Assessing Distribution, Habitat Suitability, and Site Occupancy of Great Gray Owls (*Strix nebulosa*) in California

By

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B.S (University of California, Davis) 2002

THESIS

Submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in

Avian Science

in the

OFFICE OF GRADUATE STUDIES

of the

UNIVERSITY OF CALIFORNIA

DAVIS

Approved:

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Committee in Charge

2006

Acknowledgements

I would like to thank California Department of Fish and Game, and the University of California, Wildlife Health Center for their logistical and financial support. Professor John Eadie provided immense assistance in all aspects of the project, including design and implementation, statistical and program support, technical review, and logistical and academic advice. Professors Dan Anderson and Marcel Holyoak offered constructive comments on project design, treatment, and review. CDFG biologist Chris Stermer and Kevin O'Connor provided advice and support throughout the study. Essential cooperation and collaboration was given by the U.S Forest Service and National Park Service throughout the project duration. Tiffany Manger, Aaron McFadden, Richard Montgomery, Keri O'Connor, Melissa Odell, Cotton Rockwood, Randy Shields, Todd Stansbery, Joshua Stumpf, and Ted Woods all provided outstanding assistance in the field. My lab group, Sharon Gericke, Peter Gilbert, Nicole Kosteczko, Jeremy Kwolek, Shaun Oldenburger, Matt Wilson, and Greg Yarris, provided friendly support and a listening ear. Darryl Mackenzie supplied assistance with statistical programs in a time of great need, and Jeff Maurer provided important comments project design, as well as assisting in the field. Darca Morgan and Tom Beck acted as an important liaison to the Forest Service, and John Keane and his crews provided support in the field and demonstrated a willingness to share ideas throughout the study. Malcolm North provided constructive advice on habitat sampling. Without the assistance, patience, and willingness of all these individuals and organizations this project study would have never proceeded or reached completion.

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Chapter 1
Distribution of Great Gray Owls in California

1. Introduction

Current knowledge on distribution and total population estimates for the great gray owl (*Strix nebulosa*) in California is limited, despite the fact that they have been listed as State endangered since 1980 (Winter 1980). Estimates have thus far been speculative given the limited survey effort across the entire Sierra Nevada. In addition, research is difficult due to the wary and elusive behavior of this species. This fact affects management and preservation of essential owl habitat throughout its California distribution.

The distribution of the great gray owl is circumpolar, and the Sierran population represents the most southern and disjunct in this distribution. Numerous observational and systematic studies have been conducted across the entire distribution, although studies on the California population have mainly focused on areas within the core range. Yosemite National Park, and adjacent areas in Sierra National Forest, and Stanislaus National Forest make up the core range, and few focused surveys have been conducted north or south of this area where detections are thought to become irregular.

To date, studies conducted assessing owl numbers have found the population within the core is relatively small. Winter (1986) estimated 73 individuals in the greater Yosemite region based on presence of old-growth forest. Greene (1995) provided estimates of just over 100 for the same region based on potential available habitat. Within the core range, owls generally exist at elevations between 750 and 2700 meters (Winter 1980, 1986, Greene 1995).

Great gray owls require two distinct habitat components: (1) a meadow system with a sufficient prey base, mainly *Microtus* spp. and *Thomomys* sp., and (2) an adjacent forest system able to provide adequate cover and nesting structures (Winter 1980, 1986, Greene 1995, van Riper and van Wagtendonk in press). Owls utilize the immediate surrounding forest for roosting and nesting activities, and meadow systems to hunt voles, gophers and various other prey. Characteristics of the habitat, such as vole and gopher abundance and availability, meadow vegetation height and cover, meadow soil moisture, dense forest canopy cover, and presence of large snags, are thought to influence site suitability (Winter 1986, Reid 1989, Bull and Henjum 1990, Greene 1995, Whitfield and Gaffney 1997).

Voles (*Microtus* spp.) and pocket gophers (*Thomomys* sp.) have been shown to be staples in the diet of great gray owls in California. Reid (1989) found the two taxa made up 94.6% of the total biomass in pellet analysis, in which gopher biomass was nearly twice that of voles. Winter (1986) found gopher biomass represented 81.5% in pellets, while vole biomass represented 13.8%. Bull and Duncan (1993) and Winter (1986) stress that the biomass ratio may be biased depending on where pellets are found (e.g. pellets close to the nest may represent larger prey items delivered to the young). Regardless, it is apparent that great gray owls rely on both voles and gophers as essential prey in California.

Vole and gopher abundances are tightly associated with vegetation structure, moisture, and soil characteristics within a meadow system, but habitat preferences of the two differ somewhat. Voles inhabit wet areas consisting of thick grass, forbs, and sedge cover (Smolen and Keller 1987, Greene 1995, Sera and Early 2003), whereas pocket gophers inhabit areas of deep soft soils allowing for easier burrowing and tunneling activities (Jones and Baxter 2004). Gophers are found in areas with less vegetative cover than voles, and they also tend to avoid saturated soils due to burrow flooding (Greene 1995, Ingles 1952).

The forest surrounding the meadow system is a critical component because it offers essential shade for roosting, and structures for nesting. The forest within 200-300 m of the meadow is used for nesting, forest within 10-100 m is used for roosting, and broken-top snags large enough to support nests are an important factor to facilitate breeding (Winter 1980, 1986). Greene (1995) also found owl presence to be positively correlated with montane meadows and high forest canopy closure within the 200 meter forest buffer surrounding the meadow. Studies outside of California in Oregon and Canada report similar findings, with the exception of nest type (Bryan and Forsman 1987, Bull et al. 1988, 1989, Bull and Henjum 1990, Hayward and Verner 1994, Whitfield and Gaffney 1997). In great gray owl populations outside of California there is preference for abandoned raptor nests, whereas in California owls mainly use large broken-top snags for nesting structures (Winter 1980, 1986).

Breeding, foraging, and annual home range sizes for great gray owls were examined through several radio-telemetry studies. In Oregon, Bull et al. (1988) found the maximum distance adults traveled from the nest site was 8.3 miles. In another Oregon study, Bull and Henjum (1990) found that breeding males foraged at distances between 0.43-1.90 miles from the nest site. Winter (1986) found breeding owls in Yosemite and Stanislaus National Forest to have home ranges (i.e. the approximate area most activity takes place) to be between 0.92-0.99 mi^2. In greater Yosemite, van Riper and van Wagtendonk (in press) found breeding adults ranged between 0.08-0.24 mi^2 of the nest site, and had annual home ranges of approximately 8 mi^2. This same study also found over 60% of all relocations occurred within the 100m forested buffer around meadows, and 80% occurred within the 200m buffer. These results suggest that ranges vary in different geographic regions (Oregon vs. California) and different times (breeding vs. winter). Based on the studies in California, breeding home ranges average between 0.16-0.99 mi^2, and most of the owl's time is spent in the 200m forested buffer zone.

The objective of this paper is provide further information on the current distribution of great gray owls. In addition, this study addresses several objectives of the California Department of Fish and Game, Resource Assessment Program (RAP). Five specific RAP goals relate to this work: (1) Acquire baseline information for species and habitat elements currently not addressed through other monitoring efforts; (2) integrate monitoring plans across the various biological disciplines; (3) identify important biological data gaps; (4) investigate how abundance and distribution of species change due to natural and human-caused factors; and (5) implement an adaptive management strategy (CDFG). Through promoting an ongoing monitoring for great gray owls within the Sierra Nevada and extending focused survey efforts outside of the core range, this study achieves or addresses each of the objectives listed above.

2. Methods

2.1 Site Selection for Areas of Known and Unknown Status

We used a GIS-based adaptation of a predictive model for great gray owl habitat to select survey sites in the Sierra Nevada of California. Habitat preferences were derived from the U.S. Forest Service report by Beck and Craig (1991) addressing Habitat Suitability Indices for the great gray owl in California. Four variables are included in the model and include, meadow vegetation height, vegetation cover, forest canopy cover, and snag density. For the purposes of the implementation in GIS software, we used only variables for canopy closure (USDA Forest Service Calveg 2000 Vegetation layer), meadow size (CDFG Sierra Nevada Meadow Map layer), and WHR density and WHR size classification. Using terms stated by the model (Beck and Craig 1991), we ranked each meadow according to level of suitability. We then selected survey sites, giving priority to sites with higher ranks.

During 2004 and 2005 surveys we selected and surveyed sites throughout the Sierra Nevada, and the majority of sites were outside of the recognized core range. In total, we selected 82 sites for focused surveys (Figure 1.1), five of which were surveyed in both 2004 and 2005.

2.2 Survey Protocol

We adopted survey guidelines primarily from the more extensive USDA Forest Service protocol (Beck and Winter 2000). Walking and driving transects were used for surveys depending on road access and meadow structure. Walking routes were placed along meadow borders, just inside the forest canopy. Driving routes were placed within 200 m of the meadow's edge. All survey points were spaced 0.15 to 0.20 miles apart. A calling device was used to generate broadcast calls played at each survey point. The calling sequence at each survey station lasted eight minutes followed by 2 minutes of quiet listening time.

We conducted two to six visits at each site per year, generally in March to September. According to Beck and Winter (2000) the most valuable visit is thought to be during courtship, due to territoriality of the males. Therefore, we made concerted efforts to conduct two to three nighttime visits during the early nesting season (courtship and incubation periods), occurring from sunset to 1 or 2 am. Generally, one to two nighttime visits took place within the late nesting season (brooding and post-fledge periods), occurring 2 hours before sunset lasting through 2-4 hours past sunset. At most sites we conducted a final visit during the day as a meadow search. During this time the surveyor(s) searched for molted feathers, regurgitated pellets, whitewash on snags and under roost sites, foraging perches within or near the meadow, and visual or auditory detection of an owl. A positive identification was confirmed only by visual or audio detection, or the presence of feathers.

If an owl vocally responded at any point, the surveyors recorded a compass bearing and estimated the distance to source. A follow-up visit was then performed during daylight hours near the estimated source to investigate further occupancy status within 48 hours of the original response. During the follow-up visit, the surveyors looked for molted feathers, regurgitated pellets, whitewash on snags and under roost sites, or visual/audio detection of an owl. The search continued in this manner for 2 hours or until owl(s) were located and/or occupancy status confirmed.

In 2004 we attempted to make six visits per site, and in 2005 the goal was to make at least four visits per site. Both years had an unusually high snow-load and late melt-off date making access problematic, particularly so in 2005. Ultimately, limited access to sites decreased the number of surveys conducted over both years. Sites received on average four to six visits per year (2-6 visits/site/year) with a higher concentration of visits later in the season.

3. Results

Of the 82 meadows surveyed, we detected owls at 12 sites. At one site that was surveyed in both 2004 and 2005, a resident pair was found in both years. Including fledged young, we detected 23 individual owls. We located two successful breeding pairs in each 2004 and 2005 within the Sierra National Forest. In both years, 10 of the 12 detections (83.3%) were in Sierra National Forest, and of those, 6 were located near Yosemite boundaries. Only two observations occurred within the northern and southern limits of the range, one pair in Tahoe National Forest in 2004 and one single male in Sequoia National Forest in 2005. We detected the single male once early in the season (late March) and never again despite many hours of searching both the meadow and the adjacent forest-stand and over the season. Table 1.1 summarizes our findings over 2004 and 2005. U.S. Forest Service great gray owl survey crews aided the survey effort at 13 sites across the study area. The results reported here reflect the combined effort of US Forest Service and CA Department of Fish and Game crews.

4. Discussion

One goal of this study was to shed light on great gray owl distribution throughout California. Detections dropped considerably in areas farther from the greater Yosemite region. Most of the detections were in Sierra National Forest; although this area represents a greater proportion of total sites surveyed in both 2004 and 2005 (41 out of 82 sites surveyed were in Sierra National Forest). Sections of Sierra National Forest that border Yosemite are considered in the core area for the species. There is a small population near Shaver Lake and Dinkey Creek area in Sierra National Forest, located approximately 90 to100 miles south-southeast of Yosemite. Survey records for this area are consistent since 1989, suggesting a relatively stable population.

Survey records for the southern Sierra Nevada show great gray owl territories centered near Sequoia National Park dating between 1988 and 2001. Our surveys in this area were unsuccessful at locating any owls. However, we did not survey inside of Sequoia National Park and it is likely that occupied sites are still dispersed in that area. A focused survey effort is needed to confirm population status within Sequoia National Park and the surrounding areas.

Only two detections were obtained in the extremities of the northern and southern Sierra: a pair in Tahoe National Forest detected several times in 2004 but not in 2005, and a single male in southern Sequoia National Forest detected once in 2005. The site in Sequoia National Forest was at low elevation (4500 ft.) and early in the season (March); therefore it is probable the single male was a floater awaiting access to higher elevation sites, or a disperser seeking a suitable territory. Floaters are typical for great gray owls in the winter as they tend to move down-slope when high snow load prevents foraging and as young search for suitable unoccupied territories (Bull and Duncan 1993). Moreover, a large herd of cattle (over 100 head) grazed this site in April, which quickly degraded meadow structure and made it unsuitable for both owls and prey. In addition to our surveys, a private consulting firm conducting surveys in Plumas National Forest (northern Sierra) found a great gray owl pair at a site in both 2004 and 2005. These detections are the most recent confirmed record for great gray owls in the northern region of California.

The second objective of this study was to explore current population numbers of great gray owls throughout the Sierra. Our survey results, in combination with the pair detected in Plumas National Forest, add to earlier estimates by establishing presence at 12 additional sites across the Sierra Nevada, totaling 23 individuals (Table 1.1). This increases the estimate to approximately 123 individuals across the Sierra Nevada, assuming earlier estimates are relatively static. However, many sites throughout the Sierra still remain unsurveyed making reasonable inferences about great gray owl numbers in California difficult. In addition, the Habitat Suitability Model used to select sites is not completely accurate, as shown in the following chapter, and therefore sites occupied by great gray owls may not have been captured in this study.

Several factors may have affected owl occupancy during this study. Both years produced high snow loads, although the snow-load in 2005 was particularly long lasting. Access to high elevation sites was difficult because of snow cover, and some sites remained under snow through late-June. Late-season snow conditions in the Sierras are usually icy and hard-packed, making foraging difficult for owls. In addition, it is possible that vole populations were experiencing a natural cyclic low during this study, which can perpetuate low occupancy and reproductive rates at sites otherwise suitable. To overcome such complexities, a long-term monitoring effort to determine occupancy and examine demography for the species is clearly needed for the California population.

Our surveys suggest that great gray owl populations are somewhat constrained to the greater Yosemite area, although the reasons for this remain unclear. It is possible northern and southern areas have consistently experienced low or irregular great gray owl numbers due to large distances from core population, and/or marginal habitat unable to sustain breeding owls. Other factors affecting north-south expansion may include habitat degradation via human disturbance (grazing, logging, and development), differences in regional cyclic prey abundances, and/or an overall decrease in great gray owl numbers Sierra-wide.

