Project Completion Report

1. State: California

Grant number: F07AF00074 (T-16-1)

Grant name: Habitat assessment and monitoring protocol for Sooty Grouse in the Sierra Nevada.
Project number and name: same as grant name.

2. Report Period: September 1, 2007 – June 30, 2013.

Report due date: September 28, 2013
Date of this Completion Report: September 16, 2013.

3. Location of work: Pinecrest, Summit Ranger District, Stanislaus National Forest, Tuolumne County, CA. The 167 km^2 study area was centered near Pinecrest Peak, Stanislaus National Forest, Tuolumne County, California (38E14'N, 119E56'W), on the western slope of the Sierra Nevada Mountains (Figure 1). Peaks and ridges within the area reached 2,600-2,800 m elevation. The lower boundary was set at 1,775 m elevation, ~360 m below the presumed lower limit of grouse in the region (Grinnell et al. 1918). Predominant forest types included Sierran mixed-conifer (<~2,200 m), red fir (~2,200-2,700 m), and lodgepole pine/subalpine conifer (>~2,700 m) (USFS Existing Vegetation Maps). The eastern third of the study area was located within Emigrant Wilderness Area and was relatively pristine. Elsewhere, logging, including clear-cut logging, had been widespread, but generally conducted at a small scale (1-10 ha). The entire area was usually covered with 1-4 m of snow from late November through early April

4. Objectives:

A. Determine 1) the seasonal and sex- and age-specific habitat associations of Sierra Sooty Grouse, and 2) the spatial and topographic relationships between these habitats.

B. Characterize movement patterns between seasonal habitats.

C. Determine the degree to which Sierra Sooty Grouse are associated with old forests, large trees, and mountain meadows.

D. Develop a GIS-based habitat model that will facilitate prediction and management of Sooty Grouse habitats throughout the Sierra Nevada.

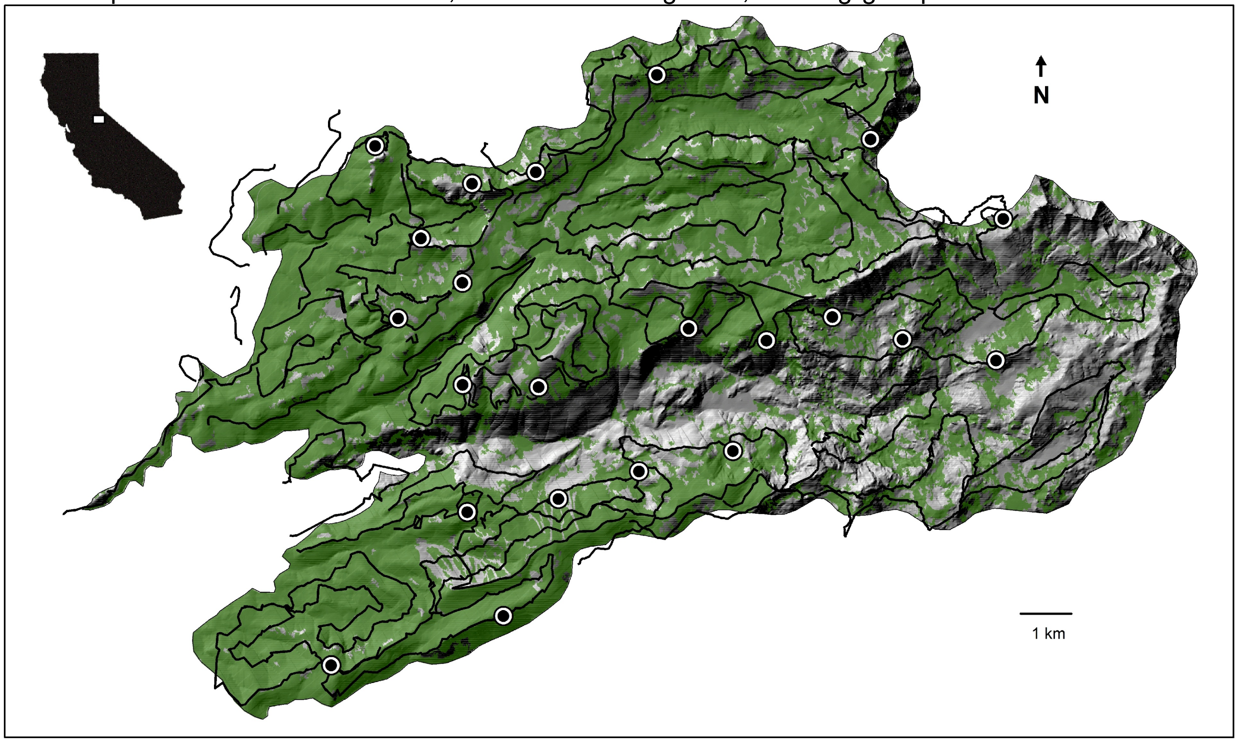
E. Develop new Sooty Grouse population survey protocols.

5. Part of Larger Project: This project is funded entirely by State Wildlife Grant funds and identified matching State funds, and is not part of a larger undertaking with other components and funding.

6. Describe how the objectives were met:

Methods:
Two complementary counting procedures were employed to census grouse throughout

Figure 1. Pinecrest study area. Green indicates areas with ≥10 % forest cover; solid lines, landscape-scale census transects; circles enclosing dots, hooting groups.



the study area, one for counting groups of hooting males at the landscape scale (landscape-scale transects) and another for counting individual males within those groups (group-scale transects). Landscape-scale censuses were conducted from 15 April-7 June, 2006-2009, along a network of line transects that intersected all forested portions of the study area (Figure 1). A single observer walked each transect on a single occasion, stopping every 300-500 m at prominent spurs or vantage points to listen for hooting grouse. If no hooting was audible, a recorded female "cackle" call was broadcast in each cardinal direction using an MP3 audio player with amplified speakers. Where hooting was detected, an *ad hoc* search was conducted to locate as many displaying grouse in the area as possible, using recorded female calls when necessary to re-initiate display. Location coordinates of displaying grouse were recorded with a handheld GPS unit while standing beneath the grouse's songpost tree. Afterward, the locations of displaying grouse were positioned on a georeferenced orthophotograph (digital orthophoto quarter quadrangle, Stanislaus National Forest) using GIS, and a transparent 100-m grid, with total dimensions of 1500 x 1500 m, was positioned over grouse locations for a given hooting group, and the photograph was trimmed to the 1500 x 1500 m grid to create a hooting group map. A group-scale transect line was then drawn on the map so it: 1) wove through successive territories, passing by known songposts at a distance of ~50-100 m, and 2) maintained a curtain of tree foliage between the observer and all known songposts. An observer slowly walked the full length of a group-scale transect, and then retraced it in the opposite direction. The initial pass served to rouse as many individuals as possible into heightened territoriality and display. Where no hooting was audible within 200-300 m, one or two cackle calls were broadcast at ~150-m intervals to induce any nearby silent males to display. Locations of displaying grouse were marked by hand onto a hooting group map. The number of persistently territorial males comprising hooting groups was estimated with standard spot-mapping methodology (Kendeigh

1944); by plotting detection locations on repeated censuses, identifying clusters of detections (within areas equal to a typical territory, ~1.5 ha), and using records of simultaneous singing to distinguish between two or more adjacent territories. Census methods are described in greater detail by Bland (2013). Fourteen adult grouse (10 males, 4 females) were captured and fitted with 18 g necklace-mounted VHF transmitters (Advanced Telemetry Systems, Isanti, MN). Males were captured at breeding territories using a female decoy, recorded female calls, and a bow net (Superior Bownet, Clinton, MD). Females were captured by night-netting at nest sites. Radio-marked grouse were relocated year-round by homing, on an ~10-day schedule, until death (n = 6), disappearance (n = 1), battery expiration (n = 4, min. 429-655 d), or the cessation of monitoring efforts (n = 3). Seasonal movements, and seasonal and annual home ranges, were estimated for 8 males and 2 females that survived $\geq$1 breeding cycle, using ArcGIS 10 (ESRI Corp., Redlands, CA), Quantum GIS (public domain), and AdehabitatHR (public domain) computer software. Seasonal ranges of individual grouse were distinguished by long-distance movements (>2 km) that occurred 1) after weeks of relative sedentariness, and 2) during broadly-defined transition periods between spring, summer-fall, and winter.

Season- and sex-specific habitat associations were assessed at two geographic scales: patch-scale and micro-scale. Habitat assessments were made at detection locations that were acquired by radiotelemetry (all seasonal habitats), group-scale censuses (male breeding habitat), nest searches (nesting habitat), and incidental detection (brooding habitat). A total of 138 male breeding locations, 10 nesting locations, 35 brooding locations, 75 postbreeding locations, and 26 winter locations were assessed. Telemetry fixes that occurred within a 100-m radius circle were merged to an average location (per grouse), in order to maintain sampling independence. Patch-scale habitat associations were assessed with available geospatial databases, including layers for terrain (10-m digital elevation model, US Geological Survey), vegetation structure and composition (Existing Vegetation and California Wildlife Habitat Relationships, US Forest Service), roads and streams (US Forest Service), and timber harvest (Forest Activities Computerized Tracking System, US Forest Service). Patches were defined as areas of vegetation the US Forest Service has determined by aerial photo interpretation to have contiguous species composition and structure. These occur as classified polygons on US Forest Service Existing Vegetation maps (EVeg, CALVEG). Within the Pinecrest study area, EVeg polygons ranged from ~1.0-335.0 ha in area. Patch-scale analysis was conducted with ArcGIS 10 and MaxEnt (public domain) computer software. MaxEnt applies machine learning algorithms to presence data and random samples to predict the likelihood of presence within map grid cells. In developing each seasonal habitat suitability model, 15% of location data were retained to validate the model. The final spatially-explicit models represent average results for 15 replications of a model. Micro-scale habitat associations were assessed with terrain and vegetation data collected in the field at each detection location and at 138 systematically placed comparison plots. Comparison plots were established on a 750 m x 750 m grid covering all forested portions of the study area, excluding 1-km buffers around male breeding territories (and therefore represent a dependent systematic sample of the study area). Because male breeding territories occur in clusters, and at very low densities (Bland 2013), these systematically sampled sites were also considered an acceptable sample of all available habitats (for the purpose of contrasting occupied plots to representative samples). Each field plot consisted of a square 4.0-ha plot with a circular 0.1-ha plot at its center. Features of the forest canopy (e.g., canopy closure, extent of edge) were measured on the 4.0-ha plot, whereas measures of trees and understory vegetation were measured on the 0.1-ha plot. A list of all habitat variables measured at field plots is provided as an appendix. Statistica computer software (StatSoft Inc., Tulsa, OK) was used to: 1) conduct univariate comparisons of seasonal micro-habitats, using Mann-Whitney *U* tests, 2) reduce the number of model variables by assessing regression coefficients of all effects non-linear regression models, and 3) assess the five best regression models for distinguishing seasonal micro-habitats from systematically sampled sites, using best subsets logistic (binary) regression. The Akaike Information Criterion was used to rank the resulting models (Burnham and Anderson 2002). All regression models for micro-scale habitats should be considered exploratory, as their discriminatory power was not verified.

Findings

Objective E *- Survey protocol and population census.*

No standardized census method existed for Sierra Sooty Grouse prior to this study, so one was developed from pioneering audio census work by J. Bendell (Stirling and Bendell 1966) and F. Zwickel (1982). The method accounts for several aspects of Sooty Grouse breeding biology that can impair auditory censuses, including low population density, clumped dispersion of breeding males, seasonality of singing, and anomalous singing by yearling males. It was found that censuses must be initiated after 1 May in order to minimize detection of anomalous early-season singing by yearling males, which could bias counts upward. Detections of yearling males can be eliminated from counts by maintaining a minimum 5-day interval between census repetitions, because yearling males only display for a few days. Censuses must also be completed by 15 June in order to reliably detect adult males who become increasingly reluctant to display after mid-May, potentially biasing counts downward. It was determined that 3-4 well-timed counts were sufficient for an accurate count. These and other logistical constraints are discussed in detail in the attached Draft Survey Protocol (Bland 2008). The final survey protocol is presented in an paper accepted for publication in Western Birds, titled "Estimating the number of territorial males in low-density Sooty Grouse populations" (Bland 2013).

The new census protocol was used to conduct repeat censuses in 2009 and 2011. Twenty-two hooting groups, or clusters of breeding males, were detected along landscape-scale transects (Figure 1). Fifteen of these groups were censused by spot-mapping between 19 April and 12 June, 2009 (available manpower limited the number of groups that could be censused). The average distance between centers of nearest-neighbor groups was 1916 m (range = 1239-3676 m, SD = 680). Average group size was 4.9 individuals (range = 2-10, SD = 2.7), and the average distance between centers of nearest-neighbor territories within a group was 209 m (range = 75-638 m, SD = 166 m). The probability of detecting an individual territorial male on a single census visit averaged 0.71 (range = 0.33-1.0, SD = 0.24). The cumulative probability of detection was 0.92 on the second census repetition, 0.98 on the third repetition, and 0.99 on the fourth repetition. The overall density of breeding males across the entire 167 km^2 study area was estimated to be roughly 0.6/km^2, based on the combined results of group-scale censuses at 13 groups and *ad hoc* counts and incomplete censuses at the 9 remaining groups. Eleven hooting groups were re-censused in 2011 (04 May-13 June), and the estimated number of territorial males was not statistically different from the 2009 estimate, indicating the Sooty Grouse population at Pinecrest had remained static over that 3-year period. Bland (2013) describes results of the repeat census in greater detail.

Objectives A (part 2) and B) - Home range and seasonal movements.

Annual home ranges averaged 1,158.5 ha (49.7-2,732.2 ha) by minimum convex polygon methods (95 % of fixes) and 748.1 ha (129.5-1,326.9 ha) by fixed kernel methods (95 % utilization). Annual home range size did not differ between sexes. Seasonal home range sizes are given in Table 1. Male breeding ranges and female brooding ranges were larger at Pinecrest than reported elsewhere (Table 1), but the differences could be largely attributed to the use of different definitions or methods.

Table 1. Average seasonal home range size (minimum convex polygon).

