UC DAVIS WILDLIFE HEALTH CENTER
DEPARTMENT OF FISH AND GAME RESOURCE ASSESSMENT PROGRAM

FINAL REPORT

TITLE OF PROJECT

Habitat Selection by Mountain Sheep and Mule Deer: A Step Toward Understanding Ecosystem Health from the Desert to the Alpine

Habitat Analyses- Reports are written independently for each of the following:
- Sierra Nevada Bighorn Sheep (Priority IA)-submitted as manuscript draft
- San Gabriel Bighorn Sheep (Priority IB)
- Priority II: Round Valley Mule Deer (Priority II)

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RH: Applying RSPFs to Species Recovery

MODELING SIERRA NEVADA BIGHORN SHEEP HABITAT: APPLYING RESOURCE SELECTION FUNCTIONS TO SPECIES RECOVERY

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Abstract: To ensure the persistence of Sierra Nevada bighorn sheep, listed as an endangered species by State and Federal governments, the Draft Recovery Plan stipulates that translocations and augmentations must occur to increase population size and distribution of bighorn sheep throughout their historic range. To assist with decisions about where to invest costly translocation efforts, we used resource selection probability functions to identify important winter and summer habitat characteristics, and generate predictive models of habitat use in unoccupied ranges. Characteristics of topography and vegetation were significant in describing bighorn sheep winter habitat use, and only topographic characteristics were significant in describing summer habitat use. Habitat models were used to determine the amount of winter and summer range within each herd

unit, the connectivity of seasonal ranges, areas at risk of contact with domestic sheep, and to simulate the effects of prescribed fire on bighorn sheep habitat. Resource selection probability models are a valuable tool for quantitatively evaluating habitat conditions and in developing conservation and management strategies.

Key words: bighorn sheep, conservation, habitat models, *Ovis canadensis sierrae*, resource selection probability functions.

Bighorn sheep in the Sierra Nevada (*Ovis Canadensis sierrae*; Wehausen et al. In Press) are the rarest of mountain sheep in North America, having the fewest number of individuals and the most restricted distribution of any subspecies. In 1998, population surveys revealed that only 125 adult Sierra Nevada Bighorn sheep (SNBS) could be accounted for, one of the lowest number ever recorded (U.S. Fish and Wildlife Service 2003). As a result, the SNBS population received emergency listing as an endangered species by the State of California in 1999, and permanent listing by the federal government in 2000. Shortly thereafter, a recovery plan was drafted, outlining management actions needed to ensure the long-term viability of SNBS.

For persistence of SNBS populations, the draft recovery plan specified that management efforts should focus on increasing the number of adult females, the reproductive segment of the population, and their spatial distribution throughout the range (U.S. Fish and Wildlife Service 2003). In the plan, 17 herd units were identified (an 18th has since been identified) in 4 distinct recovery areas. Herd unit boundaries were delineated from areas occupied by SNBS or known to have been historically occupied by

SNBS. The 4 recovery areas were established based on large natural breaks in SNBS habitat. For SNBS to be de-listed, the recovery plan stipulates that adult female bighorn must number 365 animals and occupy 14 of the herd units, with occupied herd units in all 4 of the recovery areas. Currently, 8 herd units support groups of SNBS, distributed across 3 of the recovery areas.

To increase the distribution of SNBS across their historic range, some of the objectives of the Sierra Nevada Bighorn Sheep Recovery Program were to 1) develop guidelines for bighorn sheep translocations and augmentations, 2) assess the risk of bighorn sheep contact with domestic sheep in each of the herd units, and thus, the potential for epizootic disease transmission, and 3) determine areas where habitat conditions could substantially benefit from prescribed burns (U.S. Fish and Wildlife Service 2003). To meet these objectives, it is critical that wildlife managers understand how SNBS currently use habitat, and have the ability to assess habitat quantity and quality in unoccupied areas.

Bighorn sheep are frequently described as habitat specialists, needing steep, rocky, open terrain to effectively detect and evade predators (Wilson et al. 1980, Cunningham 1989, McCarty and Bailey 1994). As a result, bighorn sheep habitat must exhibit the proper juxtaposition of various topographic and vegetation characteristics. Bighorn sheep in the Sierra Nevada are seasonal migrants, moving between winter and summer ranges with shifts in climatic and forage conditions (Wehausen 1980). In addition to requiring enough winter and summer range, seasonal habitats must have adequate connectivity to be accessible to migrating bighorn sheep.

The number of individuals in an animal population is dependent upon the amount and quality of the available habitat (Morrison et al. 1998). For success in increasing SNBS population size with translocations and augmentations, we must accurately identify areas that provide habitat conditions that allow bighorn sheep to survive and reproduce. To facilitate SNBS Recovery Plan objectives, we developed a winter and summer habitat model using Resource Selection Probability Functions (RSPF; Manly et al. 2002). By comparing habitat currently used by bighorn sheep to areas available to bighorn sheep, we identified variables important in describing winter and summer habitat selection, and then applied habitat selection coefficients from those variables to the development of predictive models of bighorn sheep habitat use in areas currently unoccupied by SNBS.

We applied SNBS habitat models to a number of tasks identified in the recovery plan. Using the models, we quantified the amount of winter and summer range available in each of the herd units, and evaluated the connectivity of those ranges. In addition, we identified areas that due to subjective bias, were overlooked as suitable bighorn habitat. Recent northward range expansions by SNBS have placed them in direct conflict with domestic sheep grazing operations. Modeling has allowed us to assess the likelihood of further range expansion, and anticipate areas in which contact between domestic sheep and mountain sheep are most apt to occur. In addition, we have used the models to evaluate how habitat enhancement projects, such as prescribed burns, may alter the probability of bighorn sheep habitat use in certain areas.

STUDY AREA

The Sierra Nevada (37°24'N, 118°41'W) is a vast mountain range in California, approximately 650 km long and ranging from 75 to 125 km wide (Hill 1975). Sierra Nevada bighorn sheep have historically inhabited areas from Sonora Pass in the north, to Olancha Peak in the south, wintering along the eastern side of the Sierra Pacific Crest and summering along the top of the Crest (Fig. 1). Along the eastern base of the range, topography is largely a result of Pliocene fault uplifting and Pleistocene glaciers that created U-shaped canyons, steep cirque headwalls and prominent peaks (Wehausen 1980). Elevations used by mountain sheep range from 1,525 to 1,825 m at the base of the eastern escarpment in the Owens Valley to over 4,000 m along the Pacific Crest (Wehausen 1980).

Climate in the Sierra Nevada is influenced by northern Pacific storms and is characterized by heavy precipitation in winter (October-April) and relatively dry conditions throughout summer (Wehausen 1980). Most storms form in the Pacific and drift eastward over the Sierra Crest causing a rain shadow, which is responsible for the desert and steppe ecosystems of the eastern Sierra (Wehausen 1980). Precipitation and temperature varies markedly, depending on year, location, and elevation.

Vegetation in the Sierra Nevada varies widely along the elevation gradient. Low elevations are characterized by Great Basin sagebrush-bitterbrush-bunchgrass scrub, while mid-elevations consist primarily of pinyon-juniper woodland, mountain mahogany, and sub-alpine meadows and forests, and vegetation at high elevations consists mostly of sparse alpine meadows (U.S. Fish and Wildlife Service 2003). Virtually all SNBS habitat is public land, managed by the U.S. Forest Service (Inyo and Sierra National

Forests) and U.S. National Park Service (Yosemite and Sequoia-Kings Canyon National Parks).

METHODS

To obtain locations of SNBS, we deployed 21 GPS collars on bighorn sheep captured with a net-gun fired from a helicopter in 2002-2004. Bighorn sheep were radio-collared in 5 different herds throughout the Sierra-Nevada, with 6 GPS collars collecting locations on males, and 15 GPS collars collecting locations on females. Because SNBS are seasonal migrants, spending winter predominately on the eastern side of the Sierra Crest and summer along the top of the Crest, we separated locations into 2 groups based on season. Habitat characteristics associated with winter locations and summer locations were analyzed independently. We classified locations collected from Dec-Mar as winter habitat use, and locations collected from Jun-Sept were classified as summer habitat use. Winter GPS locations were collected from bighorn sheep in the Wheeler Ridge, Sawmill Canyon, Mt. Baxter, Mt. Langley, and Mt. Warren herds, while summer GPS locations were collected from bighorn only the Wheeler Ridge, Sawmill Canyon, Mt. Baxter, and Mt. Warren herds (Fig. 1).

Because collars were programmed with a variety of GPS-fix schedules, we sub-sampled data such that there were ≤ 2 locations/animal/day, collected at 00:00 and 12:00 h. We collected 1524 locations during the winter months and 891 locations during the summer months. Location data for both seasons was randomly divided such that 80%

was used for model development (training data) and 20% was held-out for model validation (testing data).

We compared habitat predictor variables from GPS locations to variables at randomly selected "available" locations. We defined available habitat as all areas within the 100% annual MCP home ranges, with an additional 1 km buffer, of bighorn sheep included in the models (Bleich et al. 1997, Nielson et al. 2002). Within the available habitat we selected locations using stratified random sampling. Available habitat was overlaid by a 500 x 500 m grid, and a random location was generated within each cell of the grid. For winter habitat model development, we generated 2,884 available locations, and for summer model development we generated 2,386 available locations. Model precision is often improved by including more available locations than used locations (Fielding and Haworth 1995, Gross et al. 2002), because available locations usually include more variation than used locations, more points are needed to appropriately characterize available areas.

