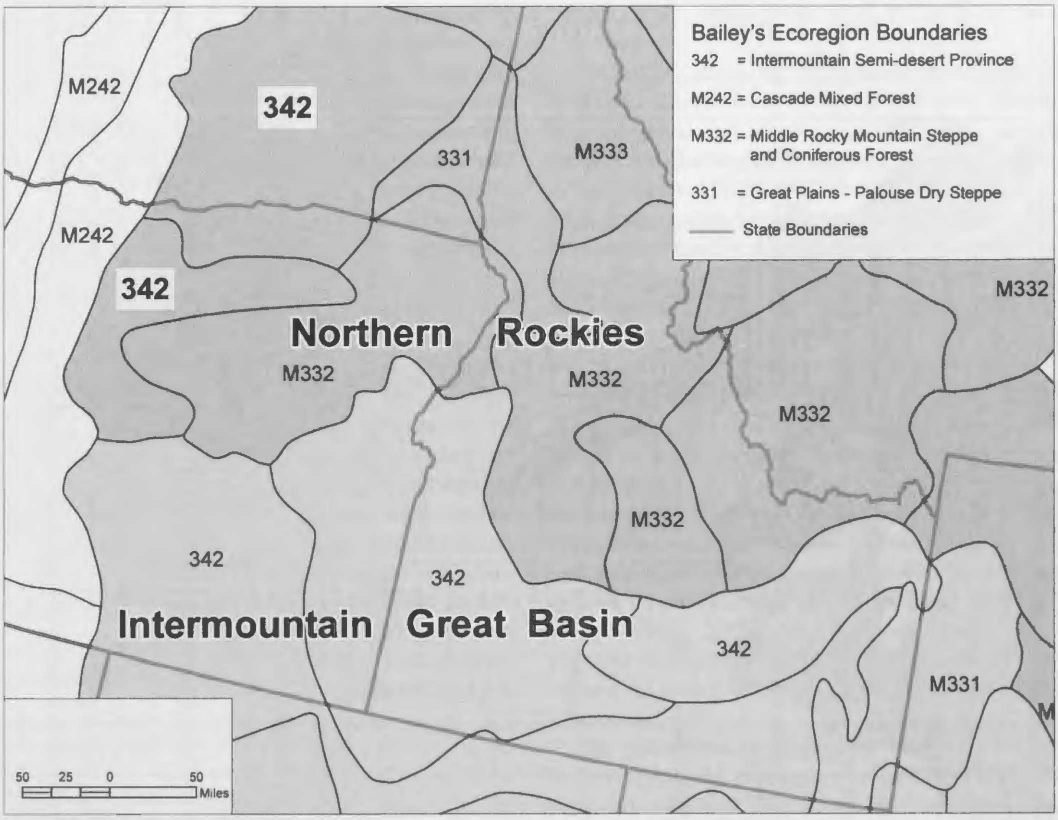

FIGURE 2. Bioregional boundaries were formed by aggregating polygons of one or more ecoregional provinces, except where these polygons were surrounded by a dissimilar province. In this example, polygons of the Intermountain semi-desert province (342, highlighted in white) were placed in the Northern Rockies bioregion rather than being included in the Intermountain Great Basin bioregion with other polygons of this province.

were also influenced by the configuration of national forests, so that no national forest would be split between two bioregions. Exceptions to this rule occurred with the Toiyabe and Inyo National Forests, both of which occur in the Cascade-Sierra and Intermountain Great Basin bioregions (Fig. 3). The striking difference in biotic and abiotic conditions between these two provinces provides strong rationale for splitting each of these national forests. Consequently, these national forests will need to report separate goshawk data for each of the two bioregions.

Goshawk movement between bioregions will occur, but bioregional boundaries often represent major physiographic features and/or changes in vegetation types that act to reduce connectivity of goshawk habitat among bioregions. In addition, bioregional boundaries reflect different ecological factors that affect goshawks such as climate, disturbance regimes, prey populations, and forest cover types. For example, a large proportion of goshawks within the Intermountain-Great Basin bioregion are migratory, occupy landscapes with little forest cover, and are strongly influenced by population dynamics of prey species associated with nonforested habitats such as Belding's ground squirrel (*Spermophilus beldingi*; Younk and Bechard 1994a). These conditions contrast with the ecology of goshawks in the adjacent Cascade-Sierra Nevada bioregion, where goshawks are largely nonmigratory, associated with coniferous forest habitats, and strongly influenced by forest-dwelling prey species such as Douglas squirrels (*Tamiasciurus douglasii*; Keane 1999).

The bioregions are truncated at the Canadian border (with the possible exception of bi-national collaboration in the Great Lakes bioregion), and we acknowledge the artificial nature of these boundaries. Trans-national movement of goshawks will be considered when population trends are reported for bioregions that border Canada.