Range type	Size in ha at Pinecrest (range)	Size in ha reported elsewhere
Male breeding (n = 7)	6.1 (0.6-21.1)	0.6-2.1 (British Columbia)
Female brooding (n = 2)	420.0 (26.5-813.1)	3.2-39.1 (British Columbia)
Postbreeding (n=9)	344.4 (4.8-1085.7)	none
Winter (n = 6)	15.1 (1.8-66.5)	2.0-90.0 (Oregon)

Breeding and wintering sites of radio-marked grouse occurred throughout the same general zone (~2000-2700 m elevation). The annual circuit of most individuals was more extensive horizontally than vertically. Wintering sites were, on average, only slightly higher than breeding sites (2347.8 vs. 2267.3 m, respectively; non-significant). Two individuals did not change elevation from spring to winter, and one moved to lower elevations in winter. The breeding and wintering sites of individual grouse were usually located in adjacent canyons. Frequently, male breeding areas were occupied in winter by individuals that had bred elsewhere. Five individuals (50 %; 3 males and 2 females) moved seasonally between geographically distinct breeding, postbreeding, and wintering areas (Figure 2). Other individuals remained in one area during two successive seasons (Figure 3). The average straight-line distance moved between seasonal ranges was 5.1 km (range = 0.8-12.7 km). The greatest altitudinal movement occurred between breeding and postbreeding areas, when individuals gained an average of 237 m elevation. The upward movement was probably related to seeking cooler, more mesic, environments in late summer. At the end of the postbreeding season, individuals descended an average 132 m to wintering areas.

Figure 2. Example of an annual circuit that included dispersed breeding, postbreeding, and wintering sites.

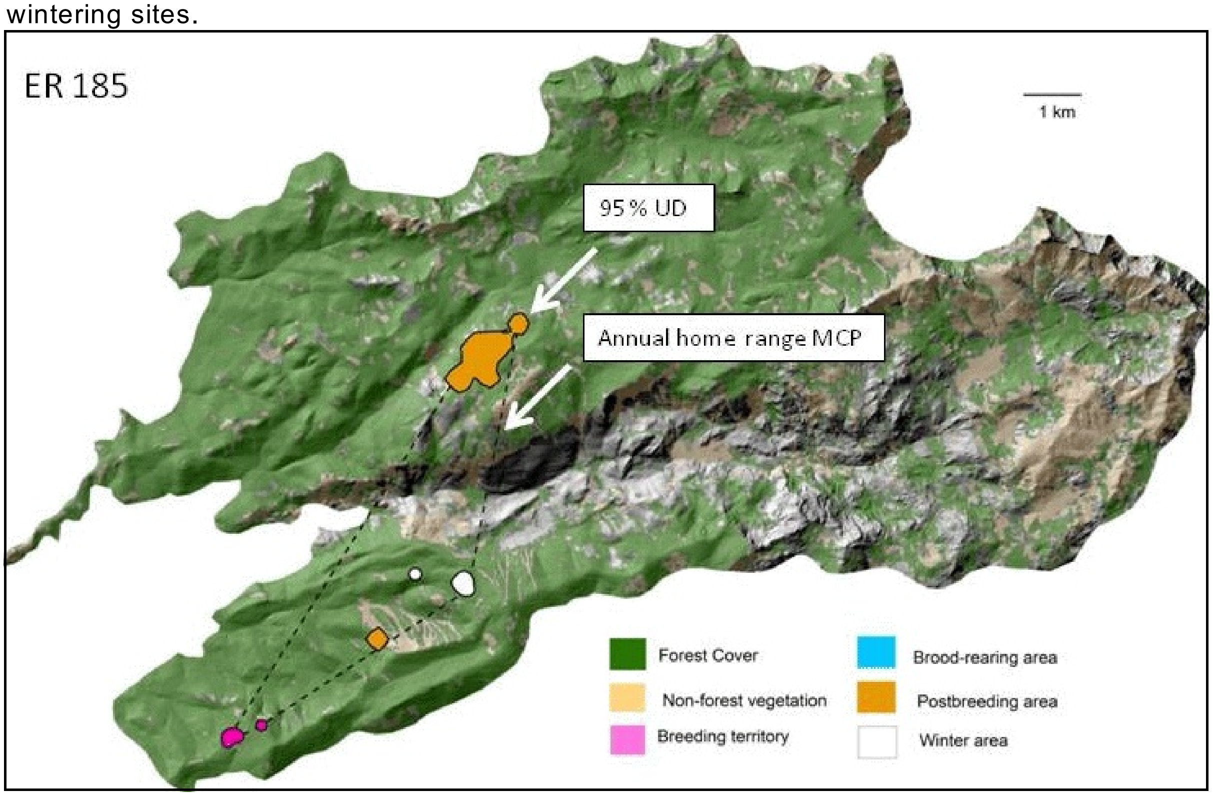
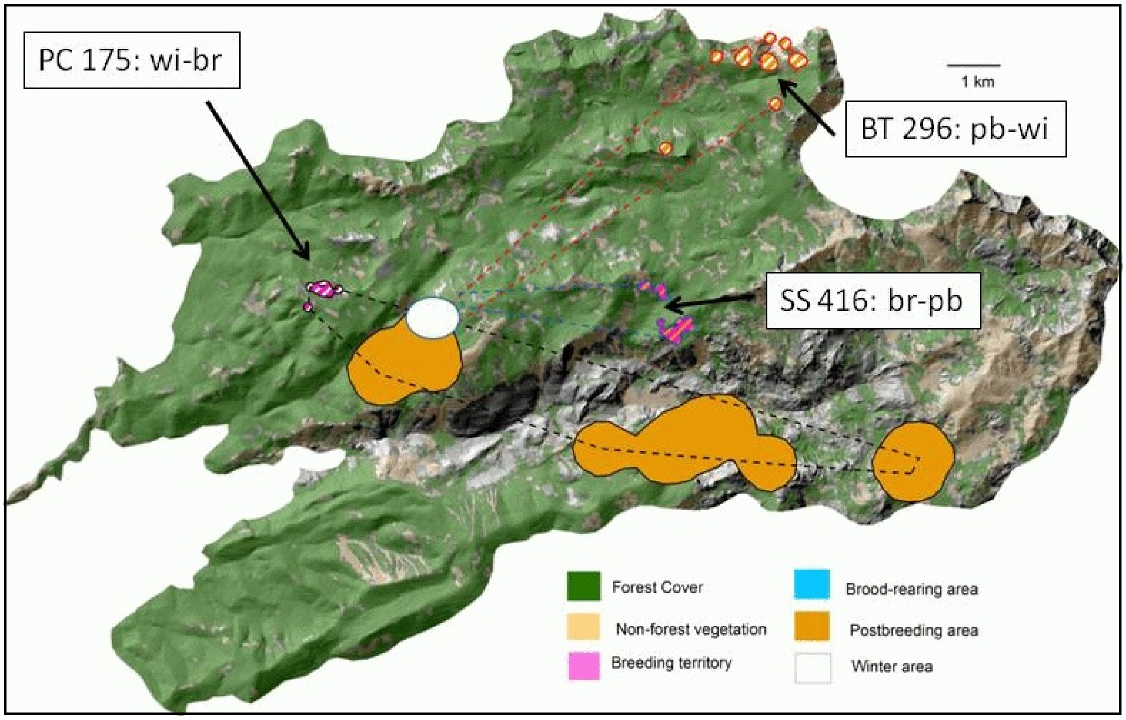


Figure 3. Annual circuits of individuals that remained in one area over two successive seasons.



Objectives A (part 1) and D - *Seasonal sex- and age-specific habitat associations.*

Male breeding habitat. At the patch scale, elevation, canopy density, solar radiation, and harvest history contributed most significantly to the MaxEnt suitability model for male breeding habitat (Table 2). A spatially-explicit application of the model is depicted in Figure 4. At the micro-habitat scale, 50 variables were found to differ significantly between male breeding sites and systematically sampled sites (Table 3).

Table 2. Variables that best distinguish male breeding habitat at the patch scale.

Elevation. 59.7 % contribution. Where elevation is ~2075-2350 m, the model predicts the probability of presence is >0.50. Suitable range (blue = standard deviation):

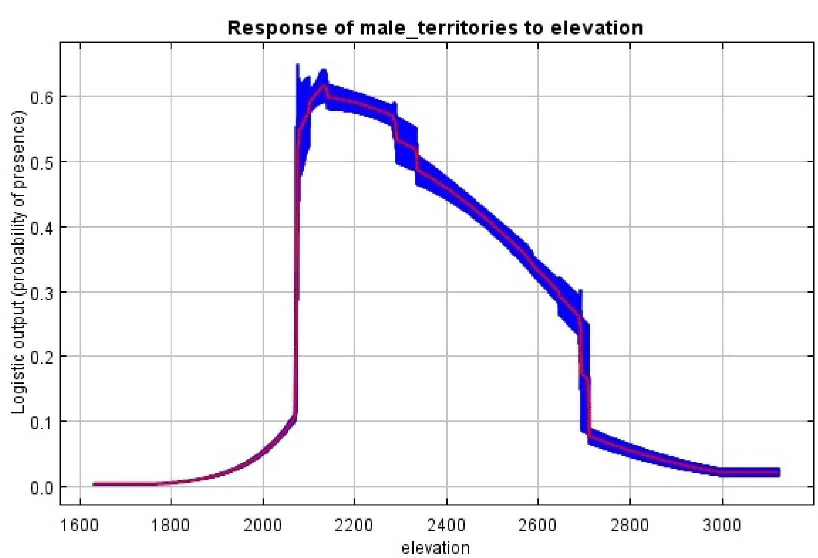
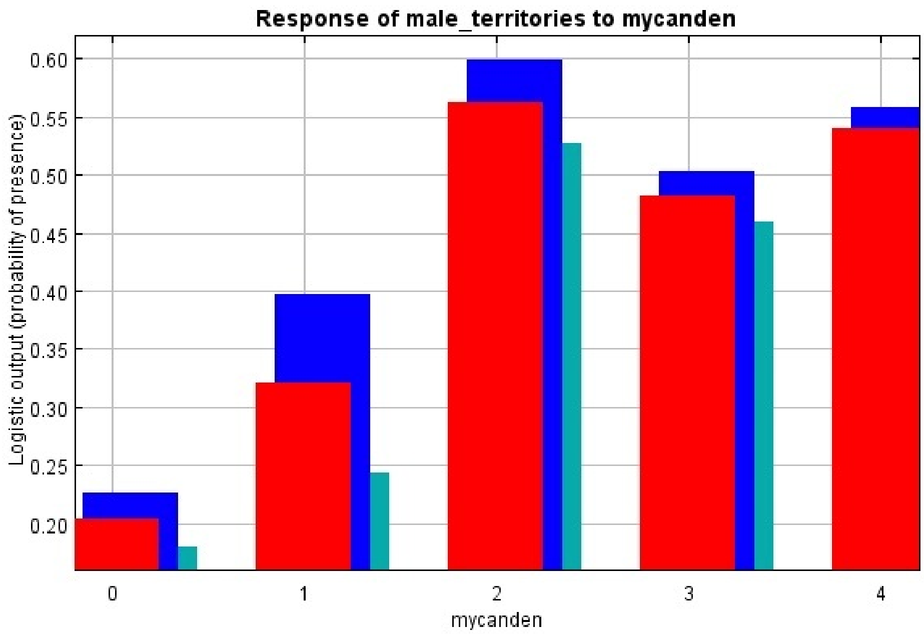


Table 2. Continued.

Canopy density. 26.1 % contribution. Where canopy density is ~25-39 %, the model predicts the probability of presence is ~0.56, ~0.54 where density is >60 %. Suitable ranges (blue = standard deviation):



Solar radiation in March. 11 % contribution. Where solar radiation during March is >1.4 x 10^5 WH/m^2, the model predicts the probability of presence is >0.50. Suitable range (blue = standard deviation):

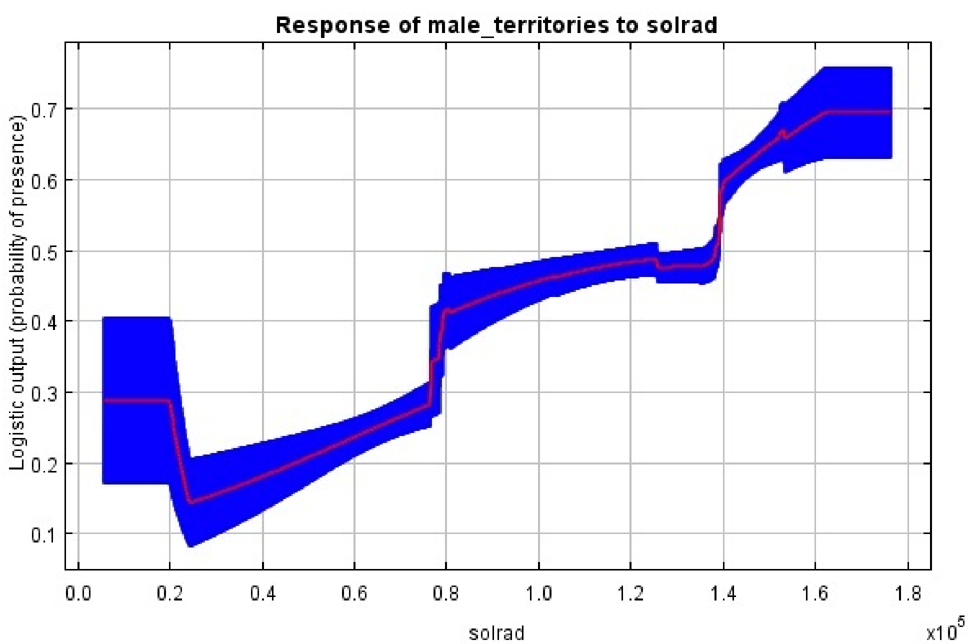


Table 2. Continued.

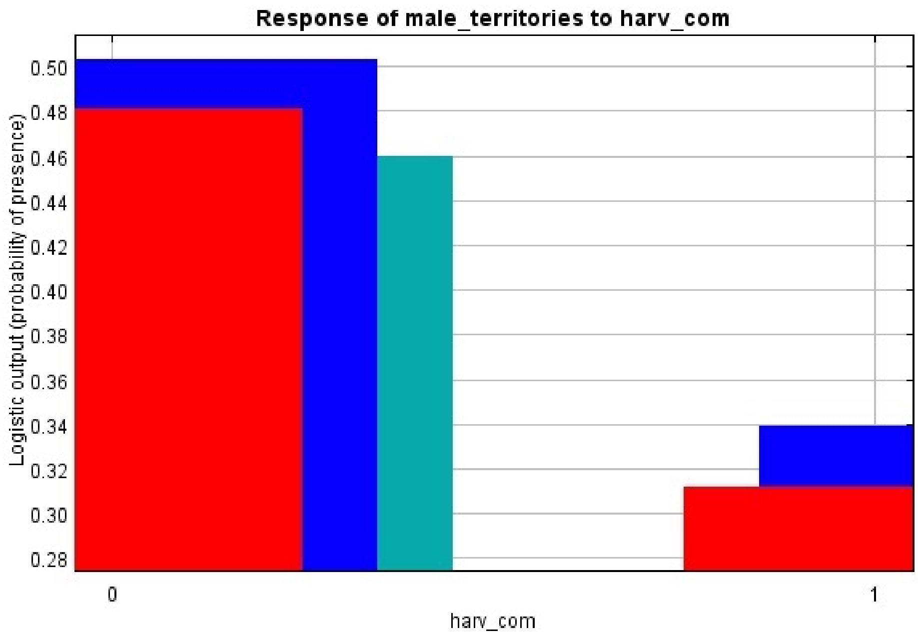
Harvest history. 3.2 % contribution. Where commercial timber harvest has occurred, the model predicts the probability of presence is only ~0.31. Suitable range (blue = standard deviation):


Figure 4. Spatially-explicit suitability model for patch-scale male breeding habitat.