For all areas of the Sierra Nevada that currently support bighorn sheep or have potential to support bighorn sheep, we developed digital raster layers for each habitat predictor variable included in model development. Habitat variables included in both the winter and summer models were elevation, slope, aspect, hillshade, terrain ruggedness, distance to escape terrain, and vegetation. For each pixel of the study area we obtained elevation from 30 m USGS Digital Elevation Models (DEMs), and used the DEMs to derive values for slope, aspect and hillshade. We classified aspect into 8 categorical variables, N, NE, E, SE, S, SW, W, and NW. Hillshade values were used as an index of sun exposure, and we set the aspect at 225º and the angle of the sun at 45º such that higher values would represent xeric, southwest slopes and low values would represent mesic, northeast slopes (Nielson et al. 2002). We estimated terrain ruggedness by calculating the product of the SD of slope and the mean angular deviation of aspect for each pixel in relation to its 9 surrounding pixels (Zar 1984, Nicholson et al. 1997). Because bighorn sheep are characteristically associated with escape terrain, or steep slopes, we also calculated the distance to escape terrain for each pixel in the study area. Escape terrain was defined as any pixel having >60% slope (Smith et al. 1991, Singer et al. 2000, McKinney et al. 2003).

Bighorn sheep require open habitats with high visibility to successfully evade predators, and thus, have been observed to avoid thick, closed canopy vegetation (Risenhoover and Bailey 1985, Etchberger et al. 1989). Bighorn sheep habitat in the Sierra Nevada spans land managed by the U.S. Forest Service (Humbolt-Toiyabe NF, Inyo NF, and Sierra NF) and the U.S. National Park Service (Sequoia-Kings NP and Yosemite NP), thus, we classified vegetation using detailed maps from both agencies. Because vegetation classification differed between land management agencies, we incorporated vegetation into winter and summer habitat models by classifying pixels as being either forested or non-forested.

To identify characteristics of topography and vegetation important in describing winter and summer SNBS habitat selection, we developed multiple logistic regression models using maximum likelihood estimation (Manly et al. 2002). For each model, the values of different habitat predictor variables were compared between "used" GPS locations and the randomly selected "available" locations. We examined habitat variables for mulitcollinearity, to determine that no two variables were highly correlated ($r < 0.7$). We used parsimonious model building techniques to generate winter and summer habitat models (Burnham and Anderson 1998), comparing candidate models using Akaike's Information Criterion (Akaike 1973, Burnham and Anderson 1998). We determined whether the continuous variables were curvilinear, and included second order polynomial terms where appropriate (Hosmer and Lemeshow 1989).

Once winter and summer models were identified, we applied coefficients from the regression models to RSPFs (Manly et al. 2002). The relative probability of bighorn sheep habitat use is given by the equation:

$$w(x) = \exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p)$$

where, x_i are the independent habitat predictor variables, and B_i represent the coefficients of those variables from the logistic regression models. We used a geographic information system (GIS) to apply the RSPFs to all herd units outlined in the Draft Recovery Plan (U.S. Fish and Wildlife Service 2003), and areas around and between adjacent herd units (Fig 2). The RSPF was calculated on a 30 x 30 m pixel basis across the study area, based on the habitat characteristics of each individual pixel. For the winter and summer habitat models, we used a sample validation procedure with the 20% testing data that was withheld from model development (Howlin et al. 2004).

All pixels in the study area that received a relative winter probability of use value in the 90-100% quartile were considered "winter range" and all pixels that received a relative summer probability of use value in the 90-100% quartile were considered "summer range." For each herd unit, we quantified the amount of winter and summer range, and indexed seasonal range connectivity. Because winter range has traditionally been assumed to be the limiting factor for SNBS populations, with snow conditions severely limiting areas available to bighorn sheep in winter months, connectivity was indexed as the distance a bighorn sheep would have to travel from a patch (contiguous group of identified pixels) of winter range to a patch of summer range. Connectivity was then defined as the average minimum distance from a patch of winter range to the nearest patch of summer range.

We used linear regression analysis to determine whether the current reproductive base of occupied ranges (Table 1; Wehausen and Stephenson 2004), adult and yearling females, was associated with quantities of winter and summer range. Winter range area was log-transformed to meet the assumptions of normality. Additionally, we used the habitat models to quantify winter and summer range areas outside herd unit boundaries, determining whether large areas suitable for bighorn sheep had been previously overlooked.

The summer RSPF model also was used to evaluate the potential for contact, and thus, disease transmission, relative to the proximity of domestic sheep on federal grazing allotments and SNBS habitat. For each herd unit, occupied and unoccupied, we calculated the distance from summer range, as identified by the RSPF model, to domestic sheep grazing allotments. The risk of contact between domestic sheep and SNBS is only present during summer months, when domestic sheep are grazing within or adjacent to SNBS habitat.

In addition, for each herd unit we used the winter habitat RSPF model to simulate the effects of prescribed burns on areas historically used by bighorn sheep, but now forested. By changing the vegetation classification from "forested" to "non-forested" and re-calculating the relative probability of use values, we were able to simulate the effects of a prescribed burn on potential habitat areas. We calculated the difference in relative probability of use in pixels that changed vegetation classification, and identified pixels that had ≥ 10%, 10-20%, 20-30%, and >30% increase in relative resource selection probabilities.

RESULTS

The winter RSPF model of SNBS habitat selection was significant (Fig. 3; -2LL = -1334.80, χ^2 = 869.29, df = 17, P < 0.001, r^2 = 0.47). Habitat predictor variables included in the model were elevation, elevation^2, slope, slope^2, hillshade, ruggedness, distance to escape terrain, distance to escape terrain^2, forested/non-forested, and aspect (Table 2). All main effects variables significantly increased model fit, and polynomial terms were added where appropriate. In general, bighorn sheep selected for areas that were lower in elevation, had rugged, steep, and xeric slopes, were non-forested, had southern aspects, and were close to escape terrain. Validation procedures classified the winter habitat model as acceptable (β_0 = 1.51, P < 0.001, 95% CI: 1.29 – 1.73).

The summer RSPF model for SNBS habitat also was significant (Fig. 4; -2LL = -474.21, χ^2 = 395.27, df = 13, P < 0.001, r^2 = 0.72). Habitat predictor variables included in the model were elevation, elevation^2, slope, hillshade, distance to escape terrain, and aspect (Table 3). Generally, during the summer months, SNBS selected for areas high in elevation, having steep, mesic slopes, close to escape terrain, and western aspects. The validation procedures, using the 20% testing data, determined that the summer habitat model also was acceptable (β_0 = 0.69, P < 0.001, 95% CI: 0.62 – 0.77).

Of all the pixels included in the study area, those having relative winter probabilities of bighorn sheep use in the 90-100% quartile were defined as winter range.

The amount of winter range within each herd unit varied from 2.70 to 23.71 km^2 (Table 4). Summer range for SNBS also was defined as any pixel from the summer predicted probability of use map that was in the 90-100% quartile. The amount of summer range in each of the herd units varied from 3.84 to 16.16 km^2 (Table 4).

Of the 8 herd units that are occupied by SNBS, the number of reproductive females currently in each herd was not associated with the relative amount of summer range of that herd ($F = 0.92$, df = 1, $P = 0.375$), but was associated with the relative amount of winter range of the herd ($F = 6.81$, df = 1, $P = 0.040$, $r^2 = 0.53$; Fig. 5).

Connectivity, the average minimum distance from a patch of winter range to a patch of summer range, varied from 367 m in the Mt. Gardiner herd unit to 2006 m in the Big Arroyo herd unit. The maximum distance between consecutive winter and summer range patches varied from 934 m in the Mt. Gardiner herd unit to 5816 m in the Coyote Ridge herd unit (Table 5).

The RSPF model for winter habitat use identified large patches of SNBS winter range, totaling 123 km^2, currently not included in any designated herd units. The most noteworthy contiguous patch of winter range not currently associated with a herd unit was 12.2 km^2 north of Mt. Gardiner, along the South Fork of the Kings River and Woods Creek (Fig. 6). Habitat modeling identified several herd units having winter range just outside their designated boundary lines. For example, an additional 3.4 km^2 of habitat was located just east of the Twin Lakes herd unit boundary, along Buckeye creek (Fig. 7), and 10.0 km^2 of winter range was identified between the Mt. Langley and Olancha Peak herd units (Fig. 8).

Along the eastern Sierra, the distance from SNBS summer range to domestic sheep grazing allotments varied between 0 and 118.4 km (Table 6). Four of the herd units, Twin Lakes, Green Creek, and Lundy Canyon in the Northern Recovery area, and Convict Creek in the Central Recovery area, had summer range that overlapped with U.S. Forest Service domestic sheep grazing allotments. Currently there are no bighorn sheep in the Twin Lakes, Green Creek, and Convict Creek herd units. The Lundy Canyon, Mt. Warren, Mt. Gibbs, and Wheeler Ridge units, all currently occupied by SNBS herds, were ≤ 3.1 km from a domestic sheep grazing allotment.

After reclassifying pixels in SNBS herd units from "forested" to "non-forested" in the winter RSPF model, we found that the probability of use of 53.8 km^2 of habitat within herd unit boundaries increased by ≥ 10% (Table 7). The amount of area positively affected by a change in vegetation varied from 0.14 km^2 in the Mt. Tom herd unit to 9.33 km^2 in the Olancha Peak herd unit (Table 7).

DISCUSSION

Using RSPF models, we compared quantities of winter and summer range in each of the herd units, using the amounts of seasonal range as indicators of translocation success and, potentially, carrying capacity. Patch size has been positively associated with bighorn sheep population size, density, occupancy, persistence, and translocation success (Singer et al. 2001, Fleishman et al. 2002, McKinney et al. 2003). The amount of winter range identified in each of the occupied SNBS herd units appeared to be an indicator of the number of reproductive females in that unit, suggesting that translocation efforts should be focused on herd units having the largest amount of classified winter range. While winter range area was a predictor of the number of females in occupied herd units, the amount of summer range was not associated with bighorn sheep herd sizes. This may either be because winter range, not summer range, is most limiting for SNBS herds, or that our summer RSPF model did not adequately capture summer range areas critical to bighorn sheep populations.

