

forest ecology

Structure of Fisher (*Pekania pennanti*) Habitat in a Managed Forest in an Interior Northern California Coast Range

Matthew R. Niblett, Stuart H. Sweeney, Richard L. Church, and Klaus H. Barber

Forest management planning across the Sierra Nevada and Northern California includes several focal wildlife species, one of which is the fisher, recently reclassified as *Pekania pennanti* (Sato et al. 2012) from *Martes pennanti*. This article presents an analysis of fisher habitat associated with privately owned forestland in Northern California. We take advantage of a high-resolution inventory database to show selective use of female fishers within this landscape. This landscape can be thought of as a matrix containing scattered mature stands of conifers and hardwoods (age >100 years) within a landscape of younger mixed conifer stands and numerous openings (24% of the area). Although stand and forest averages for habitat elements appear to score poorly using a widely used metric, we demonstrate through a new form of spatial sampling using a Kolmogorov-Smirnov (K-S) statistical test, which we call *k*-max, selective habitat use by female fishers at a relatively fine scale. This approach is novel in terms of generating population-level inferential results that are sensitive to smaller scale selection behavior, demonstrating that existing large structures, even though limited in areal extent, are critical elements in female fisher habitat.

Keywords: habitat characterization, spatial analysis, industrial forest management, habitat analysis

To achieve sustainable timber harvest levels, which may include managing forest fuel loads, forest managers rely on planning models, from vegetation simulators to optimization models focused on activities scheduled over decades. Accurate planning models are especially useful for managing habitat for wildlife species that are listed as threatened or endangered or are candidates for listing under the Endangered Species Act. On public lands in the Western United States, forest management has concentrated on fuels removal activities (mechanical removal of ladder fuels, thinning, prescribed burns, and others) to reduce the severity and size of large-scale catastrophic fires (Agee et al. 2000, Bahro et al. 2007) as a means of protecting valuable habitat, which has shifted more recently toward “ecosystem services” planning. On private holdings, a wider range of management occurs, including harvesting, thinning, and fuel breaks. In either case, special attention is placed on “key” species protection. One candidate species is the fisher (*Pekania pennanti*; see Sato et al. [2012]), the main subject of this article.

The objective of this article is to demonstrate that a new spatial sampling technique, when paired with well-established statistical testing methods, is useful for identifying important forest habitat

components that do not exist as an average forest condition for a species of concern. We use this technique to characterize significant fisher habitat structure within an industrial forest, which historically has been managed for timber yields and not for wildlife protection. This forest has been subjected to high-intensity storm events, fire, fire salvage logging, and intense logging activity in previous decades. Thus, it is a varied forest consisting primarily of younger aged stands interspersed with older trees and many forest openings, a forest not typically associated with fishers, especially within the context of the amount of open space and the lack of larger tracts of mature forest. Our study is based on a small population of fishers, known den sites, and resting locations and a very high density of stand inventory plots. To assess significance, we introduce a new method of characterizing habitat selection and incorporate randomization tests, rooted in the K-S distributional significance test, to identify key structural elements in this forest.

The fisher is a North American member of the Mustelidae (weasel) family. The fisher’s historic range encompassed boreal forests of Canada, the Cascade Range of the Pacific Northwest, the northern California Coast Range, the Sierra Nevada, and the Rocky

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Mountains of the western United States, as well as large portions of the upper-Midwest extending as far south as Tennessee, and the eastern United States (Lewis et al. 2012). In the western United States, fishers currently occupy areas of the Northern Rockies, the Cascade Range, the northern California Coast Range, and parts of the southern Sierra Nevada and are being monitored after a recent reintroduction program in the northern Sierra Nevada. The fisher has historically been associated with mature to old-growth conifer and mixed hardwood forests in the western United States (Buskirk and Powell 1994, Zielinski et al. 2004b, Lofroth et al. 2010).

Forest elements associated with fishers include the following: trees with cavities suitable as dens for the birth and rearing of kits; trees with limbs and deformities used as rest sites; holes in the ground, rock piles, and fallen trees for resting and sleeping; areas that contain prey such as rodents and birds; and canopy cover (Powell and Zielinski 1994, Zielinski et al. 2004a, 2004b). The importance of canopy cover, particularly moderate to dense cover, has been regularly associated as an important predictor of fisher habitat. In addition, dense canopy cover (vertical structure) is believed to provide refuge from predators and thermoregulatory benefits (Raley et al. 2012). However, Raley et al. (2012) note that studies using canopy cover are hard to compare because of the varying ways it has been measured and defined. It is believed that the reduction in the range of the fisher is due to increased anthropogenic activity including commercial trapping, logging, fire treatment policy, and habitat loss due to development (Powell and Zielinski 1994). Fishers are also threatened by the increased use of anticoagulant-based rodenticides within their range. These detected anticoagulants are thought to originate principally from illegal marijuana cultivation sites located on public and community lands (Gabriel et al. 2012).

Previous research has indicated that fishers in the western United States are associated with large woody elements within mature, late-successional forests (Zielinski et al. 2004b). Buck et al. (1994) indicate that fishers appear to use some form of selection or avoidance of forest types. Similarly, Jones and Garton (1994) found that fishers in Idaho use different stand classes seasonally, that nonforested areas were not used in any season, and that old-growth forest appeared to be used more during the summer. Jones and Garton (1994) also note that the tracked fishers in the young forested stands of their study area were often associated with a large forest element, such as a large tree, snag, or log that had survived a stand-replacing fire. Although the previously cited works focused on resting sites and use of habitat within a home range, the findings of Weir et al. (2012) and Lofroth et al. (2010) highlight and report on the importance of structure for denning for fishers in British Columbia and western North America, respectively. In addition, these fisher den sites were often associated with a large hardwood tree or snag, although Lofroth et al. (2010) only reported the average dbh for both conifer and hardwood den trees, rather than reporting them separately. Mature, late-successional forests contain all of the elements typically associated with fisher habitat, but more varied landscapes may contain suitable features and structures for their existence. This means that large structures distributed across a landscape of varying aged stands and sizable forest openings, a somewhat heterogeneous forest, may sustain a population of fishers, even when the forest as a whole is not classified as mature stands of mid- to late-seral forest.

This article consists of two approaches: the first approach characterizes the predicted suitability of fisher habitat using highly detailed plot-level data. This is done with the predictive habitat model of Zielinski et al. (2012), which was developed for a region of Cal-

ifornia that includes our study site. Using den and resting sites, we implemented commonly used kernel density estimation techniques to estimate female fisher home ranges. The second approach involves testing the significance of “neighborhoods” containing large structures found within the home ranges compared with the neighborhoods of the forest as a whole. We also tested the significance of structures found in small neighborhoods defined about the den sites compared with the forest neighborhoods as well as the neighborhoods within the home ranges. Although the forest contains large mature trees, they are scattered and principally surrounded by larger blocks of younger trees and include many open areas. To test the significance of structures and their location of use, we developed a method called *k*-max. This method involves testing the significance of the presence of large structures found among this landscape mixture of younger trees, vegetation, fire scars, and open areas. The structure of the article is as follows. First, a description of the study area is given, including information on the telemetry of tracked fishers. This is followed by a characterization of the habitat using the model of Zielinski et al. (2012). We then present the *k*-max methodology and our approach to inferential testing. This is followed by a presentation of results using the *k*-max method and discussion.

Study Area

Vegetation

The study area of this article lies in eastern Trinity County, California (Figure 1) and includes approximately 182 km² (45,000 acres) of which roughly 78% is private industrial timberland, 15% is within the boundaries of Shasta Trinity National Forest, and 7% is held by private nonindustrial landowners. The size of this area is comparable to that of Buck et al. (1994); however, the public-private ownership mix is reversed. The bulk of the area has undergone major landscape changes including fire, logging, and salvage logging after severe weather events that denuded trees or to recover salvageable timber after fires. Early logging activities left trees that were uneconomical to harvest. This has resulted in the larger “legacy” trees currently located within the study area.