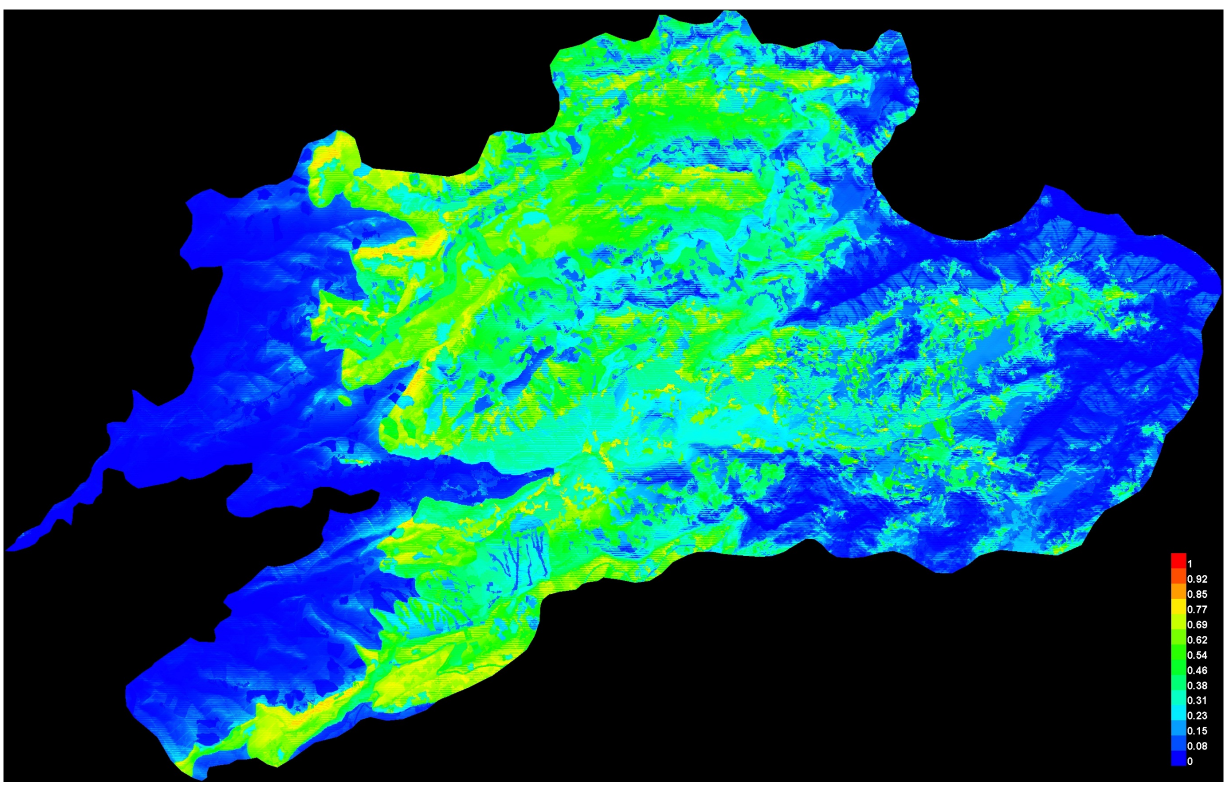


Table 3. Micro-scale habitat variables that differed significantly between male breeding sites and systematically sampled sites (univariate Mann-Whitney *U* test, *P* <0.5).

Variable	MW-U adj. z-score	Occupied mean (mode)	Unoccupied mean (mode)
Physical environment			
% slope	6.141	29.3	21.0
Vert. dist. to canyon bottom (m)	5.583	1375.1	922.8
Position on slope (1=lower 1/3, 3=upper 1/3)	4.283	(3)	(3)
Slope contour (1=gully, 3=spur)	3.331	(2)	(2)
North Aspect (N=180, S=0)	2.548	75.0	93.7
Vert. distance to ridge (m)	2.297	644.1	857.7
Forest canopy			
Total edge (m)	4.033	1949.8	1557.4
Perimeter of >60 % closure (m)	3.981	1639.6	1278.5
Edge between areas 10-60 % & >60 % closure (m)	3.774	556.7	385.8
Canopy closure @ plot center (%)	3.580	56.8	43.9
Edge between areas <10 % and >60% closure (m)	3.350	737.2	551.4
Area of 10-60 % closure (m^2)	0.959	10275.8	10428.8
Perimeter of 10-60 % closure (m)	0.338	1423.4	1217.7
Trees			
Avg. no. lg. *Abies* (>62 cm d.b.h.)	7.085	3.5	1.5
Avg. no. *Calocedrus decurrens*	6.256	0	3.4
Avg. no. *Abies*	5.120	20.9	12.4
Avg. no. lg. trees (>62 cm d.b.h.)	5.063	5.4	3.5
Avg. no. md. *Abies* (28-61 cm d.b.h).	4.519	9.6	6.1
Avg. no. sm. *Abies* (15-28 cm d.b.h.)	3.761	7.7	5.0
Avg. no. lg. *Tsuga mertensiana* (>62 cm d.b.h.)	3.098	0	0.3
Avg. no. *Tsuga mertensiana*	2.978	0.3	1.8
Avg. no. *Pinus contorta*	2.697	3.5	4.8
Avg. diam. (cm) of lg. *Abies* (>62 cm d.b.h.)	2.629	86.8	82.0

Table 3. Continued.

Variable	MW-U adj. z-score	Occupied mean (mode)	Unoccupied mean (mode)
Trees (continued)			
Avg. no. lg. *Pinus jeffreyi* (>62 cm d.b.h.)	2.626	0.6	0.3
Avg. no. *Pinus jeffreyi*	2.600	1.6	1.1
Avg. no. sm. *Pinus contorta* (15-28 cm d.b.h).	2.161	(0)	(0)
Avg. no. md. *Pinus contorta* (28-61 cm d.b.h.)	2.048	(0)	(0)
Shrubs			
Quercus vaccinifolia cover (cm line intercept)	3.655	70.8	17.0
Symphoricarpos acutus cover (cm line intercept)	3.640	123.5	27.5
Tree seedling cover (cm line intercept)	3.501	57.5	121.6
Salix (presence-absence)	3.300	(0)	(0)
Chamaebatia foliolosa cover (cm line intercept)	3.255	0	28.1
Pinus seedling cover (cm line intercept)	3.015	5.6	18.1
Cover of prostrate shrubs (cm line intercept)	2.982	248.7	101.3
Prunus emarginata cover (cm line intercept)	2.905	24.7	3.7
Arctostapylos nevadensis cover (cm line intercept)	2.520	74.4	20.6
Castanopsis sempervirens cover (cm line intercept)	2.222	38.4	7.4
Avg. no. tree saplings (40 m^2)	2.204	0.8	1.3
Cover of tall shrubs (cm line intercept)	2.137	341.4	223.3
Avg. ht. of prostrate shrubs (cm)	2.113	9.3	7.3
Arcostaphylos patula cover (cm line intercept)	2.073	24.1	35.2
Sambucus (presence-absence)	1.997	(0)	(0)
Ground cover			
Avg. herb ht. (cm)	4.435	17.35	13.9
Coarse woody debris (ranked 0-3)	3.552	(2)	(2)
Avg. grass ht. (cm)	3.396	20.4	16.4
Onion (presence-absence)	2.625	(0)	(0)
Grass cover (%)	-2.437	<10	>10

Table 3. Continued.

Variable	MW-U adj. z-score	Occupied mean (mode)	Unoccupied mean (mode)
Ground cover (continued)			
Abundance of cut stumps (ranked 0-3)	-2.250	(0)	(0)
Abundance of logs (ranked 0-3)	2.117	(1)	(1)

From Table 3 it can be concluded that male breeding micro-habitat (as compared to systematically sampled sites) tended to be located at the upper reaches of steep, south-tending slopes, where the forest canopy was moderately closed and patchy, with abundant edges comprised of high-closure patches adjacent to medium-closure or low-closure patches. Trees >62 cm d.b.h. were more abundant, as were *Abies* spp. and *Pinus jeffreyi* of all sizes. *Tsuga* trees were rare and *Calocedrus* trees were absent. Shrub cover was higher, especially cover of *Arctostapylos nevadensis, Castanopsis sempervirens, Prunus emarginata, Quercus vaccinifolia*, and *Symphoricarpos acutus. Salix* was more abundant, whereas *Chamaebatia foliolosa* was absent and *Arcostaphylos patula* and tree saplings of all species were less abundant. Grasses and herbs were taller, but there was less grass cover. Logs and coarse woody debris were more abundant, and stumps were less abundant. When the variables in Table 3 were subjected to best subsets logistic regression, ten habitat variables proved most effective for discriminating male breeding micro-habitat from systematically sampled sites (Table 4).

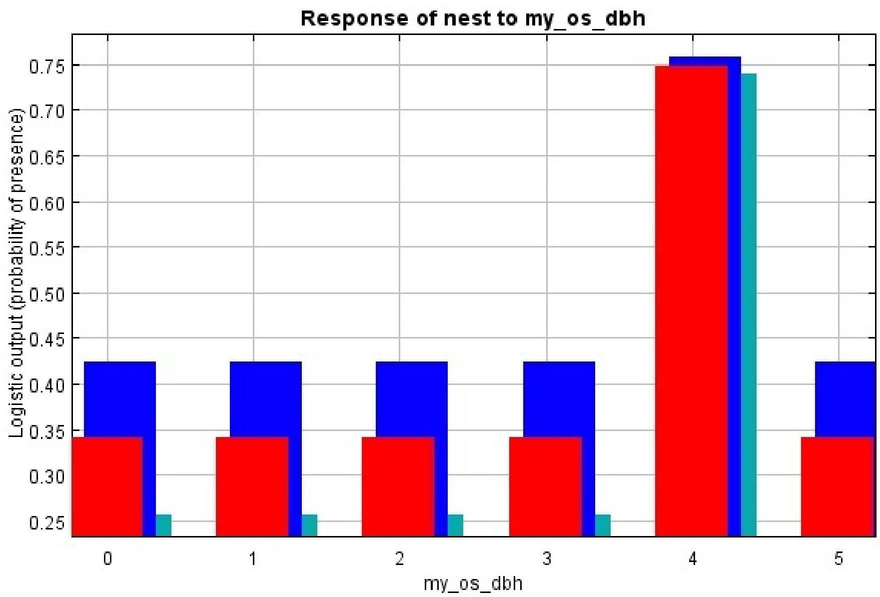
Table 4. Best five logistic regression models for discriminating male breeding micro-habitat.

Model	AIC_c
1. % slope + low:med edge + low:hi edge + canopy cover @ center + no. lg. *Abies* + no. lg. *Calocedrus* + grass ht + herb ht + slope contour + *Salix* + % slope*low:med edge	261.4
2. % slope + low:hi edge + canopy cover @ center + no. lg. *Abies* + no. lg. *Calocedrus* + grass ht + herb ht + slope contour + *Salix* + % slope*low:med edge	262.3
3. % slope + low:med edge + low:hi edge + canopy cover @ center + no. lg. *Abies* + no. lg. *Calocedrus* + grass ht + herb ht + slope contour + *Salix*	262.9
4. % slope + low:med edge + low:hi edge + canopy cover @ center + no. lg. *Abies* + no. lg. *Calocedrus* + grass ht + slope contour + *Salix* + % slope*low:med edge	263.6
5. % slope + low:hi edge + no. lg. *Abies* + no. lg. *Calocedrus* + grass ht + herb ht + slope contour + *Salix* + % slope*low:hi edge	264.4

Nesting habitat. Although just 10 nest sites were available for analysis, differences were detected between nesting sites and comparison sites. At the patch scale, overstory tree diameter, proximity to perennial water, and proximity to pine-dominated forest contributed most significantly to the MaxEnt suitability model for nesting habitat (Table 5). A spatially-explicit application of the model is depicted in Figure 5. At the micro-habitat scale, 15 variables were found to differ significantly between nesting sites and systematically sampled sites (Table 6).

Table 5. Variables that best distinguish nesting habitat at the patch scale.

<u>Overstory tree diameter</u>. 54.3 % contribution. Where average overstory tree diameter (d.b.h.) is 51-76 cm (size class 4), the model predicts the probability of presence is ~0.75. Suitable ranges (blue = standard deviation):



<u>Proximity to perennial water source</u>. 23 % contribution. Where a perennial water source occurs within 300 m, the model predicts the probability of *absence* is ~0.75. Suitable range (blue = standard deviation):

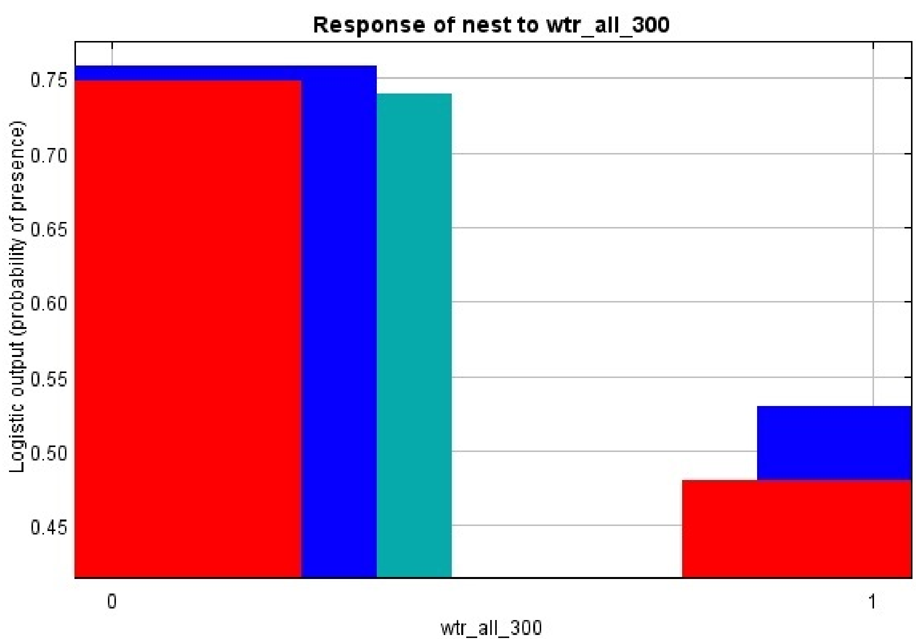


Table 5. Continued.