Translocation success and population persistence have been positively associated with migratory, as opposed to sedentary, bighorn sheep herds (Singer et al. 2000, Singer et al. 2001), however, there is little information available about the recommended juxtaposition or connectivity of seasonal ranges. While our connectivity index appears to appropriately reflect the relative distance of seasonal ranges within the herd units, it should be taken only as an index and not as a literal measurement of distance traveled by bighorn sheep during migration periods. Our connectivity score reflects an "as the crow flies" minimum average distance between seasonal ranges, and does not appropriately measure the likely travel path taken by bighorn sheep during seasonal movements. Given such considerations, the relative measure of seasonal range connectivity captures habitat differences among herd units. The two herd units with the largest distances between winter and summer range areas were the Big Arroyo and Laurel Creek units in the Kern Recovery area, neither of which is currently occupied by SNBS (Fig. 9). Lesser distances between seasonal range patches are discernable in currently occupied herd units such as Mt. Williamson, where the juxtaposition of winter and summer range demonstrates regular interspersion (Fig. 10). For translocating bighorn sheep naïve to historic migration routes into vacant herd units, proximity between seasonal ranges should be considered.

Current herd unit boundaries, as outlined in the SNBS Draft Recovery Plan were defined subjectively, and may need adjustments to be meaningful for conservation efforts. For example, the RSPF model identified 12.2 km^2 of continuous winter range habitat not currently included in any herd unit, lying along the South Fork of the Kings River (Fig. 6). Considering that half of the herd units contained < 5 km^2 of winter range habitat, as we define it, this area has high potential for supporting another herd of SNBS, or augmenting the Mt. Gardiner herd. Aside from the creation of new herd units, existing boundaries need modification. Several units had winter range that was identified just outside designated boundary lines. For example, the Wormhole canyon area, between the Mt. Langley and Olancha Peak herd units, was identified as winter range and demonstrates that SNBS habitat is relatively continuous from the north end of the Mt. Langley unit to the south end of the Olancha Peak unit (Fig. 8). Expanding or clustering those herd units may be more biologically meaningful than the current designation.

Bighorn sheep populations are highly susceptible to epizootics and catastrophic die-offs, most of which have been associated with close physical contact with domestic sheep (Buechner 1960, Foreyt and Jessup 1982, Goodson 1982, Sandoval 1988). In evaluating the risk of disease transmission from domestic sheep to SNBS, we found that summer range habitat within 4 herd unit boundaries overlaps with current USFS domestic sheep grazing allotments. Three of those herd units are part of the Northern Recovery area, and while 2 of those units, Twin Lakes and Green Creek, do not currently support bighorn sheep herds, SNBS have been located repeatedly in the Lundy Canyon unit. In 2003, SNBS were documented as having expanded northward from the Mt. Warren herd unit into the previously vacant, Lundy Canyon herd unit (Wehausen and Stephenson

2004). If SNBS continue to expand northward, they likely will come into contact with domestic sheep. For example, the RSPF model identified the west side of Kavanaugh Ridge as summer bighorn sheep habitat, the largest area of summer range in the Lundy Canyon herd unit. Currently, the boundary of a USFS domestic sheep grazing allotment is the ridgeline of Kavanaugh Ridge, providing no separation between SNBS habitat and a domestic sheep allotment (Fig. 11). Summer range along Crater Crest in the Green Creek herd unit, 1 unit further north, not only borders, but lies within a USFS domestic sheep grazing allotment (Fig. 11). While summer range in the Mt. Warren, Mt. Gibbs, and Wheeler Ridge herd units do not directly overlap with domestic sheep allotments, they are ≤ 3.1 km from active grazing allotments, and currently support herds of bighorn sheep. To reduce the risk of disease transmission, the Desert Bighorn Council has recommended that domestic sheep allotments be separated by at least 13.5 km from bighorn sheep habitat (1990), the U.S. Department of Interior, Bureau of Land Management has recommended a 16 km buffer (1992), and Singer et al. has recommended a 23 km buffer (2001). To avoid catastrophic die-offs of SNBS, grazing practices must be evaluated, and the movements of bighorn sheep intensively monitored during the grazing season when they are most at risk.

Prescribed fires are one the most large-scale forms of habitat enhancements that can be applied to mountain sheep habitat (Elliott 1978, Hurly and Irwin 1986). Burning of habitat increases visibility, necessary for bighorn sheep to detect and evade predators (McCarty and Bailey 1994), and improve forage quantity and quality (Seip and Bunnel 1985, Benz and Woodard 1988). In the San Gabriel Mountains, overgrown vegetation has been associated with increased bighorn sheep mortality due to predation, primarily by mountain lions (Holl et al. 1994). By simulating the effects of a prescribed burn within SNBS herd units, we were able to assess occupied units that would benefit most from fire, and which unoccupied herd units should potentially be burned prior to reintroducing bighorn sheep. Of the herd units that currently support SNBS, we found that the Mt. Williamson unit would be improved most by prescribed fire (Table 7). The Mt. Williamson herd has exhibited poor population growth over the past 30 years (U.S. Fish and Wildlife Service 2003), and it is likely that the cause for the decline has been the encroachment of pinyon-juniper woodland, a vegetation type that severely limits bighorn visibility. Fire simulation modeling has identified that the probability of bighorn sheep use would increase by > 10% on 5.8 km^2 of winter range, mostly in the vicinity of Shepard Creek, Bairs Creek, and George Creek (Fig. 12). Of the unoccupied herd units, Olancha Peak and Coyote Ridge may realize a >10% increase in relative probability of use values on 9.3 and 7.9 km^2 of habitat, respectively.

FUTURE RESEARCH

While we were able to use RSPFs to identify winter and summer SNBS habitat characteristics, it is important to recognize that models were based primarily on bighorn sheep locations from the Central and Southern Recovery areas, and therefore, are most useful in evaluating habitat conditions in these areas. Currently, to our knowledge, no bighorn sheep reside in the Kern Recovery Area, so we have no collars deployed there, and are assuming that bighorn sheep in those herd units would use habitat comparably to bighorn in the Central and Southern herd units. Similarly, in the Northern Recovery area, we had only 9 bighorn sheep locations available for the winter model and 108 available for the summer model. While summer habitat conditions in Northern Recovery areas are probably similar to summer conditions in the Central and Southern areas, we suspect that winter habitat selection in northern SNBS herd units may be quite different. Field observations of SNBS during winter months have revealed that in addition to low elevation ranges, bighorn sheep inhabit high elevations ridge tops, blown-free from heavy snows (U.S. Fish and Wildlife Service 2003). Since almost no winter northern herd unit GPS locations were available for inclusion in model development, the high elevation winter habitat use pattern was not described. As a result, not all winter habitat areas critical to population persistence in northern herd units were identified. While GPS data from bighorn in these areas was not available at the time of analysis, we recently were successful at deploying collars on SNBS in the Lundy Canyon, Mt. Warren, and Mt. Gibbs herds. As we collect data in the coming years, we plan on creating separate RSPF models for bighorn sheep in the north. Hence, we will evaluate differential SNBS habitat use in the northern and southern Sierra Nevada.

Although the RSPF models appeared successful in identifying seasonal bighorn sheep habitat, we hope to improve the models in the future. In addition to obtaining GPS locations from the Kern and Northern Recovery Areas, we intend to include additional sources of data to further improve our ability to assess habitat conditions and predict habitat occupancy. Using high-resolution satellite imagery of the Sierra Nevada, we plan to generate snow layers, classifying pixels as either snow covered or snow-free based on climatic conditions throughout winter. Because winter habitat is highly contingent upon snow conditions, adding this variable into the model likely will improve our predictive capabilities. Similarly, we will use satellite imagery to generate a digital layer depicting high alpine meadows. While SNBS have been observed to be largely dependent upon alpine meadows for high quality forage during the summer months, these areas are often smaller than the 5 acre minimum mapping unit used in U.S. Forest Service vegetation layers, or are not readily identified. By increasing our data resolution, we hope to improve the accuracy of predicted summer SNBS habitat.

Another change we would like to incorporate into future models of summer range is a "distance-to-winter-range" variable. The RSF model identified summer range throughout the Sierra Nevada, areas that met the summer model characteristics, but likely are too far from winter range to be appropriate bighorn sheep habitat. After determining the characteristics of SNBS winter range, we would like to include this "distance-to-summer-range" variable to more appropriately classify areas likely to be used by bighorn sheep.

CONSERVATION IMPLICATIONS

Wildlife translocations are often costly in terms of finances, time, logistical support, and personnel (Wolf et al. 1996, Fritts et al. 1997). Areas identified for translocation potential need to be assessed carefully to ensure that resources are applied to sites having the highest likelihood of succeeding. To determine herd units where SNBS should be translocated, locations need to be evaluated based on a combination of factors including the amount and quality of available winter and summer range, the connectivity of seasonal ranges, and the distance between bighorn sheep habitat and domestic sheep allotments. If herd success, as determined by the number of reproductive females, is associated with winter range area as the model suggests, then the Olancha Peak herd unit should be first to receive a translocation. This is complicated by the fact that the Olancha Peak herd unit also has one of the smallest amounts of summer range of any of the designated areas. Similarly, based on the amount of available winter range, Coyote Ridge would be the second choice for bighorn sheep translocations. While Coyote Ridge appears to have ample amounts of both winter and summer range, there is limited connectivity between these seasonal ranges. Bighorn sheep would have to travel several kilometers through less optimal habitat while making seasonal migration movements. These issues demonstrate the complexity of determining where translocation efforts should be applied, and suggests that additional research is needed to determine the accuracy of winter and summer RSPF models, and how the predictions from those models correlate with measures of herd and population success.

Ultimately, RSPF models provide biologists with a heuristic tool for quantitatively examining habitat. They are currently being used to re-define herd unit boundaries, make decisions about where efforts should be spent on translocations and prescribed burns, and in guiding domestic sheep grazing recommendations. Using quantitative spatial modeling, we can objectively assess conservation strategies and have a basis for evaluating management actions.

