The Journal of Wildlife Management 75(5):1164–1176; 2011; DOI: 10.1002/jwmg.159

Research Article

Evaluating Management Risks Using Landscape Trajectory Analysis: A Case Study of California Fisher

CRAIG M. THOMPSON,[1] *USDA Forest Service, Pacific Southwest Research Station, Sierra Nevada Research Center, 2081 E. Sierra Av., Fresno, CA 93710, USA*

WILLIAM J. ZIELINSKI, *USDA Forest Service, Pacific Southwest Research Station, Redwood Sciences Laboratory, 1700 Bayview Dr., Arcata, CA 95521, USA*

KATHRYN L. PURCELL, *USDA Forest Service, Pacific Southwest Research Station, Sierra Nevada Research Center, 2081 E. Sierra Av., Fresno, CA 93710, USA*

ABSTRACT Ecosystem management requires an understanding of how landscapes vary in space and time, how this variation can be affected by management decisions or stochastic events, and the potential consequences for species. Landscape trajectory analysis, coupled with a basic knowledge of species habitat selection, offers a straightforward approach to ecological risk analysis and can be used to project the effects of management decisions on species of concern. The fisher (*Martes pennanti*) occurs primarily in late-successional forests which, in the Sierra Nevada mountains, are susceptible to high-intensity wildfire. Understanding the effects of fuels treatments and fire on the distribution of fisher habitat is a critical conservation concern. We assumed that the more a treated landscape resembled occupied female fisher home ranges, the more likely it was to be occupied by a female and therefore the lower the risk to the population. Thus, we characterized important vegetation attributes within the home ranges of 16 female fishers and used the distribution of these attributes as a baseline against which the effects of forest management options could be compared. We used principal components analysis to identify the major axes defining occupied female fisher home ranges and these, in addition to select univariate metrics, became our reference for evaluating the effects of landscape change. We demonstrated the approach at two management units on the Sierra National Forest by simulating the effects of both no action and forest thinning, with and without an unplanned fire, on vegetation characteristics over a 45-yr period. Under the no action scenario, landscapes remained similar to reference conditions for approximately 30-yr until forest succession resulted in a loss of landscape heterogeneity. Comparatively, fuel treatment resulted in the reduction of certain forest elements below those found in female fisher home ranges yet little overall change in habitat suitability. Adding a wildfire to both scenarios resulted in divergence from reference conditions, though in the no action scenario the divergence was 4× greater and the landscape did not recover within the 45-yr timeframe. These examples demonstrate that combining the results of forest growth and disturbance modeling with habitat selection data may be used to quantify the potential effects of vegetation management activities on wildlife habitat.

KEY WORDS fisher, Forest Vegetation Simulator, fuel treatment, habitat management, landscape trajectory, *Martes pennanti*.

Effective ecosystem management requires an understanding of how variables that describe a system's condition and function vary in space and time, how this variation can be affected by management decisions, and how these decisions may therefore impact species, systems, or processes of concern. Whereas it is simple to follow changes in one variable at one point over time, it is infinitely more complex to quantify changes in multiple variables across a landscape over time. Yet this is exactly what land managers are required to do when evaluating the potential outcomes of different management options on species or communities, and the inevitable uncertainty associated with these types of projections leaves managers faced with subjective decisions, legal challenges, and numerous delays. In effect, these delays force a "no action" management plan despite evidence that this is often not an appropriate path to take. We combined biological data on a species of conservation concern with forest modeling techniques to generate a reference landscape template against which the results of a particular management scenario can be rigorously compared. Using landscape trajectory analysis, we examined how different management scenarios can be compared in a form of ecological risk assessment.

Received: 2 July 2010; Accepted: 15 October 2010;
Published: 9 June 2011

[1]*E-mail: cthompson@fs.fed.us*

Landscape trajectory analysis involves using a modeling framework to project future changes in the landscape based on vegetation growth and disturbance, quantifying the resulting landscape pattern at discrete intervals, then comparing these values to some initial, target, or reference condition (Cushman and McGarigal 2007). Coupling trajectory analysis with species or community-level habitat information provides an intuitive, interpretable framework for understanding the interactions between disturbances or management scenarios, wildlife habitat needs, and conservation goals. The approach is intuitively appealing because the trajectory can be used to evaluate habitat thresholds and to compare the relative effects of land management activities on landscape conditions.