In the 1950s and 1970s, three series of selective cuts removed larger trees based on diameter. In 1964, 3,000 acres in the center of the study area burned, and 5,000 acres in the eastern portion burned in 1996. The 1964 fire area was salvage logged and reseeded aerially; conifer regeneration establishment from the aerial seeding efforts was generally poor or patchy, and most of the area became dominated by hardwoods with a few remnant older conifer trees. The area burned in 1996 was salvage logged and mostly replanted with ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) seedlings. Overall, the study area now consists of conifer and mixed conifer-hardwood forest. The conifers primarily consist of Douglas-fir (*P. menziesii*), ponderosa pine (*P. ponderosa*), incense cedar (*Calocedrus decurrens*), and white fir (*Abies concolor*). Dominant hardwood species are black oak (*Quercus kelloggii*) and canyon live oak (*Quercus chrysolepis*).

The study area forest is relatively young, with an average forest age of ~67 years (with SD of ~28 years) and low biomass volume per acre. The average basal area for conifer and hardwood trees is 22.83 m² ha⁻¹ (99.43 ft² acre⁻¹) in the study area. Many of the hardwood trees tend to be >40.64 cm (>16 in.) dbh and have grown and persisted in areas where conifers were logged. Overall, the forest landscape is a somewhat connected set of stands of various ages interspersed with legacy trees and many openings. Approximately 24% of the study area consists of open area (no tree canopy).

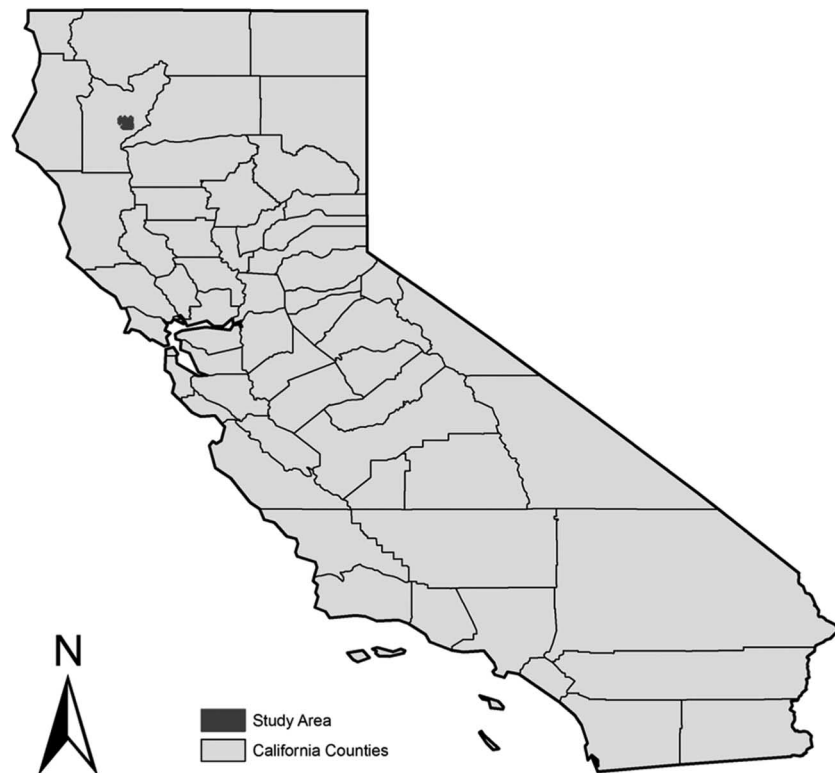


Figure 1. Southwest Weaverville study area in California.

If one uses the California Wildlife Habitat Relationship system classification of Mayer and Laudenslayer (1988) for open to sparse tree canopy cover (areas of $<40\%$ canopy cover), 49% of the study area is in this classification range. Areas that are open and have low canopy cover are evenly distributed throughout the forest. Thus, the landscape is somewhat heterogeneous because of the scattering of open areas and the wide variation in forest composition of forested areas. Given the high heterogeneity of the forest stands, Sierra Pacific Industries, the current owner of the industrial private lands, wished to inventory the area. They commissioned registered professional foresters to oversee the sampling design and surveying of their holdings and some of the holdings of the US Department of Agriculture (USDA) Forest Service within Trinity National Forest to generate the inventory.

The resultant inventory plot data set was generated using an angle gauge and variable plot cruising in 2006. The data set is a systematic sample with a random starting point consisting of 10,615 unique plot points containing several attributes (see Table 1 for a sample of measured attributes). Plot points are generally established every 80.4672 m (264 ft) along transects running in a north-south cardinal direction, which are systematically spaced every 201.1680 m (660 ft) across in an east-west cardinal direction. The plot sampling design was established such that there is a plot sample for approximately every 1.61874 ha (4 acres) (80.4672 m by 201.1680 m rectangle), while also accounting for topography and ownership. We will subsequently refer to the ~ 1.62 -ha area plots in the article as high-resolution plots. The high density of the sample points provides a much greater level of spatial detail than most forest inventory data sets, such as the USDA Forest Service Forest Inventory Analysis (FIA) plots. For example, there is approximately one FIA plot for every 2,428.114 ha (6,000 acres). FIA plots are sampled using four detailed subplots (USDA 2005). Figure 1 shows the

Table 1. Table of tested attributes measured at each 4-acre inventory plot along with their description.

Attribute	Description
QUADMEAN	Quadratic mean diameter of all trees (cm)
BASAL_PP	Total basal area of ponderosa pine ($\text{m}^2 \text{ha}^{-1}$)
BASAL_DF	Total basal area of Douglas-fir ($\text{m}^2 \text{ha}^{-1}$)
BASAL_HW	Total basal area of hardwood trees ($\text{m}^2 \text{ha}^{-1}$)
BASAL_HW8	Total basal area of hardwood trees >8 in diameter ($\text{m}^2 \text{ha}^{-1}$)
BASAL_TOT	Total basal area of live trees ($\text{m}^2 \text{ha}^{-1}$)
BASAL_SNAG	Basal area of snag trees ($\text{m}^2 \text{ha}^{-1}$)
SCRIB_DF	Scribner's volume of Douglas-fir (board-feet acre $^{-1}$)
SCRIB_TOT	Scribner's volume of total live trees (board-feet acre $^{-1}$)
TREES_DF	Total number of Douglas-fir trees per ha
TREES_HW	Total number of hardwood trees per ha
TREES_HW8	Total number of hardwood trees > 20.32 cm diameter per ha
TREES_TOT	Total number of trees per ha
TREES_SNAG	Total number of snag trees per ha
CANOPY	Percent canopy (100% = complete canopy cover)
BIOMASS_AG	Aboveground biomass (metric-tons per ha)
RRHS	Relative resting habitat suitability score (scored from 0 to 1), computed using the model of Zielinski et al. (2012)

location of the study area in California. The area in the figure that is shaded darker gray represents areas covered by a forest inventory grid.

Fishers

Fishers were trapped for a collaborative tracking effort between Sierra Pacific Industries (SPI) and the California Department of Fish and Wildlife (CDFW). The three goals of their trapping effort were to document the presence of male and female fishers, to identify and describe the home ranges of female fishers, and to identify their natal dens, where parturition occurred, and maternal dens, where kits were reared (Reno et al. 2008). Fishers were trapped from

Feb. 21 to Mar. 14, 2006, Feb. 5 to Mar. 2, 2007, and Feb. 25 to Mar. 14, 2008 with a total of 1,112 trap nights. During each trap effort, an average of 30 traps were set approximately 50 m from a road and 1.5 km apart. Traps were placed based on fisher observations recorded in the CDFW National Diversity Data Base and by suggestions of local foresters. Gusto, a commercial scent lure, was used to attract fishers to the traps. Female fishers were collared with VHF transmitters from Advanced Telemetry Systems (model M1930). Male fishers were uniquely identified at trap locations; no further attempt at tracking males was made. Telemetry data was collected over a span of 2 weeks every month from Feb. 22, 2006 through Dec. 14, 2007, on the ground and aerially from helicopter by SPI and fixed wing aircraft by CDFW. Relocations were recorded using Telonics model TR-2 receivers with 14K and 2AK "H" style antennas. Resting locations measured from the ground and by helicopter were used in this study because the location accuracy is considerably better than that measured by fixed-wing aircraft; a fisher was determined to be at rest if the signal remained strong and constant for longer than 15 minutes. This ensured that the fisher activity could be determined (e.g., moving or at rest) and that an accurate triangulation could be obtained. Triangulation readings helped SPI and the CDFW locate den sites for the females. Removal of radio collars occurred during the last period of trapping in 2008.