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Table 1. Reproductive base (adult and yearling females combined) for herds of Sierra Nevada Bighorn Sheep, California, 2003 (Wehausen and Stephenson 2004).

Herd	No. Reproductive Females
Mt. Langley	33
Mt. Williamson	7
Mt. Gardiner	8
Mt. Baxter	20
Sawmill Canyon	12
Wheeler Ridge	40
Mt. Gibbs	4
Mt. Warren	11

Table 2. Multiple logistic regression coefficients for winter resource selection of Sierra Nevada bighorn sheep, California.

Variable	Coefficient	Robust SE	z	P>|z|	Lower 95%	Upper 95%
Elevation	0.0044	0.0024	1.84	0.066	-0.0003	0.0090
Elevation^2	-1.28E-06	4.49E-07	-2.86	0.004	-2.16E-06	-4.03E-07
Slope	0.2968	0.0987	3.01	0.003	0.1034	0.4902
Slope^2	-0.0031	0.0012	-2.57	0.010	-0.0054	-0.0007
Hillshade	0.0038	0.0021	1.82	0.068	-0.0003	0.0078
Ruggedness	0.0012	0.0005	2.65	0.008	0.0003	0.0021
Distance to Escape Terrain	0.0241	0.0138	1.74	0.081	-0.0030	0.0512
Distance to Escape Terrain^2	-0.0002	0.0001	-1.83	0.067	-0.0003	0.0000
Forested/Non-forested	-0.4168	0.1758	-2.37	0.018	-0.7613	-0.0722
Aspect[a]						
East	-0.5729	0.5108	-1.12	0.262	-1.5740	0.4283
North	-2.9814	0.5971	-4.99	0.000	-4.1518	-1.8110
Northeast	-1.7568	0.5001	-3.51	0.000	-2.7370	-0.7767
Northwest	-3.4586	0.7104	-4.87	0.000	-4.8510	-2.0663
Southeast	0.0670	0.3671	0.18	0.855	-0.6526	0.7865
Southwest	-0.6302	0.2847	-2.21	0.027	-1.1883	-0.0721
West	-3.8115	0.6812	-5.59	0.000	-5.1467	-2.4763
Constant	-9.1167	4.6930	-1.94	0.052	-18.3149	0.0815

[a] Reference value for aspect was set to “South.”

Table 3. Multiple logistic regression coefficients for summer resource selection of Sierra Nevada bighorn sheep, California.

Variable	Coefficient	Robust SE	z	P>|z|	Lower 95%	Upper 95%
Elevation	0.0109	0.0019	5.69	0.000	0.0071	0.0146
$Elevation^2$	-1.58E-06	3.09E-07	-5.09	0.000	2.18E-06	9.69E-07
Slope	0.0606	0.0199	3.04	0.002	0.0216	0.0996
Hillshade	-0.0133	0.0044	-2.99	0.003	-0.0220	-0.0046
Distance to Escape Terrain	-0.0285	0.0215	-1.33	0.185	-0.0707	0.0136
Aspect[a]						
East	-2.9439	1.4458	-2.04	0.042	-5.7776	-0.1101
North	-10.1353	3.0818	-3.29	0.001	-16.1756	-4.0950
Northeast	-6.3701	2.2395	-2.84	0.004	-10.7596	-1.9807
Northwest	3.1806	3.0477	1.04	0.297	-2.7929	9.1541
Southeast	-1.4787	0.7715	-1.92	0.055	-2.9909	0.0334
Southwest	0.9706	1.0728	0.90	0.366	-1.1321	3.0732
West	3.2295	1.7627	1.83	0.067	-0.2253	6.6842
Constant	-13.2305	5.8414	-2.26	0.024	-24.6795	-1.7816

[a] Reference value for aspect was set to "South."

Table 4. Amount of winter and summer range (km^2) in herd units designated in the Sierra Nevada Bighorn Sheep Draft Recovery Plan. Winter and summer range based on the 90-100% quartiles of the relative resource selection probability (RSP) of all pixels in the study area, Sierra Nevada, California. Herd units are listed in order from north to south.

Herd Unit	Summer Range (km^2) ≥ 90% Quartile RSP	Winter Range (km^2) ≥ 90% Quartile RSP
Twin Lakes	4.08	9.33
Green Creek	7.09	1.54
Lundy Canyon	3.98	4.20
Mt. Warren	8.23	3.38
Mt. Gibbs	8.02	1.81
Convict Creek	16.16	7.81
Wheeler Ridge	13.60	15.70
Mt. Tom	14.22	1.92
Coyote Ridge	11.23	22.51
Taboose Creek	7.32	4.77
Sawmill Canyon	8.12	7.00
Mt. Gardiner	7.29	5.91
Mt. Baxter	11.20	10.45
Mt. Williamson	10.86	13.09
Big Arroyo	3.84	4.18
Mt. Langley	5.88	11.84
Laurel Creek	5.01	3.90
Olancha Peak	4.05	38.16

Table 5. Index of winter and summer range connectivity for herd units designated by the Sierra Nevada Bighorn Sheep Draft Recovery Plan. Connectivity is indexed by the average minimum distance of a winter range patch to the closest summer range patch within each herd unit.

Herd	Average distance (m)	SD	Max distance (m)
Mt. Gardiner	367	213	934
Mt. Williamson	629	514	3152
Mt. Langley	630	433	2908
Mt. Warren	651	517	2735
Lundy Canyon	835	521	2462
Mt. Baxter	870	506	2075
Convict Creek	960	731	2955
Wheeler Ridge	1067	732	2912
Taboose Creek	1078	695	3286
Sawmill Canyon	1095	878	4038
Olancha Peak	1243	844	3841
Mt. Gibbs	1379	1042	4072
Mt. Tom	1440	962	3413
Green Creek	1465	1108	4067
Coyote Ridge	1465	1252	5816
Twin Lakes	1522	1308	5495
Laurel Creek	1751	1461	5533
Big Arroyo	2006	1457	4591

Table 6. The minimum distance from summer range, as identified by the resource selection probability model, to a domestic sheep grazing allotment (km) for each herd unit; herd units are listed from north to south.

Herd Unit	Recovery Area	Min distance to Allotment
Twin Lakes	Northern	0.0
Green Creek	Northern	0.0
Lundy Canyon	Northern	0.0
Mt. Warren	Northern	2.0
Mt. Gibbs	Northern	1.4
Convict Creek	Central	0.0
Wheeler Ridge	Central	3.1
Mt. Tom	Central	11.9
Coyote Ridge	Southern	17.6
Taboose Creek	Southern	34.2
Sawmill Canyon	Southern	51.4
Mt. Baxter	Southern	59.1
Mt. Williamson	Southern	75.0
Big Arroyo	Kern	94.7
Mt. Langley	Southern	97.1
Laurel Creek	Kern	111.5
Olancha Peak	Southern	118.4

Table 7. Area (km^2) of each herd unit that increased in relative probability of bighorn sheep use (indicated by percent increase in probability value) when forested areas were simulated to be burned in bighorn sheep winter range.

Herd Unit	>0 - 10%	10 - 20%	20 - 30%	>30%	≥ 10%
Big Arroyo	11.94	1.42	0.61	0.20	2.23
Convict Creek	16.52	0.82	0.26	0.08	1.16
Coyote Ridge	34.82	4.38	2.59	0.90	7.87
Green Creek	21.11	1.88	0.32	0.09	2.29
Laurel Creek	15.74	2.72	1.16	0.31	4.19
Lundy Canyon	4.06	0.72	0.20	0.08	1.00
Mt. Baxter	16.82	0.78	0.40	0.12	1.30
Mt. Gardiner	25.87	2.35	1.35	0.43	4.13
Mt. Gibbs	15.75	0.47	0.13	0.04	0.64
Mt. Langley	17.25	2.19	1.76	0.71	4.66
Mt. Tom	14.62	0.10	0.03	0.01	0.14
Mt. Warren	13.23	0.60	0.17	0.04	0.81
Mt. Williamson	17.33	3.33	1.84	0.64	5.81
Olancha Peak	31.32	4.62	3.46	1.25	9.33
Sawmill Canyon	12.71	1.28	0.44	0.13	1.85
Taboose Creek	5.09	0.34	0.06	0.02	0.42
Twin Lakes	14.69	2.63	1.56	0.56	4.75
Wheeler Ridge	19.44	0.91	0.27	0.09	1.27

Figure 1. Recovery and herd units for Sierra Nevada bighorn sheep (SNBS) as identified by the SNBS Draft Recovery Plan. Yellow herd units are currently occupied by bighorn sheep.