We conclude that the great gray owl distribution extends throughout the Sierra Nevada; however, greater densities occur in the central region including Stanislaus and Sierra National Forests and Yosemite National Park. As Winter (1986) suggests, the opportunity for range expansion exists within the Sierra, however unknown factor(s) may limit dispersal and population stability outside of the core range. Population estimates throughout the Sierra are steadily increasing as more surveys are conducted. Nevertheless, numbers are still low compared to the large area of potential habitat the Sierra Nevada offers. These small populations are extremely sensitive to disturbance, habitat degradation, climate change, pollution, and disease and, for this reason, continued monitoring and research is critical to ensure the sustainability of California’s great gray owl population(s).

During this study we began to fill essential data gaps for this species. Information on great gray owl distribution and population numbers was expanded by means of an initial monitoring effort. Further research investigating key habitat components and factors relating to site occupancy are the next steps to broaden our knowledge and facilitate better management decisions.

Tables and Figures

Figure 1.1. Map of California indicating 2004 and 2005 great gray owl survey sites and detections.

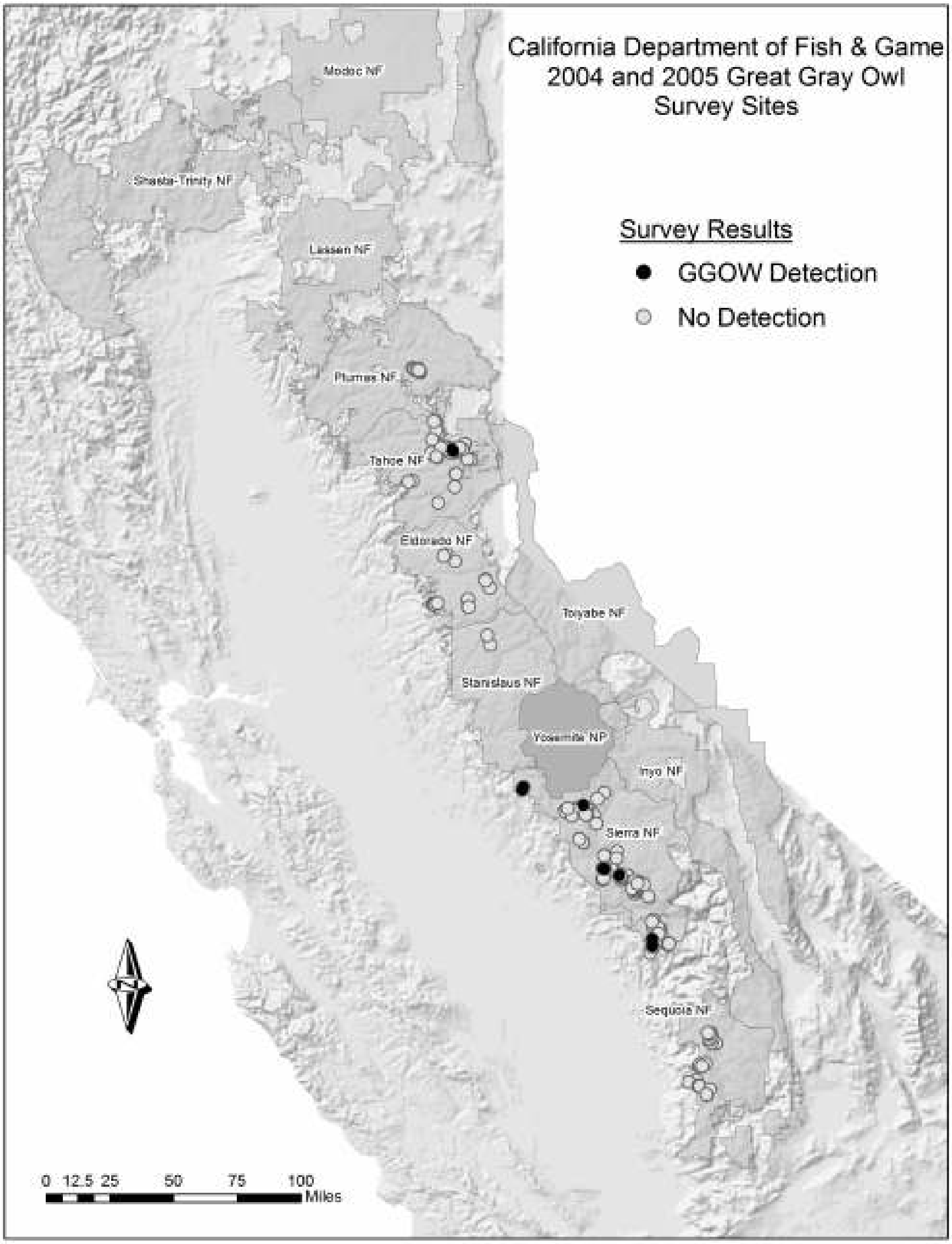

Table 1.1 Surveys performed across the Sierra Nevada in 2004 and 2005. a) 2004 survey results, b) 2005 survey results, c) total between 2004 and 2005. U: Unknown Sex, M: Male, Pair: indicates both male and female were heard/seen concurrently.

a) 2004

Number of Sites Surveyed in 2004	**National Forest**	**# Sites with owls**	**# GGOW**	**Status**
2	Plumas	0	0	
15	Tahoe	1	2 new	1 Pair
20	Sierra	4	8 new	1 Single U 1 Single M 1 Pair 1 Pair 2 Young

b) 2005

Number of Sites Surveyed in 2005	**National Forest**	**# Sites with owls**	**# GGOW**	**Status**
1 resurvey	Tahoe	0	0	
8	Eldorado	0	0	
16 4 resurveys	Sierra	7	12 new 2 from 2004	4 Pairs 1 Pair 2 Young 2 U (only feathers found)
21	Sequoia	1	1 new	1 Single M

c) Total for 2004 and 2005

Number of Sites Surveyed in 2005	**National Forest**	**# Sites with owls**	**# GGOW**	**Status**
2	Plumas	0	0	
15 1 resurveyed	Tahoe	1	2	1 Pair
8	Eldorado	0	0	
36 4 resurveyed	Sierra	10	20	1 Single U 1 Single M 7 Pair 4 Young 2 U (only feathers found)
21	Sequoia	1	1	1 Single M
82 (5 resurveyed in 2005)		**12**	**23**	

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Chapter 2

Assessing Habitat Suitability and Site Occupancy of Great Gray Owls (Strix nebulosa) in California

1. Introduction

The great gray owl (*Strix nebulosa*) is one of the most elusive owls found within the Sierra Nevada mountain range. The distribution of the great gray owl is circumpolar, and the Sierran population represents the most southern in its range. The Californian population was listed as endangered in 1980 due to population declines (Winter 1980). Since then, studies on the California population have focused on the greater Yosemite region (inclusive of areas outside the park in Stanislaus and Sierra National Forests), although numerous observational and systematic studies have been conducted across the entire distribution.

As reported in Chapter 1, studies in California's Sierra Nevada range over the last 25+ years indicate that great gray owls require two distinct habitat components: 1) a meadow system that supports voles (*Microtus* spp.) and gophers (*Thomomys* sp.), the preferred prey for great gray owls (Winter 1980, 1986, Greene 1995), and 2) an adjacent forest system to provide adequate roosting cover and nesting structures (Winter 1980, 1986, Greene 1995, van Riper and van Wagtendonk in press). Since owls utilize the forest for roosting and nesting activities and meadow systems to hunt prey, characteristics of this habitat become important in assessing suitability, use, and long-term occupancy. Studies performed across North America have shown certain key characteristics, such as vole and gopher abundance and availability, meadow vegetation height and cover, meadow soil moisture, forest canopy cover, and presence of large snags, influence site suitability (Winter 1986, Reid 1989, Bull and Henjum 1990, Greene 1995, Whitfield and Gaffney 1997).

One of the more traditional methods to predict habitat is through Habitat Suitability Index (HSI) models. These models are developed to aid in management of species through synthesis of information on specific habitat requirements and subsequent prediction of suitable habitat based on these attributes (Piorecky et al. 1999). The USDA Forest service developed such a model for great gray owls in California (Beck and Craig 1991). The model is based on a small sample of sites in prime habitat of Yosemite and integrates known habitat attributes to create a method to predict suitable habitat for great gray owls throughout the Sierra Nevada. Information on great gray owl requirements for areas outside the core range was sparse at the time of HSI model development. Accordingly, Beck and Craig (1991) state "this model is based on limited information for the Sierra Nevada and should be regarded as preliminary." Given the historic and somewhat restrictive nature of the present model, representation of suitable habitat may be unreliable for the species throughout the entire Sierra Nevada.

A number of approaches have been used to assess the effects of false negative errors (i.e. recording a species as absent when it is actually present) on wildlife-habitat relationships, parameter estimates, site occupancy, and population estimates and trends, including logistic regression, discriminant function analysis, zero-inflated binomial models, and General Linear Models (Azuma et al. 1990, Stauffer et al. 2002, Tyre et al. 2003, Gu and Swihart 2004, Defos du Rau et al. 2005, Field et al. 2005).

Recently, considerable effort has been directed at ways of estimating abundance and distribution while accounting for imperfect detection rates among species through the use of occupancy modeling. Mackenzie et al. (2002) developed a formalized method to estimate the proportion of sites occupied by a species while accounting for imperfect detection probabilities (e.g. the probability of detecting a species, if present, is less than one). These methods utilize maximum likelihood functions to estimate occupancy and detection probability. The model can incorporate covariates to assess the effects of habitat variables on both occupancy and detection probability. Such a model can provide important insight into the distribution, proportion of area occupied (e.g. abundance), and habitat requirements of a species (e.g. suitability), and can help to refine survey protocols and allocation of effort.

Several recent studies have illustrated the utility of this approach. Ball et al. (2005) used occupancy models to determine the distribution and habitat requirements of the Palm Springs ground squirrel (*Spermophilus tereticaudus chlorus*), and assess the effectiveness of current management plans. Finley et al. (2005) used occupancy models to evaluate the importance short grass prairie on occupancy and detection probabilities for the threatened swift fox (*Vulpes velox*). Another study on foxes (*V. vulpes*) used the model to estimate detection probabilities, and thus maximize survey efficiency (Field et al. 2005). Wintle et al. (2005) estimated detection probability to evaluate survey effort allocation for two species of forest owls and four species of marsupials. The effect of barred owl (*Strix varia*) presence on northern spotted owl (*S. occidentalis caurina*) occupancy and detection probability was assessed by Olson et al. (2005). Occupancy models were also used for various anuran species to assess the effects of habitat variables and abundance on occupancy rates and detection probabilities, effectiveness of survey protocol, and species distribution (Schmidt and Pellet 2005, Pellet and Schmidt 2005). Bailey et al. (2004) similarly explored the effects of survey method and effort, sampling variables (i.e. duration of survey), and habitat variables on occupancy and detection probabilities for terrestrial salamanders.

In the present study we evaluate the ability of several analytical approaches to designate key habitat components related to great gray owl presence across the Sierra Nevada of California. We also develop functional site occupancy models to estimate the proportion of suitable area occupied by great gray owls in the Sierra. The long-term benefits of this project will include a refined understanding of great gray owl habitat requirements throughout its entire California range, demonstrate an application of a current modeling approach, and help to refine management efforts for the species.

2. Methods

2.1 Study Area

We collected survey and habitat data in the Sierra Nevada mountain range in California in areas across its entire expanse, including sites in Plumas, Tahoe, Eldorado, Sierra, and Sequoia National Forests, and Yosemite National Park. All sites were surveyed by CDFG crews with the exception of those within Yosemite National Park. Yosemite sites were surveyed by a NPS biologist and Forest Service crew in 2005. All surveys followed the same protocol and are therefore comparable in nature.

2.2 Survey Protocol

Survey guidelines were adopted from the more extensive USDA Forest Service protocol (Beck and Winter 2000). All survey points were spaced 240-320 m (0.15 to 0.20 mi) apart at the meadows edge or within the 200 meter forested buffer zone surrounding each meadow. A calling device was used to generate broadcast calls played at each survey point. The calling sequence at each survey station lasted eight minutes followed by two minutes of quiet listening time.

Each site was visited up to six times per year. Visits were timed to the breeding season which generally lasted March through September depending on region and elevation. According to Beck and Winter (2000) the most essential visit is thought to be during courtship, when males are most territorial. Therefore, we undertook strong efforts to conduct two to three nighttime visits during the early nesting season (courtship and incubation periods). In addition, we conducted one to two nighttime visits within the late nesting season (brooding and post-fledge periods). Our final visit was conducted during the day to search for molted feathers, regurgitated pellets, whitewash on snags and under roost sites, foraging perches within or near the meadow, or visual detection of an owl. A positive detection was confirmed only by visual or audio detection, or the presence of feathers.

2.3 Site Sampling

Previous studies to monitor great gray owls have been limited to portions of Stanislaus and Sierra National Forests, and Yosemite National Park. We surveyed both sites with historical use by great gray owls and sites where use by great gray owls was unknown. In total, 60 sites were surveyed for owls and sampled for habitat components in 2004 and 2005. Sixteen sites were sampled within the core range, and 44 were sampled outside of that range (including known and unknown occupancy status) (Figure 1). We selected 26 sites with historic use across the Sierra Nevada, of which 10 were outside the core and 16 were inside the core. Thirty-four sites were selected with unknown status, of which all were outside the core range.

We utilized knowledge of great gray owl habitat preferences to produce a GIS-based habitat suitability model, which was then used to select survey sites in the Sierra Nevada of California outside the owl's core range. Habitat preferences were derived partially from the Habitat Suitability Index (HSI) model and management prescription for the Great Gray Owl in California (Beck and Craig 1991), and partially on habitat requirements known from the past research in California (Winter 1986, Greene 1995). The HSI model was designed to predict habitat that is "comprised of mature or old-growth conifer forests with dense canopy and numerous snags in close proximity to large meadows or meadow systems" (Beck and Craig 1991). Based on a portion of the HSI model criteria and known habitat preferences, we used variables for canopy closure

(USDA Forest Service Calveg 2000 Vegetation layer), meadow size (CDFG Sierra Nevada Meadow Map layer), and Wildlife Habitat Relationship System (WHR) density and size classification in GIS software to rank each meadow according to level of suitability. We then selected sites representative of all status types for owls (i.e. known, unknown, and historic), giving priority to sites with higher suitability ranks.

It was necessary to compare areas outside the core to those inside, and to increase the sample size. Therefore we targeted 11 additional sites inside the core range in 2005 to include in the analysis. Sites within the core range have been monitored extensively over time and there is either a historic (i.e. records show owl detections at some point in the past) or current (i.e. owls have been currently detected at site) record for all the sites selected at the start of the surveys in 2005. When we selected the 11 sites in the core range, 8 were known to have current great gray owl presence and 3 were known to have historic records but presence was not currently noted for that year. By the end of the season, all but one of the 11 sites had documented owl presence.