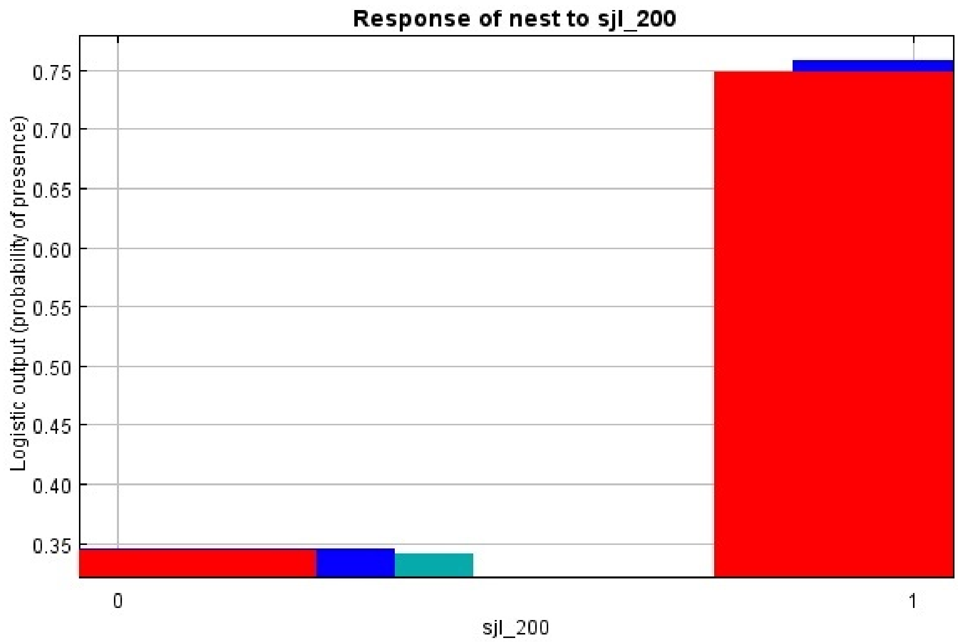
Proximity to pine-dominated forest. 22.8 % contribution. Where pine-dominated forest occurs within 200 m, the model predicts the probability of presence is ~0.75. Suitable range (blue = standard deviation): 

Figure 5. Spatially-explicit suitability model for patch-scale nesting habitat.

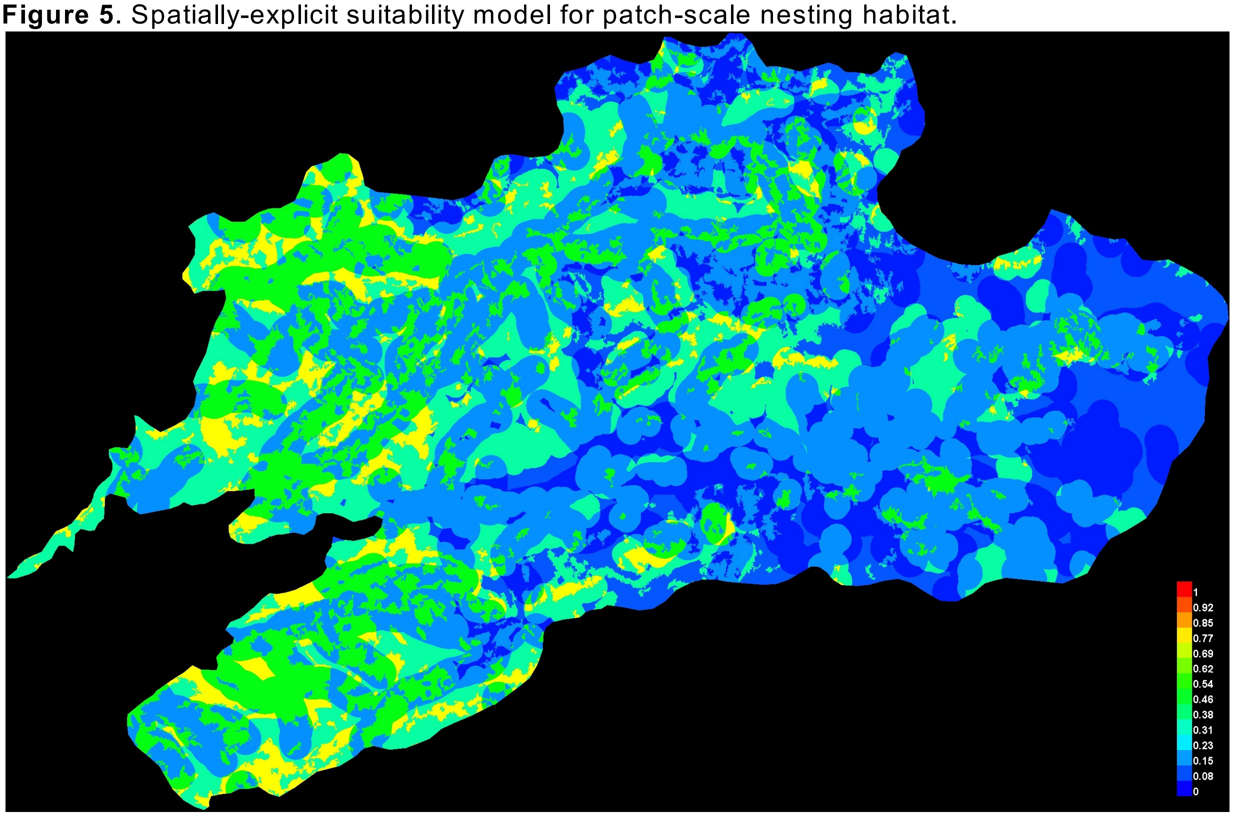


Table 6. Micro-scale habitat variables that differed significantly between nesting sites and systematically sampled sites (univariate Mann-Whitney *U* test, *P* <0.5).

Variable	MW-U adj. z-score	Occupied mean (mode)	Sample mean (mode)
Physical environment			
% slope	3.240	36.7	21.0
Cliff area (ranked 0-2)	2.593	(1, 2)	(0)
Forest canopy			
Canopy closure @ plot center (%)	2.949	73.4	43.9
Trees			
Avg. no. lg. trees (>62 cm d.b.h.)	2.422	6.4	3.5
Avg. no. *Abies* (>15 cm d.b.h.)	3.039	28.3	14.3
Avg. no. lg. *Abies* (>62 cm d.b.h.)	4.411	5.7	1.5
Shrubs			
Castanopsis sempervirens cover (cm line intercept)	3.842	53.9	7.38
Avg. ht. of prostrate shrubs (cm)	2.269	17.6	7.3
Cover of prostrate shrubs (cm line intercept)	2.172	286.8	101.3
Symphoricarpos acutus cover (cm line intercept)	3.688	209.2	27.5
Ground cover			
Abundance of logs (ranked 0-3)	2.228	(3)	(1)
Coarse woody debris (ranked 0-3)	2.529	(3)	(2)
Grass cover (%)	-3.881	<10	>10
Herb cover (%)	-4.346	<10	>10
Combined grass and herb cover (ranked 0-10)	-2.978	<10	>20

From Table 6 it can be concluded that nesting micro-habitat (as compared to systematically sampled sites) occurred on steeper slopes, nearer to cliffs, where forest canopy closure was higher, *Abies* trees were more abundant, and large trees, particularly large *Abies*, were more abundant. *Castanopsis* and *Symphoricarpos* were more abundant in the shrub layer, and prostrate shrubs were taller and more dense. At ground level, logs and coarse woody debris were more abundant, and there was lower grass and herb cover. Best subsets logistic regression of the variables in Table 6 identified five habitat variables that were most effective for discriminating nesting micro-habitat from systematically sampled sites (Table 7).

Table 7. Best five logistic regression models for discriminating nesting micro-habitat.

Model	AIC_c
1. no. lg. *Abies* + low shrub ht + *Symphoricarpos* cover + herb cover + cliff area	43.4
2. no. lg. *Abies* +*Symphoricarpos* cover + herb cover + cliff area	44.4
3. no. lg. *Abies* + low shrub ht + *Symphoricarpos* cover + cliff area	45.3
4. no. lg. *Abies* + low shrub ht + herb cover + cliff area	46.9
5. no. lg. *Abies* +*Symphoricarpos* cover + herb cover	48.3

Brooding habitat. At the patch scale, elevation, mixed shrub vegetation, solar radiation, average tree diameter, and % slope contributed most significantly to the MaxEnt suitability model for brooding habitat (Table 8). A spatially-explicit application of the model is depicted in Figure 6. At the micro-habitat scale, 28 variables differed significantly between brooding sites and systematically sampled sites (Table 9).

Table 8. Variables that best distinguish brooding habitat at the patch scale.

Elevation. 27.4 % contribution. Where elevation is ~2400-2750 m, the model predicts the probability of presence ranges from 0.50 to 0.62. Suitable range (blue = standard deviation):

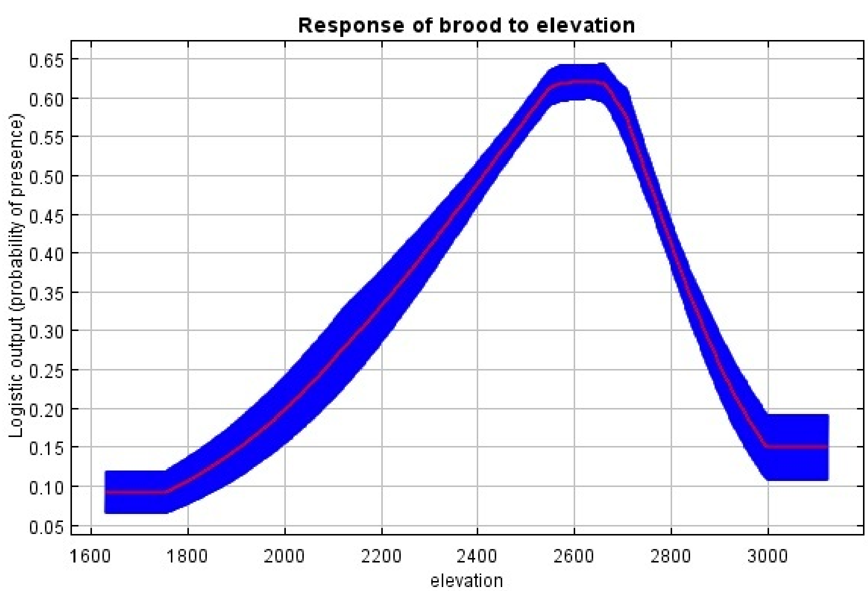


Table 8. Continued.

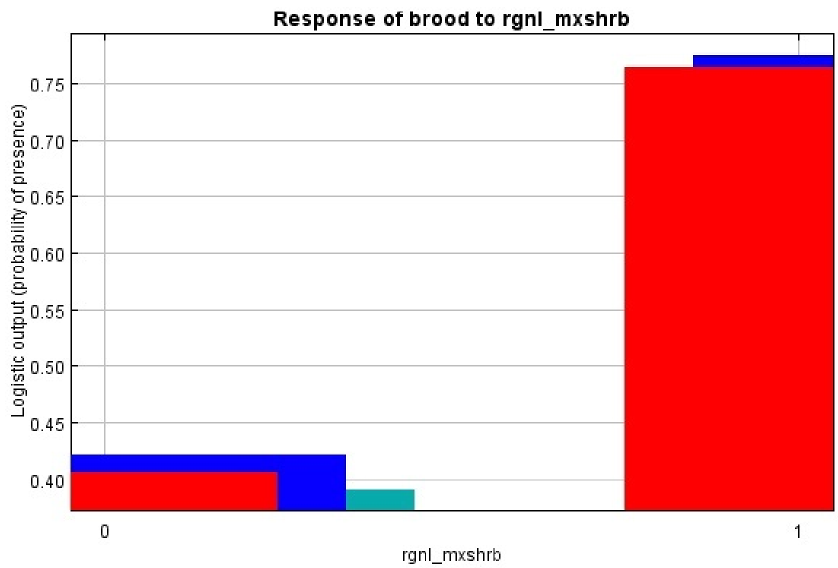
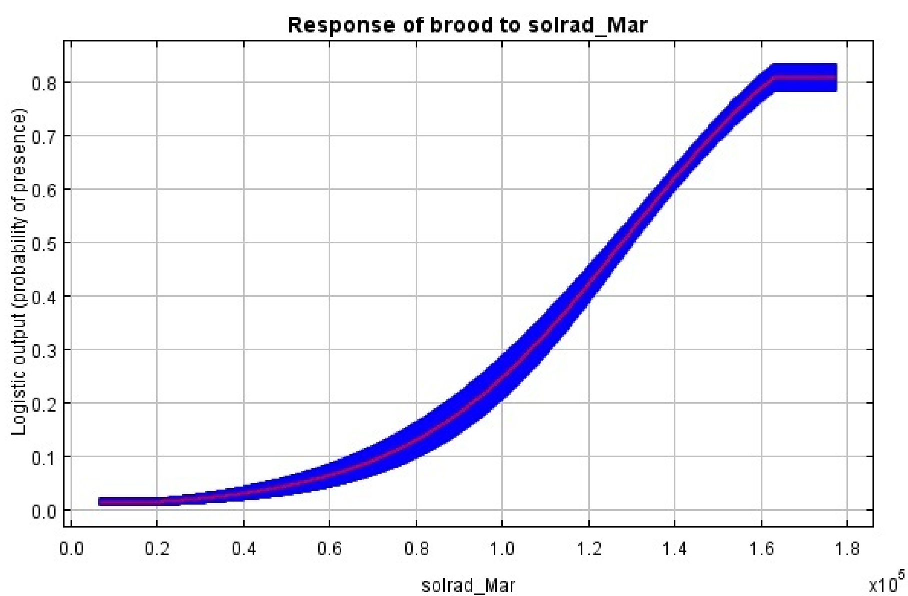
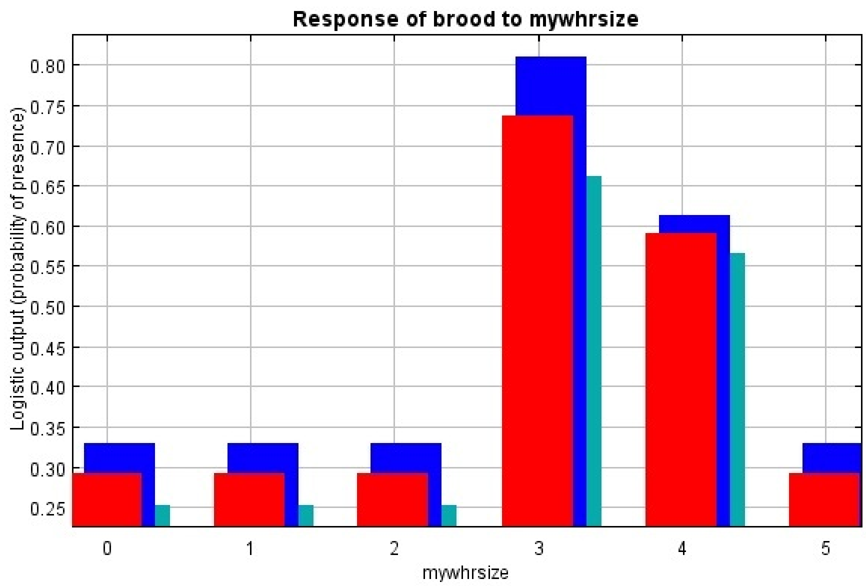
<u>Mixed shrub vegetation</u>. 25.5 % contribution. Where mixed shrub vegetation occurs, the model predicts the probability of presence is ~0.76. Suitable range (blue = standard deviation): 
<u>Solar radiation in March</u>. 21 % contribution. Where solar radiation during March is >1.3 x 10^5 WH/m^2, the model predicts the probability of presence ranges from 0.50 to 0.81. Suitable range (blue = standard deviation): 

Table 8. Continued.