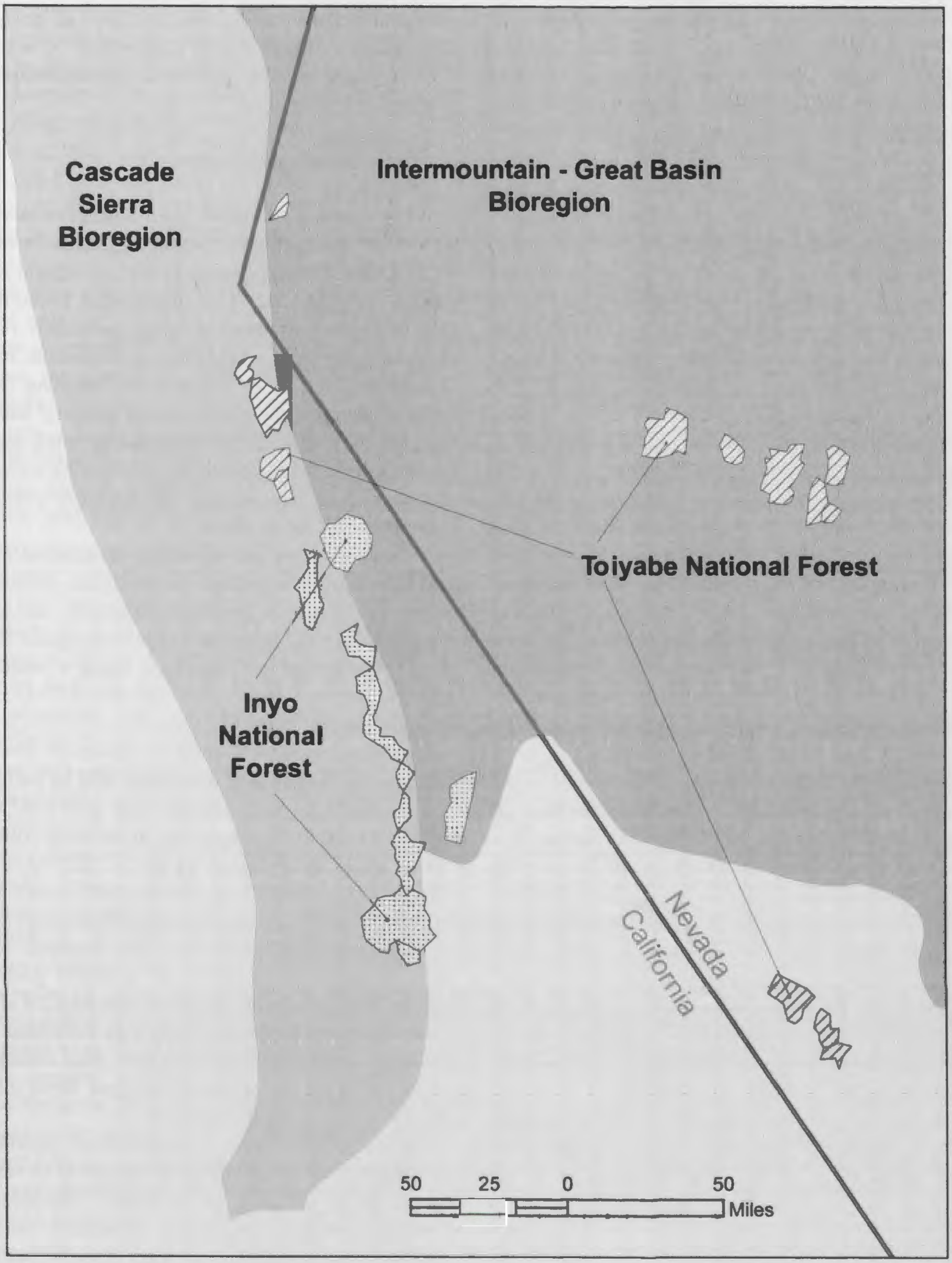

FIGURE 3. The Inyo and Toiyabe National Forests are the only national forests that straddle two bioregions.

Sampling Units

The PSU is the scale of resolution at which goshawk presence is determined, and the total number of PSUs that are surveyed represent the sample size. Secondary sampling units (SSUs) are call points within a PSU where goshawk vocalizations are played, and each PSU has up to 120 call points, depending on the amount of available habitat. The area between call points is considered part of the survey because any detections of goshawks, nests, or molted feathers that are made while walking between call points contribute to the outcome of presence for that PSU.