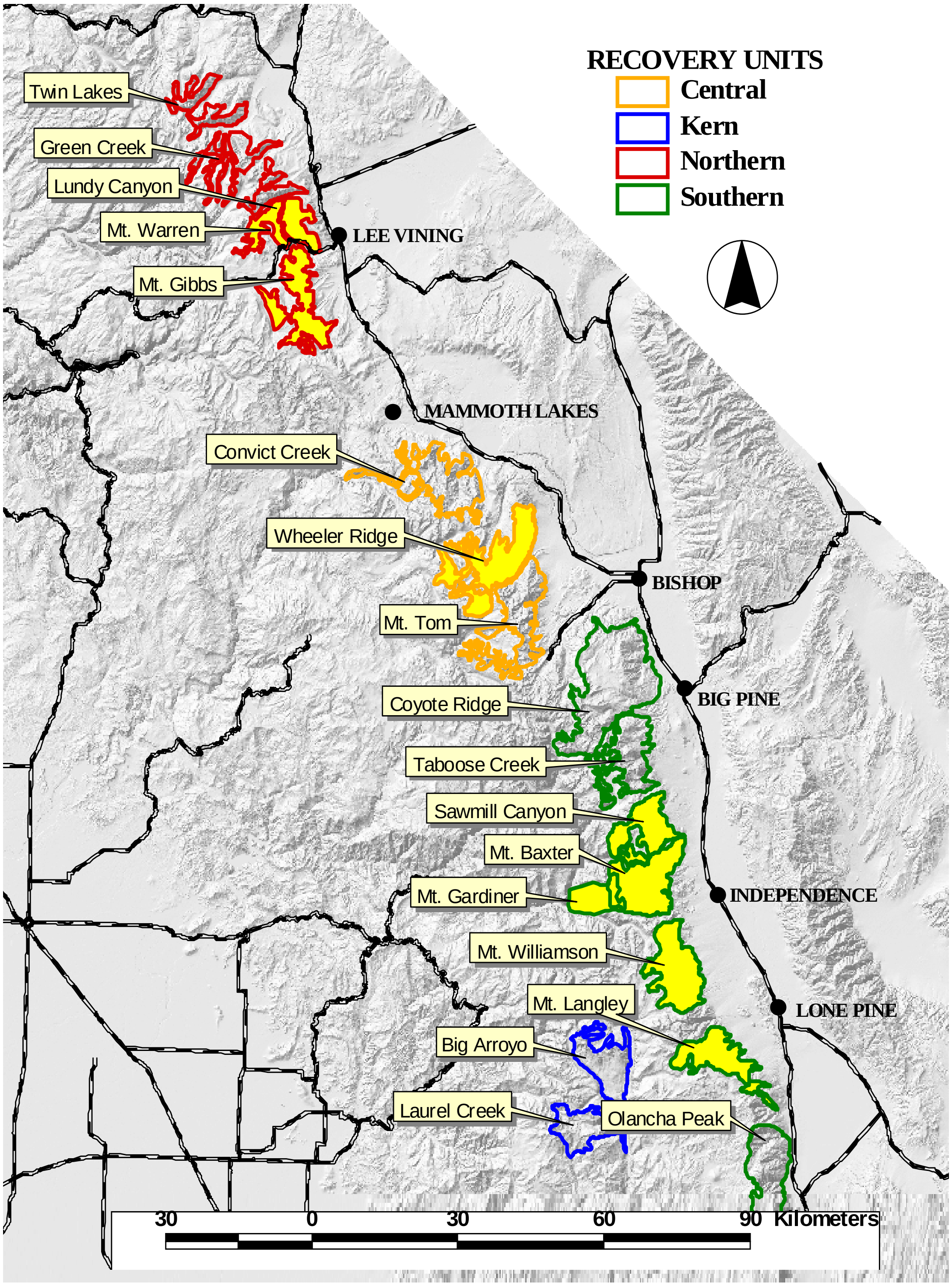

Figure 2. Area of the Sierra Nevada, California, included in bighorn sheep resource selection probability function analysis.

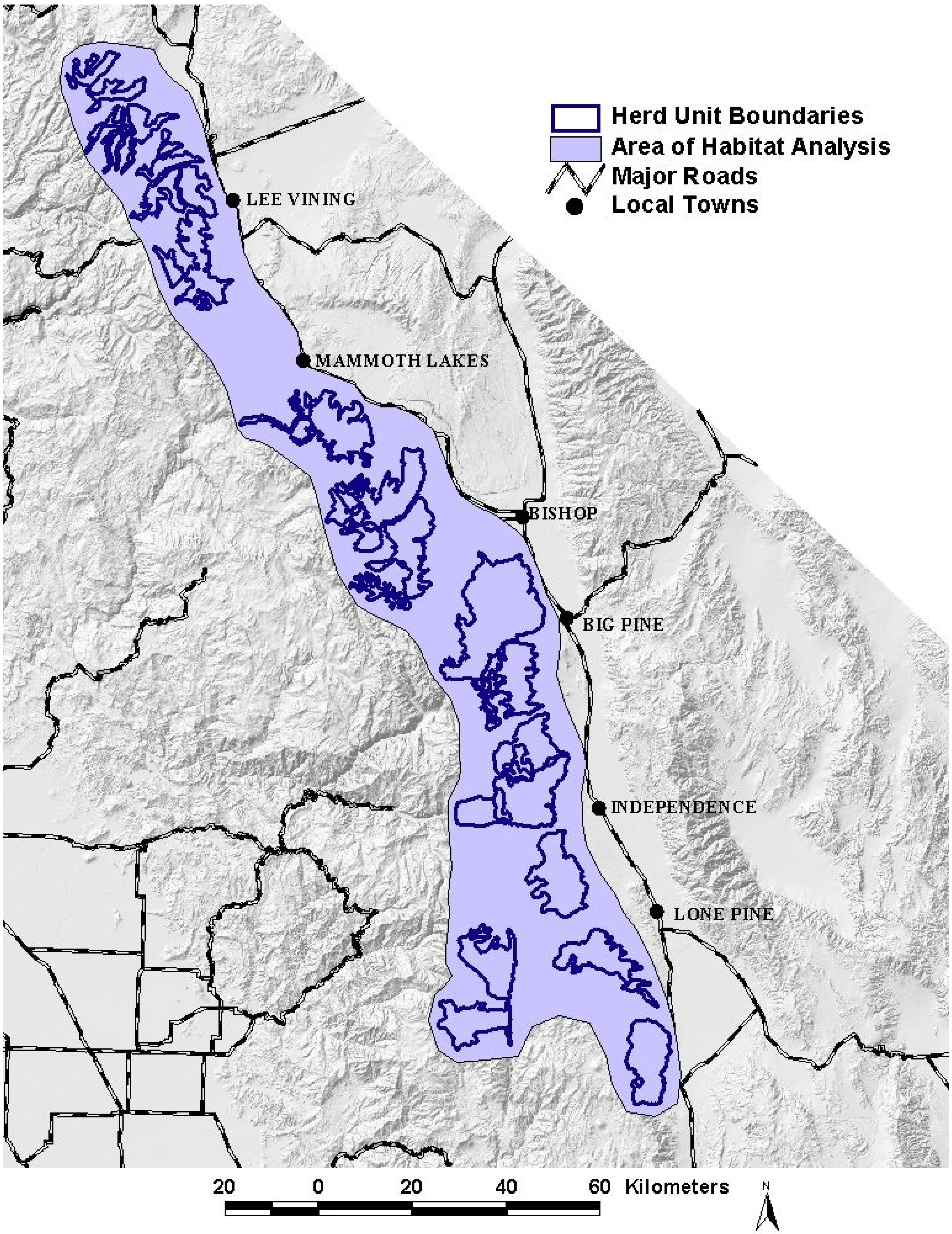

Figure 3. Predictive model of winter Sierra Nevada bighorn sheep habitat use, generated from a resource selection probability function.

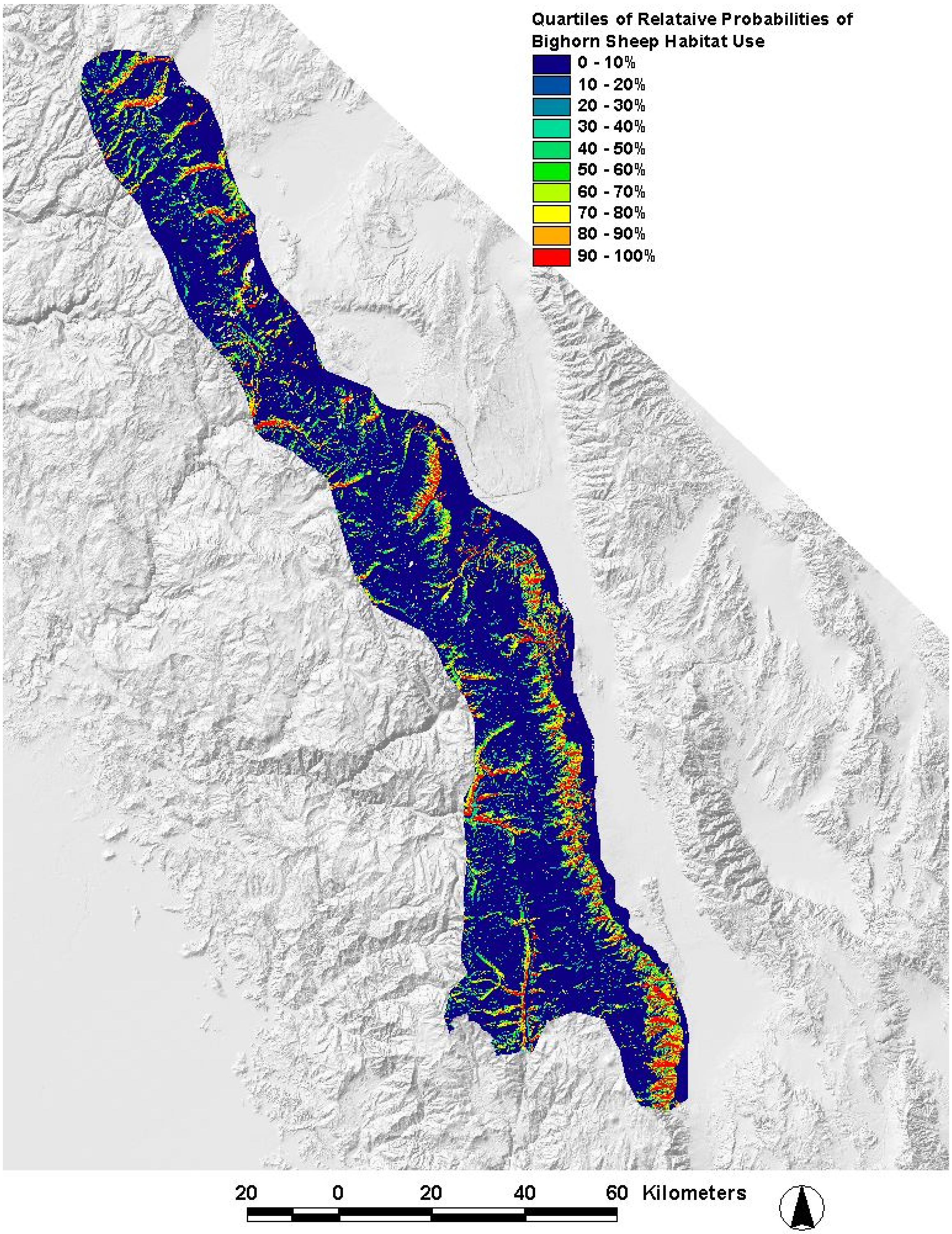

Figure 4. Predictive model of summer Sierra Nevada bighorn sheep habitat use, generated from a resource selection probability function.