Tree diameter. 16.2 % contribution. Where average tree diameter (d.b.h.) is 28-61 cm, the model predicts the probability of presence is ~0.59; and ~0.74 where average d.b.h. is 15-27.9 cm. Suitable range (blue = standard deviation):



% Slope. 9.8 % contribution. Where slope is ~15-30 %, the model predicts the probability of presence ranges from 0.50 to 0.64. Suitable range (blue = standard deviation):

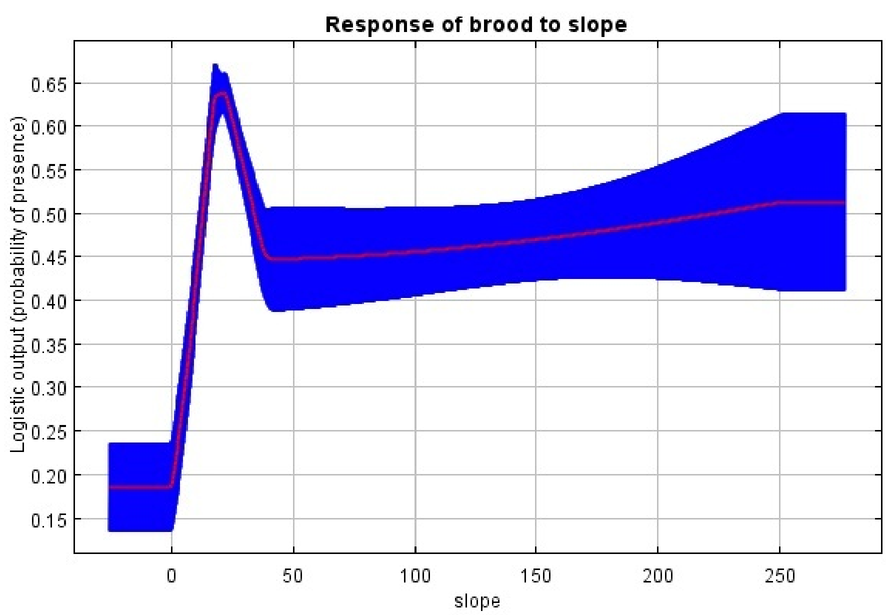


Figure 6. Spatially-explicit suitability model for patch-scale brooding habitat.

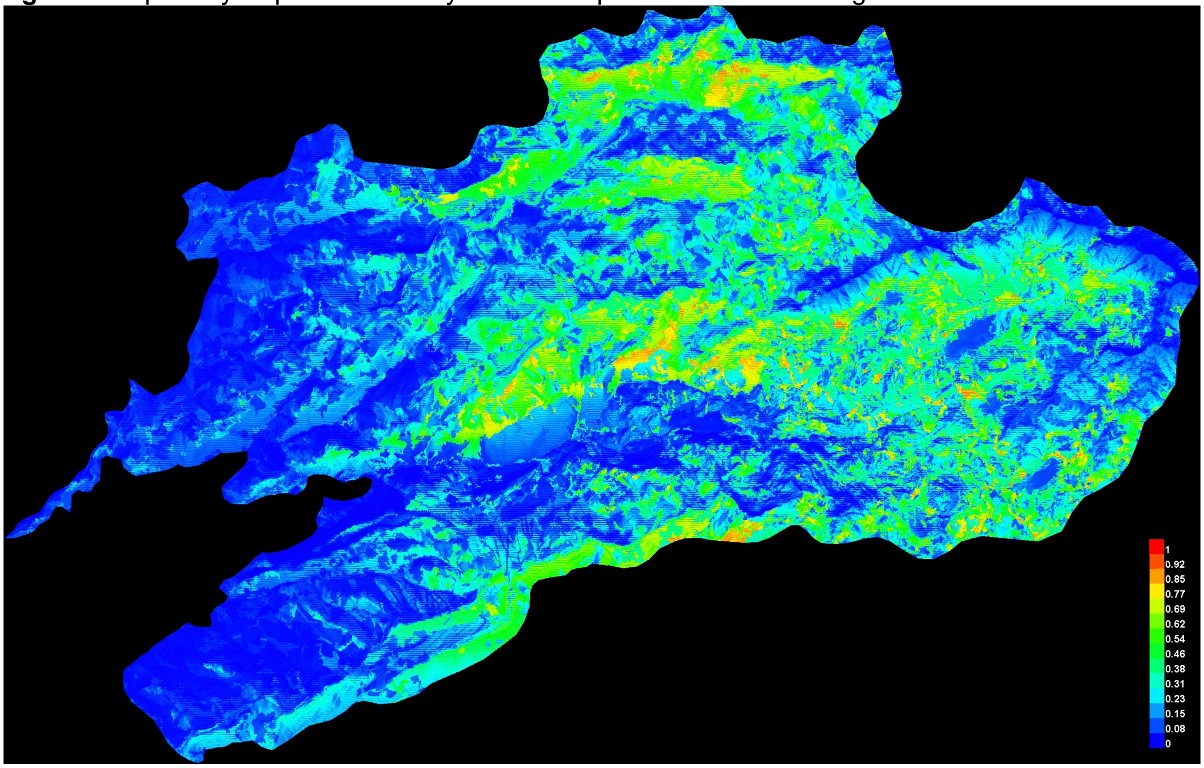


Table 9. Micro-scale habitat variables that differed significantly between brooding sites and systematically sampled sites (univariate Mann-Whitney *U* test, $P < 0.5$).

Variable	MW-U adj. z-score	Occupied mean (mode)	Sample mean (mode)
Physical environment			
Elevation (m)	3.137	2530.9	2312.9
% Slope	3.257	28.9	21.0
North Aspect (N=180, S=0)	-4.223	49.0	93.7
West aspect (W=180, E=0)	-2.369	95.9	116.2
Vert. distance to ridge (m)	-2.969	475.3	857.6
Forest canopy			
Total edge (m)	3.236	2006.5	1557.4
Perimeter of >60 % closure (m)	3.297	1823.2	1278.5
Perimeter of <10 % closure (m)	4.937	2131.5	1412.5
Area of <10 % closure (m^2)	3.588	19112.4	13021.4
Edge between areas <10 % & >60 % closure (m)	5.132	1260.9	551.4
Canopy closure @ plot center (%)	-1.997	31.4	43.9

Table 9. Continued.

Variable	MW-U adj. z-score	Occupied mean (mode)	Sample mean (mode)
Trees			
Avg. no. md. trees (28-61 cm d.b.h.)	-2.657	3.1	15.0
Avg. no. sm. trees (15-28 cm d.b.h.)	-2.524	7.5	13.4
Avg. no. *Calocedrus decurrens*	-3.412	0	3.4
Avg. no. *Juniperus occidentalis*	2.833	1.0	0.6
Avg. no. *Pinus* spp.	-2.276	5.5	7.2
Avg. d.b.h. of lg. *Pinus contorta* (>62 cm d.b.h.)	2.599	103.9	77.0
Shrubs			
Avg. ht. of tall shrubs (cm)	3.894	91.3	53.1
Cover of tall shrubs (cm line intercept)	3.492	695.4	223.3
Artemesia tridentata cover (cm line intercept)	4.131	106.5	14.0
Holodiscus discolor cover (cm line intercept)	3.524	86.7	7.8
Prunus emarginata cover (cm line intercept)	3.135	33.2	3.7
Sambucus (presence-absence)	1.965	(0)	(0)
Ground cover			
Coarse woody debris (ranked 0-3)	-2.749	(1)	(2)
Veratrum californicum (presence-absence)	2.308	(0)	(0)
Grass cover (%)	-3.569	1.0	1.1
Avg. grass ht (cm)	5.456	27.8	16.4
Avg. herb ht (cm)	5.229	28.6	13.9

From Table 9 it can be concluded that brooding micro-habitat (as compared to systematically sampled sites) occurred on steeper, more southeast-tending slopes, at higher elevations, where the forest canopy was comprised of patches with high (>60 %) and low (<10 %) canopy closure. *Calocedrus* and *Pinus* were relatively sparse, as were small- and medium-sized trees of all species. *Juniperus* trees were more abundant, and large *Pinus contorta* had larger average d.b.h. Cover and height of tall shrubs was higher, especially of *Artemesia* and *Holodiscus* at xeric sites and *Prunus* and *Sambucus* at mesic sites. At ground level, coarse woody debris and grass cover were relatively sparse, whereas the height of grasses and herbs was taller. *Veratrum* (corn lily) was present more often. Best subsets logistic regression of the variables in Table 9 identified seven habitat variables that were most effective for discriminating brooding micro-habitat from systematically sampled sites (Table 10).

Table 10. Best five logistic regression models for discriminating brooding micro-habitat.

Model	AIC_c
1. % slope + north aspect + tall shrub ht + grass cover + herb ht + elderberry	103.8
2. % slope + north aspect + tall shrub ht + grass cover + herb ht + coarse debris + % slope*north aspect	104.6
3. % slope + north aspect + tall shrub ht + grass cover + herb ht + elderberry + coarse debris	106.1
4. % slope + north aspect + tall shrub ht + grass cover + herb ht + elderberry + coarse debris + % slope*north aspect	106.8
5. % slope + north aspect + tall shrub ht + grass cover + herb ht + elderberry + % slope*north aspect	107.0

Postbreeding habitat. At the patch scale, elevation, meadow vegetation, red fir forest, solar radiation, and % slope contributed most significantly to the MaxEnt suitability model for brooding habitat (Table 11). A spatially-explicit application of the model is depicted in Figure 7. Due to time and manpower limitations, it was not possible to assess micro-scale attributes at postbreeding sites. Nonetheless, some micro-scale physical features were assessed from GIS data sets. Four of these differed significantly between postbreeding sites and systematically sampled sites (Table 12).

Table 11. Variables that best distinguish postbreeding habitat at the patch scale.

Elevation. 52.6 % contribution. Where elevation is ~2225-2750 m, the model predicts the probability of presence ranges from 0.50 to 0.70. Suitable range (blue = standard deviation):

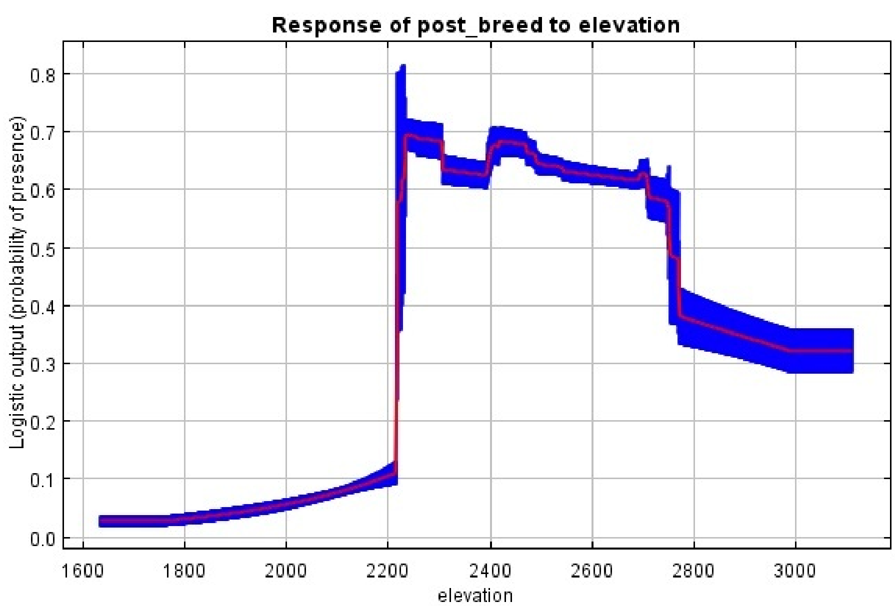
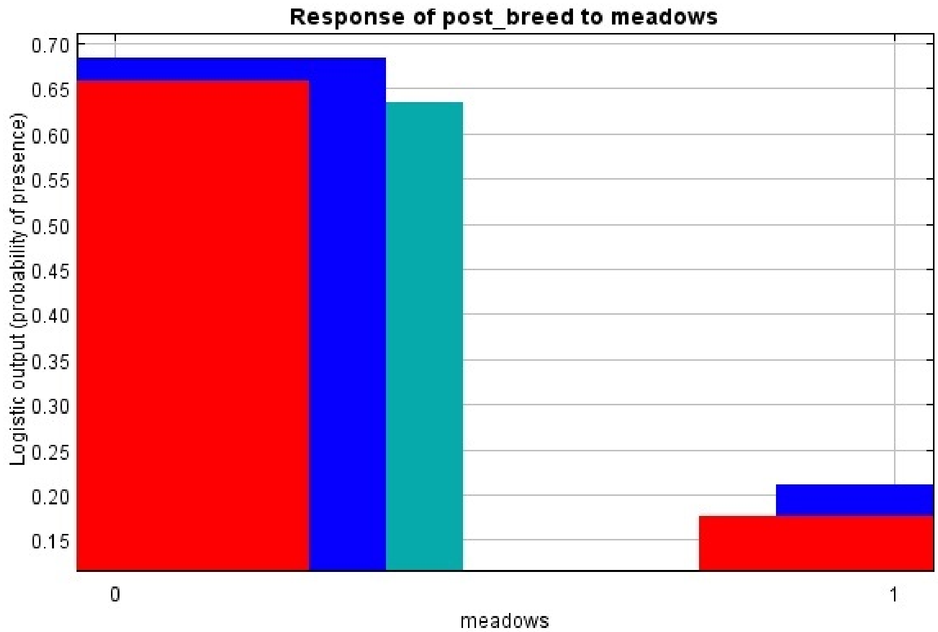


Table 11. Continued.