2.4 Habitat Variable Sampling

Previous analyses have shown strong positive relationships between several habitat components and great gray owl presence. These include prey abundance, mainly voles (*Microtus* spp.) and pocket gophers (*Thomomys* sp.), and meadow characteristics that influence the presence of these prey species, such as medium-tall vegetation height, high vegetation cover, and high soil moisture (Ingles 1952, Rhodes and Richmond 1985, Winter 1986, Smolen and Keller 1987, Reid 1989, Greene 1995, and Sera and Early 2003). The forest within 100-200 m of the meadows edge is used for nesting and roosting activities (Winter 1980, 1986, van Riper and van Wagtendonk in press). Within this buffer, forest stand components such as dense forest canopy cover used for shade, amount of fir (*Pseudotsuga spp.*), presence of large snags suitable for nesting structures, are important factors for assessing suitability (Winter 1986, Bryan and Forsman 1987, Bull et al. 1988, Bull et al. 1989, Reid 1989, Bull and Henjum 1990, Hayward and Verner 1994, Greene 1995, Whitfield and Gaffney 1997, and Fetz et al. 2003).

During the 2004 and 2005 field seasons, we measured variables representing these documented habitat requirements (Table 2). We placed random transects both in the meadow and adjacent forest at each site to measure related habitat values such as prey sign, meadow vegetation traits, forest stand structure, and snag density (Figure 2). To ensure consistency of data collection we followed methods used by Greene (1995), Winter (1986), and CNPS Releve Protocol (2003).

Based on these data, we collected habitat data on key meadow components such as average vegetation height, percent ground cover, meadow moisture, and dominant vegetation type. In addition, we calculated snag density and percent forest cover within the 200 meter forested buffer zone surrounding each meadow.

We used randomly placed line transects to measure meadow components at equally spaced points (10 m) along the transect using a 1x1 m frame with 16 intersections of 8 crosshairs (four by two). Each transect started at the edge of the meadow and followed an arbitrary bearing. The frame's right-hand corner was positioned at each data point along the transect where we estimated vegetation height, percent ground cover, and dominant vegetation. We estimated vegetation height by measuring the height of the tallest vegetation at each crosshair intersection in 2004, and measuring the height of the tallest vegetation at each corner of the frame in 2005. We estimated percent ground cover by counting the number of crosshairs directly over live or dead-rooted vegetation. We estimated meadow moisture at each point by labeling as dry, moist, saturated, or standing water after a visual inspection and depression of the soil within the 1x1 m frame. Lastly, we classified dominant vegetation as grass, sedge, rush, forbs, shrub, or unknown within the 1x1 m frame at each data point. We continued in this manner until 50 data points were collected at each site.

Prey signs were also noted along the same random line transects at equally spaced points (30 m in 2004 and 20 m in 2005) within the meadow. At these data plots we noted number of vole runways, gopher mounds, and gopher plugs, and the presence of clippings and feces, within a 1 m radius of right hand corner of 1x1 m frame. We continued in this manner until 20 (2004) or 25 (2005) data points were collected at each site.

Some sites consisted of several small meadows in close proximity to each other. In these cases a portion of the vegetation and prey plots were assigned to each. For example, if a site contained 3 meadow of size ratio 10:9:5 acres, then 20:20:10 vegetation plots and 10:10:5 prey plots were performed in each one respectively.

We placed three to five random belt transects within the 200 m forested buffer running perpendicular to and starting at the meadow’s edge, where the number of transects depended on meadow size (Figure 2). The belt transects were 210 m in length and 20 m wide, and five data points were spaced every 40 m along the transect.

We measured forest canopy closure using a spherical densiometer at each of the five data points within each transect. Four readings, one in each cardinal direction, were taken and then averaged to obtain a final reading for that point. We measured tree species and tree diameter at breast height (DBH) using DBH -tape on live trees within a

10 m radius of every 40 m data point. In 2004 we measured all trees greater or equal to 5 in DBH, and in 2005 we reduced measurements to all trees greater or equal to 18 in DBH for the sake of time.

Great gray owls in California mainly use large broken-top snags for nesting structures (Winter 1980, 1986), therefore we measured snags over 5 in DBH within a 10 m radius of every 40 m data point (species noted if possible). We calculated the area where snags were measured to obtain a snag density index value (snags per hectare) for each site.

Meadow size was obtained from a digital polygon meadow layer provided by California Department of Fish and Game (CDFG). During a general meadow assessment in accordance with the CDFG Sierra Meadow Project, we performed a visual inspection for evidence or presence of cattle at each site in both 2004 and 2005.

2.5 Data Analysis

We first implemented the Habitat Suitability Index model (Beck and Craig 1991) to provide a means of field-validation. We used correlation matrices to examine relationships among habitat variables. We also used Principle Components Analysis to reduce the number of variables to a manageable size for further analyses. Finally, we used site occupancy modeling to estimate occupancy and to assess the influence of habitat components. We constructed 3 sets of occupancy models using: (1) Individual *a priori* habitat variables for 52 sites inside and outside the core; (2) PC factors for 52 sites inside and outside the core; (3) HSI values for 52 sites inside and outside the core; and 4) comparative occupancy models using covariates from the top models produced by each of the above analyses. The final results of these models were then used to compare techniques related to HSI, PCA, and Occupancy modeling.

2.6 Habitat Suitability Index Field Validation

Beck and Craig's (1991) HSI model is based on four variables representing a cover/reproductive component (i.e. factors relating to reproductive suitability, such as snags greater or equal to 24 inch DBH and percent tree canopy closure) and a food component (i.e. factors relating to prey presence, such as herbaceous height between 13-38 cm and percent herbaceous cover). These values are then combined to produce an overall HSI value for each site (Figure 3). HSI values range between zero and one, where values closer to 1 are considered more suitable then values closer to 0.

To evaluate the predictive ability of Beck and Craig's (1991) model we used the model structure to calculate habitat suitability values for our sites. We formatted our habitat data to fit the variable criteria of the model. For example, V1 is defined as snags per hectare greater or equal to 24 in DBH. In the habitat dataset, we included the number of snags meeting this criterion and excluded all snags that did not. We then calculated the value for each site based on slope of the suitability index curves of the model (Figure 4). Descriptions for each variable, limits, and equations used to calculate values, and the actions taken to integrate the habitat dataset are shown in Table 1. Sites were then evaluated based on predicted suitability by comparing the survey results with the HSI value, where high values equate to high suitability.

2.7 Site Occupancy Model Design and Selection

Using the 2004 and 2005 survey data, we developed a single-season, single-species site occupancy model for great gray owls in California. The model was designed to estimate the proportion of sites occupied in an area of interest, Ψ, while accounting for detection probability, p (Mackenzie et al. 2002, 2006). These estimates account for a species with detection probabilities less than one (e.g. present but not detected; false-negative surveys).

Briefly, the occupancy model is fashioned after mark-recapture closed population models, as it assigns encounter histories based on survey visits (MacKenzie et al. 2002). For example, if a site has six survey visits over a season, and has detections during the 2nd and 5th visits, the encounter history is written as h = 010010. The model likelihood equation for this history would then be,

$$L(\Psi, p) = \Psi(1\text{-}p1)p2(1\text{-}p3)(1\text{-}p4)p5(1\text{-}p6) \qquad (1)$$

In this manner, when a species is detected at least once during an encounter history it is possible to calculate estimations for Ψ and p. The model requires at least two surveys per site during a survey season, where a species is known to be using a defined area, often during a breeding season.

Occupancy models are effective at integrating covariate information that may influence Ψ and p. These parameters can be described as varying or constant over time. Covariates for Ψ are those that remain constant throughout the survey season, such as elevation or forest structure. Covariates for p can also be constant over time, but typically vary over the survey season (e.g. temperature during each visit or duration of visit). Each covariate can be incorporated into the model through use of logistic regression, and can then be assessed for covariate effects on occupancy and detection.

Due to logistic and fiscal constraints, six visits were not possible at all sites over the two-year monitoring period. However, the occupancy model is able to accommodate missing observations. In this case, the missing observation is omitted from the model likelihood equation and bears no weight in parameter estimation.

For interpretation of the resulting models to be valid it is important to assess how the model of interest fits the observed data (Cooch and White 2005, MacKenzie et al. 2006). As recommended by MacKenzie et al. (2004) we assessed goodness-of-fit to the global model (most complex model with the greatest number of parameters) using bootstrapped chi-square.

There are several assumptions of the model: (1) occupancy at each site should not change over the survey period; that is sites are closed to changes in occupancy over the season; (2) probability of occupancy should be constant across sites, or the differences in occupancy are accounted for by including measured covariates in the model; (3) the probability of detection should be constant across all sites and surveys unless accounted for by measured covariates; that is. there is no unmodeled heterogeneity in detection probability; (4) detection of the species should be independent across all sites; and (5) there are no false-positive detections of the species. In particular, assumptions 1 and 4 become important when considering the species of interest and when defining study design.

We addressed each assumption by considering what is currently known about great gray owl ecology. The survey “season” took place during the breeding season of great gray owls and was identified according to predefined guidelines set by the survey protocol (Beck and Winter 2000). The season began when owls were setting up territories and actively courting, and ended near the time owls were likely to migrate down-slope. The season spanned from approximately February to September depending on region and elevation. This strategy meets the seasonal closure assumption of the model (Assumption 1).

Great gray owl territories vary widely between seasons, but commonly are within the bounds of 0.08-0.99 mi^2 during the breeding season (Winter 1986, van Riper and van Wagtendonk in press). The probability of occupancy, probability of detection, and site independency assumptions (Assumptions 2-4) were reasonably met by ensuring all sites were located at least 1 mile from any other site, or had some geographical barrier separating them, such as a ridge. If sites were closer than 1 mile or had no barrier, they were grouped into meadow complexes and surveyed during the same visit.

Individual surveyors were trained in-depth to recognize great gray owls by both visual and auditory means. Consequently, false-positive detections (Assumption 5) were unlikely. If a detection was unconfirmed, that record was entered as “negative” in the survey dataset.

Variables considered in the model building process were attained from habitat data collected at selected sites including, tree size and type, forest canopy closure, snag density index, meadow moisture, meadow vegetation type, height, and cover, relative vole and gopher abundances, meadow size, elevation, and grazing disturbance (Table 2).

The dataset used in the model included sites having at least 2 surveys and where measured habitat variables were collected. One site had survey and habitat data for both 2004 and 2005. In this case we randomly excluded one year’s data for this site to meet independence assumed in the model. Six more sites were excluded due to missing survey histories. The total sample size of sites with survey and habitat data was 52, 15 of which had owl detections.

Data transformation using Box-Cox transformations was used to normalize data (Krebs 2003). The basic transformation equations for cases when $\lambda \neq 0$ and when $\lambda = 0$ are represented by:

$$X' = (X^\wedge \lambda - 1)/ \lambda \qquad \lambda \neq 0 \qquad (2)$$

$$X' = \log(X) \qquad \lambda = 0 \qquad (3)$$

where λ is the power of transformation estimator. To choose the best transformation for respective data we tested values for λ that maximized the log-likelihood function:

$$L = -(v/2)\log_e S^2_T + (\lambda - 1)(v/n) \sum (\log_e X) \qquad (4)$$

where, L = value of the log-likelihood function
v = degrees of freedom $(n - 1)$
S^2_T = variance of transformed X values (from 3 or 4)
X = original data values

Zero values cannot be solved using log functions, therefore we added the constant 0.5 to the original data types where 0's were present, following Krebs (2003). Once a proper transformation was decided, we used the z-transformation so all variables had comparable standard errors.

We considered no more than two covariates per model due to our small sample sizes (Anderson and Burnham 2002). The models were run using the program PRESENCE 2.0, and thereafter ranked using Akaike's Information Criterion (AIC) (Burnham and Anderson 2002). We corrected AIC values for over or under dispersion using c-hat (quasi-likelihood parameter) and small sample size according to Burnham and Anderson (2002), hereafter referred to as QAICc. A c-hat >1 represents data over-dispersion, while a c-hat <1 represents under-dispersion. We calculated ΔQAICc for each model to represent the difference in QAICc between all models, where all ΔQAICc values sum to one across candidate models (Burnham and Anderson 2002). We only considered models with ΔQAICc values <2 as those best explaining the data (Burnham and Anderson 2002). We calculated Akaike weights to indicate the support of each model relative to one another (Burnham and Anderson 2002). To account for uncertainty in model selection procedures, we calculated parameter estimates (Ψ and p) based on model-averaged Akaike weights across the set of models (Burnham and Anderson 2002).

We reduced the number of habitat variables by considering previous knowledge on habitat requirement and correlations among the 20 habitat variables measured. Correlation analysis indicated strong relationships among several continuous variables (Appendix A). In view of these results, we chose nine *a priori* variables to use as covariates in occupancy models; eight continuous variables based on current knowledge of great gray owl and prey habitat requirements (ELEV, FCOV, SNAGD18, HGHT, PTSED, PTFORB, MO, and GOVO), plus one categorical variable (GRAZ).

We first ran two simple models using the 52-site dataset for inside and outside the core range, where Ψ was held constant over time and p was either held constant or varied over time (Ψ(.)p(.) and Ψ(.)p(t)). Between these simple models, time dependence was better supported. However, after exploratory model development we found all Ψ(covariate)p(t) models lacked numerical convergence in parameter estimations. This was most likely due to the large number of parameters for models with time-dependence, in addition to the effects of small sample sizes. Therefore, we focused subsequent model development on time constant detection probability (Ψ(covariate)p(.)). Although this study does not address specific issues relating to detection probability estimates, preliminary research can be reviewed in Appendix D.

We then included each of the nine *a priori* variables as single site covariates for Ψ. We also considered combinations of covariates that represented meaningful models based on our current knowledge on habitat requirements. For example, Ψ(FCOV+SNAG18)p(.) indicates the role of a forest component on owl occupancy, Ψ(GOVO+MO)p(.) indicates the role prey component, and Ψ(ELEV+FCOV)p(.) indicates the role of elevation and forest canopy cover. In total, 21 models in the form Ψ(covariate)p(.) were developed for this analysis.

In our second set of models, we used Principle Components Analysis (PCA) to reduce the number of variables considered in the models. PCA identifies a smaller subset of variables that retained much of the variation in the original data. We used the resulting PC factors as covariates in the site occupancy model to evaluate how this method compared to reducing the variables based on current knowledge (*a priori*). The results were used solely to compare between strategies and to compare predictive ability concerning critical habitat variables. We did not use these models for parameter estimation.

Our purpose in utilizing the HSI model was two-fold; (1) to perform field validation of the model, and (2) to provide a means of comparing modeling techniques. To address the second purpose, we evaluated the Beck and Craig model (1991) by including individual HSI variables (V1, V2, V3, V4) and overall HSI value for each meadow as covariates in the site occupancy model. Again, we did not use these models for parameter estimation, but instead, only as a means of comparison between strategies.