PSU size of 600 ha is based on ecological factors and sampling considerations. Ideally, PSU size should be large enough to obtain a reasonable probability of detecting a goshawk, while maintaining a size that reflects the spacing of goshawk breeding sites, so that an outcome of presence represents no more than one nesting pair and their offspring. To determine optimum PSU size, we compared the spacing of goshawk breeding sites (geometric centroid of all known alternate nests) in three geographical areas. Mean nearest-neighbor distances among goshawk nesting areas on the Kaibab Plateau of Arizona (Reynolds et al. 2005), southern Cascade Mountains (Woodbridge and Dietrich 1994), and Modoc Plateau are remarkably similar, ranging from 3–4 km. One-half of this distance, a radius of 1.5–2 km, yields an area of 706–1,257 ha, which approximates territory size. We tested a range of potential PSU sizes from 405–1,214 ha at 202.3 ha increments, by overlaying each size with several maps of goshawk nest sites at known density and spacing. As expected, the greater the size of the PSU, the greater the proportion of PSUs that contained the core area of a goshawk territory (Table 2), which translates to an increased probability of detecting a goshawk. At a PSU size of 607 ha, however, 0.3% of the PSUs contained core areas of two adjacent territories. This suggested that a PSU size >607 ha could potentially confound survey results because a detection in the PSU could represent either one or two family groups. By selecting a PSU size of approximately 600 ha, the PSUs would generally contain only one territory, and would also fit proportionally within the sampling design of the forest inventory analysis (FIA) program, which collects vegetation data across the US on all land ownerships at a scale of one monitoring point per 2.402 ha. The USFS is moving toward a strategy whereby wildlife monitoring data are collected in concordance with the FIA sampling design. If the PSU were exactly 600.7 ha, the ratio of goshawk PSU area to FIA grid cell size would be 4:1; we have selected 600 ha as a close approximation to that size.

TABLE 2. PRIMARY SAMPLING UNITS (PSU) SIZE IN RELATION TO NUMBER OF TERRITORIES WITHIN THEM.

PSU size	Number of PSUs	Percentage of PSUs with 0, 1, or 2 territories		
(hectares)	(N)	0	1	2
405	429	85.3	14.7	0
607	292	78.8	20.9	0.3
809	229	73.4	25.8	0.9
1,012	182	67.6	30.2	2.2
1,214	158	64.6	31.6	3.2

SAMPLING FRAME AND STRATIFICATION

The sampling frame for each bioregion includes all habitats potentially occupied by goshawks on all lands owned or managed by parties collaborating in goshawk monitoring. The bioregional coordinator identifies potential habitat using published literature and knowledge of existing nest locations in the bioregion. All habitats suitable for breeding (nesting and foraging) are considered primary habitat. Habitats with little or no prior documented use by goshawks are marginal habitat. Unforested areas are not considered habitat and are therefore excluded from the sampling frame.

A base map for the bioregion is constructed or acquired using vegetation cover types, structural stages, slope, aspect, elevation, landform, and landownership. A grid comprised of 600 ha square PSUs is automated over the base map, using a randomly selected universal transverse mercator (UTM) coordinate as the initial anchor.

Each bioregion will need to determine whether grid cells with split land ownership will be included in the sampling frame. Ideally, only grid cells with ≥90% ownership by one of the monitoring collaborators should be included, to ensure that surveyors have access to all suitable habitats within each PSU for sampling. However, in some bioregions with checkerboard land ownership, this standard could result in substantial removal of potential goshawk habitat from the sampling frame, reducing the effectiveness of the monitoring design. In such case it is preferable to obtain permission from land owners to conduct surveys for goshawks so that these mixed ownership PSUs can be included.

The sampling frame is stratified to provide a reasonable estimate of goshawk frequency of occurrence with an efficient use of funds. Stratification is needed because systematic or simple random sampling would result in a large commitment of monitoring funds in areas that are likely not used by goshawks, with the inherent risk that little would be learned about goshawk population status. The stratified design uses knowledge of currently occupied habitat coupled with information on road access to target areas that can be easily sampled and have a reasonable expectation of goshawk presence, while ensuring that marginal and less accessible habitats are included in the sample.

The sample design consisted of four strata:

1. Primary habitat, easy to access.
2. Primary habitat, difficult to access.
3. Marginal habitat, easy to access.
4. Marginal habitat, difficult to access.

Bioregional coordinators can use any procedure to assign PSUs to the four strata. Errors in assignment are to be expected, especially if goshawk habitat is poorly understood in a bioregion and/or if accessibility is unknown. Nevertheless, even crude stratification can provide a more efficient design than simple random sampling. A bioregion might contain several thousand PSUs, and in the absence of stratification, the survey effort is likely to overemphasize the more abundant marginal habitats and provide little new information about goshawk presence.