Meadows. 14.9 % contribution. Where patch-scale meadow vegetation is present, the model predicts the probability of *absence* is ~0.65. Suitable range (blue = standard deviation):



Red fir forest. 10.8 % contribution. Where red fir forest is present, the model predicts the probability of presence is ~0.60. Suitable range (blue = standard deviation):

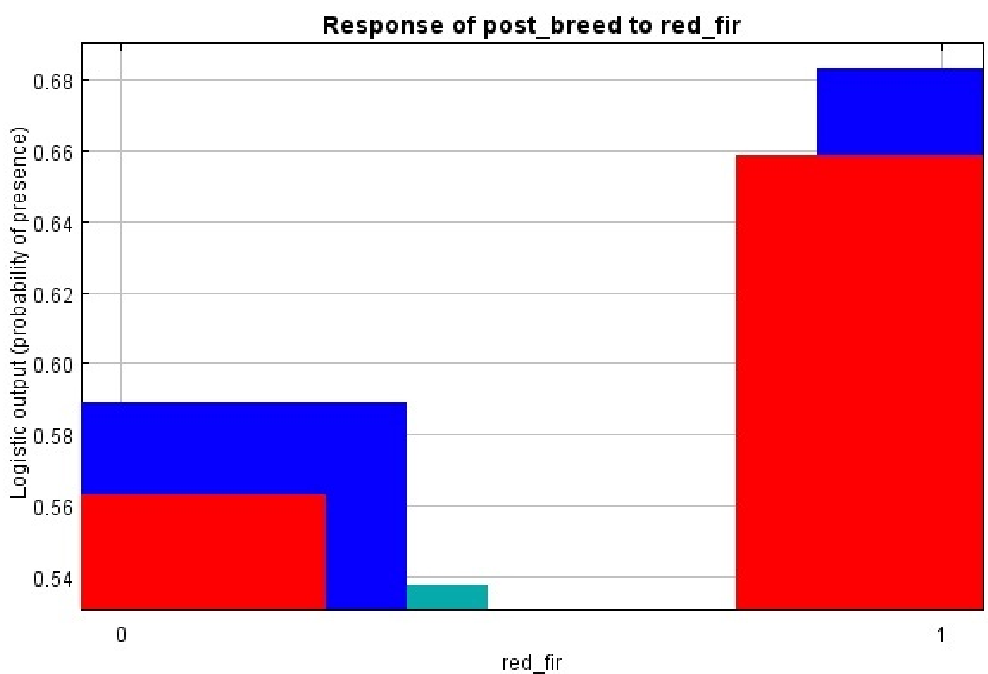


Table 11. Continued.

Solar radiation in March. 8 % contribution. Where solar radiation in March is <1.4 x 10^5 WH/m^2, the model predicts the probability of presence ranges from 0.50 to ~0.80. Suitable range (blue = standard deviation):

% Slope. 6.6 % contribution. Where slope is ~15-60 %, the model predicts the probability of presence ranges from 0.50 to 0.67. Suitable range (blue = standard deviation):

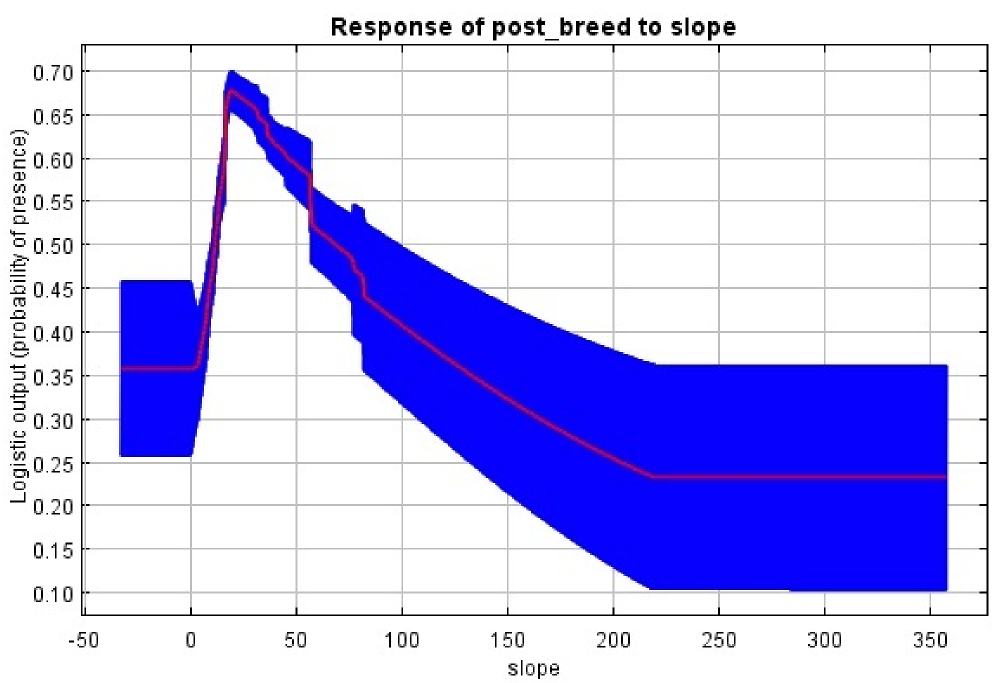


Figure 7. Spatially-explicit suitability model for patch-scale postbreeding habitat.

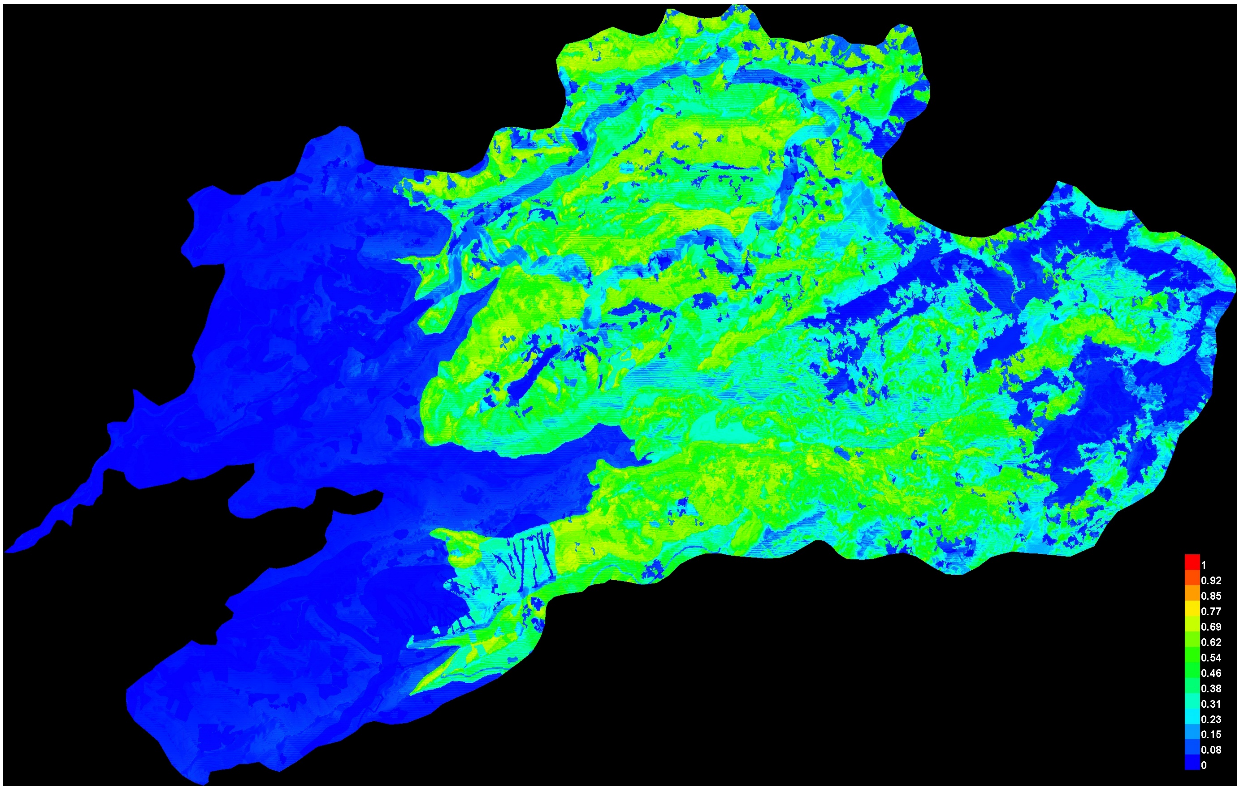


Table 12. Micro-scale habitat variables that differed significantly between postbreeding sites and systematically sampled sites (univariate Mann-Whitney *U* test, *P* <0.5). Vegetation variables were not assessed at postbreeding sites.

Variable	MW-U adj. z-score	Occupied mean (mode)	Sample mean (mode)
Physical environment			
Elevation (m)	3.069	2498.9	2312.9
Vert. dist. to ridge (m)	-2.189	623.9	857.7
Vert. dist. to canyon bottom (m)	2.226	1052.9	922.8
Position on slope (1=lower 1/3, 3=upper 1/3)	2.864	(3)	(3)

Table 12 indicates postbreeding micro-habitat occurred on the upper portions of slopes at relatively high elevations. Best subsets logistic regression of the variables in Table 12 identified four environmental variables that were most effective for discriminating brooding micro-habitat from systematically sampled sites (Table 13).

Table 13. Best five logistic regression models for discriminating postbreeding micro-habitat (physical environment only).

Model	AIC_c
1. Elevation + position on slope	243.7
2. Elevation + vert. dist. to ridge + position on slope	245.5
3. Elevation + vert. dist. to canyon bottom + position on slope	245.6
4. Elevation + vert. dist. to ridge + vert. dist. to canyon bottom + position on slope	247.4
5. Elevation + vert. dist. to ridge	258.6

Wintering habitat. At the patch scale, elevation, fir forest, solar radiation, timber harvest, and overstory tree diameter contributed most significantly to the MaxEnt suitability model for wintering habitat (Table 14). A spatially-explicit application of the model is depicted in Figure 8. Because winter habitats are covered with a deep layer of snow when occupied, shrub and ground layers were considered inconsequential to winter habitat selection, and were not assessed at wintering sites. Sixteen other variables differed significantly between postbreeding sites and systematically sampled sites (Table 15).

Table 14. Variables that best distinguish wintering habitat at the patch scale.

Elevation. 40.3 % contribution. Where elevation is ~2100-2400 m, the model predicts the probability of presence ranges from 0.50 to 0.80. Suitable range (blue = standard deviation):

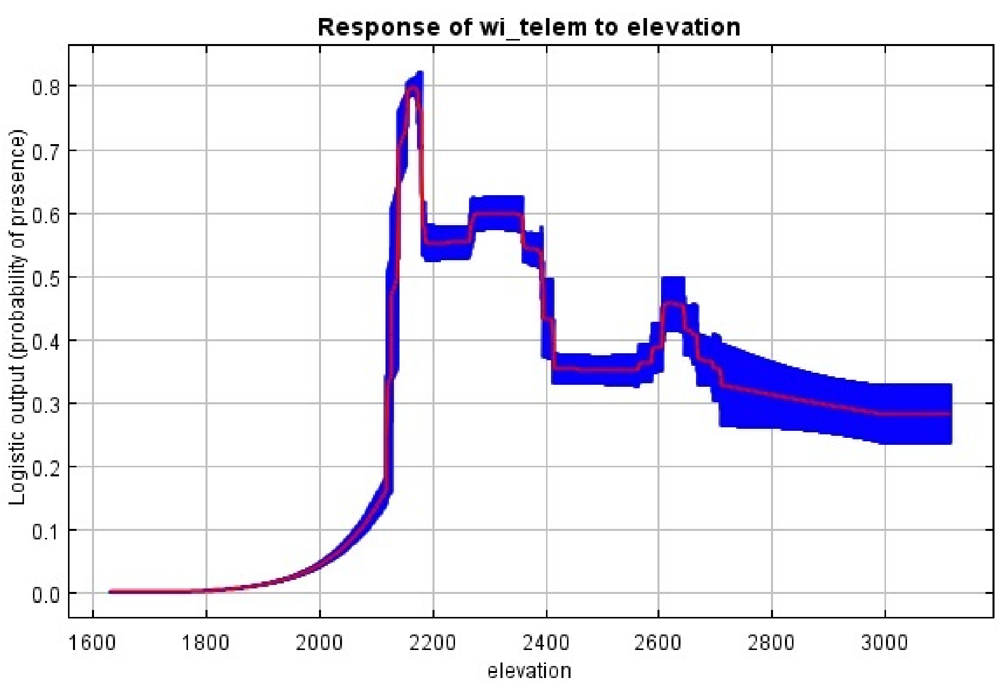


Table 14. Continued.