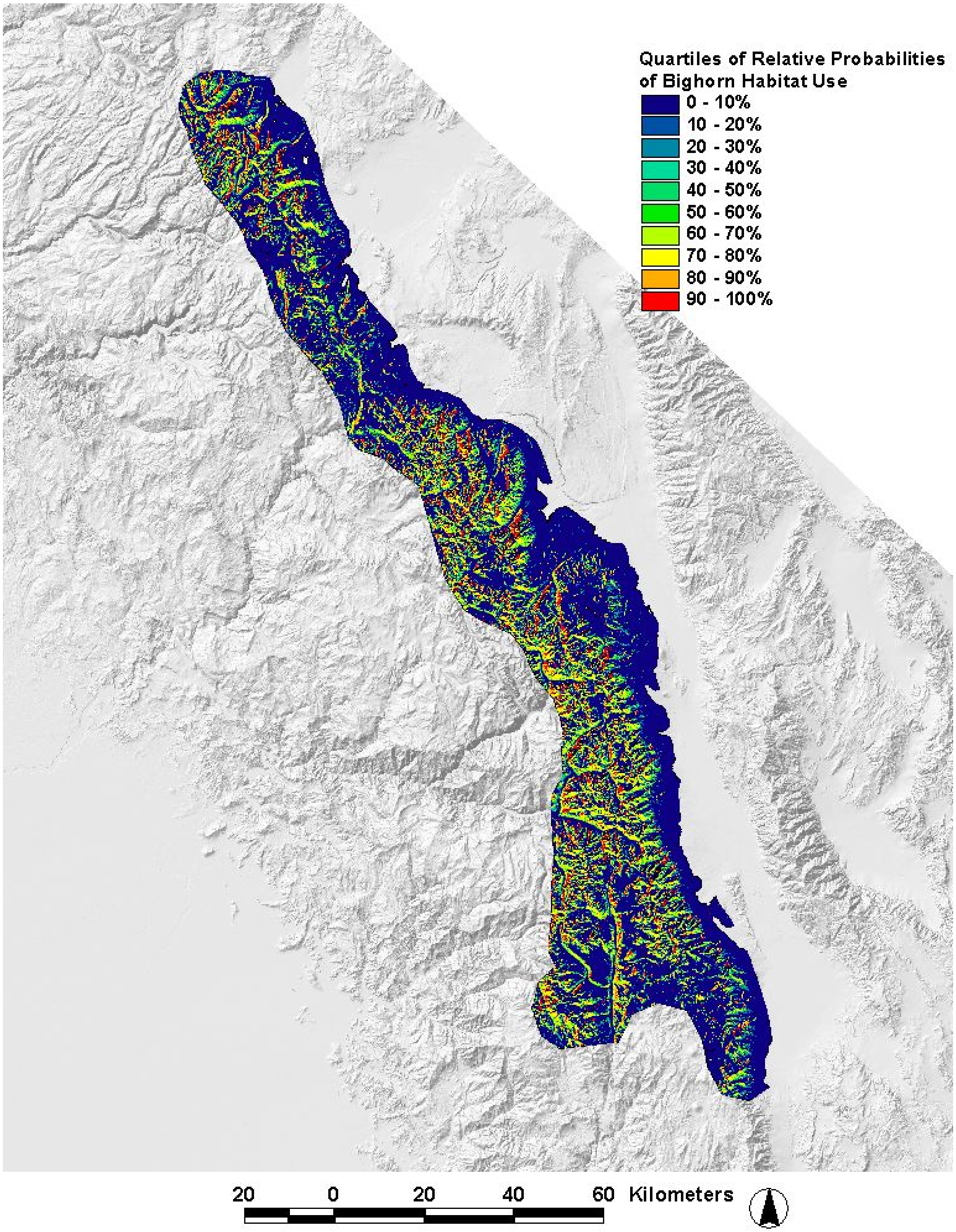

Figure 5. Linear regression line of the number of reproductive females in each herd unit by the amount (km^2) of winter range in the herd unit (No. Reproductive Females = -0.0273 + 1.9549 Log Winter Range, $F = 6.81$, df = 1, $P = 0.040$, $r^2 = 0.53$).

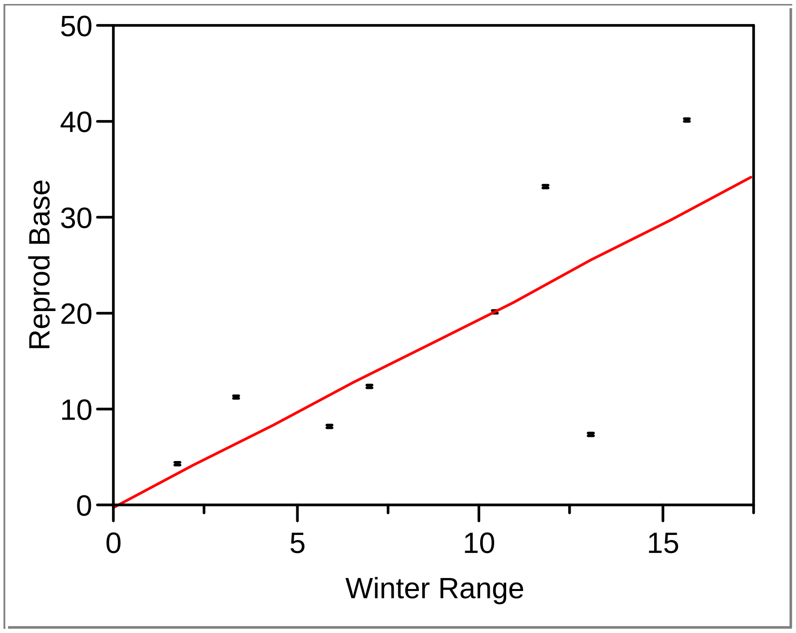

Figure 6. Winter range area (12.2 km^2), identified from the resource selection probability model, north of the Mt. Gardiner herd unit. Currently this area is not incorporated in any of the herd units.

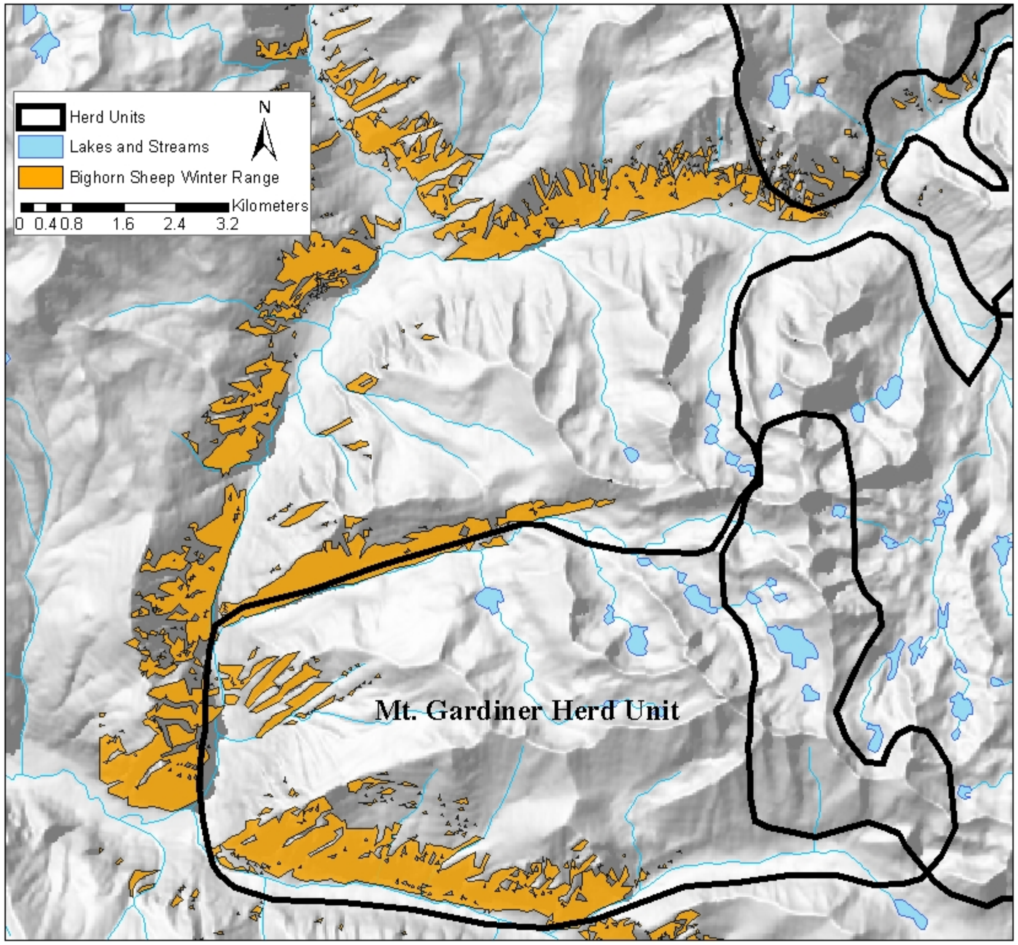

Figure 7. Winter range area (3.4 km^2), identified from the resource selection probability model, located just east of the Twin Lakes herd unit boundary.