The following procedure (S. Joy, R. Reich, and V. Thomas, unpubl. report) was used to stratify PSUs on the San Juan and Rio Grande National Forests into primary and marginal habitat for a field test of the monitoring design. A geographic information system (GIS) layer was created for each national forest, consisting of goshawk nests known to be active in at least one of the past 10 yr. This layer was used in conjunction with a vegetation layer obtained from common vegetation unit polygons that provided several variables of forest composition and structure. A GIS analyst then centered a square on each nest that was 600 ha so that it was comparable to the size of a PSU, and obtained the following habitat attributes from each square: percent cover of trees, shrubs, grass, bare soil, and water, percent cover of the first, second, and third dominant tree species, the structural stage, tree species diversity, elevation, slope, aspect, and presence or absence of aspen. To sample the range of topographic and vegetative variability on each forest, the analyst also generated a number of random points, commensurate with the number of nests on each national forest, centered a 600 ha square on each, and collected the same set of habitat attributes. The attribute coverages for nest squares and random squares were merged (but were separate for each national forest), with nest squares assigned a value of one and random squares a value of zero. A logistic regression was used to determine which habitat attributes contributed most to distinguishing nest squares from random squares. For the San Juan National Forest, the most significant variables were mean elevation, mean slope, tree cover, aspect, and land contour. For the Rio Grande National Forest, the most significant variables were elevation and low amounts of grass cover, with high grass likely being a surrogate for non-forested areas. The results of the model were then applied to the actual grid of PSUs for each forest. The analysis generated a probability surface using the coefficient of the logistic regression model, and selected threshold probability values for each habitat attribute that maximized the overall accuracy of correctly classifying a PSU as primary habitat. The logistic model for each forest was then applied to the PSU grid, identifying which PSUs were primary habitat. Marginal habitat was any forested habitat that did not meet the model criteria of primary habitat.

Accessibility categories were not formally assigned during the goshawk test. We recommend that these categories be based on roads, wilderness areas, and travel distances from field offices. The accessibility layer is laid over the primary-marginal habitat layer to produce the four strata listed above.

Before leaving the topic of stratification, we add the caveat that the map of primary and marginal habitat is not intended to be used for management decisions and conservation measures. Stratification is based on our best, current understanding of goshawk habitat use, but this understanding could be biased by a previous emphasis of goshawk surveys in areas with roads and proposed timber sale areas. The purpose of the map is to provide better efficiency in goshawk surveys, but the results of the surveys could greatly change our understanding of habitats used by goshawks. Certain habitats that are initially classified as marginal will gain importance if surveys yield detections in these habitats.

Sample Size

The number of sampled PSUs must be sufficiently large to meet the objectives for this monitoring design with the desired precision and confidence. Each of the three objectives has a different sample size requirement, but the bioregional coordinator should choose the largest sample size needed to meet all three objectives. The largest sample size will likely be needed for the third objective, to assess changes in the relative abundance of goshawks in relation to changes in habitat or other environmental factors. Unfortunately, this sample size is the most difficult to calculate because it requires not only within-year variance but also between-year variance, as well as variance associated with different habitat variables. It is easiest to estimate the sample size needed for a single year estimate of P. We recommend that bioregional coordinators begin by estimating this sample size, and then increase this sample size by a safety margin, perhaps 10–15%, to meet the sample size needs for the other objectives.

The sample size needed for a single year estimate of P will vary by bioregion, depending on the representation of total PSUs in each of the four strata, the average cost of sampling a PSU in each stratum, and the probability of goshawk presence in each stratum. Pilot data specific to the bioregion are needed in order to provide an estimate of cost and the probability of goshawk presence.

The sample size is allocated among the four strata to minimize, for a fixed total cost, the standard error of $\hat{P}$ (the estimate of the actual frequency of occurrence of territorial adult goshawks, P). This procedure begins by using pilot data to calculate coefficients for probabilities of presence and for cost factors for each of the four strata. The coefficients are used to derive a variance for the maximum likelihood estimator of overall goshawk presence. The formula for sample size estimation and allocation is based on the sample size estimation algorithm for a binomial distribution, but the variance is larger by an additive term than the usual variance associated with a binomial distribution because detection probabilities are less than one. The procedure also uses information on the total number of PSUs in each stratum to provide a weighted average for sample size allocation. Although the weighted averages account for differences in PSU representation among the four strata, they do not result in proportional sampling because of the influence of the coefficients for goshawk presence, detectability, and cost. The procedure also assumes that a fixed cost is to be allocated among the four strata.

An interactive spreadsheet for sample size calculation and allocation has been developed by Jim Baldwin (USDA Forest Service, Pacific Southwest Research Station). Bioregional coordinators can obtain a copy of the spreadsheet by contacting us.

DATA COLLECTION

Annual Schedule

The design calls for two surveys per sampled PSU. Survey 1 occurs when goshawks are tending nestlings and survey 2 occurs during late nestling and post-fledging periods. The dates of the two survey periods are determined from local information on nesting phenology, but generally, the nestling phase occurs from late May through late June or early July, and the late nestling and post-fledging periods occur from late June through late August. Surveys can be conducted any time from dawn to dusk.