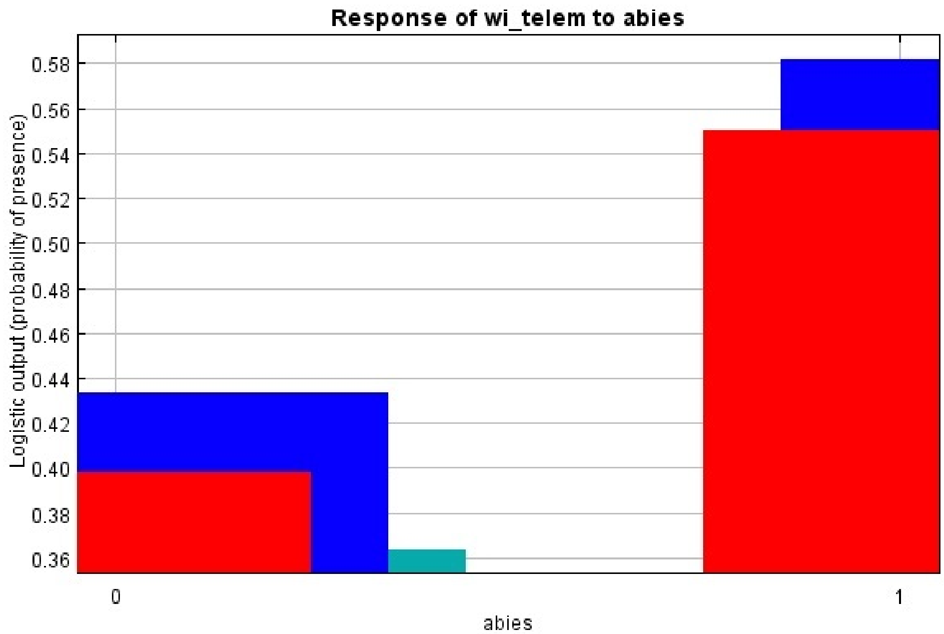
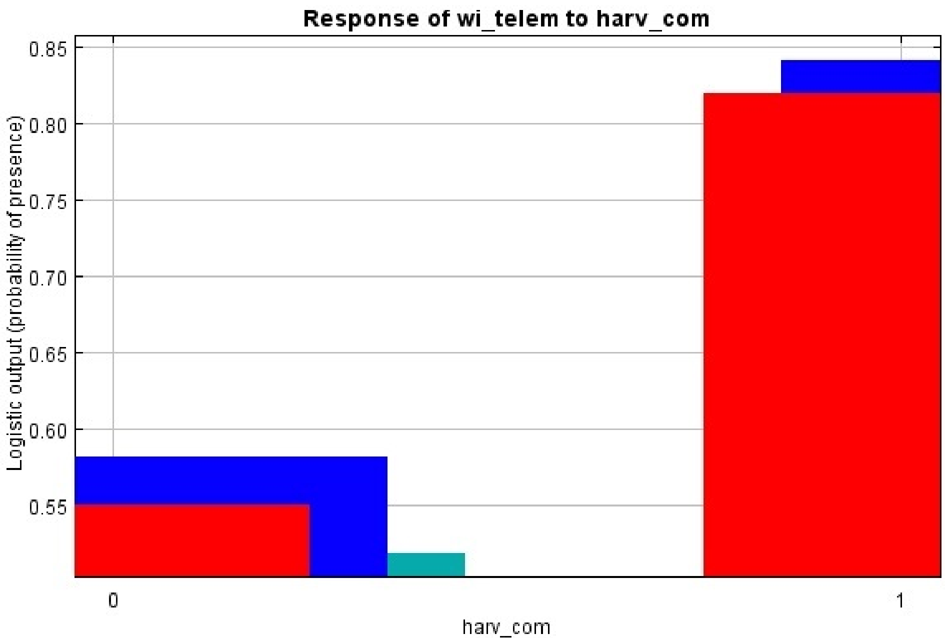
Fir forest. 16.8 % contribution. Where fir forest occurs, the model predicts the probability of presence is ~0.55. Suitable range (blue = standard deviation): 
Solar radiation in March. 15.8 % contribution. Where solar radiation in March is <1.2 x 10^5 WH/m^2, the model predicts the probability of presence ranges from 0.50 to 0.75. Suitable range (blue = standard deviation): 

Table 14. Continued.

Commercial timber harvest. 15.5 % contribution. Where commercial timber harvest has occurred, the model predicts the probability of presence is ~0.82. Suitable range (blue = standard deviation):



Overstory tree diameter. 11.5 % contribution. Where average overstory tree diameter (d.b.h.) is above or below 51-76 cm, the model predicts the probability of presence is <0.38. Suitable range (blue = standard deviation):

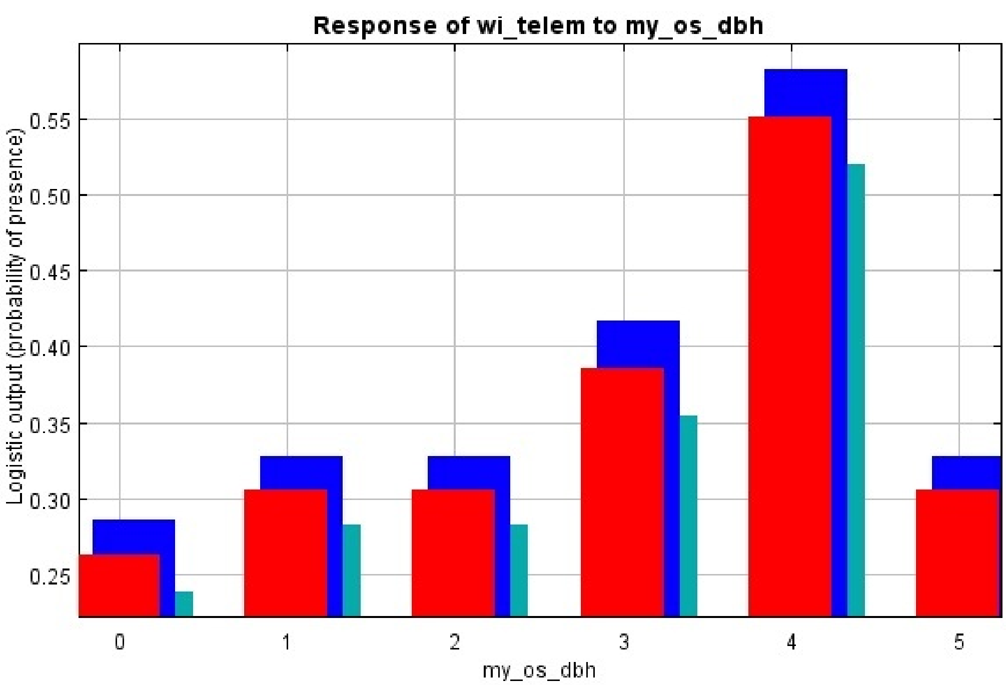


Figure 8. Spatially-explicit suitability model for patch-scale wintering habitat.

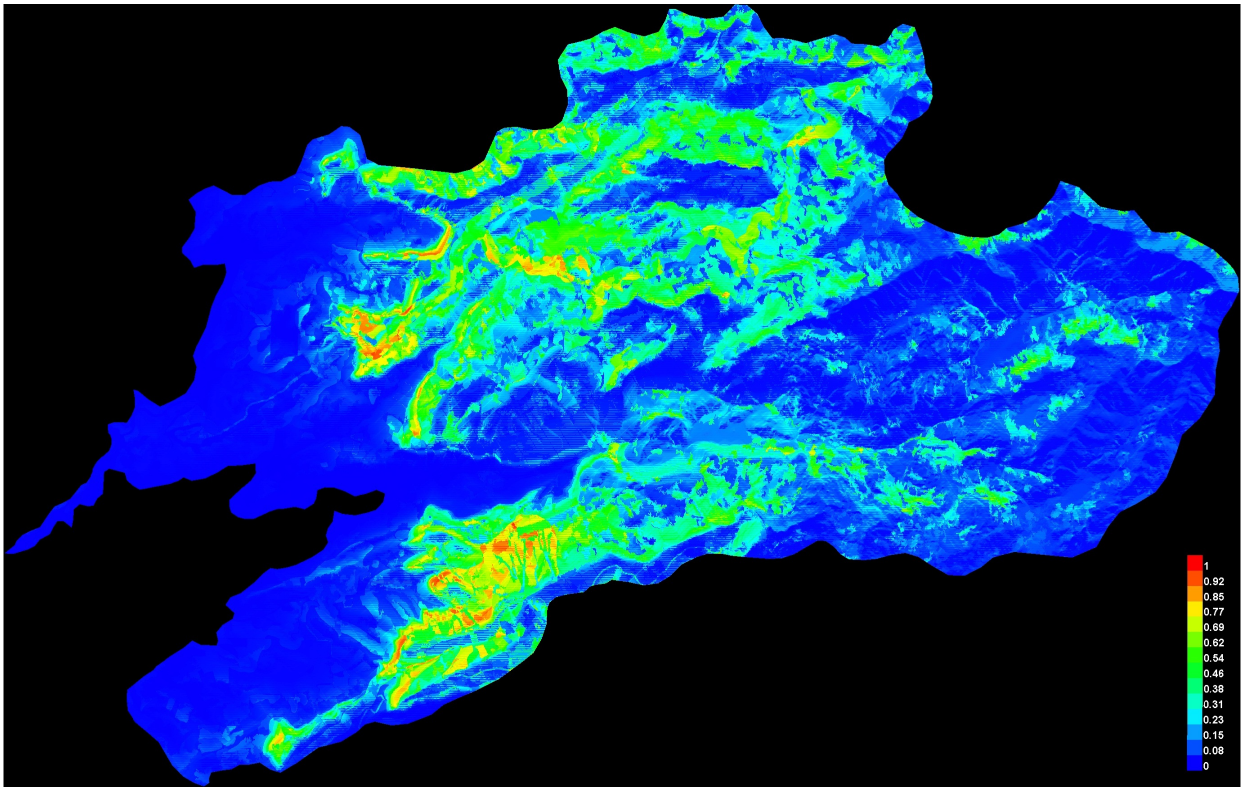


Table 15. Micro-scale habitat variables that differed significantly between wintering sites and systematically sampled sites (univariate Mann-Whitney *U* test, $P < 0.5$). Shrub and ground cover variables were not measured at wintering sites.

Variable	MW-U adj. z-score	Occupied mean (mode)	Sample mean (mode)
Physical environment			
% Slope	2.279	27.3	21.0
Vert. dist. to ridge (m)	-2.292	512.1	857.6
Vert. dist. to canyon bottom (m)	2.691	1397.8	922.8
Position on slope (1=lower 1/3, 3=upper 1/3)	2.723	(3)	(3)
Forest canopy			
Perimeter of <10 % closure (m)	2.854	1859.5	1412.5
Perimeter of >60 % closure (m)	4.066	1964.9	1278.5
Edge between areas <10 % & >60 % closure (m)	4.806	1164.5	551.4
Total edge (m)	2.818	2081.2	1557.4

Table 15. Continued.

Variable	MW-U adj. z-score	Occupied mean (mode)	Sample mean (mode)
Trees			
Avg. no. trees (>15 cm d.b.h.)	2.283	33.5	26.2
Avg. no. lg. trees (>62 cm d.b.h.)	3.264	5.7	3.5
Avg. no. *Abies* (>15 cm d.b.h.)	4.416	27.3	12.4
Avg. no. lg. *Abies* (>62 cm d.b.h.)	5.140	4.3	1.5
Avg. no. *Calocedrus decurrens* (>15 cm d.b.h.)	-2.604	0	3.4
Avg. no. *Pinus* (>15 cm d.b.h.)	-2.650	2.5	7.2
Avg. no. *Pinus contorta* (>15 cm d.b.h.)	-3.333	0.2	4.8
Avg. no. lg. *Pinus contorta* (>62 cm d.b.h.)	-2.759	0	0.6

From Table 15 it can be concluded that wintering micro-habitat (as compared to systematically sampled sites) occurred at lower positions on steeper slopes, where a relatively patchy forest canopy was comprised of adjacent patches of with high (>60 %) and low (<10 %) canopy closure. Trees were more abundant, particularly large trees (>62 cm d.b.h.) and *Abies* spp. *Calocedrus* and *Pinus* spp. were relatively sparse. Best subsets logistic regression of the variables in Table 15 identified nine habitat variables that were most effective for discriminating wintering micro-habitat from systematically sampled sites (Table 16).

Table 16. Best five logistic regression models for discriminating wintering micro-habitat.

Model	AIC_c
1. Perimeter of low cover + perimeter of high cover + low:hi edge + tot. edge + no. lg. trees + no. *Abies* + no. *Pinus contorta*	86.45
2. Perimeter of high cover + low:hi edge + tot. edge + no. lg. trees + no. *Abies* + no. *Pinus contorta*	87.02
3. Perimeter of low cover + perimeter of high cover + low:hi edge + tot. edge + no. *Abies* + no. lg. *Abies* + no. *Pinus contorta*	87.85
4. Perimeter of low cover + perimeter of high cover + low:hi edge + tot. edge + no. lg. trees + no. *Abies* + no. *Pinus contorta* + position on slope	88.16
5. Perimeter of high cover + low:hi edge + tot. edge + no. lg. trees + no. *Abies* + no. *Pinus contorta* + position on slope	88.21

Objective C - *Associations with old forests, large trees, and mountain meadows*.

Among the habitat variables assessed, seven were indicative of old forest (or the lack thereof). At the patch scale, these included average d.b.h. of overstory trees (USFS medium and large size classes (51-76 cm and >76 cm d.b.h., respectively)), average tree d.b.h. (California Wildlife Habitat Relationships “medium/large” (>62 cm d.b.h.)), and history of commercial harvest. At the micro-scale, the number of trees >62 cm d.b.h., the average diameter of trees >62 cm d.b.h., the abundance of logs, and the absence of cut stumps were indicative of old forest. Variables indicative of meadows included classified meadow vegetation at the patch scale and presence of corn lily (*Veratrum californicum*) at the micro-scale.

Breeding males were positively associated with trees >62 cm d.b.h., large *Abies* trees, and logs, and negatively associated with timber harvest and cut stumps (Tables 2 and 3). Nesting females were positively associated with large overstory tree d.b.h., trees >62 cm d.b.h., and logs (Tables 5 and 6). Brooding females were positively associated with large *Pinus contorta* and corn lily (a meadow-indicating species, Table 9). Postbreeding males and females were negatively associated with meadows (Table 11). Other associations with old forest features during the postbreeding season remain unknown because micro-scale attributes were not measured at postbreeding sites. Wintering males and females were positively associated with timber harvest at the patch scale (Table 14). However, because they were also positively associated with large overstory tree d.b.h. and trees >62 cm d.b.h. at the micro-scale (Table 15), it can be concluded they were using sites within harvested areas where large trees remained abundant.

<u>Summary and conclusions</u>

This project produced the first empirical data available on the density, seasonal movement, home range, and seasonal habitat associations of Sierra Sooty Grouse, as well as the first empirically-supported census protocol. Population density was unusually low at Pinecrest, ~0.6 males/km^2. Even though male territories were clumped and yearling males occasionally sung, it was possible to census males accurately with just 3-4 census repetitions by conducting censuses between 1 May and15 June and maintaining a minimum 5-day census interval. The number of Sooty Grouse in the study area remained static between 2009 and 2011. Census methods developed during this project should be adopted by resource agencies for monitoring Sooty Grouse populations throughout the Sierra Nevada.