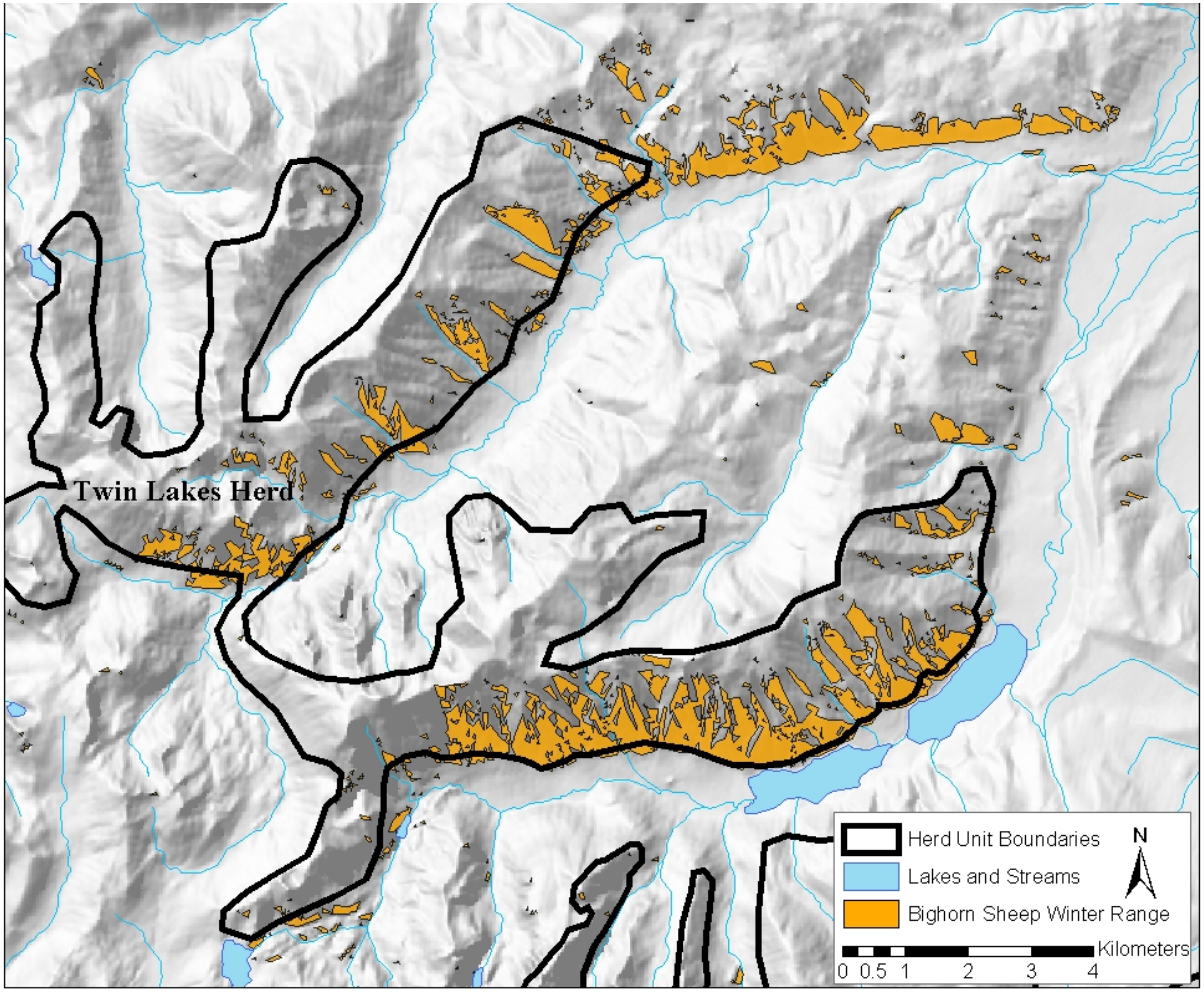

Figure 8. Winter range area (10.0 km^2), identified from the resource selection probability model, located between the Mt. Langley and Olancha Peak herd units.

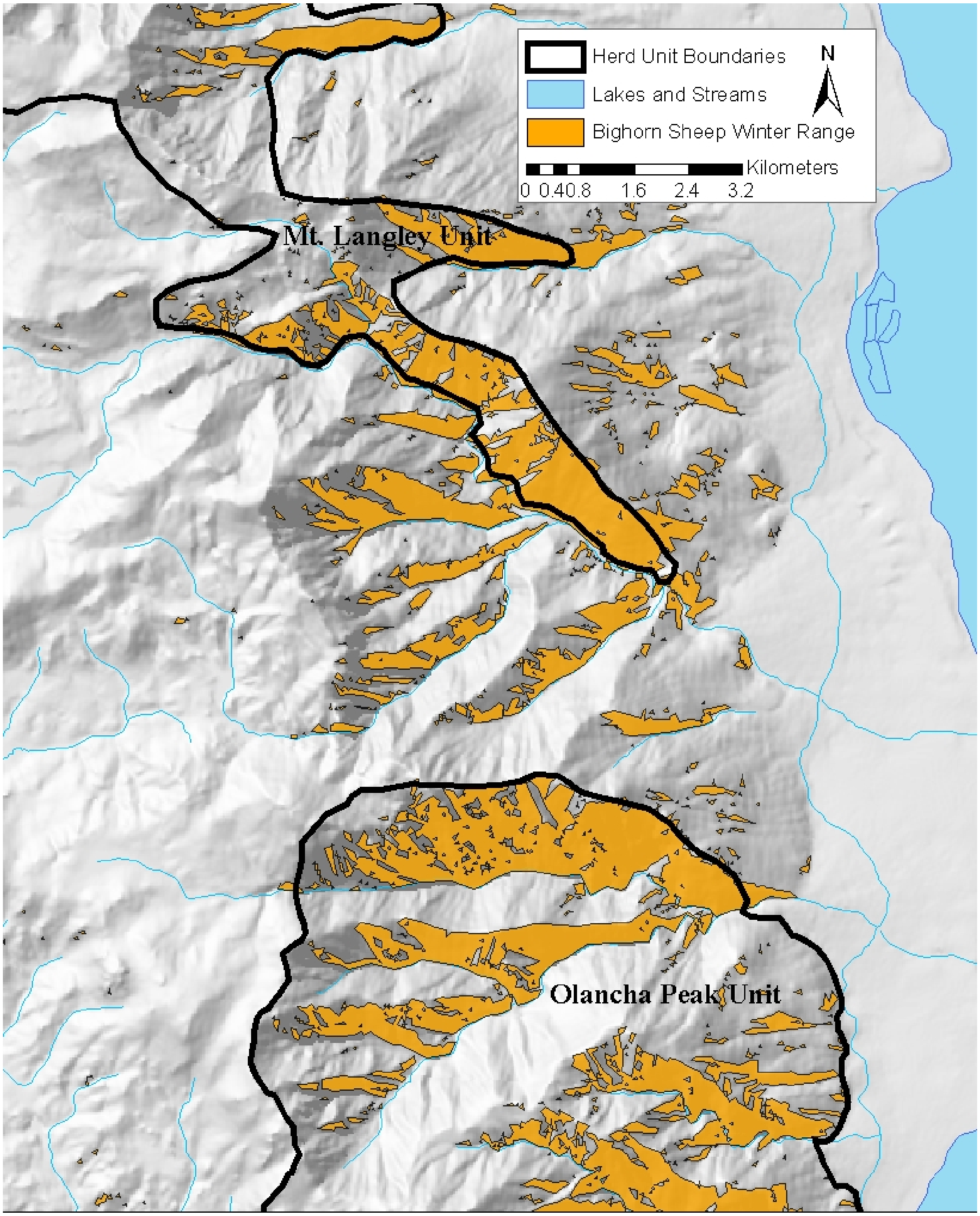

Figure 9. Winter and summer range, as identified by resource selection probability models, in the Kern Recovery Area (Big Arroyo and Laurel Creek herd units).