It is important to note that site selection was partially based on habitat preferences mentioned in the Beck and Craig (1991) HSI model. Therefore, it is plausible that results of the occupancy models that incorporate variables at these sites reflect biases of the HSI model performance and may contain some amount of circularity. That is, if the HSI model performed poorly then we would expect some sites occupied by owls were overlooked. Consequently, variables sampled at these sites would show a bias away from suitable habitat. However, habitat preferences were not only derived from the HSI model, but also on habitat requirements known from the past research. Thus these types of biases are not expected to play a major role in occupancy model results.

Finally, using the occupancy model framework, we ran models incorporating covariates included in the top models (ΔQAICc<1) from each analytical approach to effectively compare and contrast which is better able to represent the data and predict suitable habitat.

3. Results

3.1 Habitat Suitability Index Field Validation

We evaluated the reliability of the HSI model by contrasting the suitability value assigned to each site with actual survey results. The lowest ranked site with owl presence was 0.41, therefore we assigned this value as the lower boundary designating suitable habitat. Sites above 0.41 were interpreted as more suitable, sites below this value were less suitable, and sites with values of zero were not suitable. Discrepancies in the model results are evident (Appendix B). Variables V1 (snag density), V2 (tree cover), and V3 (vegetation height) tend to reduce the HSI value to zero in some instances where owls were actually present. Overall, 56% percent of the sites were correctly predicted by the HSI model, with 25% of sites with birds labeled “suitable”, and 31% without birds labeled “unsuitable” (Table 3). Seven out of 59 sites (12%) were labeled “unsuitable” yet had owl presence. Furthermore, 32% of the sites were labeled suitable, but had no detections. Conflicting results can be categorized into “unsuitable but occupied” (12% of sites) or “suitable and unoccupied” (32% of sites).

3.2 Site Occupancy Model

The global model showed slight over-dispersion (c-hat of 1.33). Great gray owls were detected at 15 of the 52 sites, thus the naïve proportion of sites occupied was 0.2885 (15/52).

In examining the set of *a priori* variables, the top models were Ψ(ELEV+SNAGD18)p(.) (QAICc weight = 0.3546) and (ELEV+MO)p(.) (QAICc weight = 0.3192) (Table 4). The weighted average for Ψ was 0.301, indicating approximately 30% of suitable sites were occupied by owls. It is important to note that Ψ varies with each site according to the covariates included, meaning there is an individual estimate of Ψ for every site within the model. Therefore the weighted average given for Ψ represents an overall average for all sites combined.

3.3 Modeling Habitat Variables using Principle Component

Seven factors with eigenvalues >1 retained 75.1% of the variance seen in the original data (Table 5). Factor 1 loaded high in vegetation type (% grass, and % sedge), meadow moisture, and vole and gopher abundance. Factor 2 loaded high in elevation, % sedge, gopher and vole abundance, forest cover, and % fir. Factor 3 loaded high in herbaceous cover and height, and % moist soil. Factor 4 loaded high in vegetation type (% grass, % forb, and % rush), forest cover, and snag density. Factor 5 loaded high in meadow size (acres) and % forb. Factor 6 had no high loadings and so was not included in further analysis.

Models using PCA factors 1 through 5 were developed to examine variable subsets that retain most of the variation of the dataset. Goodness-of-fit was assessed using the global model, where c-hat was 1.33, indicating slight overdispersion. The model including PC factors 1 and 2 (Ψ(PC1+PC2)p(.); QAICc weight = 0.3546) was the top model (Table 6). Variables that loaded high in factors 1 and 2 included % grass, % sedge, meadow moisture, prey abundance, elevation, forest cover, and % fir. When comparing these models to the top two occupancy models with individual *a priori* covariates (Ψ(ELEV+SNAGD18)p(.) and Ψ(ELEV+MO)p(.)), the QAICc weight of the top model using PC factors decreased to 0.0771 (Table 8).

3.4 Modeling HSI Values

As an alternative method to evaluate the Beck and Craig (1991) model and to compare modeling techniques, we used the calculated HS values (V1, V2, V3, and V4) and the overall HSI value as covariates in another set of occupancy models. Goodness-of-fit was assessed using the global model, where c-hat was 1.18, indicating slight overdispersion.

The HSI covariates (V1, V2, V3, V4, and Overall HSI) showed similar QAICc weights, however all models had very low the QAICc weights (Table 7). Habitat suitability variables representing snags (V1), vegetation height (V3), and vegetation cover (V4), rated above the overall HSI Value. However, when compared to the top two *a priori* occupancy models, the QAICc weights for the top model decreased to 0.0046 (Table 8).

3.5 Contrasting Top Models

To compare different analytical approaches we used six covariates (ELEV, SNAGD18, MO, PC1, PC2, and V3) from the top two *a priori* models and the top models from PC and HSI analysis in the occupancy model framework. We also included both simple models in the analysis. The c-hat of the global model was 1.19 indicating slight overdispersion. We found the models using *a priori* variables had better support over models incorporating PC factors or HSI values (Table 8).

4. Discussion

4.1 Habitat Suitability Index Field Validation

The Beck and Craig (1991) HSI model performed relatively poorly in predicting great gray owl occurrences in the study area. Owls were present at 25% (15/59) of the sites that were identified as suitable, and were absent at 31% (18/59) of the sites identified as unsuitable. The model also indicated that 32% (19/59) of the sites were "suitable", yet these sites did not have owl occupancy. Conceivably "suitable but unoccupied" sites may be a factor of low population numbers, range limitations (geographic barriers), stochastic distribution, and/or false-negative detections. Overall, the HSI model is slightly better at predicting where owls will not occur, as opposed to where owls will occur.

Of more concern are the 12% (7/59) of sites that were labeled "unsuitable" but were occupied by owls. Such a discrepancy is likely explained by the inefficiency of the model to properly designate suitable habitat. The model tends to misrepresent snag density, tree cover, and herbaceous height (many of the sites with owl occupancy show unsuitable habitat for these variables). Either data collection is inefficient at measuring these variables, or the HSI model does not properly predict limiting criteria.

As Greene (1995) suggests, great gray owls are probably not limited by the density of snags, but rather the presence of at least one snag suitable for nesting activities. Therefore, we need a dependable index of snags in an area of interest that meet the requirements for a nest structure. A more comprehensive snag density index could be constructed by incorporating random 1/10 hectare circular plots within the 200 m forested buffer zone surrounding a meadow system (Malcolm North pers. comm.). Samples would be stratified among different forest types (e.g. disturbed, undisturbed, late-seral, mid-seral, etc.), with five plots per type.

The HSI model suggests limiting criteria for suitable vegetation height to be in the range of 13-38 cm. Voles are likely to avoid short vegetation, and in fact prefer taller vegetation for protection from predators (Smolen and Keller 1987, Sheffield et al. 2001). Greene (1995) demonstrated that voles occurred more often in vegetation height over 30 cm, while gophers occurred more often in vegetation ranging from 10 to 30 cm. Great gray owls have often been observed hunting in deep vegetation by employing a diving behavior similar to that used for hunting in snow conditions (Winter 1986). At one of our sites in 2005, vegetation height averaged just over 65cm (2 ft) in most of the meadow, yet a pair was consistently detected at this site throughout the season. Our data show vegetation in meadows where great gray owls were present ranged between 12.5 and 65.3 cm. Therefore it appears prey availability is not completely suppressed when tall vegetation is present. We recommend revision of the HSI model criteria to include vegetation height between 10 and 65 cm to more accurately predict vole and gopher availability.

Field-testing of the HSI model demonstrated its shortcomings in assigning great gray owl habitat suitability across the entire Sierra Nevada. Accordingly, we suggest revision of model criteria or the use of alternate modeling techniques to better predict great gray owl suitability/occupancy based on a current review of habitat requirements of great gray owls.

4.2 Occupancy Models in Assessing Suitable Habitat

We assessed several occupancy models based on *a priori* variables, PC factors, and HSI values. Time-variance in detection probability (detection probability varied across survey visits) was better supported across most models. However, we did not incorporate this variance when assessing habitat covariates (except for $\Psi(.)p(t)$) due to small sample size and the resulting lack of numerical convergence in parameter estimation.

The top two models, $\Psi(\text{ELEV+SNAGD18})p(.)$ and $\Psi(\text{ELEV+MO})p(.)$, indicated effects of elevation, large snag density, and meadow moisture on owl presence. Studies in California have found owls occur at elevations ranging between 750 and 2700 meters (Winter 1980, 1986, Greene 1995). Our results indicate sites at the highest elevations are less likely to be occupied, implying that owls avoid these areas (Appendix C). This may be a unique consequence of the high snow-load and late melt-off high elevations sites experienced in 2004 and 2005. Foraging efficiency is greatly reduced in deep hard snow-pack, and so it would be expected owls might avoid hunting in areas experiencing these conditions.

The top models also indicated that sites with a higher density of large snags were more likely to be occupied (Appendix C). Previous studies demonstrate that owls depend on broken-top snags for their nest structure (Winter 1980, 1986), and establish a critical connection to successful breeding pairs and the availability of snags. In contrast, Greene (1995) found that there was no connection between snag density and sites where great gray owls were found. Our results support the idea that the number of large snags in an area influence site occupancy. This trend may be a result of lower owl abundances outside the core range, in that the most suitable sites with presumably more nest structure choice will be occupied first.

Vole and gopher species are tightly associated with meadow moisture. Voles prefer wetter areas consisting of thick grass, forbs, and sedge cover (Rhodes and Richmond 1985, Smolen and Keller 1987, Greene 1995, Sera and Early 2003), while gophers avoid saturated soils due to burrow flooding (Ingles 1952, Greene 1995). Pocket gophers are associated with areas of deep soft unsaturated soils allowing for easier burrowing and tunneling activities (Jones and Baxter 2004), in areas with less vegetative cover than voles (Greene 1995). Winter (1986) reported a loose connection between high vole abundance and breeding success in great gray owls by showing owls had improved breeding success in years of high vole abundance. If true, this suggests vole abundance plays a critical role in breeding ability, whereas gophers may serve to supplement diet in low vole abundance years, but do not provide adequate energy for breeding activity due to high gross food yield per unit effort (Winter 1986).

The potential for high vole abundance is represented by the higher moisture content in most of the sites great gray owls occupied in 2004 and 2005. Although our analyses indicate a negative relationship between prey abundances and site occupancy (Appendix C), we speculate that this relationship may be a result of low vole abundance due to natural cyclic patterns compounded by the effects of the prolonged snow pack. It is also possible that overall low vole and gopher abundances are the cause of the near absence of breeding pairs during the duration of our study throughout the California range. As suggested by Winter (1986) and supported by Greene (1995), low prey abundances (particularly voles) limit breeding capability. At sites visited in 2004 and

2005, prey abundances may have sustained daily activity of individual owls but did not allow for breeding to occur. In addition, the low prey abundance may have facilitated more of a migratory response in the foraging behavior of the great gray owl population.

Some habitat features, such as meadow moisture, herbaceous height, and herbaceous cover, are variable over the course of the year. For example, moisture is at its highest and vegetation height at its lowest during May and June due to recent snow cover and continuous source of water from melting snow packs. Likewise, later months (e.g. the Fall months of August and September) experience dry meadow and vegetation conditions which directly relate to prey availability. Therefore depending on the time of the season certain parameters will vary across time at a site. For this reason time constant variables, such as elevation and snag density, may provide more robust predictors of site occupancy.

When contrasting occupancy models incorporating PC factors and HSI values as covariates with models incorporating *a priori* variables, models did not adequately compare. The PCA analysis produced six factors, of which five largely overlapped *a priori* variables. All six factors accounted for 75.1% of the variation in the data, however, models that were developed containing these factors held almost no weight compared to the top individual variable models. PCA can be valuable to reduce the number of variables one considers in the modeling process, yet such an approach was not useful in our study. Selecting variables that were believed to be useful predictors based on current knowledge of great gray owl habitat requirements, proved to be more effective in our study.

To provide a larger base of comparison between analytical approaches, we built several models based on HSI variables and overall value. We found individual HS variables representing herbaceous height, herbaceous cover, and snag presence had better strength than the overall HSI value, however, when compared to top *a priori* models, HSI models also show almost no weight. Contrasts between PC, HSI, and *a priori* models suggest that selecting individual *a priori* covariates was better method to assess of key habitat components related to great gray owl presence.

4.3 Occupancy Models in Estimating Ψ

For models incorporating a priori variables, the weighted model average for site occupancy (Ψ) was 0.301, indicating that approximately 30% of sites with suitable habitat were occupied by great gray owls across the study area. This was only marginally better than the naïve estimate of 0.289, indicating the naïve estimate slightly under-represents the actual proportion of site occupied across the study area. According to MacKenzie et al. (2002), estimates of Ψ tend to be positively biased with small number visits per site, which may be the case in our study with an average of 4.6 visits per site per year. Regardless, the low proportion of sites occupied suggests that suitable habitat is not being filled by great gray owls. We believe this is mainly due to low population numbers, however site availability may add to the issue. Site availability may be affected by barriers to dispersal (i.e. site connectivity) such as isolation of suitable sites by large distances or impassable geography, however, these questions were not addressed within the scope of this study.

4.4 Implications of Study

It is important to note that inclusion of sites within the core range represents a fundamental difference in the sampling scheme throughout the regional scope of the project. Site selection inside the core range was not uniquely based off of GIS mapping as were areas outside of the core. Undoubtedly this could lead to parameter estimation bias and surveyor bias (i.e. surveyors may anticipate owl detections at historic sites or know specific locations of historic detections thus positively biasing survey results). However, we felt justified in using a pooled dataset containing sites both inside and outside the core range due to similar distributions of key habitat variables for all sites visited in 2004 and 2005 (Appendix C), and we believe overall results can prove useful in assessing parameter estimations, survey effectiveness, and important habitat characteristic differences inside and outside the core range.

In this study we have been successful in evaluating Beck and Craig's (1991) HSI model using sites located throughout the entire Sierra Nevada and at recommending improvements to the model to better represent suitable habitat. We were able to assess the application of several modeling techniques and found using *a priori* variables in the occupancy model better supported the available data. We were also able to estimate proportion of sites occupied by great gray owls throughout the Sierra, and to designate important habitat components related to site occupancy.

We recognize the shortcomings of our study mainly due to small sample sizes and differences in sampling scheme. Obtaining a large sample size is difficult when working with a rare species outside its core range, but such an effort will be necessary for over the long term to fully comprehend factors that relate to the sustainability of great gray owls. A uniform sampling scheme for all sites would be recommended for future studies.