Traps captured 33 unique fishers: 9 female and 24 male. The body mass of the trapped male fishers averaged 3.65 kg and ranged from 2.90 to 5.00 kg; female body mass averaged 2.13 kg and ranged from 1.80 to 2.40 kg. Of the fishers trapped in the collaborative effort, 13 of the 24 males and 7 of the 9 female fishers were within the region for which detailed plot data are available, the study area of this article. Of those 7 females, 5 retained their radio collars over the 2-year tracking period. The other 2 fishers provided a limited number of telemetry coordinates, enabling natal and maternal den sites to be located, but not enough points to generate kernel density estimates of their home ranges.

For the 5 females with complete tracking data, 243 unique telemetry points were obtained, an average of 48 locations per individual during the 2-year tracking period. One of the 7 adult females died during the tracking effort at the end of June 2007; it is thought to have been preyed on by a mountain lion based on the pattern of tooth marks on the skull. In addition to the telemetry points, 46 den sites were located comprising 7 natal dens and 39 maternal dens. Furthermore, natal and maternal dens were identified and confirmed to contain kits through the use of remote cameras, audio, and visual cues. Data on the den site itself, tree type, height, and dbh were collected. In addition, data measuring the quadratic mean diameter of the surrounding forest was collected using a fixed-radius plot design centered at the den site, but excluding the structure tree.

The fixed-area plot resembled a cross; each arm of the cross was 35 m long and 10 m wide and oriented in a cardinal direction. Of the 7 natal dens, 5 were in black oaks and 1 each was in a live oak and a Douglas-fir tree. Of the 39 maternal dens, 20 were in black oaks, 7 were in live oaks, 6 were in Douglas-fir snags, 2 were in Douglas-fir trees, and 1 each was in a black oak and a live oak snag, a live oak limb fall, and a big leaf maple (*Acer macrophyllum*). Two fishers had kits in 2006 and five had kits in 2007. The average dbh for den hardwoods and conifers is 65.16 and 129.79 cm, respectively. Table 2 lists the number of dens, average dbh, and average height for each species of tree in which a den was located. Although only one conifer type, Douglas-fir, was used for denning by fishers in our study area, the average dbh for living and snag den trees is 129.79 and 119.43

Table 2. Mean dbh and height of fisher den trees and snags in the study area.

Tree species	Total no. of dens	Dbh (cm)	Height (m)
Black oak	25	53.34	15.14
Live oak	8	102.10	15.27
Big leaf maple	1	30.98	13.71
Douglas-fir	3	129.79	36.78
Black oak snag	1	37.33	9.44
Live oak snag	1	43.94	4.87
Douglas-fir snag	6	119.43	20.82

cm, respectively. However, 80.4% of den trees in our study area were hardwoods, of which 70.3% were black oaks. We include a live oak limb fall in the above den tree percentage as being a type of hardwood snag because it fell from a large hardwood tree, although we do not include the limb fall in the reported measures of dbh. Black oaks used for denning have lower average dbh (53.34 cm) than the average hardwood dbh used for denning (65.16 cm).

Method of Analysis

Several predictive models have been developed for fisher habitat suitability (Carroll et al. 1999, Zielinski et al. 2006, 2010a, 2010b, 2012), conservation planning (Carroll et al. 2010, Spencer et al. 2011), and the potential effects of fire and fire fuels management strategies on fisher habitat (Scheller et al. 2011, Thompson et al. 2011). One of the most recently developed habitat suitability models is that of Zielinski et al. (2012). This is a predictive model of relative resting habitat suitability, a major element in fisher habitat. We applied the model of Zielinski et al. (2012) because our study area lies within that used to develop their model, and our plot data set contains attributes that are similar to those employed in their model. The Zielinski et al. (2012) approach uses a set of forest attributes to determine a relative resting habitat suitability (RRHS) score. A series of attribute entries are required to obtain the score: canopy cover, average age of conifer trees, total basal area of live trees, volume of large downed wood, and hardwood basal area. The RRHS score was determined for each of the FIA plots and 4-acre plots using a spreadsheet model (see Zielinski et al. 2012). Computing the FIA-based RRHS scores of Zielinski et al. (2012) may help to predict the likelihood of a fisher considering the study area as a whole, whereas the higher resolution ~1.62-ha (4-acre) plot scores can be useful in predicting suitable resting habitat locations within the study area, i.e., places of refugia within the matrix of forest stands.

The high-resolution plot (~1.62 ha) RRHS scores were computed using nearly the same attributes found within the FIA plot data, except that the volume of large downed wood was measured using logs with a diameter of ≥ 60.96 cm (24 in.) on the large end, whereas Zielinski et al. (2012) based their analysis on logs that were ≥ 25.40 cm (10 in.) in diameter. We believe, however, that this will not have a significant effect on our analysis, as a sensitivity test for this attribute within the RRHS function revealed that downed wood was not a dominant determinant for the model (see the Appendix for a description of sensitivity testing of FIA and high-resolution plot data using the Zielinski et al. [2012] model). All attributes of the high-resolution plots were measured in imperial units and were converted to metric measurements for use in the RRHS model. Zielinski et al. (2012) state that their model indicates strong negative selection for RRHS values of <0.15 , and for RRHS scores of

>0.35 , selection steadily increases. Because our data set contains similar measures of the FIA plot data and the data are in terms of rates/proportions (e.g., $\text{m}^2 \text{ ha}^{-1}$, percentage of an area), issues related to the modifiable areal unit problem, which is of scale and aggregation, should be minimal (Jelinski and Wu 1996). Given that our study area lies within that used to calibrate the Zielinski et al. (2012) model and the model testing outlined in the Appendix, we have retained the classification system suggested in their article. Herein, we characterize the plots as being “poor” when RRHS is <0.15 and “good” when RRHS is >0.35 .

To be sure, one can expect that a large swath of mature forest will have a high resting habitat suitability score. Expert opinion would also grade this as good, supportive habitat. But, how should one view a forest with scattered sites of high resting suitability, among a larger swath of dense young forest and many scattered open areas? Virtually all FIA plot RRHS scores within and adjacent to the study area are poor, which would suggest, at the resolution of the FIA plots using their metric, that viable habitat is not likely to exist. However, several fishers (7 females and 13 males) were trapped in this area and a number of den sites were located. With use of high-resolution plot data, our goal is to identify whether there is statistically significant selection/use of this industrial forest.

Our approach to testing habitat selectivity attempts to determine the small-scale nature of behaviors such as denning and resting by focusing on “best of the best in neighborhood.” Technically, this is implemented by computing the distribution of the maximum values among a set of k -nearest neighbors (k -max), i.e., the distribution set of maximums of each group of k -nearest neighbors. The fundamental question is: Do fishers select habitat based on the availability of critical landscape attributes (e.g., large trees, dense canopy, large amounts of basal area per ha, and density of trees per ha) being minimally present in small patches (neighborhoods of these elements) that are defined by the ability of fishers to find and use them? Implementation of this idea could be the presence of at least one high-scoring RRHS plot or some other feature of the landscape within a neighborhood defined on the set of inventory plots. Testing for the existence of such preferences amounts to inference about the nonequivalence of two distributions of k -max measures where one distribution is defined based on where fishers are observed and the other is a reference distribution. The k -max measure and our inferential tests were developed to detect this preference for the type of scattered forest plots that have high RRHS scores; however, we can also use it for any scattered element of interest. This approach is based in part on the observation that fisher resting and den sites are found among the best structural elements: i.e., areas containing dense canopy cover with few forest openings, large amounts of basal area, and large proportions of mid- to late-seral stands, including larger oak and coniferous trees (Zielinski et al. 2004a, 2004b, Purcell et al. 2009, Raley et al. 2012, Zhao et al. 2012, Aubry et al. 2013). We suspect that this observation is true for den sites (natal and maternal) as well (Weir et al. 2012, Zhao et al. 2012). The remainder of this section describes the k -max approach in further detail.