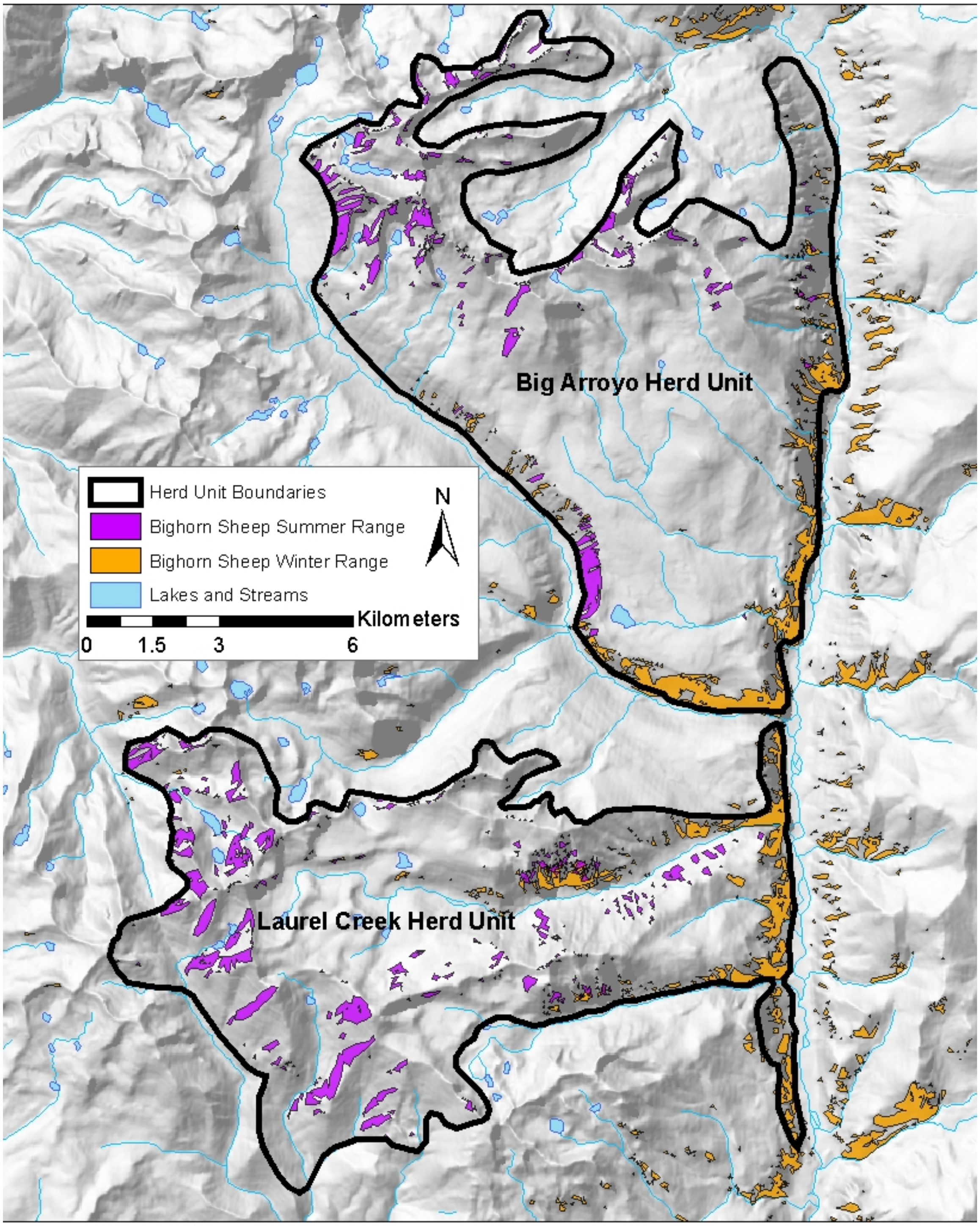

Figure 10. Winter and summer range, as identified by the resource selection probability model, in the Mt. Williamson herd unit.

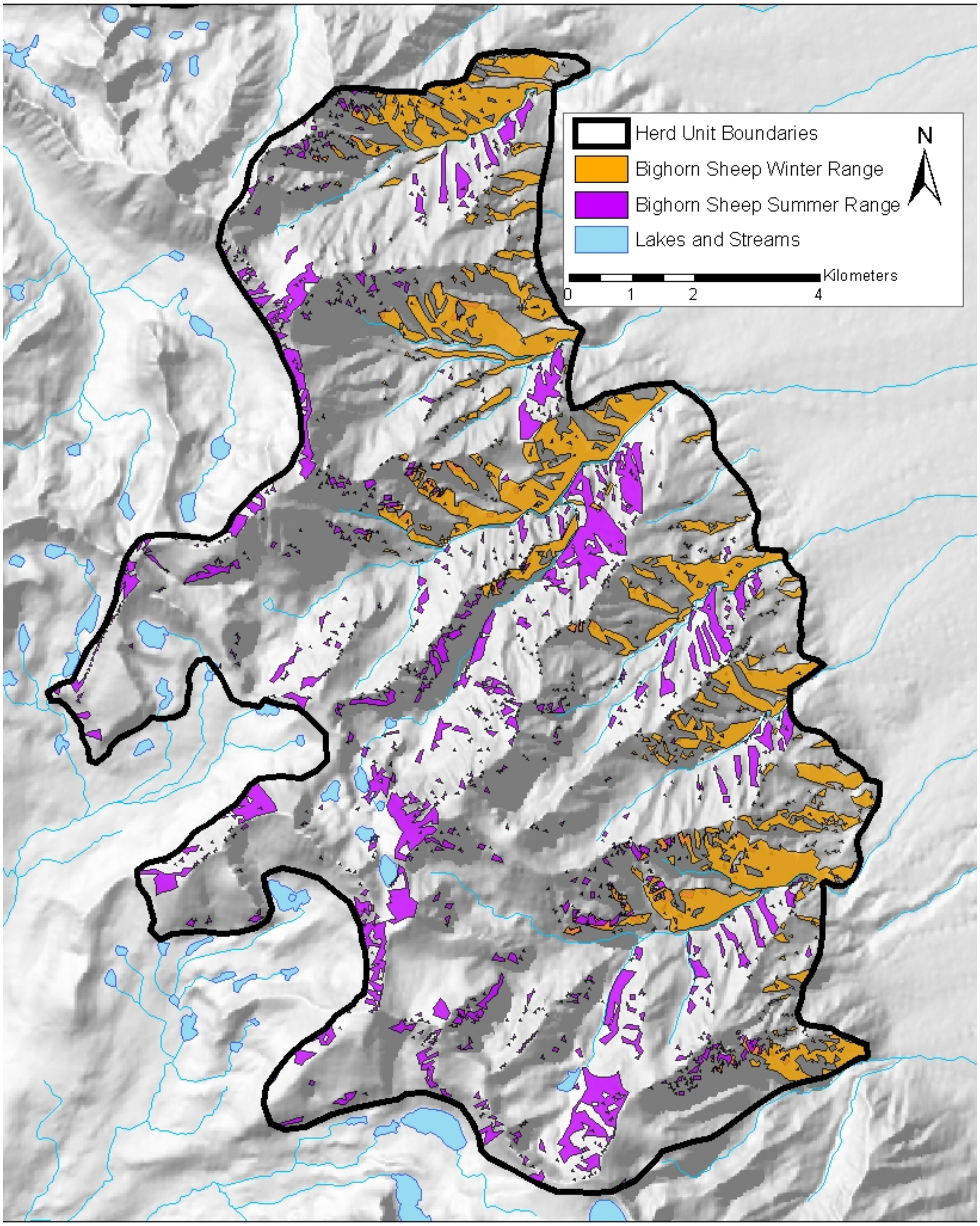

Figure 11. Sierra Nevada Bighorn Sheep summer range, as identified by the resource selection probability model, in the Green Creek and Lundy Canyon herd units in close proximity to USGS domestic sheep grazing allotments.

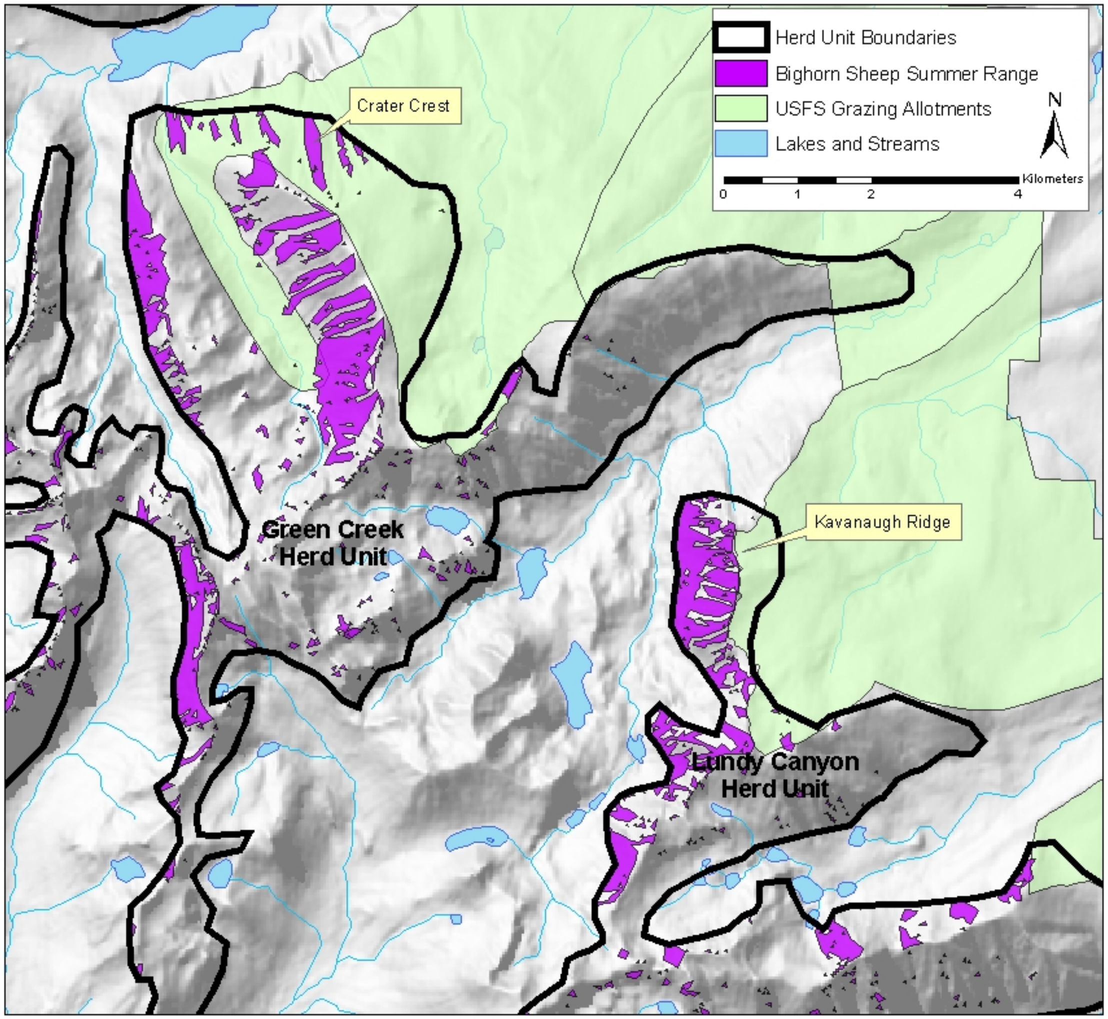

Figure 12. Increase in the relative resource selection probability for pixels in the Mt. Williamson Sierra Nevada bighorn sheep herd unit, when vegetation conditions were changed from "forested" to "non-forested."