We consider this study as part of a working base for further study in California. Areas in need of additional research include: (1) continued monitoring in potentially suitable habitat across the entire Sierra Nevada to further understand great gray owl distribution; (2) banding and radio tracking to understand winter/summer foraging habits and source/sink dynamics; (3) concentrated habitat sampling of sites to understand possible habitat preference differences and similarities inside and outside of the core range; (4) development of dependable indices to assess important habitat components such as food availability and snag density; (5) small mammal trapping to understand how prey abundance relates to occupancy and breeding success; (6) genetic sampling of individuals across the range to assess differences/similarities of genetic relatedness between the isolated populations in California to other populations within the continent, and (7) revision of survey protocol.

Figures and Tables

Figure 1. Map of California indicating 2004 and 2005 habitat assessment sites.

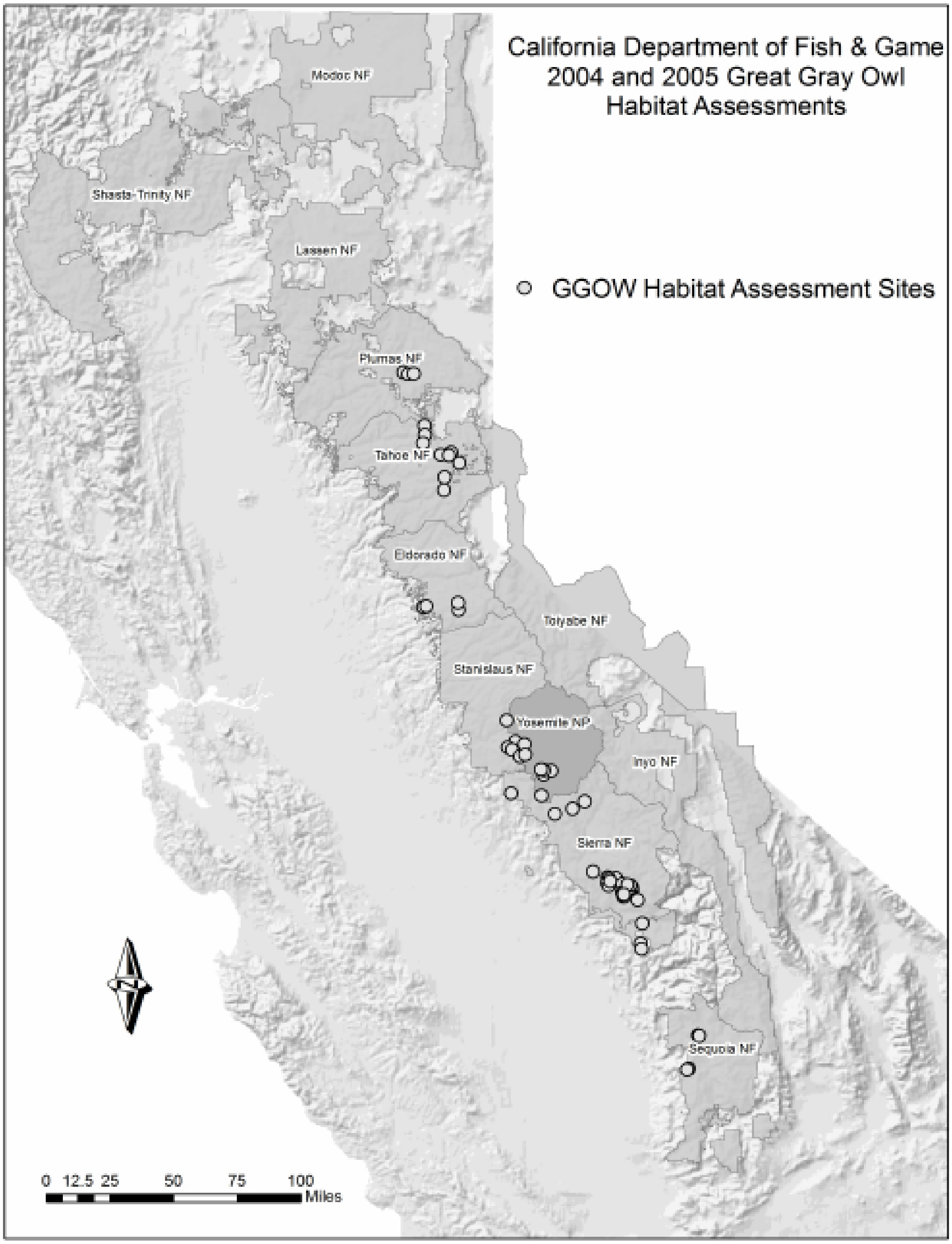


Figure 2. Diagram of habitat sampling scheme showing meadow and forest transects. Image adopted from Greene (1995).

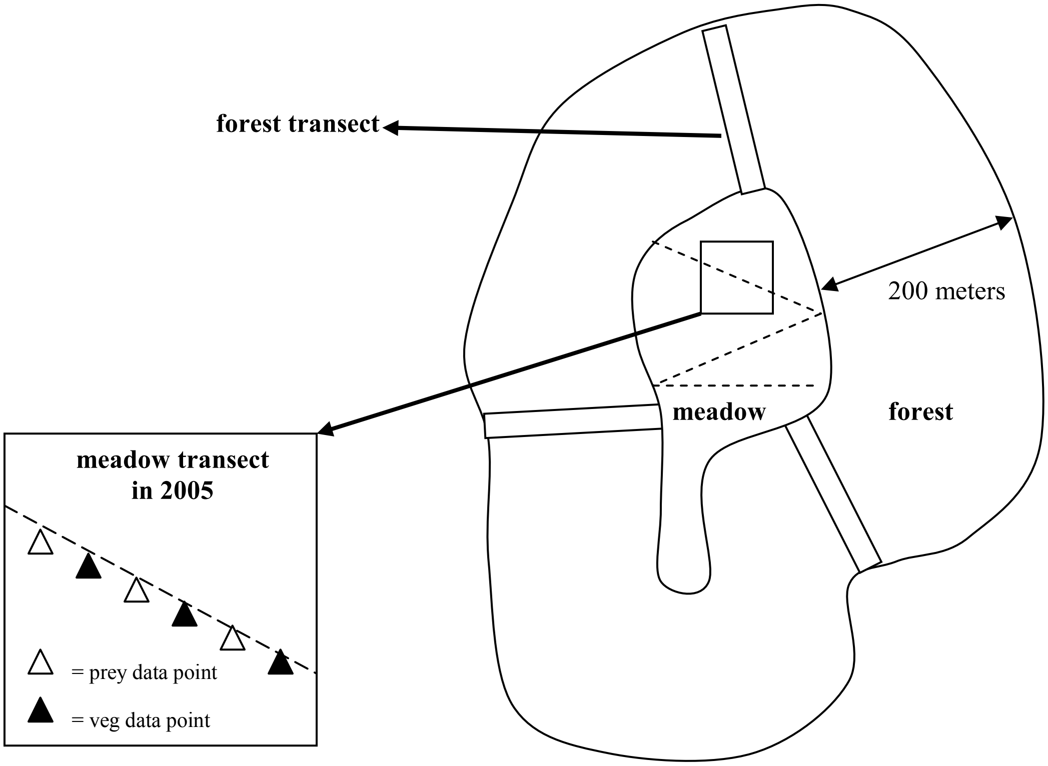


Figure 3. Schematic representation of HSI values and equation relationship. Representations of variables are coded as follows: V_1 = snags per hectare, V_2 = percent tree canopy cover, V_3 = herbaceous height, and V_4 = percent herbaceous cover.

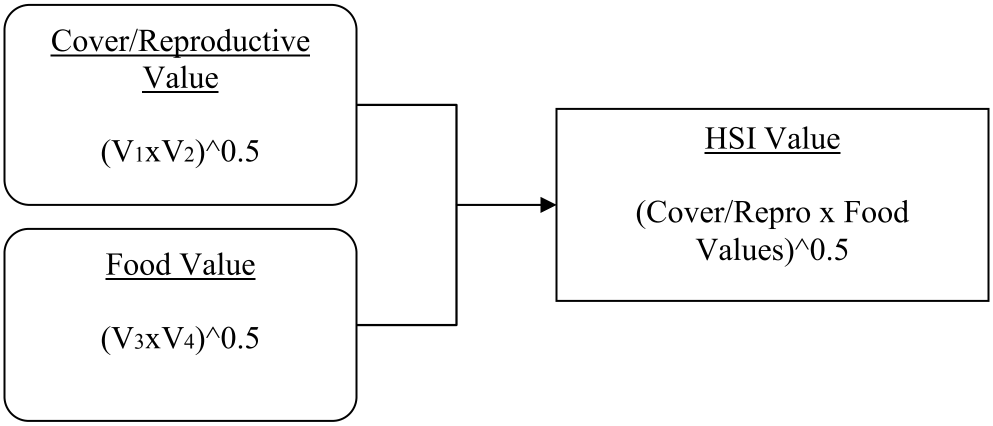


Figure 4. Habitat Suitability Curves of HSI model. The y-axis is variable HS value. The x-axis is variable units.


a) V1: Snag/ha

c) V3: Size of Meadow (ha) with veg 13 to 38cm tall


b) V2: % Forest Canopy

d) V4: % Herbaceous Cover

Table 1. Variables used in HSI calculation and validation. Slopes were extrapolated from the original HSI model and variables calculated using Vx equation. Limits are those imposed on the habitat variables by the original HSI model, and represent upper and lower limits of suitability. The HSI model requires a certain data type (HSI data requirements). If needed, actions were taken to transform the 2004 and 2005 dataset.

	V1: Snags/ha	V2: % Tree Canopy Closure	V3: Herbaceous Height	V4: % Herbaceous Cover
Slope of HSI graph:	0.107	2.5	0.168	2.64
Vx Equation:	$y^2 = 0.107x^2 - 0.07$	$y^2 = 2.50x^2 - 0.8$	$y^2 = 0.168x^2 - 0.675$	$y^2 = 2.64x^2 - .032$
Limits:	if over 10 snags/ha enter 1	if over 72% enter 1 if under 30% enter 0	if over 10 enter 1 if under 4 enter 0	if over 50% enter 1 if under 11% enter 0
HSI data requirements:	snags/ha >= to 24in	% tree canopy	# hectares with herbaceous	% herbaceous cover
2004/2005 Dataset:	snags/ha of all size classes	% tree canopy	proportion of sites with all	% herbaceous cover
Actions taken:	a) summed all snags meeting HSI criteria, excluded all other size classes	none	a) summed proportion of sites with vegetation height between 13-38cm, b) calculated hectares with veg between 13-38cm	none

Table 2. Abbreviations and definitions for continuous and categorical habitat variables collected at 52 sites across the Sierra Nevada in 2004 and 2005.

Abreviation:	**Definition:**
ELEV	Elevation of site (feet)
ACRES	Size of meadow (acres)
HCOV	% herbaceous cover in meadow
PTGRASS	% grass in meadow
PTFORB	% forbs in meadow
PTRUSH	% rush in meadow
PTSEDGE	% sedge in meadow
HGHT	Average herbaceous height in meadow (cm)
PTDRY	% dry soil in meadow
PTMOIST	% moist soil in meadow
PTSAT	% saturated soil in meadow
PTSTW	% standing water in meadow
MO	Moisture index in meadow (1 to 4 = dry to standing water)
GO	Gopher abundance index in meadow
VO	Vole abundance index in meadow
GOVO	Combined gopher and vole abundance index in meadow
FCOV	% forest canopy cover
SNAGD	Total snag density index (snags/hectare)
SNAGD18	Snag >= 18in dbh density index (snags/hectare)
PTFIR	% fir species in 200m forested buffer surrounding meadow
GRAZ (categorical variable)	Current grazing activity (1=grazed, 2=not grazed)

Table 3. Summary of results after application of Beck and Craig HSI model to sites where surveys and habitat collection was conducted in 2004 and 2005. (+) indicates an HSI value greater or equal to 0.41, (-) indicates an HIS value under 0.41. Sierra NF was split into sites inside and outside core range. HSI (+)/ Surv (+) = sites with high HSI value and great gray owl detections, HSI (-)/ Surv (-) = sites with low HSI values and no great gray owl detections, HSI (+)/ Surv (-) = sites with high HSI values and no great gray owl detections, and HSI (-)/ Surv (+) = sites with low HSI values and great gray owl detections.

Area:	**HSI (+)/ Surv (+)**	**HSI (-)/ Surv (-)**	**HSI (+)/ Surv (-)**	**HSI (-)/ Surv (+)**
Plumas NF	0	2	0	1
Tahoe NF	1	1	7	0
Eldorado NF	0	3	1	0
Stanislaus NF	3	0	0	0
Yosemite NP	7	0	0	2
Sierra NF (inside core)	3	0	1	0
Sierra NF (outside core)	0	8	7	4
Sequoia NF	1	3	3	0
Proportion Correct:	**15/59 = 25%**	**18/59 = 31%**		
Proportion in Conflict:			**19/59 = 32%**	**7/59 = 12%**

Table 4. Site occupancy model and parameter estimation for individual *a priori* variables ranked according to Akaike's Information Criteria corrected for small sample size and dispersion (QAICc). ΔQAICc is the difference between the given model and the model with the lowest QAICc, and QAICc weight is the Akaike weighted value for the given model. Ψ is the estimate for proportion of sites occupied, and (SE) is the associated standard error.

Model:	**QAICc**	**ΔQAICc**	**QAICc weight**	**Number of Parameter**	**Ψ (SE)**
Ψ(ELEV+SNAGD18) p(.)	99.88	0.0000	0.3546	4	0.2995 (0.0556)
Ψ(ELEV+MO) p(.)	100.09	0.2104	0.3192	4	0.3122 (0.0589)
Ψ(ELEV) p(.)	102.41	2.5274	0.1002	3	0.3010 (0.0601)
Ψ(ELEV+GOVO) p(.)	103.76	3.8823	0.0509	4	0.3029 (0.0597)
Ψ(ELEV+FCOV) p(.)	104.74	4.8569	0.0313	4	0.3012 (0.0601)
Ψ(HGHT) p(.)	106.00	6.1166	0.0167	3	0.2949 (0.0644)
Ψ(GOVO) p(.)	106.49	6.6154	0.0130	3	0.2983 (0.0626)
Ψ(SNAG18+GOVO) p(.)	106.96	7.0836	0.0103	4	0.3014 (0.0621)
Ψ(.) p(.)	107.00	7.1173	0.0101	2	0.3020 (0.0639)
Ψ(MO) p(.)	107.13	7.2500	0.0095	3	0.2984 (0.0620)
Ψ(SNAG18) p(.)	107.29	7.4135	0.0087	3	0.3033 (0.0635)
Ψ(GRAZ) p(.)	107.45	7.5749	0.0080	3	0.3012 (0.0642)
Ψ(FCOV) p(.)	107.47	7.5856	0.0080	3	0.3003 (0.0627)
Ψ(HGHT+GRAZ) p(.)	107.58	7.6983	0.0076	4	0.2993 (0.0639)
Ψ(FCOV+GOVO) p(.)	107.93	8.0525	0.0063	4	0.2998 (0.0628)
Ψ(SNAG18+MO) p(.)	108.06	8.1754	0.0059	4	0.2997 (0.0641)
Ψ(FCOV+SNAGD18) p(.)	108.24	8.3556	0.0054	4	0.3005 (0.0644)
Ψ(GOVO+PTSED) p(.)	108.37	8.4933	0.0051	4	0.3014 (0.0633)
Ψ(GOVO+MO) p(t)	108.58	8.6987	0.0046	4	0.3024 (0.0638)
Ψ(PTSED) p(.)	108.63	8.7457	0.0045	3	0.2995 (0.0656)
Ψ(.) p(t)	108.81	8.9257	0.0041	7	0.2987 (0.0649)
Ψ(PTFORB) p(.)	108.88	9.0015	0.0039	3	0.2999 (0.0654)
Ψ(PTSED+PTFORB) p(.)	110.44	10.5597	0.0018	4	0.2991 (0.0645)

Table 5. PC factors (with high loadings in bold), eigenvalues, variance contribution of each factor , and factor grouping descriptions.