Partitioning an area into two distributions to be compared is a classic way to determine habitat selection preference by animals (Allredge and Ratti 1992, Manly et al. 1993, Allredge and Griswold 2006). The k -max approach follows this tactic to compare distributions of a structural element, Z , within a landscape, W . More formally, suppose the total study domain W is partitioned into two sets V and $W \setminus V$,¹ where V could be compact or could be com-

posed of a set of regions (islands) within W . The definition of V is dependent on the type of comparison to be made. In this article, V is either the set of den sites (compared against reference distributions for either the forest or to the domain within the kernel density estimates) or the domain defined by kernel density estimates (compared with the reference distribution of forest not including the kernel domains). We want to test a hypothesis of distributional equivalence, $H_0: F_{Z|V} = F_{Z|W \setminus V}$, against $H_A: F_{Z|V} \neq F_{Z|W \setminus V}$, where F is some characterization of the distribution of Z . The following describes how the k -max distributions were developed and how a permutation approach using a K-S distributional equivalence test was implemented.

To compare and determine the significance of an area, we needed to partition the landscape into unique neighborhoods with a meaningful spatial grouping composed of the underlying high-resolution plot data. In this case, the forest neighborhoods represent the area that uniquely surrounds a den site. The area unique to a den site can be thought of as those areas within half of the average move distance between den sites. In a certain way, the unique areas can be viewed as a series of tessellated squares over a landscape; each “square” would contain the k -plots representative of the area within it. The area uniquely represented as a set of k -neighbors can be defined as a quadrature set. The entire forest is represented as a set of unique quadratures.

Rather than using Z measured at every observed plot in V and $W \setminus V$, we instead focus on the “best of the best in each neighborhood or quadrature” or in mathematical terms the set of greatest elements of subsets defined over k -nearest neighbors. In spatial terms, we can compare the set of the best plot of quadratures for distribution V to the set of the best plot of quadratures in the remaining distribution $W \setminus V$. For example, several quadratures could represent the area unique to a home range (V) compared with the quadratures representing the remaining forest ($W \setminus V$). By comparing the preeminent high-resolution plots unique to a larger area, we can examine the best structural components of a forest and avoid issues related to the modifiable area unit problem and gain a better understanding of the best elements that are lost when included in an areal average. Groups of quadratures can be thought of as those uniquely representing den locations, home ranges, or the rest of the forest. We term the set of the best plots, the best from each quadrature, the k -max set. To make this more precise mathematically, we introduce three sets of spatial location indices all contained within W . These are the following: s , the location of plot centers; t , the location of den sites (natal and maternal); and u , the location of a set of regularly spaced quadrature points. A quadrature point can be thought of as the centroid of a tessellated polygon defined by the set of points contained within it (the k -neighborhood).

There are several ways to conduct hypothesis tests of habitat preference (Allredge and Ratti 1992, Manly et al. 1993, Allredge and Griswold 2006). The most basic approach to habitat selection testing is based on monitoring animals’ choices (moves) among a set of habitats that are exhaustive and have a one-to-one mapping into the study domain; each location on the map has only one habitat among the set of habitats found in the study region. Within that framework, the χ^2 test is the simplest and has been one of the most popular, despite many of the assumptions (minimum cell counts, independence of observations, etc.) not being satisfied (Allredge and Ratti 1992, Allredge and Griswold 2006). In our case, we have

very rich and high-resolution inventory and detailed tracking records for a small number of fishers. We therefore focus on comparing complete distributions of single landscape attributes between selected (areas where fishers are known to have been proximally) and nonselected (areas where fishers are not known to have been proximally) areas, and we use robust resampling-based methods for inferential testing. As explained in detail below, our measure of distance between the two distributions is defined on empirical cumulative distribution functions as in the K-S test. Whereas we report results for χ^2 tests and standard K-S tests, the permutation (randomization-based) tests provide a more robust nonparametric alternative, given that we know certain assumptions of the other tests are not satisfied (Manly 2007).

In this case, we observe plot characteristics Z_s measured at locations s . Next, we define two types of neighborhood sets: b_t consists of the k closest points in s to a point in t , and b_u consists of the k closest points in s to a point in u . The landscape variables we work with are then defined on locations t or u as

$$Z_t = \max_{s \in W_t} Z_s \quad \text{and} \quad Z_u = \max_{s \in W_u} Z_s. \quad (1)$$

We focus on the k -max sets, Z_t or Z_u , because we assert that fishers are selecting domains of the landscape based on satisfying structural requirements within a general neighborhood. That is, they tend to choose locations within the forest that have qualities closer to mature to late-seral forest characteristics (e.g., large trees, dense canopy, high levels of basal area, and others). Specifically, in this study we set $k = 10$. The reason for choosing the 10 closest plots is that this approximates the area within a 201.168-m (660 ft) radius of the den. Because the average den site move, the distance between natal to maternal and maternal to maternal sites, for a female fisher in our study area was approximately 402.336 m (1,320 ft), we assert that the area about a den at half that distance is likely to uniquely represent an area for a potential den. Thus, a 201.168 m (660 ft) neighborhood radius around a den can therefore be reasonably expected to contain the unique structures surrounding a given den site. The quadrature points, u , are introduced to provide an approximate partitioning of the plot centers into nonoverlapping sets of 10 plots. Because of some irregularities in the shape and orientation of inventory plots, the resulting k -max sets include a small amount of overlap among the 10 nearest neighbors.²

We want to conduct three different tests of distributional equivalence for each landscape feature, Z . These are the following

1. k -max about the den sites compared to the complete forest (W) or k -max about all quadratures, $H_0: F_{Z_{t \in \{W\}}} = F_{Z_{u \in \{W\}}}$,
2. k -max about the den sites compared to the k -max quadratures representing the home range domain (V), $H_0: F_{Z_{t \in \{V\}}} = F_{Z_{u \in \{V\}}}$, and
3. k -max about all quadratures within the home range domain (V) compared with the rest of the forest k -max quadratures, $H_0: F_{Z_{u \in \{V\}}} = F_{Z_{u \in \{W \setminus V\}}}$.

We defined the home ranges, V , using kernel density estimation with the bandwidth selection chosen using cross-validation and incorporating edge correction following Diggle (1985, 2003).³ The results reported in the next section for tests 2 and 3 above involved using the 75th quantile of the kernel density to define the domain of V . The 75th quantile of the kernel density estimates was used because this is likely to provide the best approximation for areas known to be used by fisher. For tests of type 2, the plot centers in V were

divided into disjoint sets that are either among the 10 nearest neighbors of a den site or not. Those that are not are available to be associated with a quadrature point u in V . The full forest domain, W , was also reduced to exclude nonforest elements before any tests were conducted. Areas consisting of 40 acres or more of nonforested land (mostly areas of recent severe wildfire) were excluded from the study to reduce the number of low k -max values. This reduces the likelihood that an element will be identified as statistically significant as we have compared only quadratures containing some forested areas; if these quadratures are included, statistical significance is even stronger.

For each of the pairwise comparisons between distributions “A” and “B” (den/forest, den/kernel, and kernel/forest), we present three related inferential tests of distributional equivalence: χ^2 , K-S, and a permutation test that uses K-S as a distance measure. The first two tests, χ^2 and K-S, are well-known tests with inference based on comparison of the test statistics to a known reference distribution. The drawback of the χ^2 test is that the continuous data are aggregated into a set of threshold bins; the binned counts in A are then compared with the expected bin counts under the distribution of bin counts in B. Information is lost in the binning process and for most of the attributes tested. We do not satisfy the requirements for the χ^2 distribution to hold and thus the resulting P values may be misleading. This is probably the most well-known test but is also the least robust. We include it primarily for comparison to the other two test results.