Multi-year Schedule

The design employs a 100% annual re-measurement schedule wherein a fixed number of PSUs are repeatedly sampled each year. We considered a design that samples a portion of the total sample annually, known as the serial alternating panel design (Urquhart and Kincaid 1999), because it enables a bioregion to obtain a larger sample size over a multi-year sampling period. That approach, however, could result in higher variance for $\hat{P}$ because each annual sample is smaller than if 100% annual re-measurement took place. Moreover, sampling only part of the total each year requires stable funding for each annual increment in order to stay on schedule for the entire sample to be surveyed. Furthermore, from a logistical perspective, 100% annual re-measurement allows for increased efficiency as the sample territories become well known over a period of years. In contrast, the serial alternating panel design creates new logistical challenges each year, as new PSUs are initiated into the sample.

Survey Method

Each PSU is surveyed using the broadcast acoustical survey method (Kennedy and Stahlecker 1993, Joy et al. 1994, USDA Forest Service 2000a) The sampling grid in each PSU is comprised of call stations located on 10 transects that are 250 m apart, with 12 call stations per transect. Call stations along each transect are 200 m apart, and adjacent transect stations are offset 100 m to maximize coverage. This spacing ensures that each call point is within auditory detection distance (roughly 150 m) of the next adjacent call point within the stand (Woodbridge, unpubl. data). If the entire PSU consists of potential goshawk habitat, there will be 120 call points, but points that fall >150 meters from potential habitat are not surveyed. Areas considered to be non-habitat are cliffs, talus slopes, non-forested areas, and water bodies. The actual number of call points will therefore vary for each PSU. Transect lines and call points are permanently marked and/or recorded with a global positioning system instrument (GPS).

Field tests indicate that a two-visit survey with the recommended transect and call point spacing results in a detection rate >90% for actively breeding goshawks and >80% for non-breeding adults during the nesting season (Woodbridge and Keane, unpubl. data; Table 3). This rate is higher than that reported by Kennedy and Stahlecker (1993) and by Watson et al. (1999). However, neither of these studies used the full complement of transects and call stations in the protocol to obtain detection rates.

The procedure is to survey the PSU until a detection is made or until all potential habitat within the

TABLE 3. COMPARISON OF DETECTION RATES OF TWO SURVEY METHODS FOR NORTHERN GOSHAWKS (KEANE AND WOODBRIDGE, UNPUBL. DATA).

	Territory plot status		
Method	Nesting	Occupied non-nesting	Unoccupied-old nests[a]
Broadcast acoustical survey protocol			
One visit	0.90	0.64	0.36
Two visits	0.94	0.87	0.59
Three visits[b]	1.00	0.96	0.73
Stand search survey protocol			
One visit	0.97	0.74	0.43
Two visits	1.00	0.93	0.67
Three visits	1.00	0.98	0.81

[a] Rate is for detection of old nests at unoccupied territory plots.
[b] Three-visit probability calculated using binomial expansion of 1-visit detection *P*.

PSU is completely surveyed. We anticipate 10–30 hr to survey each PSU. For efficiency, surveyors start in areas of the PSU with the highest likelihood of goshawk presence. Transect lines and call points can be established with GIS prior to field work, and surveyors can use GPS units to obtain the most efficient and economical survey coverage rather than run transect lines systematically. However, surveyors should avoid using roads to walk or drive between call points, because part of the survey method is looking and listening for goshawk or any goshawk sign, such as nests, plucking posts, molted feathers, and whitewash, between call points.

This protocol calls for two surveyors working together. Most time is spent walking between stations, so it is important to be alert for goshawks approaching, often silently, to investigate the surveyors. Use of two observers enhances the probability of visual detections of goshawks or molted feathers, because one person can focus upward to look for nests or silently approaching goshawks while the other can focus downward to look for feathers and whitewash.

If a detection occurs, the PSU is recorded as having goshawk presence and the survey is ended. If a detection does not occur, the surveyors continue on to call points with increasingly less likelihood of goshawk presence. The detection of an unused nest is not considered presence. The detection of a molted goshawk feather results in a present outcome for a PSU, but we encourage surveyors to continue to survey the PSU with broadcast calls because of the additional information associated with an aural response or visual detection.

Following Kennedy and Stahlecker (1993), the surveyors conduct two, three-call sequences in a circle centered on the call point, for a minimum of 3 min spent at each call point. Each sequence begins with broadcasting a call at 60° from the transect line for 10 sec, then listening and watching for 30 sec. This is repeated two more times, each time rotating 120° from the last broadcast. After the second sequence of three broadcasts, the surveyors move to the next call point, walking at an easy pace while listening and watching carefully for goshawk calls and sign.