We applied this approach to questions regarding the potential impacts of vegetation management options on the habitat of fishers (*Martes pennanti*) in the forests of the Sierra Nevada Mountains. In the western United States, fishers prefer dense canopy, late-successional forests with high-basal area, stem density, and coarse woody debris (Aubry and Houston 1992; Zielinski et al. 2004*a*,*b*; Davis et al. 2007; Purcell et al. 2009), the same characteristics that make a forest susceptible to high-intensity wildfire (Spencer et al. 2011). Although fisher conservation is only one of many competing concerns for land managers in the Sierra Nevada, the species is rapidly gaining attention due to the perceived conflict between its habitat requirements and the growing need for fire and fuel management (U.S. Fish and Wildlife Service 2004). Managers of public lands, and the citizens that seek to help guide that management, are uncertain about the relative loss of fisher habitat due to fuels treatments compared to the loss that could occur via uncharacteristically severe wildfire if fuels are untreated. As a result, management projects designed to reduce fuels have been blocked or delayed due to an incomplete understanding of the effects of the proposed actions on the landscape conditions that foster fisher occupancy.

By example, we demonstrate the utility of landscape trajectory analysis for fisher habitat conservation for proposed forest management projects on the Sierra National Forest, California. Lee and Irwin (2005) conducted a similar analysis focusing on the potential change in one variable (canopy cover) and the related impacts to spotted owl (*Strix occidentalis*) habitat. We expanded their approach to include multiple habitat composition variables as well as variables describing landscape configuration. We defined reference conditions for fisher habitat using home range data from past and ongoing research in the Sierra National Forest, and compared this with alternative landscape trajectories in order to evaluate the relative risk with different management scenarios. This application is based on the premise that if we manage landscapes to resemble the features that characterize home ranges currently being used by fishers, then the resulting landscapes will have the greatest likelihood of retaining fisher occupancy. Our quantitative approach avoids the subjective realm of expert opinion and directly compares alternative scenarios in a rigorous framework. This, in turn, should make management actions that affect sensitive species easier to design, defend, and implement.

STUDY AREA

The Kings River Project (KRP) was located in the High Sierra Ranger District of the Sierra National Forest, approximately 50-km east-northeast of Fresno, California (Fig. 1). The area ranged from 1,100-m to 2,282-m elevation and overlapped the elevational range of fishers in the Sierra Nevada (Zielinski et al. 2005). Dominant forest types included montane hardwood-conifer, Sierran mixed conifer, and ponderosa pine (*Pinus ponderosa*; Mayer and Laudenslayer 1989). We analyzed 2 examples of target landscapes in the KRP: the Bear Fen and the Glen Meadow management units. The 892-ha Bear Fen management unit averaged 75% canopy cover and consisted primarily of Sierran mixed conifer (50%) and ponderosa pine (*Pinus ponderosa*, 47%) forest type. The remaining 3% included small patches of montane chaparral, montane hardwood conifer, and barren rock. The 654-ha Glen Meadow unit averaged 55% canopy cover and consisted primarily of 83% Sierran mixed conifer forest type with 13% barren rock. The remaining landscape included small amounts (0.5–1%) of ponderosa pine and montane chaparral habitat, wet meadows, and scattered private inholdings.

METHODS

We evaluated the potential influence of 4 fuel treatment scenarios on habitat included in home ranges of female fishers in the Sierra National Forest, Fresno County, California. We did not evaluate home ranges or landscapes on the basis of fitness (i.e., habitat quality); instead we assumed that home ranges chosen and occupied by adult female fishers met some minimum level of suitability. Female fishers are more selective of habitat than males (Buck et al. 1994, Zielinski et al. 2004*a*) and their survival is crucial to population persistence; thus we limited our analysis to landscapes used by adult females. We presumed that the more a treated landscape resembled the composition of an average female fisher home range, the more likely it was to be occupied by a female and therefore the lower the risk that the treatment would negatively affect the population.