The K-S test is useful because it is a nonparametric test for comparing a set of observations with an underlying continuous distribution. The test essentially measures the distance between the empirical cumulative distribution function of A and the empirical cumulative distribution function of B. The drawback of the K-S test is that valid inference requires that the distributions compared are truly continuous; as the number of ties increases, the basis for inference erodes. Because of this, we suppress the test results when the distributions compared have <70% of the values being unique. However, it is still useful as a reference to compare P values from the K-S test with those from the permutation test.

The permutation test uses the variation in our observations to numerically derive a P value. Assume that distribution A has n_a values, distribution B has n_b values, and we have a function $M(A, B)$ that yields a measure of distance between distributions A and B. The function $M(\cdot)$ in this case is the K-S test used to derive the test statistic as a measure of distance between distributions. Take $M(A, B)$ as the observed test statistic, and then generate R replications of $M(\cdot)$ where the input distributions A_r with n_a values and B_r with n_b values are random samples without replacement from the vector $\langle A, B \rangle$. The permutation P value reported below is calculated as

$$\frac{1}{R+1} \sum_r I(M(A_r, B_r) < M(A, B)) \quad (2)$$

where $I(\cdot)$ is an indicator function that takes the value 1 if true and 0 otherwise. The permutation test simply yields the probability of the observed distance between distributions A and B occurring due to “chance” as defined under the null hypothesis. Permutation testing was conducted using 999 replications. The permutation test should yield valid results even in the presence of ties. Of the three tests, this is the test in which statistical significance is the most robust

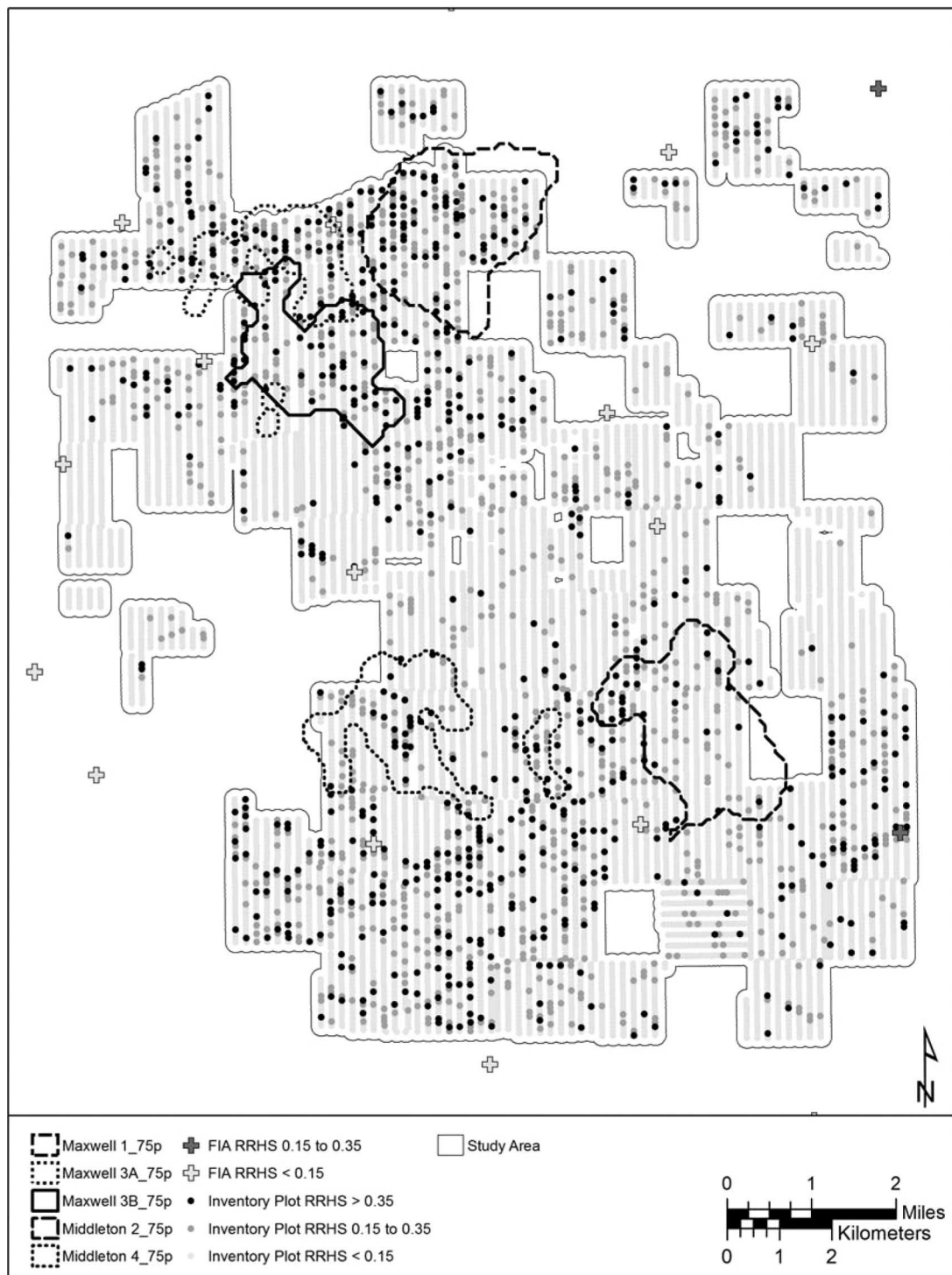


Figure 2. RRHS map characterizing poor (<0.15) and good (>0.35) habitat with 75% kernel density contours of 5 female fishers.

to the peculiarities of the distributions we are analyzing. The attributes tested using the k -max approach are listed in Table 1. Several of these attributes have been suggested as being useful for characterizing fisher habitat and therefore were chosen for use in the analysis (Zielinski et al. 2006, 2010a, 2010b, 2012, Thompson et al. 2011, Aubry et al. 2013).

Results

The results of the characterization of the study area using the model developed by Zielinski et al. (2012) are shown in Figure 2.

This figure shows both the FIA and ~ 1.62 -ha (4-acre) plot RRHS scores as characterized by the method of Zielinski et al. (2012) as being poor (RRHS of <0.15), neutral ($0.15 \leq \text{RRHS} \leq 0.35$) or good (RRHS of >0.35); see the Appendix for a discussion related to scoring and thresholds. In addition, isolines representing the 75% quartile of fisher use density within each individual home range were plotted. Sixteen of 18 FIA plots within 2 km of the study area were characterized as being poor fisher habitat (RRHS of <0.15); 2 of the 18 plots, located in the eastern edge of the study area, were characterized as neutral. The average FIA plot score of the study area was

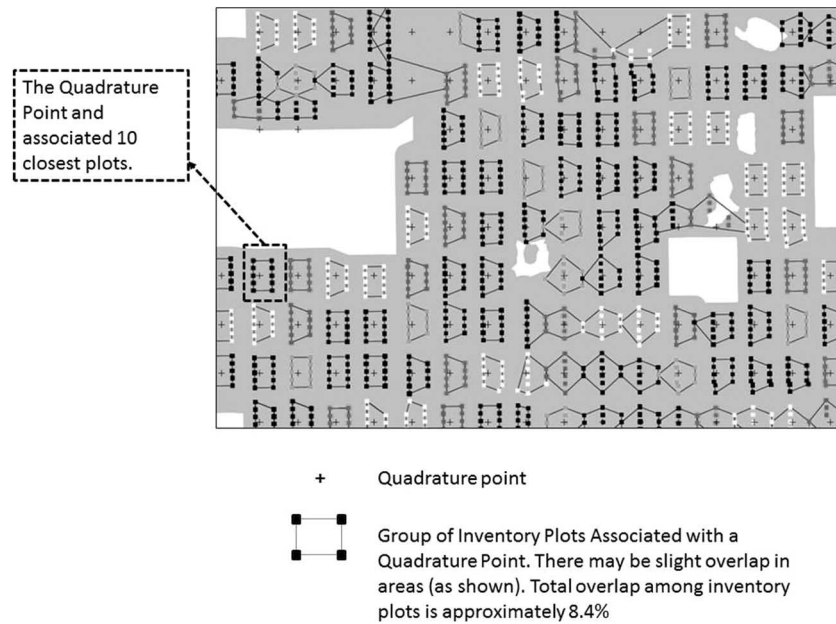


Figure 3. A portion of the region depicting quadrature points with the closest 10 plots: there is a total overlap of 8.4% across the entire forest.