Surveyors do not survey under conditions such as winds >15 mph or rain that may reduce ability to detect goshawk responses. To avoid misidentifying broadcasts of co-workers, simultaneous surveys are conducted no closer than two transect widths apart. To ensure accurate identification of feathers, feathers are compared to known samples or to pictures of feathers. A useful resource is *Feathers of Western Forest Raptors and Look-alikes*, a CD with color images of raptor feathers created by B. Woodbridge and produced by E. Frost. A companion CD created by B. Woodbridge, *Voices of Forest Raptors and Sound-alikes*, is useful for broadcast surveys as well as identification of response calls. Both CDs are available through an email request to C. Vojta (cvojta@fs.fed.us).

During the nestling period, surveyors broadcast the adult alarm call. During the late nestling and post-fledging period, the wail or juvenile food-begging call is broadcast because it is more likely to elicit responses from juvenile goshawks. Effective coverage of a survey area is dependent on the surveyors' ability to broadcast sound that can be detected at least 200 m from the source.

Kennedy and Stahlecker (1993) and Fuller and Mosher (1987) recommend using equipment producing at least 80–110 dB output at 1 m from the source. Until recently, the most commonly used broadcast equipment has been a small personal cassette player connected to a small megaphone. Recent developments include compact disk and MP3 players as storage media and improved digital amplifiers that store goshawk calls on internal chips. Other equipment required for surveys include compass, binoculars, flagging or other station markers, and plastic baggies and labels for feathers and prey remains. GPS units are highly recommended, because they provide the surveyors with greater flexibility in traveling between call points.

When the surveyors hear a response, they record the type of response, compass bearing, station number and distance from transect. Response types fall into one of three categories as defined by Joy et al. (1994): vocal non-approach, silent approach, and vocal approach. Surveyors attempt to locate the goshawk visually and determine the sex and age (adult versus juvenile or fledgling) of the responding individual.

Habitat Data

The monitoring design uses two sources of habitat data: landscape variables associated with each sampled PSU, and data from all forest inventory analysis (FIA) points within the bioregional sampling frame. This section describes the purpose and acquisition of each type of data. Because the bioregional monitoring plan is in its infancy, we anticipate the need for numerous discussions among land managers, the academic community, and bioregional coordinators to identify specific habitat components and other environmental factors that might influence goshawk abundance. We view this section on habitat data to be the starting point for those discussions.

Data collected from each sampled PSU are used to compare forest composition, forest structure, and landscape pattern of PSUs with and without goshawk detections. These data can be used in habitat relationship models to predict goshawk presence and to inform management decisions, especially when the data are supported with research studies that have investigated the underlying mechanisms of the observed relationships. They can also be used to assess changes in landscape pattern and structure over time, in relation to changes in goshawk occurrence.

The bioregional coordinator acquires habitat information from all sampled PSUs, regardless of survey outcome, using the best available vegetation coverage with pixel resolution between 20–30 m. The variables for which data are collected are: (1) number of vegetation patches, (2) number of vegetation cover types, (3) size of largest vegetation patch (including patch area that extends beyond the PSU boundary), (4) percent of PSU in primary, marginal, and non habitat as defined by the initial PSU stratification process, (5) proportion of PSU in each structural stage (using structural stage classes standard within the bioregion), (6) estimated proportion of PSU that has been thinned and/or burned under prescription in the last 20 yr, (7) estimated proportion of PSU that has been harvested in the last 20 yr (from commercial thinning, overstory removal or clearcutting), and (8) straight-line distances from the PSU center to the nearest permanent water including springs, road (regardless of use status), trail, and meadow edge.

The second source of habitat data is from the FIA program, which is the national forest inventory that has been in existence since 1930. The FIA program consists of a coast-to-coast hexagonal grid, each hexagon 2,403 ha in size, with one point per hexagon, and a set of plots at each point. Forest composition and structure data are obtained from each set of plots to enable the FIA program to report on status and trends of forest area, species composition, tree growth and mortality, and other aspects of forest lands. Data from individual FIA points cannot explain goshawk presence at any given detection point, but the summary of FIA information across a bioregion can be used to assess overall habitat availability and to observe changes in habitat availability over time.

The bioregional coordinator acquires data from all FIA plots within the bioregional sampling frame by making a request through the appropriate FIA regional office, which is associated with the Forest Service Research and Development branch (see http://fia.fs.fed.us). The bioregional coordinator can request FIA personnel to provide summary information on stand structural variables that characterize overall habitat condition, e.g., basal area, stand density, and dbh. These data are available after each period of FIA data collection (usually annually). The coordinator uses the summary information to assess changes in habitat condition over time, and to look for possible correlations between changes in the bioregional estimate of goshawk occurrence and changes in habitat.