Variable:	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 6**
Elev	0.065	**0.789**	-0.359	-0.094	0.096	0.230
Acres	-0.259	-0.393	-0.013	0.195	**-0.540**	0.394
Hcov	0.486	0.212	**0.648**	0.018	-0.103	-0.121
PtGrass	**-0.548**	-0.350	-0.203	**-0.545**	-0.165	0.024
PtForb	0.083	-0.014	0.126	**0.453**	**0.684**	0.254
PtRush	0.161	-0.135	-0.330	**-0.564**	0.081	-0.248
PtSedge	**0.510**	**0.536**	0.266	0.101	-0.301	-0.219
Hght	0.321	0.023	**0.552**	0.319	-0.172	-0.193
Ptdry	**-0.807**	0.100	-0.030	0.092	0.122	-0.436
PtMoist	-0.026	-0.063	**0.679**	-0.223	-0.184	0.465
PtSat	**0.807**	0.226	-0.243	-0.206	-0.029	0.017
PtStw	**0.713**	-0.223	-0.262	-0.163	-0.023	-0.151
Mo	**0.928**	0.017	-0.081	-0.149	0.042	0.228
Goph	**-0.699**	0.106	-0.083	0.068	0.176	0.347
Vole	**-0.552**	**0.634**	0.177	-0.092	-0.128	-0.186
Goph&Vole	**-0.715**	**0.519**	0.163	0.048	-0.070	-0.023
FCov	0.140	**-0.507**	0.138	**0.572**	0.286	-0.196
Snagd	-0.059	-0.076	**-0.535**	**0.561**	-0.377	-0.048
Snagd18	0.163	0.194	-0.461	**0.655**	-0.290	0.054
Ptfir	0.223	**0.738**	-0.208	0.062	0.151	0.150
Eigenvalue:	5.080	2.892	2.313	2.221	1.367	1.138
Variance Proportion:	0.254	0.145	0.116	0.111	0.068	0.057
Grouping Description:	% Grass % Sedge Moisture Prey Base	Elevation % Sedge Prey Base Forest Cover % Fir	Herb Cover Herb Height % Moist Snag density	% Grass % Forb % Rush Forest Cover Snag density	Acres % Forb	None

Table 6. Site occupancy model and parameter estimation for PC factors according to Akaike's Information Criteria corrected for small sample size and dispersion (QAICc). ΔQAICc is the difference between the given model and the model with the lowest QAICc, and QAICc weight is the Akaike weighted value for the given model. The purpose of this table is to compare model weights, therefore parameter estimates are not shown.

Model:	**QAICc**	**ΔQAICc**	**QAICc weight**	**Number of Parameters**
Ψ(PC1+PC2) p(.)	103.29	0.00	0.2882	4
Ψ(PC1) p(.)	105.23	1.94	0.1091	3
Ψ(PC2) p(.)	105.41	2.12	0.0997	3
Ψ(PC1+PC4) p(.)	106.13	2.84	0.0698	4
Ψ(PC2+PC5) p(.)	106.16	2.87	0.0686	4
Ψ(PC2+PC4) p(.)	106.26	2.97	0.0654	4
Ψ(PC1+PC5) p(.)	106.28	2.99	0.0646	4
Ψ(.) p(.)	107.14	3.85	0.0421	2
Ψ(PC1+PC3) p(.)	107.28	3.99	0.0393	4
Ψ(PC2+PC3) p(.)	107.66	4.37	0.0324	4
Ψ(PC4) p(.)	107.90	4.61	0.0288	3
Ψ(PC5) p(.)	108.17	4.87	0.0252	3
Ψ(.) p(t)	108.93	5.64	0.0172	7
Ψ(PC4+PC5) p(.)	108.93	5.64	0.0172	4
Ψ(PC3) p(.)	109.23	5.94	0.0148	3
Ψ(PC3+PC4) p(.)	110.12	6.82	0.0095	4
Ψ(PC3+PC5) p(.)	110.37	7.08	0.0084	4

Table 7. Site occupancy model and parameter estimation for HSI values according to Akaike's Information Criteria corrected for small sample size and dispersion (QAICc). ΔQAICc is the difference between the given model and the model with the lowest QAICc, and QAICc weight is the Akaike weighted value for the given model. The purpose of this table is to compare model weights, therefore parameter estimates are not shown.

Model:	**QAICc**	**ΔQAICc**	**QAICc w**	**Number of Parameters**
Ψ(.) p(.)	120.30	20.4184	0.37	2
Ψ(.) p(t)	120.75	20.8662	0.29	7
Ψ(V3) p(.)	121.12	21.2365	0.24	3
Ψ(V1) p(.)	121.35	21.4661	0.22	3
Ψ(V4) p(.)	121.39	21.5086	0.21	3
Ψ(HSI Value) p(.)	121.42	21.5426	0.21	3
Ψ(V2) p(.)	122.34	22.4609	0.13	3
Ψ(V3+V4) p(.)	122.71	22.8308	0.11	4
Ψ(V1+V2) p(.)	123.56	23.6811	0.07	4

Table 8. Comparison of top site occupancy models for *a priori*, PC, and HSI analyses. Models are ranked according to Akaike's Information Criteria corrected for small sample size and dispersion (QAICc). ΔQAICc is the difference between the given model and the model with the lowest QAICc, and QAICc weight is the Akaike weighted value for the given model. The purpose of this table is to compare model weights, therefore parameter estimates are not shown.

Model:	**QAICc**	**ΔQAICc**	**QAICc weight**	**Number of Parameters**
Ψ(ELEV+SNAGD18) p(.)	110.36	0.00	0.4808	4
Ψ(ELEV+MO) p(.)	110.59	0.23	0.4275	4
Ψ(PC1+PC2) p(.)	114.02	3.66	0.0771	4
Ψ(.) p(t)	119.42	9.07	0.0052	7
Ψ(.) p(.)	118.82	8.47	0.0070	2
Ψ(V3) p(.)	119.66	9.31	0.0046	3

Appendices

Appendix A. Correlation matrix for all habitat variables. Absolute values of 0.5 or above between variables were considered high.

Correlation Matrix

	Elev	Acres	Hcov	Ptgrass	Ptforb	Ptrush	Ptsedge	Hght	Ptdry	PtMoist	Ptsat	Ptstw	Mo	Go	Vo	govo	Fcov	Snagd	Snagd18	Ptfir
Elev	1.000	-.268	-.050	-.172	.037	.026	.254	-.225	-.039	-.163	.334	-.011	.160	.128	.366	.094	-.436	.047	.218	.633
Acres	-.268	1.000	-.230	.213	-.118	-.154	-.229	.041	.002	.108	-.254	-.169	-.206	.148	-.117	.099	.047	.220	.105	-.322
Hcov	-.050	-.230	1.000	-.421	.060	-.088	.499	.525	-.283	.389	.368	.146	.357	-.321	-.014	-.252	.033	-.239	-.088	.039
Ptgrass	-.172	.213	-.421	1.000	-.405	.236	-.548	-.400	.308	.061	-.356	-.123	-.381	.311	.147	.176	-.218	-.086	-.307	-.363
Ptforb	.037	-.118	.060	-.405	1.000	-.134	-.136	.104	-.081	-.017	-.102	.001	.100	.121	-.071	.071	.336	-.024	.100	.019
Ptrush	.026	-.154	-.088	.236	-.134	1.000	-.213	-.120	-.083	-.103	.229	.381	.222	-.190	-.073	-.111	-.230	-.064	-.145	-.055
Ptsedge	.254	-.229	.499	-.548	-.136	-.213	1.000	.267	-.303	.039	.432	.167	.369	-.464	.178	-.309	-.124	-.072	.137	.328
Hght	-.225	.041	.525	-.400	.104	-.120	.267	1.000	-.185	.170	.078	.154	.206	-.223	-.050	-.092	.212	-.115	.109	-.006
Ptdry	-.039	.002	-.283	.308	-.081	-.083	-.303	-.185	1.000	-.261	-.590	-.567	-.873	.496	.474	.590	-.027	.062	-.107	-.119
PtMoist	-.163	.108	.389	.061	-.017	-.103	.039	.170	-.261	1.000	-.233	-.177	.039	.025	.095	-.065	-.094	-.292	-.316	-.166
Ptsat	.334	-.254	.368	-.356	-.102	.229	.432	.078	-.590	-.233	1.000	.584	.802	-.414	-.382	-.458	-.162	-.045	.100	.335
Ptstw	-.011	-.169	.146	-.123	.001	.381	.167	.154	-.567	-.177	.584	1.000	.712	-.463	-.395	-.355	.111	.059	.124	-.102
Mo	.160	-.206	.357	-.381	.100	.222	.369	.206	-.873	.039	.802	.712	1.000	-.526	-.502	-.614	.015	-.126	.109	.259
Go	.128	.148	-.321	.311	.121	-.190	-.464	-.223	.496	.025	-.414	-.463	-.526	1.000	.294	.628	-.170	.053	-.016	-.061
Vo	.366	-.117	-.014	.147	-.071	-.073	.178	-.050	.474	.095	-.382	-.395	-.502	.294	1.000	.546	-.400	-.051	-.058	.155
govo	.094	.099	-.252	.176	.071	-.111	-.309	-.092	.590	-.065	-.458	-.355	-.614	.628	.546	1.000	-.166	.145	-.047	-.092
Fcov	-.436	.047	.033	-.218	.336	-.230	-.124	.212	-.027	-.094	-.162	.111	.015	-.170	-.400	-.166	1.000	.165	.108	-.243
Snagd	.047	.220	-.239	-.086	-.024	-.064	-.072	-.115	.062	-.292	-.045	.059	-.126	.053	-.051	.145	.165	1.000	.664	-.067
Snagd18	.218	.105	-.088	-.307	.100	-.145	.137	.109	-.107	-.316	.100	.124	.109	-.016	-.058	-.047	.108	.664	1.000	.278
Ptfir	.633	-.322	.039	-.363	.019	-.055	.328	-.006	-.119	-.166	.335	-.102	.259	-.061	.155	-.092	-.243	-.067	.278	1.000

Appendix B. HSI variables, overall HSI value, and survey results for 2004 and 2005. Values in bold represent discrepancies of HSI model results with actual field results. In some instances, the variables V1 (snag density), V2 (tree cover), and V3 (vegetation height) push HSI values to zero, thus assigning sites as “unsuitable and occupied”.

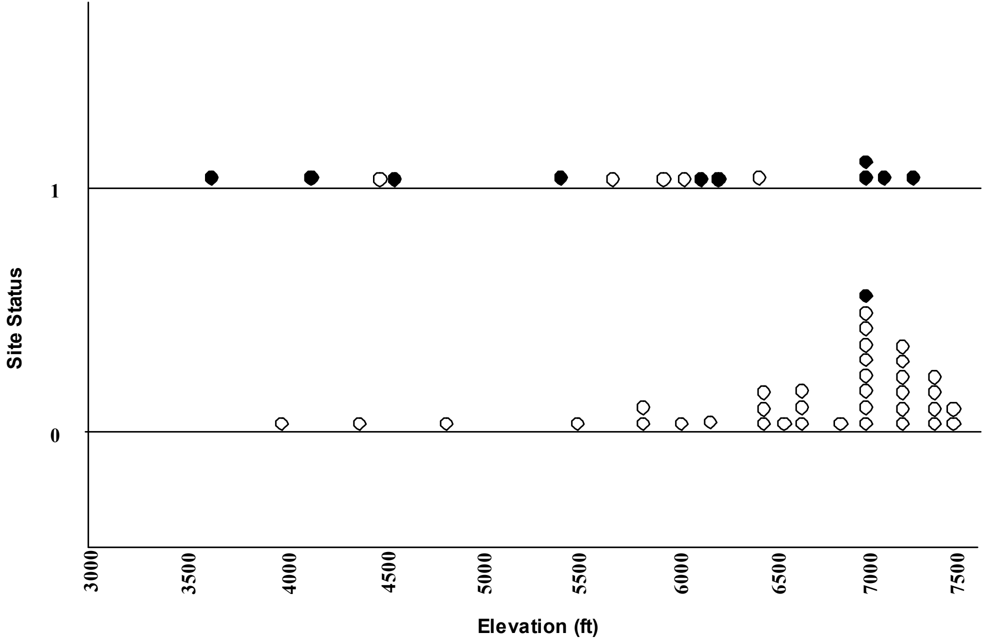
Site Number:	V1 (snag) :	V2 (tree cov):	V3 (veg hght):	V4 (veg cov):	HSI Value:	Survey Results:
Site 1	1	1	1	1	1	Single Female
Site 2	1	1	1	1	1	Pair
Site 3	1	1	1	1	1	Pair
Site 4	1	1	1	1	1	Single Adult
Site 5	1	1	1	1	1	Pair
Site 6	1.52	0.95	0.57	1	0.95	-
Site 7	1	1	0.68	1	0.91	Pair
Site 8	1.07	1	0.64	1	0.91	-
Site 9	0.61	1	1	1	0.88	Pair
Site 10	0.61	0.83	1	1	0.84	-
Site 11	0.61	0.8	1	1	0.84	-
Site 12	0.61	0.8	1	1	0.84	Single Male
Site 13	0.84	0.55	1	1	0.82	-
Site 14	0.61	0.7	1	1	0.81	Pair
Site 15	1	0.5	0.73	1	0.78	Pair
Site 16	0.38	0.93	1	1	0.77	-
Site 17	0.61	0.45	1	1	0.72	-
Site 18	0.27	1	1	1	0.72	-
Site 19	0.27	0.93	1	1	0.71	-
Site 20	1	0.98	0.25	0.95	0.69	-
Site 21	0.61	0.75	0.38	1	0.65	-
Site 22	0.16	1	1	1	0.63	-
Site 23	0.16	1	1	1	0.63	Breeding Pair
Site 24	0.16	0.98	0.86	1	0.6	-