Table 3. *k*-max *P* values for distributional comparison: dens versus forest, 75% kernels versus forest, and dens versus 75% kernels.

		Dens versus forest			75% kernels versus forest			Dens versus 75% kernels		
Variable: A		χ^2 test: B	K-S test: C	Permutation: D	χ^2 test: E	K-S test: F	Permutation: G	χ^2 test: H	KS test: I	Permutation: J
1	QUADMEAN	0.211	0.294	0.260	0.000	0.000	0.001	0.146	0.619	0.534
2	BASAL_PP	0.177		0.044	0.258		0.200	0.001		0.024
3	BASAL_DF	0.002	0.001	0.002	0.000	0.000	0.001	0.323	0.207	0.161
4	BASAL_HW	0.028	0.003	0.008	0.000	0.005	0.005	0.073	0.124	0.103
5	BASAL_HW8	0.000	0.009	0.007	0.001	0.008	0.010	0.000	0.189	0.156
6	BASAL_TOT	0.000	0.000	0.001	0.000	0.000	0.001	0.269	0.018	0.016
7	SCRIB_DF	0.004	0.000	0.001	0.001	0.000	0.001	0.117	0.137	0.116
8	SCRIB_TOT	0.003	0.000	0.001	0.001	0.000	0.001	0.018	0.058	0.054
9	TREES_DF	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.292	0.224
10	TREES_HW	0.018		0.006	0.004		0.003	0.142		0.191
11	TREES_HW8	0.026		0.319	0.005		0.005	0.591		0.970
12	TREES_TOT	0.001	0.000	0.001	0.000	0.000	0.001	0.036	0.360	0.333
13	CANOPY	0.401		0.040	0.021		0.056	0.346		0.182
14	BASAL_SNAG	0.000		0.001	0.000		0.001	0.003		0.120
15	TREES_SNAG	0.000		0.001	0.000		0.001	0.006		0.057
16	BIOMASS_AG	0.001	0.000	0.001	0.000	0.000	0.001	0.163	0.007	0.012
17	RRHS	0.000	0.004	0.003	0.000	0.000	0.001	0.000	0.216	0.187

0.074. Of the high-resolution plots, a majority of them, 8,699 of 10,615, were classified as being poor (RRHS of <0.15), 683 were characterized as being good (RRHS of >0.35), and 1,233 were characterized as being selectively neutral (Figure 2). The average RRHS score of the high-resolution plots is 0.081. This indicates that the high-resolution study area average is in near agreement with the lower resolution FIA plot average. This result is not surprising, because the large-scale aggregate measure of the FIA plots should be approximately the value of the detailed fine-scale plots.

Figure 3 shows a subset of the quadrature point locations within the study area, and the ~ 1.62 -ha (4-acre) plots that have been allocated to them. The area shown in Figure 3 is where several of the plots have been associated with more than one quadrature point due to the sampling structure of the inventory plots. Quadrature points were placed such that the number of overlaps was minimized when inventory plots were grouped into neighborhoods of 10. The place-

ment of the quadrature points minimized the number of inventory plot overlaps to 8.4%. As noted above, openings of >40 acres with no forest cover were excluded, so as not to include low *k*-max values that could bias the results of significance testing.

The test results based on the *k*-max measure are summarized in Table 3. It is important to stress here that rather than comparing quadratures based on variable averages found among the *k*-plots of a quadrature, the *k*-max test is associated with comparing the best of the *k*-values of that variable found in each quadrature. For the *k*-max test, most variables have statistically significant differences at the 0.05 level for the den/forest and kernel/forest comparisons and a few more at the 0.10 level. Three sets of inferential tests are reported: the first set presents the dens versus forest *k*-max comparisons (columns *B*, *C*, and *D*), the second set gives the 75% kernel versus forest *k*-max comparisons (columns *E*, *F*, and *G*), and the third set reports the dens versus 75% kernel *k*-max comparisons (columns *H*, *I*, and *J*).

Table 4. Average values and average *k*-max values for selected variables of the ~1.62-ha (4-acre) plots.

	Variable: <i>A</i>	Plots		<i>k</i> -max				
		75% KDE: <i>B</i>	Study area: <i>C</i>	75% KDE: <i>D</i>	75% KDE ND: <i>E</i>	Study area NKDE: <i>F</i>	Study area: <i>G</i>	Den: <i>H</i>
1	QUADMEAN	29.276	26.566	68.321	67.793	64.864	65.138	65.306
2	BASAL_PP	2.039	2.589	10.547	10.432	12.182	11.988	13.784
3	BASAL_DF	10.495	7.201	36.636	33.830	26.911	28.154	42.221
4	BASAL_HW	15.467	12.285	60.309	59.001	48.400	49.952	64.696
5	BASAL_HW8	10.931	8.518	39.603	37.854	32.497	33.473	43.442
6	BASAL_TOT	28.701	22.826	78.188	75.406	64.209	66.022	83.158
7	SCRIB_DF	6,655.59	4,425.83	25,139.16	21,891.88	17,733.41	18,757.94	27,078.72
8	SCRIB_TOT	8,115.75	5,842.46	27,746.70	24,639.71	21,086.85	22,000.30	29,614.04
9	TREES_DF	399.819	262.354	2,666.260	2,737.391	1,667.952	1,789.113	6,057.247
10	TREES_HW	529.996	427.489	3,241.135	3,148.780	2,462.000	2,577.883	8,922.826
11	TREES_HW8	152.115	131.566	722.348	689.129	627.946	641.112	1,757.664
12	TREES_TOT	1,144.734	929.684	5,706.197	6,121.917	4,289.452	4,493.088	1,3013.349
13	CANOPY	57.872	49.063	98.522	97.855	95.104	95.534	100.000
14	BASAL_SNAG	2.303	1.611	13.211	12.370	9.080	9.669	3.543
15	TREES_SNAG	3.923	2.639	33.930	36.111	21.138	22.623	7.507
16	BIOMASS_AG	176.604	132.836	451.758	434.250	357.890	370.626	1,193.931
17	RRHS	0.112	0.081	0.413	0.388	0.320	0.333	0.458

The FIA RRHS average is 0.074.

The classic K-S test results are not provided in cases where the assumption of no ties is strongly violated; operationally, we only report results for the K-S test when 70% or more of the values in the distribution are unique.

For example, consider the aboveground biomass attribute found on line 16 of Table 3. Overall, given a significance threshold of 0.05, one can see that the distribution of *k*-max values (i.e., the highest amount of aboveground biomass found in the 10-plot neighborhood) for all three comparisons is significantly different from the distribution of *k*-max values for the comparison set under the null hypothesis. Comparing the *k*-max distributions in the neighborhood of dens to the distribution of *k*-max values for neighborhoods centered on quadrature points in the forest (first set of columns), the best of the *k*-neighborhood about a den is significant compared with the best of the *k*-neighborhoods across the rest of the forest. As another example, the number of hardwoods >20.32 cm (8 in.) in diameter (Table 3, line 11) is not significantly different when dens are compared with the rest of the forest. Table 4 lists the average *k*-max values for the three levels of comparison: the 75% kernel density estimate (75% KDE), 75% KDE without the den sites (75% KDE ND), the study area excluding the 75% KDE (study area NKDE), the study area, and the den sites. The following subheadings break down the results of the *k*-max tests for each of the three levels of comparison: dens versus forest, dens versus 75% kernels, and 75% kernels versus forest.