The bioregional coordinator should acquire additional information to aid in interpreting the annual bioregional estimate of goshawk occurrence. For example, climatic data, especially measures of precipitation and temperature could prove useful because climatic factors are likely to have a direct influence on the timing and success of nesting efforts, and on prey availability. Prey availability is a significant factor affecting goshawk reproduction and abundance (Lindén and Wikman 1983, Doyle and Smith 1994). Where red squirrels (*Tamiasciurus hudsonicus*) and Douglas squirrels are known primary prey of goshawks, cone crop data can be a useful surrogate for prey availability (Keane 1999).

We also recommend acquiring data on land management activities for the bioregion, such as an estimated areal extent of hazardous fuel reduction activities. In many cases, these data might already be collected by other entities and might be available at little or no cost to the bioregional monitoring effort.

DATA ANALYSIS

Estimating the Relative Abundance of Goshawks

The parameter of interest is P, the proportion of all PSUs in a bioregion with goshawk presence. P is estimated from the proportion of all PSUs with goshawk presence in each of the four strata, or:

$$P = \frac{\text{Total number of sites with presence}}{\text{Total number of sites}}$$

$$= \frac{N_1P_1 + N_2P_2 + N_3P_3 + N_4P_4}{N_1 + N_2 + N_3 + N_4}$$

where N_1, N_2, N_3, and N_4 are, respectively, the total number of PSUs in each of the four strata and P_1, P_2, P_3, and P_4 are, respectively, the proportion of PSUs with presence in each of the four strata.

Data from each sampled PSU are independent because the sampled PSUs were randomly selected within each stratum. Moreover, data from each visit are independent because the outcome of the first visit does not change the probability of detecting presence during the second visit, assuming that the presence status remains constant throughout each year's sampling season.

Each visit has a constant probability of missing presence when a goshawk is present but those probabilities (q_n and q_f) differ between surveys because of differences in goshawk behavior between the nestling and fledging periods. The detection probability is $1 - q_n$ for the nestling period and $1 - q_f$ for the fledging period.

In order to estimate P, the bioregional coordinator must first estimate 6 parameters: the proportion of PSUs with goshawk presence for each of the four strata, P_1, P_2, P_3, and P_4, and the two probabilities of missing presence, q_n and q_f. These parameters are derived from the particular sequence of presence/absence data recorded for up to two surveys at each site, which can be one of the following sequences: 00, 01, 1•, 10, or 11. The sequence labeled 1• denotes where just one survey was made.

In order to provide data for sequences 11 and 10, a proportion, r, of all PSUs with detections during survey 1 must be randomly selected and visited a second time. The bioregional coordinator may choose to include all PSUs (*i.e*, $r = 1$) with detections rather than a proportion of them. If not all PSUs have two surveys, then r needs to be selected to provide a minimum of 30 PSUs that are surveyed a second time.

The probability that selected PSU j in stratum i will have a particular sequence of presence status (x_{ij}) follows (ignoring any adjustments related to sampling without replacement from a finite population) (J. Baldwin, pers. comm., MacKenzie et al. 2002):

$$\begin{aligned} f(x_{ij}) &= (1 - P_i) + P_i q_n q_f && \text{for } x_{ij} = 00 \\ &= P_i(1 - q_n)\, q_f\, r && \text{for } x_{ij} = 10 \\ &= P_i q_n (1 - q_f) && \text{for } x_{ij} = 01 \\ &= P_i(1 - q_n)(1 - q_f)r && \text{for } x_{ij} = 11 \\ &= P_i(1 - q_n)(1 - r) && \text{for } x_{ij} = 1\bullet \end{aligned}$$

The likelihood function will be the product of all of the individual probabilities

$$L = \prod_{i=1}^{4}\prod_{j=1}^{n_i} f(x_{ij})$$

with the log of the likelihood equal to

$$\log L = \sum_{i=1}^{4}\sum_{j=1}^{n_i} \log f(x_{ij})$$

The estimation procedure results in values for P_1, P_2, P_3, P_4, q_f, and q_n that maximize log$L$.

Maximizing either the likelihood function or the log of the likelihood results in the same values of the parameter estimates, but it is numerically more convenient to use the log of the likelihood function. Standard errors will be estimated using a bootstrap process. The sample size of each bootstrap sample is the same as the original sample for each stratum, but the bootstrap samples are created by random sampling with replacement.

Missing values will almost certainly occur because of weather, snowpack, fire, or lack of available crews, and some PSUs might receive additional surveys. Adjustments can be made to the definition of $f(x_{ij})$ (the probability of observing sequence x_{ij}) to allow for such occurrences. For now the above formulas are adequate for planning purposes.