Unlike most Sooty Grouse populations studied elsewhere (primarily British Columbia), which migrate seasonally between distant breeding and winter ranges, at Pinecrest Sooty Grouse bred and wintered in one general area (between ~2000 and 2700 m elevation). Male breeding areas were frequently used as wintering sites by individuals that bred elsewhere. This phenomenon has not been described previously. Annual home ranges averaged 1,158.5 ha by minimum convex polygon methods and 748.1 ha by fixed kernel methods, and did not differ between sexes. Half of the individuals fitted with radio transmitters moved seasonally between dispersed breeding, postbreeding, and wintering areas, whereas the other half spent two consecutive seasons in one area. The average straight-line distance traveled between seasonal ranges was 5.1 km. Traditional breeding sites (used year after year) are essential habitats for Sierra Sooty Grouse because they are centers of breeding and wintering activity for local populations. Land management agencies should inventory these sites and maintain the forest composition and structure for Sooty Grouse.

Five seasonal habitat types were distinguishable from randomly or systematically sampled sites (here, only the variables that contributed significantly to habitat models are summarized). Suitable male breeding habitat occurred on steep slopes at elevations between ~2075 and 2350 m, where slope contours tended to be convex and incoming solar radiation was high. Canopy closure ranged from moderately low to high, and a patchy forest canopy was comprised of high density patches adjacent to low or medium density patches. Large *Abies* trees were relatively abundant, whereas large *Calocedrus* were absent. There was little or no history of timber harvest. *Salix* was present more often than at systematically sampled sites, and grasses and herbs were relatively tall. Suitable nesting habitat was located closer to cliffs, perennial water, and pine-dominated forest than systematically sampled sites. The average diameter of overstory trees was large, and large *Abies* were more abundant. Prostrate shrub species were relatively tall, *Symphoricarpos* cover was high, and herb cover was low. Suitable brooding habitat occurred at moderately high elevations, on moderately steep, south-tending slopes, where incoming solar radiation was high and shrubby vegetation was relatively extensive. Compared to systematically sampled sites, average tree diameter was smaller, elderberry was more frequent, tall shrub species and herbs were taller, grass cover was lower, and coarse woody debris were more abundant. Suitable postbreeding habitat occurred at relatively high elevations, near the upper reaches of moderately steep slopes, in areas where incoming solar radiation was relatively low. Red fir forest was present more frequently than at randomly sampled sites, and meadow vegetation was present less frequently. Micro-scale features of postbreeding habitat were not assessed. Suitable wintering habitat occurred on the upper portions of slopes, at intermediate elevations, where incoming solar radiation was low. A patchy forest canopy was comprised of adjacent high and low density patches. Fir-dominated forest and timber harvest were present more often than at randomly sampled sites. Average overstory tree diameter was high, as was the number of large trees, particularly large *Abies*. The number of *Pinus contorta* was low. Shrub and ground layers were not assessed at wintering sites because they were covered by snow in winter, and therefore assumed to be inconsequential for winter habitat selection. The habitat suitability models produced by this project should be used by resource agencies to streamline population surveys and habitat inventories for Sierra Sooty Grouse. Patch-scale models should be used to initially identify GIS polygons that appear to offer suitable habitat. These areas should then be check in the field to determine whether the values for key micro-scale features are optimal.

In breeding and winter seasons, there was a strong association with large trees (>62 cm d.b.h.) and logs, which are both considered characteristic elements of old forest (Spies 2004). Breeding males were negatively associated with harvested forest. In a 2006 pilot study preceding this project, territorial males were found to select trees averaging 97.9 cm d.b.h. as territorial songposts (Bland 2006). Although there was a positive wintertime association with harvested forest at the patch scale, at the micro-scale there remained a strong positive association with large trees. Brooding females were strongly associated with large *Pinus contorta.* Only brooding females exhibited a positive association with mountain meadows. Corn lily, a moist meadow indicator species, was present more frequently at brooding sites than at systematically sampled sites. Most brooding activity however, took place in open, shrubby, environments. Both males and females were negatively associated with meadows during the postbreeding season. Sooty Grouse has frequently been described as an early-successional species (Zwickel and Bendell 1985) which "does well" in harvested forest (Zeiner et al. 1990). This is sometimes true in the Pacific Northwest, but on the western slope of the Sierra Nevada, Sooty Grouse are strongly associated with large trees and other elements of old forest, at least during breeding and wintering seasons (in late summer and fall broader use is made of meadows and shrubby environments, especially by females with broods). The current status of Sierra Sooty Grouse as "not dependent upon" old forest (Graber 1996) is possibly erroneous, and could potentially result in mismanagement of Sooty Grouse habitats. Land management agencies should consider the findings of this project when planning management or restoration of habitats occupied by Sierra Sooty Grouse.

7. Discuss differences: The project was conducted as proposed, except fewer grouse were fitted with radio-transmitters (10 males and 4 females versus the proposed 12 and 12) because they proved more difficult to trap than anticipated. Completion was delayed due to a State budget crisis, which resulted in spending and travel freezes.

8. List any publications or in-house reports resulting from this work:

Scientific papers:
Bland, J. D. 2013. Estimating the Number of Territorial Males in Low-density Populations of the Sooty Grouse. *Western Birds* 44:279-293.

In-house reports:
Bland, J. D. 2008. Draft Survey Protocol for Sooty Grouse in the Sierra Nevada Mountains. Draft manuscript, California Department of Fish and Wildlife, Sacramento, CA.

Oral presentations:
First Repeat Census of Sierra Sooty Grouse. Annual Meeting of the Western Section of the Wildlife Society. Sacramento, February, 2012.

Home Range and Seasonal Movements in a Southern Population of Sooty Grouse. Annual Meeting of the Western Section of the Wildlife Society. Sacramento, February, 2013.

<u>Literature cited</u>

Bland, J. D. 2006. Features of the forest canopy at Sierra Sooty Grouse courtship sites. Contract no. S0680003, California Department of Fish and Wildlife, Sacramento, CA.

Bland, J. D. 2008. Draft Survey Protocol for Sooty Grouse in the Sierra Nevada Mountains. Draft manuscript, California Department of Fish and Wildlife, Sacramento, CA.

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Appendix: Micro-scale habitat variables measured at field plots.

MEASURED AT THE CENTER OR THROUGHOUT SQUARE 4-HA PLOTS:

Variable	Description
ELEVATION	Elevation: meters above sea level, estimated from 50-m contour lines on topographic basemap.
% SLOPE	Slope: % Slope @ center of 4 plot, estimated from 50-m contour lines on topographic basemap.
ASPECT	Aspect: degrees azimuth of line perpendicular to basemap contour line @ center of plot.
NORTH ASPECT	Northward orientation: North = 180^{o} (max), West & East = 90^{o}, South = 0^{o}.
WEST ASPECT	Westward orientation: West = 180^{o} (max), North & South = 90^{o}, East = 0^{o}.
SLOPE CONTOUR	1 = gully, 2 = sloping plane or ridgeline, 3= spur. Estimated from 50-m contour lines within a 500x500-m area on topographic basemap.
DIST TO RIDGE	Vertical distance to ridge: meters from plot center to primary ridge above, measured by line perpendicular to 50-m contour lines on topographic basemap.
DIST TO CANYON	Vertical distance to canyon bottom: meters from plot center to perennial stream below, measured by line perpendicular to 50-m contour lines on topographic basemap.
POSITION ON SLOPE	1 = lower 1/3 of slope, 2 = mid-1/3 of slope, 3 = upper 1/3 of slope. Measured by lines perpendicular to 50-m contour lines on topographic basemap.
CLIFF AREA	M^2 of cliff area within 4-ha plot. Measured with GPS software from polygons hand-drawn on aerial photos in the field. Cliff defined as rocky terrain that would require the use of hands to traverse. Presence/absence conversion also provided because raw data are highly skewed.
AREA OF <10 % COVER	Area of Cover Class 1: total area (m^2) of polygons with overstory cover <10%. Measured with GPS software from polygons hand-drawn on aerial photos in the field.

Appendix. Continued.

PERIMETER OF <10 % COVER	Perimeter of Cover Class 1: total length (m) of perimeters of polygons with overstory cover <10%. Where polygon abuts boundary of 4-ha plot, plot boundary forms polygon perimeter. Measured from polygons hand-drawn on aerial photos in the field.
AREA OF 10-60 % COVER	Area of Cover Class 2: total area (m^2) of polygons with overstory cover 10-60%. Measured from polygons hand-drawn on aerial photos in the field.
PERIMETER OF 10-60 % COVER	Perimeter of Cover Class 2: total length (m) of perimeters of polygons with overstory cover 10-60%. Where polygon abuts boundary of 4-ha plot, plot boundary forms polygon perimeter. Measured with GPS software from polygons hand-drawn on aerial photos in the field.
AREA OF >60 % COVER	Area of Cover Class 3: total area (m^2) of polygons with overstory cover >60%. Measured with GPS software from polygons hand-drawn on aerial photos in the field.
PERIMETER OF >60 % COVER	Perimeter of Cover Class 3: total length (m) of perimeters of polygons with overstory cover >60%. Where polygon abuts boundary of 4-ha plot, plot boundary forms polygon perimeter. Measured with GPS software from polygons hand-drawn on aerial photos in the field.
EDGE BETWEEN AREAS <10 % & 10-60 % COVER	Edge comprised of Class 1 and Class 2 cover: total length (m) of edge where Class 1 and Class 2 polygons abut. Measured with GPS software from polygons hand-drawn on aerial photos in the field.
EDGE BETWEEN AREAS <10 % & >60 % COVER	Edge comprised of Class 1 and Class 3 cover: total length (m) of edge where Class 1 and Class 3 polygons abut. Measured with GPS software from polygons hand-drawn on aerial photos in the field.
EDGE BETWEEN AREAS 10-60 % & >60 % COVER	Edge comprised of Class 2 and Class 3 cover: total length (m) of edge where Class 2 and Class 3 polygons abut. Measured with GPS software from polygons hand-drawn on aerial photos in the field.
EDGE TOTAL	Combined length (m) of edge where Cover Classes abut (1, 2, & 3). Measured with GPS software from polygons hand-drawn on aerial photos in the field.
INDICATOR PLANT SPECIES	Presence/absence (0/1) of plant species hypothesized to have potential for indicating suitable seasonal habitat. Absence (0) indicates failure to detect, not absolute absence. Recorded species include onion, corn lily, willow, elderberry, and mule's ear.

MEASURED AT THE CENTER OR THROUGHOUT A CIRCULAR 0.1-HA SUBPLOT:

Variable	Description
CAN COVER	% overstory canopy cover: the average of 4 readings from a forest densiometer at subplot center.
NO. TREES	Number of trees: count of all trees >15 cm d.b.h. within subplot.

Appendix. Continued.

NO, LG TREES	Number of large trees: count of all trees >62 cm d.b.h. within subplot. Size determined with a Bitterlich stick.
LG TREE DBH	Diameter of large trees: average d.b.h. of all trees >62 cm d.b.h. within subplot. Measured with a diameter tape.
NO. MD TREES	Number of medium-size trees: count of all trees 28-62 cm d.b.h. within subplot. Size determined with a Bitterlich stick.
NO. SM TREES	Number of small-size trees: count of all trees 15-28 cm d.b.h. within subplot. Size determined with a Bitterlich stick.
NO. [*SPECIES*] TREES	Number of trees by species: count of all trees >15 cm d.b.h. within subplot, by species. Size determined with a Bitterlich stick. Categorical conversion provided where raw data are highly skewed.
NO. LG. [*SPECIES*] TREES	Number of large trees by species: count of trees >62 cm d.b.h. within subplot, by species. Size determined with a Bitterlich stick. Categorical conversion provided where raw data are highly skewed.
LG. [*SPECIES*] DBH	Diameter of large trees by species: average d.b.h. of all trees >62 cm d.b.h. within subplot, by species. Measured with a diameter tape.
NO. MD. [*SPECIES*]	Number of medium-size trees by species: count of trees 28-62 cm d.b.h. within subplot, by species. Size determined with a Bitterlich stick. Categorical conversion provided where raw data are highly skewed.
NO. SM. [*SPECIES*]	Number of small-size trees by species: count of trees 15-28 cm d.b.h. within subplot, by species. Size determined with a Bitterlich stick. Categorical conversion provided where raw data are highly skewed.
LOGS	Abundance of logs: relative abundance of downed logs >28 cm diam, ranked 0-3.
CUT STUMPS	Abundance of stumps: relative abundance of cut tree stumps, ranked 0-3.
COARSE WOODY DEBRIS	Abundance of branches: relative abundance of dead branches (coarse woody debris) on the ground, ranked 0-3.

MEASURED AT EIGHT 1x5-M MICROPOLTS IN EACH 0.1-HA SUBPLOT:

Variable	Description
TALL SHRUB HT	Height of tall shrubs: modal height of “tall” shrub species, averaged over the eight microplots. “Tall” defined as normally growing to heights >1m.
LOW SHRUB HT	Height of low shrubs: modal height of “low” shrub species, averaged over the eight microplots. “Low” defined as normally growing to heights <1m.

Appendix. Continued.

GRASS HT	Height of grasses: modal height of grasses, averaged over the eight microplots. Grasses were defined as grasses, rushes, and sedges.
HERB HT	Height of herbs: modal height of herbs, averaged over the eight microplots. Herbs were defined as non-woody dicots and monocots other than grasses, rushes, and sedges.
GRASS COVER	Density of grass cover: number of 1x5-m microplots in which grass cover was >50%. Grass cover in each 1x5 microplot was ranked in increments of 10% by visual estimation. Grasses were defined as grasses, rushes, and sedges.
HERB COVER	Density of herb cover: number of 1x5-m microplots in which herb cover was >50%. Herb cover in each 1x5 microplot was ranked in increments of 10% by visual estimation. Herbs were defined as non-woody dicots and monocots other than grasses, rushes, and sedges.
NO. OF SAPLINGS	Number of saplings: count of sapling trees in all eight microplots, defined as <15 cm d.b.h., >2.5m ht, and most foliage >1 m above ground.

MEASURED ALONG FOUR 10-M TRANSECTS IN EACH 0.1-HA SUBPLOT:

Variable	Description
TALL SHRUB COVER	Cover of “tall’ shrubs: total line intercept (cm) of shrub species that normally grow to heights >1m.
LOW SHRUB COVER	Cover of “low’ shrubs: total line intercept (cm) of shrub species that normally grow to heights <1m.
[*SPECIES*] COVER	Cover of individual shrub species: total line intercept (cm) by species. Categorical conversions also provided where raw data are highly skewed.