Dens versus Forest

Table 3 shows that all but two of the attributes tested were significant at the 0.05 confidence level when the set of the best plots found in den quadratures are compared with the set of the best plots found in forest quadratures; quadratic mean diameter and the number of hardwood trees >20.32 cm (8 in.) in diameter were not significant. Table 4 shows that the average den site *k*-max attribute values are 2–7 times higher than the average forest value. When the quadratures containing dens are compared with the forest quadratures, all of the tested den *k*-max attributes are higher. The average den site RRHS *k*-max is 0.458 compared with the average study area *k*-max score of 0.333.

75% Kernels versus Forest

All but two forest attributes (canopy cover and ponderosa pine basal area) were significant at the 0.05 confidence threshold when the 75% KDE *k*-max values were compared with the forest *k*-max values (Table 3). At the 0.10 confidence threshold, canopy cover is significant. Of the average *k*-max attributes, all but the basal area of ponderosa pine are greater in the *k*-max of the 75% KDE than those of the remaining forest (Table 4). The average RRHS 75% KDE *k*-max is 0.413, whereas the average study area *k*-max score without the kernels (study area NKDE) is 0.320.

Dens versus 75% Kernels

In a comparison of den with 75% KDE *k*-max, only ponderosa pine basal area, total basal area, and aboveground biomass were found to be significant at the 0.05 confidence threshold (Table 3). Total Scribner's volume and the number of snags per ha are significant at the 0.10 confidence threshold. Average attribute *k*-max values for quadratic mean diameter, the number of Douglas-fir trees, the number of total trees, and the number of snags were lower in den quadratures than in the remaining 75% KDE quadratures, but not significantly (Table 4). All of the other average *k*-max attributes of the den quadratures are greater than those of the remaining 75% KDE. The average RRHS dens *k*-max is 0.458 compared with the 0.388 for the 75% KDE excluding dens, although this difference is not significant.

Discussion

One can think of this forest as a matrix containing a somewhat consistent scattering of prized habitat. Much of the landscape is classified as being considered poor for resting tree selection, although there are areas in which “good” RRHS classifications are spatially distributed. That is, the average forest is scored quite low, whereas there are plots that score well. This is evidenced by the fact that only 683 plots or 6.4% of the study area was predicted to provide “good” resting site habitat, although 26.5% of these lie within the estimated 5 female home ranges. However, the distribution of the best within each ~16.2-ha (40-acre) neighborhood

within the kernels is statistically significant for large structural elements compared with the distribution of the best in each neighborhood for the rest of the forest. For example, although only one conifer type, Douglas-fir, was identified for denning fisher in our study area, the average dbh for live (129.79 cm) and snag (119.43 cm) Douglas-fir denning trees is similar to the dbh of live conifer (117.3 cm) and snag conifer (119.8 cm) resting trees reported by Zielinski et al. (2004b). These are also greater than the average dbh Purcell et al. (2009) described for live conifer (97.40 cm), and snag (98.83 cm) resting trees used by female fishers in the southern Sierra. In addition, it is notable that the black oaks, the trees used most often for den sites, have a much lower average dbh than the average hardwood dbh in the study area. Furthermore, black oaks used for denning (average dbh of 53.34 cm) are smaller than the other hardwoods used for denning (average dbh of 65.16 cm), both of which are less than the average resting hardwood (dbh of 69.0 cm) reported by Zielinski et al. (2004b). However, the hardwoods are still large trees that contained cavities where kits were reared. Thus, fisher locations appear to be selective for these larger elements. This observation is consistent with what the existing literature characterizes as important structural components of fisher resting habitat (Zielinski et al. 2004a, 2004b, Purcell et al. 2009, Lofroth et al. 2010, Aubry et al. 2013). However, what is not consistent is the fact that these larger elements comprise only a small portion of the total area. For example, plots with a RRHS score of >0.35 comprise $<6.5\%$ of the study area.

Lofroth et al. (2010) have presented a data summary of known den sites for fishers in Northern California. This summary is based on 170 den sites (natal and maternal), which include the 45 den sites in our study area (26% of their data). Of the 125 unique den trees that are not part of our study area, 66.4% of dens were within hardwoods (living or snags) and 33.6% were in conifers (living or snags). In comparison, of the 45 den sites reported in Lofroth et al. (2010) that fall within our study area, 80.0% are hardwood and 20.0% conifers. Thus, our study area has a higher percentage of hardwood trees used as den sites than found in other studies.

The number of hardwoods used as dens in our study area could be due to the fact that usable cavities form within hardwoods at a younger age than those of conifers and at a dbh that is much smaller than that of a comparable conifer tree. These oak trees could also provide food and cover in a manner similar to the southern Sierra fisher (Zielinski et al. 2004a). As Zielinski et al. (2004a) note, female fisher home ranges included a greater proportion of forest types in the densest canopy class than did male home ranges and they could not distinguish whether this relationship was proportional or absolute. Even though the proportion of mature stands and large trees within our study area is low, female fishers selectively use such areas and such selection is statistically significant. What we do not address here is estimating the absolute minimum in terms of large trees and their spatial distribution that underpins whether a female fisher is able to maintain a viable home range in a particular location over time. The use of den trees similar in size to those found used as resting sites in previous studies (Zielinski et al. 2004b, Purcell et al. 2009) suggests that although these large trees may be somewhat scarce within this landscape, they are critical components.

Weir et al. (2012) point out that den site selection appears to occur within a forest at a fine scale and that this selection may be harder to identify at larger aggregate scales. Our study supports that claim, as at the aggregate scale (lower resolution), the study area appears to be less than desirable when a published metric is used, but

at a higher-resolution elements do exist that are differentially selected. Fine-scale selection may also be teased out using LiDAR (light detection and ranging) data instead of a high number of inventory plots. For example, Zhao et al. (2012) have used LiDAR data to determine locations potentially suitable for fisher den sites in the southern Sierra.

The findings of this article suggest that preference is given to areas containing large structural components as others have found. However, the density of apparent suitable structures is quite low (6.5% of the landscape), as these structures occur very infrequently across the study area and in stands composed of primarily young trees, whose average age is 67 years, rather than mature (100- to 200-year) or late-seral (>200 -year) stands. Whereas old, mature forests contain numerous large elements for potential resting and denning, this study demonstrates that elements of mature to late-seral stands appear to be significant components of fisher habitat even if not very prevalent.

It is important to note that our study is somewhat limited by the small number of female fishers tracked for an extended period. It would have been nice to have had data tracking individuals and their progeny for longer periods to determine long-term use patterns. However, the average weight of fishers in our study area (3.65 kg for males and 2.13 kg for females) is similar to that of two other studies in California, one located near our study area and the other in the southern Sierra Nevada range. Although both studies contain few females (3 each), Buck et al. (1979) reported an average body weight of 3.5 kg for males and 1.8 kg for females. Similarly, Boroski et al. (2002) report a median weight of 3.6 kg for males and a mean weight of 2.1 kg for females. Thus, it appears as though the fishers in this study are not terribly different in terms of weight from fishers in other areas of California, particularly those from a study conducted nearly 40 years ago very close to the current study area.

In addition, females had kits during the 2 years of tracking, although what happened to the kits after their rearing is not known. It is unfortunate that no information was collected on male fishers other than the number of males trapped and their trap location. Because of this, we are not able to determine home ranges maintained by males and any similar or dissimilar landscape use for them. Even though averages across scales of hundreds of acres tend to be low in terms of basal area, large structural elements, and average tree age as well as RRHS scores, at a finer scale fisher selectivity toward larger structural elements is statistically significant. Without this new spatial sampling approach, this selectivity cannot be identified and without it one might conclude that the area is not suitable habitat. Simply put, female fisher home ranges are statistically different from the background forest in terms of the largest structures and scattered mature stands that are present. The spatial sampling and testing approach developed in this article is useful for characterizing critical habitat components, even when they may be scattered and lost in average measures over larger areas. It also shows that high-resolution forest inventory plots are useful for describing the critical components of habitat where forest variation is great.