Assessing Change in Goshawk Relative Abundance Over Time

The bioregional coordinator can begin to assess change in the relative abundance of goshawks after 5 yr. By graphing $\hat{P}$ and the associated confidence interval for each year, the coordinator can visually assess the pattern prior to conducting a statistical analysis. We anticipate that the data will show upward or downward spikes in $\hat{P}$ rather than a smooth trend, and that a model other than a simple linear model will be needed to test whether a change has occurred in the proportion of PSUs with goshawk presence.

The ability to detect changes in P across years will depend on the values of P for each year relative to 0.5. It is more difficult to detect absolute changes in P when values approach 0.5 than when values are at either end of the continuum (e.g., <0.3, >0.7), as the variance of $\hat{P}$ will tend to be largest when P is around 0.5. We anticipate that values of P (and therefore also of $\hat{P}$) will fall in the lower range of potential values for marginal habitat, and could likely fall in the higher range of potential values for primary habitat.

The observed history of presence for each PSU is needed in order to evaluate whether a change in P has occurred (MacKenzie et al. 2003). If a PSU is observed to have goshawks present in 1 out of 5 yr, its likelihood contribution for use in the maximum likelihood estimation process is different than a PSU with no observed goshawks in all 5 yr. In the second example (no observed presence), the probability that the PSU has a goshawk present is weighted by the average of the probabilities that the PSU truly contains no goshawks, or that goshawks were present but not observed.

MacKenzie et al. (2003) illustrate how detection history is used to estimate changes in occupancy status of potential Northern Spotted Owl (*Strix occidentalis caurinus*) territories after 5 yr. The authors first used the detection history to estimate the probability that a territory was occupied in any given year. They then developed a set of models in which colonization and extinction rates were year-specific or were held constant, and chose the best model with respect to Akaike's information criterion (AIC; Akaike 1974). The authors concluded that the best model suggested a fairly static average level of occupancy over 5 yr. The process for estimating change in the relative abundance of goshawks would be similar, but PSUs rather than territories would be the sampling unit for which change would be measured.

Evaluating the Role of Habitat and Environmental Factors in Goshawk Population Trends

Habitat and other environmental data provide opportunities to look for patterns between population change and environmental factors such as habitat structure, precipitation, prey abundance, or management actions. To look for possible correlations, we recommend using environmental variables as covariates in a series of logistic models, and information theoretics as a means of model comparison. (Akaike 1974, Burnham and Anderson 2002). Relevant variables to use in model development are discussed in the data collection section above.

Simple correlations between goshawk population trends and environmental changes are insufficient, however, for developing meaningful conservation strategies. We need knowledge of the mechanisms that affect population size in order to make recommendations for management. Therefore, status and trend monitoring should be accompanied by research aimed at understanding causal relationships. Although the bioregion is an appropriate spatial scale for monitoring goshawk populations, it is not necessarily the best scale for investigating the mechanisms driving population change (Keane and Morrison 1994), so research will likely occur separately from bioregional monitoring. Correlations observed during population monitoring can suggest fruitful directions for research, but research studies do not necessarily have to wait for results from population monitoring in order to test meaningful hypotheses. There is currently enough knowledge of goshawk ecology to establish research studies concomitant with population monitoring, so that research results can be used to interpret monitoring trends during the same time frame.

COORDINATION AMONG BIOREGIONS

The bioregional monitoring plan provides an opportunity to aggregate information if data are collected in a consistent fashion between bioregions. In particular, consistency is needed in carrying out the broadcast acoustical survey method. Detection probabilities could be affected if the spacing of call points and transect lines is altered or if the number of visits to a PSU is increased. Training should be coordinated between bioregions to ensure that surveyors move at similar paces and have similar identification skills.

Consistency is also needed in classifying goshawk habitat. Although each bioregion will likely differ in habitats used by goshawks, there may be important similarities at coarse scales. For example, geographic differences in vegetation associations can be aggregated into similar physiognomic classes. In order to build consistency in landscape variables such as the number of vegetation types and the number of structural stages in each PSU, it is important to first agree on what is meant by a vegetation type and a structural stage. Without coordination and agreement, bioregions will differ in how finely these classifications are made.

SUMMARY

We recognize the ambitious scope of this monitoring plan and acknowledge that adequate and consistent funding is necessary for it to succeed. We are encouraged, however, by the success of several monitoring programs and survey designs that have occurred at a scale comparable to our proposed bioregions. Most notable are several land-bird-monitoring programs (Howe et al. 1997, Hutto and Young 2002, Robbins et al. 1986), and monitoring of the Northern Spotted Owl (Lint et al. 1999) and the Marbled Murrelet (*Brachyramphus marmoratus*; Madsen et al. 1999). Commonalities shared by these programs are a well-stated objective, clear statistical design, data-collection protocol, centralization for data analysis and reporting, and adequate funding. We have built from these examples in developing this monitoring plan for goshawks.

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