The landscape trajectory analysis process involved the following steps: 1) select a reference condition for fishers—in our case the characteristics of female fisher home ranges, 2) compile data from as many female fisher home ranges as available, 3) develop univariate and multivariate descriptions of the central tendency and variation of select landscape characteristics of female fisher home ranges, 4) simulate the future effects of proposed management actions (e.g., no action, fuels treatments via thinning) on target landscapes, and 5) determine whether the future condition of these landscapes (their trajectory) is moving toward or away from the types of conditions that resemble the places where female fisher establish home ranges.

Fisher Data

We used the range of variability in the home range composition of adult female fishers throughout the KRP area to identify target landscape conditions and to provide a baseline against which the effects of fuel management efforts could be

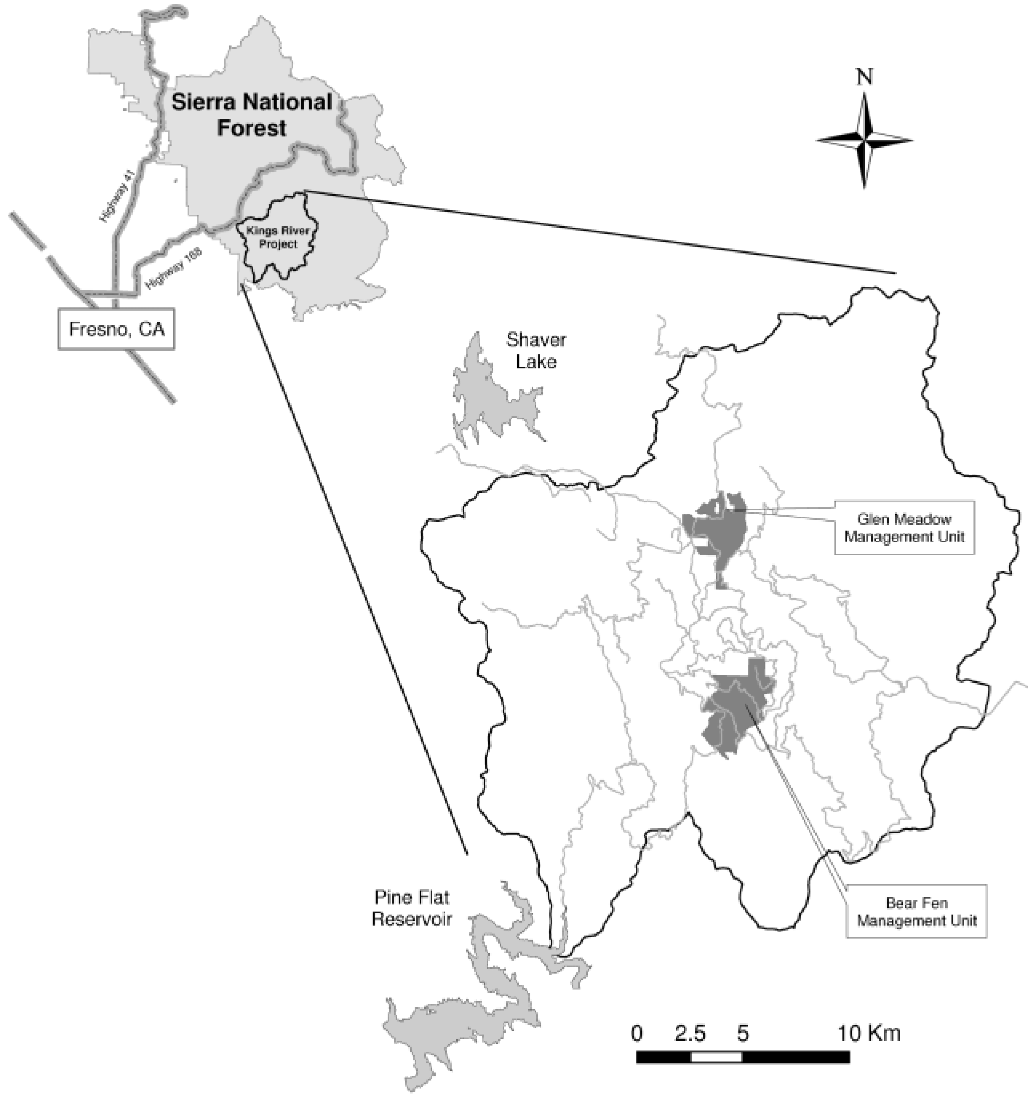

Figure 1. Study area showing the placement of the Kings River Fisher Project within the Sierra National Forest, California, USA, and the location of the Glen Meadow and Bear Fen management units within the Kings River Project, 2007–2011.

compared. Although these home ranges may or may not represent the best habitat for Sierran fishers, we know that female fishers were able to survive, and in many cases, reproduce there (see below). In practice, this approach is analogous to the historic range of variability used by land managers to define management and restoration guidelines (Agee 2003, Nonaka and Spies 2005).

We combined data from 2 discrete fisher research projects in the KRP area for our analysis. Between 1999 and 2001, 6 adult female fishers were captured, collared, and monitored as part of study examining fisher habitat selection (Mazzoni 2002). The reproductive status of these animals was not determined. In 2007 and 2008, 28 fishers were captured and radiocollared as part of the ongoing Kings River Fisher Project (C. Thompson and K. Purcell, U.S. Department of Agriculture Forest Service [USFS], unpublished data). Of these, 12 were adult females and 10 were known to be reproductively active based on either den monitoring or teat condition at capture. For our analysis and to emphasize habitat selection by adult females, we used home range data from 16 female fishers: 6 monitored in 1999–2001 and 10 monitored in 2007–2008.