Thus, a metric applied across a large area (represented by FIA plot data) may undervalue important features such as scattered mature stands and scattered groups of large trees when they exist. Although a large area covered with mature stands contains such elements in abundance and average values will reflect this fact, a different approach is necessary to measure suitability when needed elements are scattered and are not abundant. The k -max test was developed to detect whether scattered elements are significant in

selected use. One issue that remains is, when scattered elements exist, at what level and numbers are such elements supportive of a species, like the fisher, and at what threshold below which are they not supportive for a local population? This question may be answered by expanding the k -max test to search for a significant threshold of need, e.g., the best three plots of a quadrature must contain large trees suitable for denning, and, thus, is part of ongoing research.

Summary and Conclusions

We have studied an area of approximately 180 km² that existing models predictively characterized as poor or nonexistent fisher habitat. Previous field surveys in 2006 and 2007 trapped 33 fishers (9 female and 24 male). Of these, 5 female fishers were tracked over several seasons, which resulted in the identification of 7 natal dens, 39 maternal dens, 19 observed resting sites, and 253 additional telemetry locations. In addition, the study region has been inventoried at a very high density of field plots, averaging one plot per ~1.62 ha (4 acres). This has allowed us to statistically characterize structural use and habitat elements at a finer scale than existing work, with the exception of that of Zhao et al. (2012). Although the number of home ranges is somewhat small, this falls within a range of data set sizes that have been used in many other studies of the fisher. However, it is still important to state that this sample size may limit the extent to which the conclusions reached here are fully applicable elsewhere.

FIA plots (one per 6,000 acres) have been used to characterize the landscape at a broader scale. Of the 18 FIA plots within a region bounded by a 2-km buffer of the study area, two are classified as neutral with respect to the Zielinski et al. (2012) RRHS scores and 16 are classified as poor. The two that were scored as neutral fell on the eastern edge of the study area, where no traps had been deployed. The validity of the RRHS score applied to a forest area that is more varied and containing many less-than-mature stands appears to hold only when applied at a finer scale compared with areawide averages. Habitat use by females tends to occur in and around those stands that score highly even though they are often surrounded by stands of younger trees, larger openings, and areas with low levels of canopy cover. This means that the RRHS scoring system can be used to characterize habitat elements when higher spatial resolution data are available for forests that are not large homogeneous swaths of mature stands, which should not be a major surprise, as the RRHS scores were developed to identify those features that had high correlation with use. What is a bit of a surprise is that these elements do not need to be as abundant as what would be found in a large mature forest.

Even though fisher dens tend to be found on the plots with the highest RRHS scores, these valuable plots tend to be scattered among a matrix of younger trees. To demonstrate this observation, as well as test other possibly important attributes, we have developed the k -max approach and imbedded it into an inferential framework based on permutations. One can think of this as a test of the best of the attributes found among a point and its k -nearest plots (called the k -neighborhood). When we compared the den site neighborhoods to the forest in general, virtually all of the measured attributes were statistically significant at the $P = 0.05$ level. Further, the k -max tests of the RRHS scores of Zielinski et al. (2012) are also statistically significant at the neighborhood level but not at the landscape level. What this work shows is that the scale of analysis is tantamount to

classifying fisher habitat in varied landscapes (including many openings), a scale that is finer than that used in most previous work.

We believe that the methodology proposed in this article can be useful in characterizing the habitat of fishers and other animals in a varied landscape. What is needed in this approach is high-resolution landscape data, whether generated from a land-based survey or aerial-based survey (e.g., LiDAR). What remains to be determined for fisher management is the needed amount and distribution of habitat elements, e.g., the minimum density of denning and resting trees, which would not be necessary if the habitat consisted principally of mature to old-growth stands. Estimating such thresholds may be done by expanding the k -max approach and comparing the overall distributions of ranked quadrature elements. That is, it is possible to compare the sets of second best plots to second best plots, third best plots to third best plots, and so on until the “worst of the worst” are compared among quadratures. This may provide valuable insight as to the needed distribution of elements in the classification of potential female habitat.

Endnotes

1. $W \setminus V$ is read as W excluding elements in V . This is standard set notation used in mathematics and statistics.
2. The reason for plot overlap is that the plot samples are not all equally spaced within the forest due to odd parcel shapes. The odd parcel shapes required adjustments to the inventory grid such that each parcel is inventoried at the prescribed frequency where differing topographic features are evenly sampled.
3. This was implemented in the Spatstat package found in R (version 2.15).

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Appendix

The Zielinski et al. (2012) model requires five attribute measures to compute a RRHS score. These variables are average age of dominant conifer trees (in years), total basal area ($\text{m}^2 \text{ha}^{-1}$), canopy cover (% of cover), hardwood basal area ($\text{m}^2 \text{ha}^{-1}$), and volume of large downed wood ($\text{m}^3 \text{ha}^{-1}$). Each of the five required variables to compute the RRHS score were used in the FIA and 1.61874-ha (4-acre) fine-scale plot data. Stand age in the FIA and fine-scale plot data set used in this article are computed in a similar manner. Conifer age is estimated by the field crew or analyst based on the trees that were cored and any other information they might have about the plot. Age tends to correspond to the age of the canopy dominants in forests with severe disturbance regimes but is more of a weighted average in stands with multiple partial disturbances (natural or management). Canopy cover is measured through the use of an algorithm, as is the FIA plot; both assure that canopy cover of >100% does not occur. Total basal area and hardwood basal area are computed using the same methodology. The volume of large downed wood is the only variable that is not computed in the same manner as that used in Zielinski et al. (2012). In this case, the fine-scale plots, the volume of large downed wood was measured using logs with a diameter of ≥ 60.96 cm (24 in.) on the large end,

whereas Zielinski et al. (2012) based their analysis on logs that were ≥ 25.40 cm (10 in) in diameter.

The Zielinski et al. (2012) model was tested for sensitivity in regard to variable inputs. This was done using the FIA and fine-scale plot data; in this case, the average attributes of the included 99 FIA plots in the Zielinski et al. (2012) Excel workbook and the best plot in each forest k -max neighborhood. The data were tested using two methods. The first method incremented through each variable, one at a time. The first variable, say age, was zeroed out and the RRHS was recalculated to obtain a score. Once this was done, the original variable value was replaced, and the process was repeated with the next variable. The attribute most sensitive to a zero value is the basal area variable; this produced a 98% reduction in the RRHS score. A zero for the volume of large downed wood entry reduced the RRHS score by 41%. A zero for hardwood basal area reduced the score by 24%. A zero for canopy cover increased the RRHS score by 23%. However, most of these attributes are likely to be correlated; a test for subtle variation among all variables is likely to be more informative of changes to an RRHS score. This is why a second test was used.

The second method followed the previous one, except that instead of setting a variable value to zero, the variable was tested for a 10% increase and decrease of the mean attribute value. Basal area was again the most sensitive to this variation; a range of 0.08958 occurs for a $\pm 10\%$ change. The volume of large downed wood was

the fourth most sensitive variable of the five input variables, having an RRHS range of change of 0.01778 between the 10% decrease and increase. Given these two tests, as applied to both data sets, it appears that basal area is the most important variable in the computation of the RRHS score and that the large downed wood is not a dominant determinant when there is a $\pm 10\%$ change in value. Given that the 4-acre plot data are computed in a manner similar to that for the FIA plot data, the slight variation in the measurement of large downed wood should not greatly affect the RRHS score.

We believe that the application of this model, using proportional measures similar to those found in the FIA plot data, helps to identify those areas in the forest matrix that are likely to have greater potential resting habitat. This is supported by an analysis using the k -max “bests” found within the 75% KDEs compared with 499 randomly rotated and placed KDE k -max “bests” within the study area. An empirical cumulative density function can then be used to determine significant dissociation, neutrality, or significant association. Significant association/dissociation was determined using a 0.05 confidence interval. This test suggested that selection was significantly associated with RRHS values of >0.35 and neutral for values of ≤ 0.35 , results that are in line with the findings of Zielinski et al. (2012) related to FIA plot RRHS scoring.