Site Number:	V1 (snag) :	V2 (tree cov):	V3 (veg hght):	V4 (veg cov):	HSI Value:	Survey Results:
Site 25	0.16	0.83	1	1	0.6	Single Male
Site 26	0.16	0.75	1	1	0.59	Pair
Site 27	0.16	0.73	1	1	0.58	-
Site 28	1	0.1	1	1	0.56	-
Site 29	0.16	0.45	1	1	0.52	-
Site 30	0.1	0.65	1	1	0.51	-
Site 31	0.16	0.45	0.84	1	0.49	-
Site 32	0.38	0.8	0.11	1	0.43	-
Site 33	0.16	1	0.21	1	0.42	Pair
Site 34	0.16	1	0.19	1	0.41	Single Adult
Site 35	0.84	1	0.03	1	0.4	-
Site 36	0.16	1	0.1	1	0.35	-
Site 37	0.84	0.1	0.1	1	0.3	-
Site 38	0.61	0.63	0.02	1	0.29	-
Site 39	0.61	0.65	0	0.68	0	-
Site 40	0	0.75	1	1	0	-
Site 41	0	0.3	1	1	0	-
Site 42	**0**	1	1	1	**0**	Pair
Site 43	**0**	**0**	1	1	**0**	Single Male
Site 44	**0**	0.5	0.27	1	**0**	Single Adult
Site 45	**0**	0.45	0.51	1	**0**	Breeding Pair
Site 46	0.16	0.75	0	1	0	-
Site 47	0	1	0.57	1	0	-
Site 48	0.38	0.9	0	1	0	-
Site 49	0.38	0.7	0	1	0	-
Site 50	0	0.83	0	1	0	-
Site 51	0	0.53	0	1	0	-

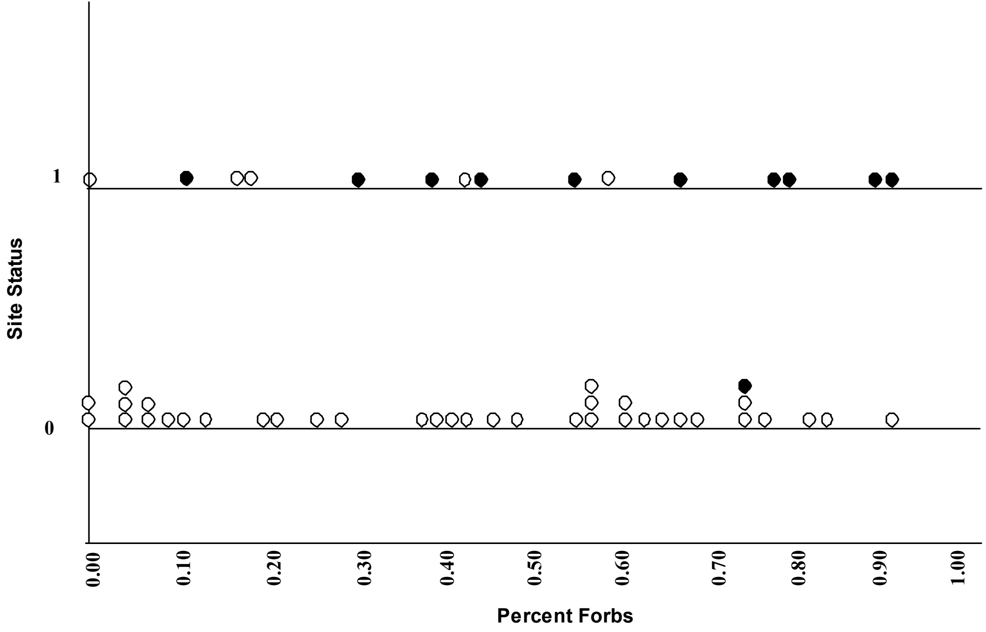
Site Number:	V1 (snag) :	V2 (tree cov):	V3 (veg hght):	V4 (veg cov):	HSI Value:	Survey Results:
Site 52	**0**	1	1	1	**0**	Pair
Site 53	0	1	1	1	0	-
Site 54	0	1	0	1	0	-
Site 55	0	1	1	1	0	-
Site 56	0.84	1	**0**	1	**0**	Pair
Site 57	0.16	0.95	**0**	1	**0**	Single Male
Site 58	0	0.85	1	1	0	-
Site 59	0	1	0	1	0	-

Appendix C. Stacked dot plots of 8 a priori variables showing relationships between presence (1) and absence (0) in sites inside (closed dots) and outside (open dots) the core range: a) elevation (ft), b) percent forbs, c) percent sedge, d) meadow vegetation height (cm), c) moisture index, e) gopher and vole abundance, f) percent forest canopy cover, and g) snag density >18in DBH per hectare.

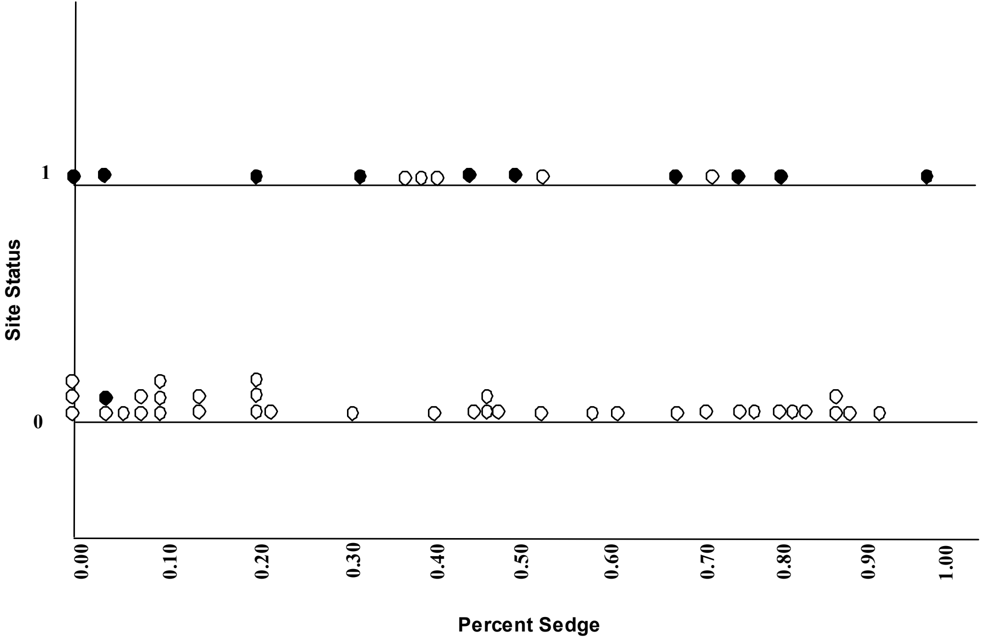
a) elevation (ft)



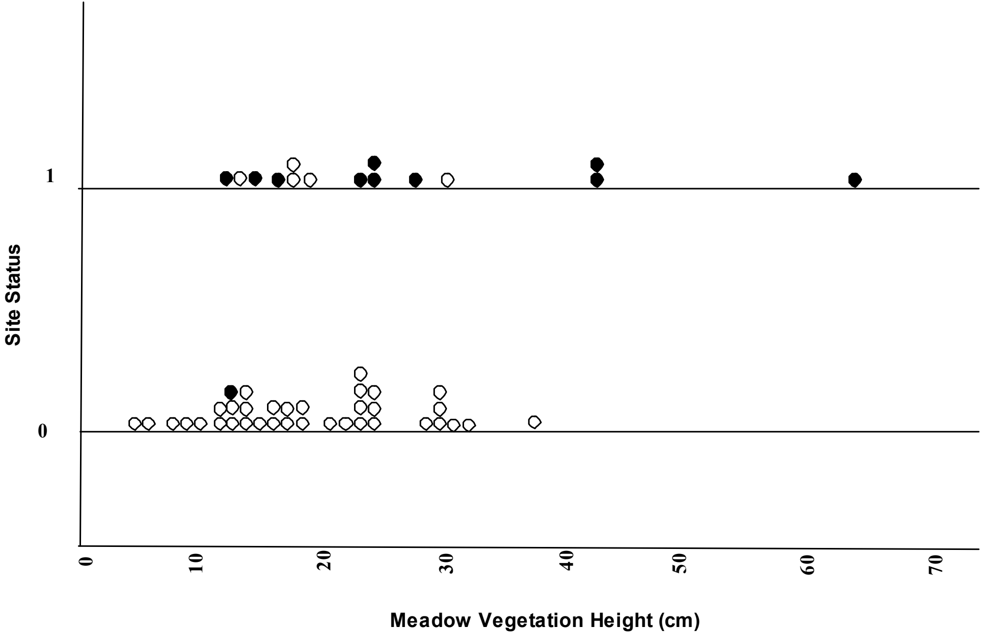
b) percent forbs



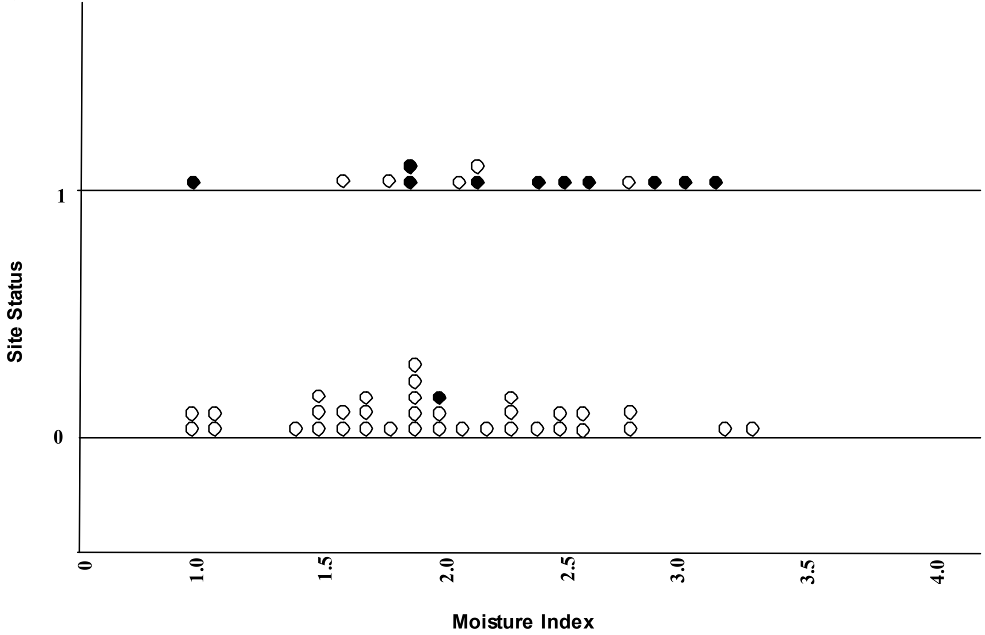
c) percent sedge



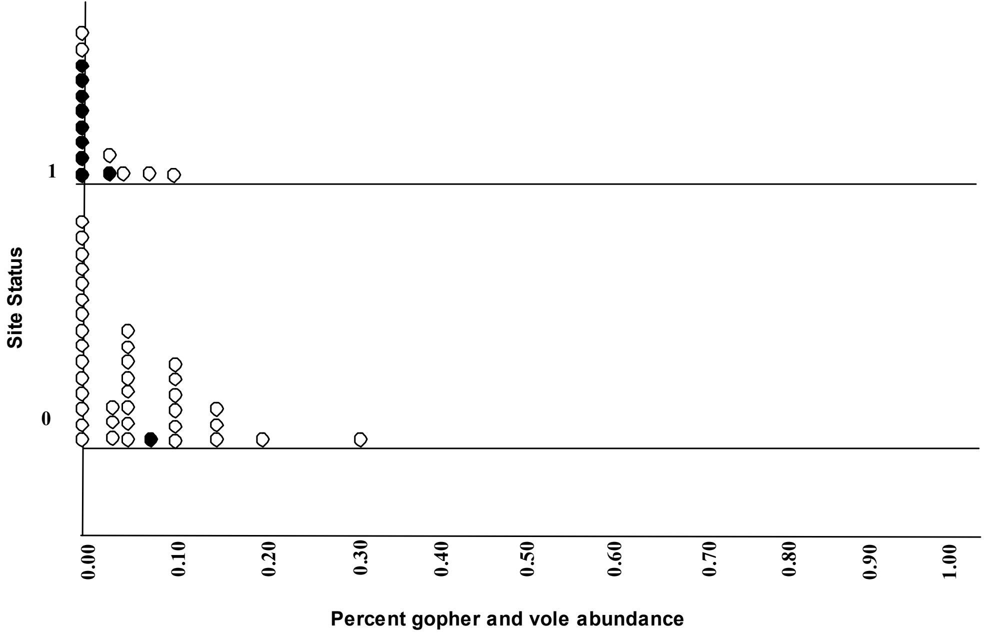
d) meadow vegetation height (cm)



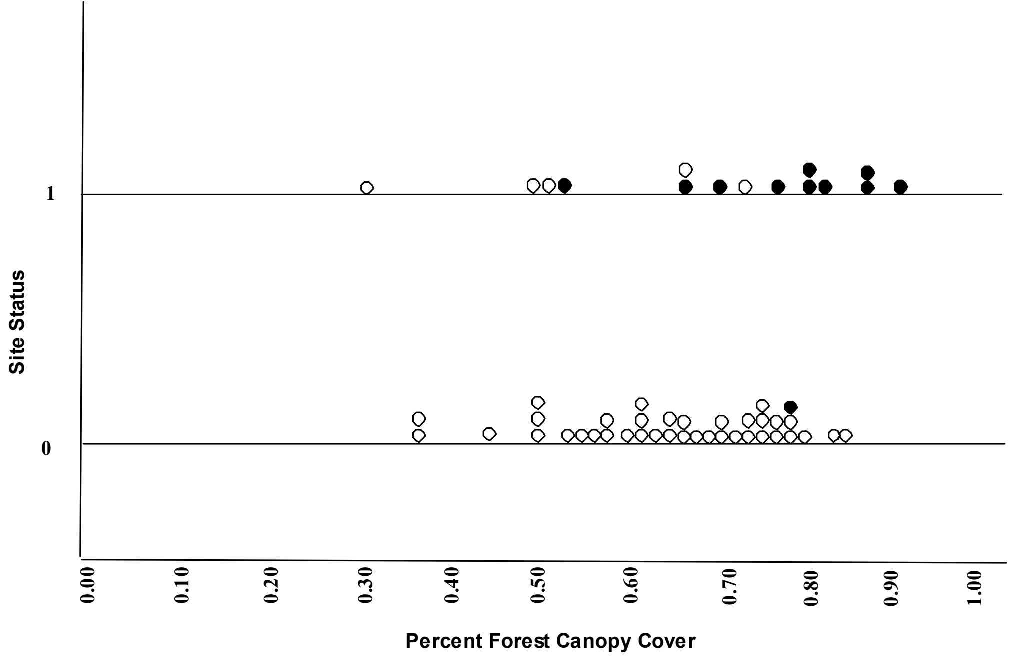
c) moisture index



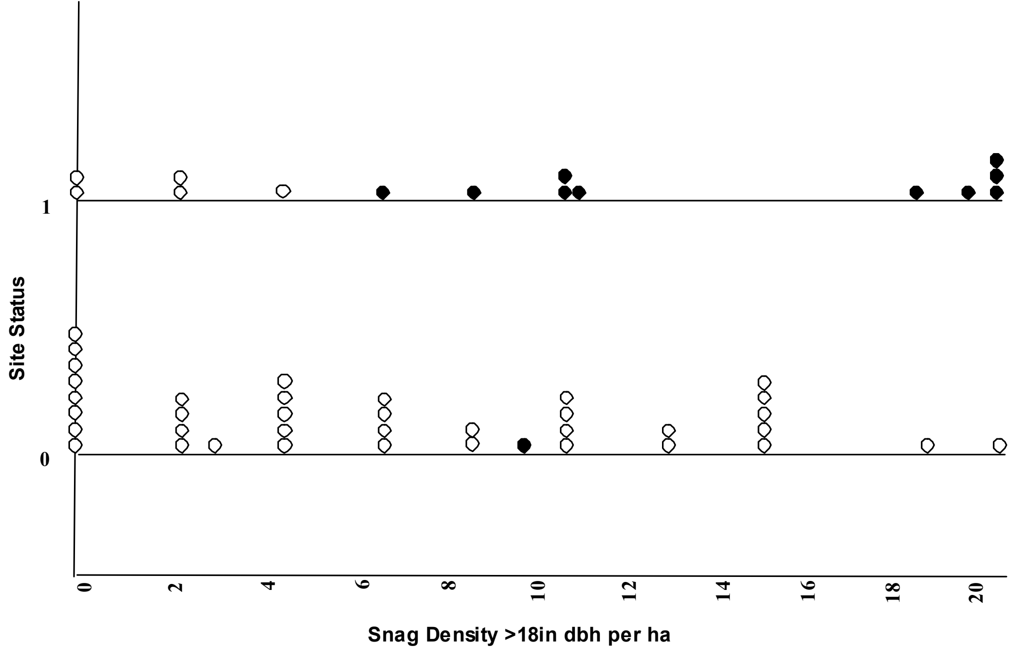
e) gopher and vole abundance



f) percent forest canopy cover



g) snag density >18in DBH per hectare



Appendix D. Great Gray Owl Survey Protocol Revision Recommendations Incorporating Detection Probability.

1. Introduction

Survey protocols are essential players in the role of species conservation. Researchers and managers utilize protocols to monitor populations, assess population numbers and distribution, and much more. Understanding great gray owl populations in California has become an important goal since the species was listed as State Endangered in 1980 due to population declines (Winter 1980). Developing effective protocols is one of the first steps to understanding the dynamics of this threatened population.

The current survey protocol for great gray owls was formulated by many experts in the field, and requires six visits per year to a site, for two consecutive years, to determine occupancy status (Beck and Winter 2000). Assuming an average of eight hours survey time per site (including travel time to and from and actual survey time), we can approximate a 48 hour investment per site, per year, per surveyor. However, many projects are limited in resources, such a money and time, making these guidelines hard to meet.

Each survey period is timed to the seasonal cycle of great gray owls. The earliest visits coincide with courtship, incubation, and brooding, while the later visits coincide with the fledging and the fall molting cycle. According to various experts in the field, the first visit is often impracticable due to limited and difficult access in Sierra snow conditions. However this visit is considered the most important due to the increased territoriality of great gray owls during courtship behavior (Beck and Winter 2000). Furthermore, experts note successful detections in subsequent visits vary in degree within a season. That is, some visits seem to be more successful at detecting owls than others.

Assuming these statements are accurate, survey protocol should be examined to assess success at detecting owls and feasibility of performing surveys. An effective protocol not only saves valuable resources, but will allow wildlife managers and conservation biologists to more successfully monitor the Sierra population of great gray owls, and ultimately protect them from further decline.

McArdle (1990) developed a method to determine the number of visits required at a site by incorporating error estimates into the assumption of a species' absence with a specified confidence. That is, the study developed a method to address questions relating to the number of surveys needed with negative results to be confident a species is actually absent from a site and not merely overlooked. For example, if we want a 95% confidence level to determine if a site is unoccupied, we set $\acute{\alpha} = 0.05$ and use the equation:

$$\text{Nmin} = \log \acute{\alpha} \,/\, \log (1-p) \qquad (1)$$

Where p is the estimated detection probability, and Nmin is the resulting minimum number of visits to attain the specified confidence level.

Kery (2002) applies this method on several snake species that have low detection rates. However the study goes one step further by using a generalized linear mixed model able to assess the relationship between detection probability and variables such as habitat type, size of site, population size, and time of visit.

Our main objective in this study is to examine overall survey protocol for effectiveness and variability in survey visit detection rates. To achieve this goal we will: (1) use simple occupancy models to obtain an estimate on the detection probability (p); and (2) determine the number of visits required to a site to establish occupancy status. Original objectives incorporated survey specific covariates, such as temperature and survey initiation time, to evaluate detection probability estimates and variables affecting survey visit success. However, due to an absence of temperature and initiation time data for all sites included in the dataset, we were unable to evaluate variables that may affect detection probability at this time.

2. Methods

2.1 Study Area

We collected survey and habitat data in the Sierra Nevada mountain range in California in areas across its entire expanse, including sites in Plumas, Tahoe, Eldorado, Sierra, and Sequoia National Forests, and Yosemite National Park. All sites were surveyed by CDFG crews with the exception of those within Yosemite National Park. Yosemite sites were surveyed by a NPS biologist and Forest Service crew in 2005. All surveys followed the same protocol and are therefore comparable in nature.

2.2 Survey Protocol

We adopted survey guidelines primarily from the more extensive USDA Forest Service protocol (Beck and Winter 2000). Walking and driving transects were used for surveys depending on road access and meadow structure. Walking routes were placed along meadow borders, just inside the forest canopy. Driving routes were placed within 200 m of the meadow's edge. All survey points were spaced 0.15 to 0.20 miles apart. A calling device was used to generate broadcast calls played at each survey point. The calling sequence at each survey station lasted eight minutes followed by 2 minutes of quiet listening time.

We conducted two to six visits at each site per year, generally in March to September. According to Beck and Winter (2000) the most valuable visit is thought to be during courtship, due to territoriality of the males. Therefore, we made concerted efforts to conduct two to three nighttime visits during the early nesting season (courtship and incubation periods), occurring from sunset to 1 or 2 am. In addition, one to two nighttime visits took place within the late nesting season (brooding and post-fledge periods), occurring 2 hours before sunset lasting through 2-4 hours past sunset. At most sites we conducted a final visit during the day as a meadow search. During this time the surveyor(s) searched for molted feathers, regurgitated pellets, whitewash on snags and under roost sites, foraging perches within or near the meadow, and visual or auditory detection of an owl. A positive identification was confirmed only by visual or audio detection, or the presence of feathers.

2.3 Site Sampling

We utilized knowledge of great gray owl habitat preferences to produce a GIS-based habitat suitability model, which was then used to select survey sites in the Sierra Nevada of California outside the owl's core range. Habitat preferences were derived partially from the Habitat Suitability Index (HSI) model and management prescription for the Great Gray Owl in California (Beck and Craig 1991), and partially on habitat requirements known from the past research in California (Winter 1986, Greene 1995). The HSI model was designed to predict habitat that is "comprised of mature or old-growth conifer forests with dense canopy and numerous snags in close proximity to large meadows or meadow systems" (Beck and Craig 1991). Based on a portion of the HSI model criteria and known habitat preferences, we used variables for canopy closure (USDA Forest Service Calveg 2000 Vegetation layer), meadow size (CDFG Sierra Nevada Meadow Map layer), and Wildlife Habitat Relationship System (WHR) density and size classification in GIS software to rank each meadow according to level of suitability. We then selected sites representative of all status types for owls (i.e. known, unknown, and historic), giving priority to sites with higher suitability ranks.

We surveyed both sites with historical use by great gray owls and sites where use by great gray owls was unknown. In total, 60 sites were surveyed for owls and sampled for habitat components in 2004 and 2005. Sixteen sites were sampled within the core range, and 44 were sampled outside of that range (including known and unknown occupancy status) (Figure 1). Eight of these sites were excluded from the dataset due to lack of partial data or duplicate surveys over multiple years. Therefore the total number of sites used in subsequent analyses was 52. The GIS-based model was not used to select sites inside the core, but rather were selected based on historic owl presence to increase sample size.

2.4 Data Analysis

Following MacKenzie et al. (2002), we used site occupancy modeling to estimate detection probabilities. We ran two simple models using the 2004 and 2005 52-site dataset for areas inside and outside the core range, where Ψ was constant over time and p was either constant or variable over time ($\Psi(.)p(.)$ and $\Psi(.)p(t)$).

The models were run using the program PRESENCE 2.0, and thereafter ranked using Akaike's Information Criterion (AIC) (Burnham and Anderson 2002). We corrected AIC values for over or under dispersion (using c-hat; the quasi-likelihood parameter) and small sample size according to Burnham and Anderson (2002), hereafter referred to as QAICc.

To examine the number of visits required to ascertain great gray owl absence at a site, the time-constant detection probability estimate was used in equation (1). We then calculated the minimum number of visits to a site to affirm a site is not occupied during a survey season with a 95% confidence level by setting ά = 0.05.

3. Results

In 2004 we attempted to make six visits per site, and in 2005 the goal was to make at least four visits per site. Both years had an unusually high snow-load and late melt-off date making access problematic, particularly so in 2005. Ultimately, limited access to sites decreased the number of surveys conducted over both years. Sites received on average 4.6 visits per year (2-6 visits/site/year) with a higher concentration of visits later in the season.

Between the simple models, time dependence ($\Psi(.)p(t)$; QAICc weight = 0.8547) was better supported (Table A), and had a detection probability of 0.5862 (Table B). Using this parameter in equation (1), Nmin equaled 3.40, indicating that one must make at least 4 survey visits per site to affirm absence with a 95% confidence. The time dependent detection probabilities for the model $\Psi(.)p(t)$ were 0.7454, 1.000, 0.6014, 0.2264, 0.6546, and 0.7498 for visits 1 through 6 respectively (Table B).

4. Discussion

Survey protocol success is important to understanding owl distribution and abundances. Management and conservation plans depend on protocols that use resources sparingly while maintaining a level of effectiveness. The number of visits per site and confidence in species detection are important considerations.

Our study showed varying degrees of detection probability among visits; the 1st, 2nd, and 6th visits had higher detection probability, the 3rd and 5th had moderate detection probability, and the 4th visit had the lowest detection probability. These visits correspond to seasonal life cycles of breeding great gray owls (Table C). It is reasonable the first and second visit (courtship/incubation) and last visit (post-molt) show high detection probability. Male owls tend to be more territorial during the courtship period and readily respond to playback calls (Beck and Winter 2000). The last visit consists of a daytime search to look for signs of owl presence. If owls have been using the site regularly it is relatively easy to find molted feathers in the vicinity.

Moderate detection probabilities were found for the post-fledge period (visit 5), which denotes the time after which the young fledge from the nest but remain dependent on the parents for food. Visit 5 is a highly vocal period for the young as begging for food is regular. Broadcast calls played during this time include begging calls of the young and female nest chatter. It is thought that playing these calls will readily instigate vocalizations from the young, if in fact young are present. Young were only found at two sites during 2004 and 2005 surveys, however, they did respond to the broadcast calls through immediate and intense begging calls.

The brooding period (visit 4) shows a much lower detection probability. If breeding, during this time the owls have settled into caring for the young. Females rarely leave the nest at this point, and males are busy finding for the female, young, and himself (Bull and Duncan 1993). It is possible during this period responses are further reduced due to predator evasion, as the young and mother are more susceptible to attacks from great horned owls, ravens, and various other raptors. The number of successful breeding sites was low during the length of the study, therefore some other undetected factor must have been acting to reduce detection probabilities during this period.

We would expect visit 3 (incubation) to also have a low detection probability similar to visit 4, however this was not the case. If adults were tending an active nest, we would expect a lower detection probability, especially from the nest area. However, the seemingly low breeding activity and success would generate a higher detection rate than expected under high breeding activity.

Current protocol calls for six visits per site per year to determine residency of great gray owls. This equates to twelve visits, averaging 48 hours investment per site per year (approximately 8 hours/visit counting survey time and travel time). Taking into account the time-constant detection probability (0.5862), our results indicate number of surveys can be reduced from 6 to 4 while maintaining a 95% confidence the species is absent if recorded absent for all surveys. We recommend limiting surveys to include visits 2, 3, 5, and 6. This would decrease resource investment by approximately 33% while assuring a certain degree of confidence. If however early season access is granted, visit 1 is preferable to visit 3.

By reducing number of surveys required we can reduce the number of hours spent at a site, and ultimately reduce resource expenditures. In addition, by decreasing the number of surveys to a site we can allocate more effort into increasing survey coverage across the entire Sierra Nevada. This will allow information gaps, such as an understanding of complete distribution and population numbers, to be bridged. And lastly, the consequences of an effective survey protocol will aid efforts of wildlife managers and conservation biologist to develop management plans that will sustain the great gray owl population throughout the entire Sierra.

Table A. Simple occupancy models for PC factors according to Akaike's Information Criteria corrected for small sample size and dispersion (QAICc). ΔQAICc is the difference between the given model and the model with the lowest QAICc, and QAICc weight is the Akaike weighted value for the given model.

Model:	**QAICc**	**ΔQAICc**	**QAICc weight**	**Number of Parameter**
Ψ(.) p(.)	90.29	0.0000	0.8547	2
Ψ(.) p(t)	93.80	3.5143	0.1475	7

Table B. Estimates of detection probability parameters for simple occupancy models. Visits 1-6 are represented by the detection probability p1-p6 respectively.

Model:	**p1**	**p2**	**p3**	**p4**	**p5**	**p6**
Ψ(.) p(.)	0.5862	0.5862	0.5862	0.5862	0.5862	0.5862
Ψ(.) p(t)	0.7454	1.0000	0.6014	0.2264	0.6546	0.7498

Table C. Current survey protocol visit number relating to great gray owl breeding season cycles. Detection probability based on top two models shown for each visit.

Survey Protocol Visit Number	**Breeding Season Cycle Period**	**Detection Probability Estimates**
1	Courtship	0.6634
2	Courtship/Incubation	0.8325
3	Incubation	0.6804
4	Brooding	0.2810
5	Post-fledge	0.6074
6	Post-molt	0.8834

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