During the 1999–2001 project, trapping occurred over approximately half of the Kings River area. During 2007 and 2008, we used a grid-based system to ensure equal effort across the entire project area. We divided the project area into 1-km^2 grid cells, and we selected the best habitat within each cell as a trap site. We captured and radiocollared fishers using methods approved by the California Department of Fish and Game and the University of California at Davis Institutional Animal Care and Use Committee. We collected location data using a combination of ground triangulation and walk-in techniques, conducted using 3-element yagi antennas and handheld receivers (Communication Specialists, Orange County, CA and Telonics Inc, Mesa, AZ). We calculated 95% fixed kernel home ranges using the Home Range extension for ArcGIS (Environmental Systems Research Institute [ESRI], Redlands, CA) based on locations collected over an average of 9 months (range: 5–18 months; $\bar{x}$: 48 locations/animal, range: 25–129 locations).

Landscape Data

To accurately describe the level of landscape heterogeneity encountered and used by fishers, we relied on fine-scale, sub-stand level vegetation dataset developed by the Sierra National Forest (S. Parks and R. Rojas, unpublished data). They subdivided stands into sub-stand polygons based on aerial photo interpretation, with new polygon boundaries being drawn around areas of homogenous vegetation. Across the Kings River Area, subdivision resulted in identification of 13,125 sub-stand polygons ranging from 2-ha to 136-ha each. They assigned sub-stand polygons vegetation characteristics based on 1,995 Common Stand Exam (CSE; CSE 2003) vegetation plots conducted within the Kings River Area. If $\geq$1 plot had been conducted within the sub-stand polygon, they characterized the polygon according to those plots. If the sub-stand polygon had no plots, they assigned data to that polygon using the Most Similar Neighbor (MSN) program (Crookston et al. 2002). The MSN program relies on canonical correlation analysis to recognize relationships between remotely sensed or Geographic Information System (GIS) data and plot-level data. In effect, they assigned an unsampled polygon the vegetation characteristics of the closest, most similar, sampled polygon (S. Parks and R. Rojas, unpublished data).

We selected our 2 management units (Bear Fen and Glen Meadow) specifically because they differed in respect to their perceived quality as fisher habitat. The 892-ha Bear Fen management unit was initially considered for fuel treatment, however the unit was considered high-quality fisher habitat due to the amount of late seral forest and structural diversity present. As a result, treatment plans were dropped due to concern about possible negative impacts on fishers. During trapping efforts, multiple female fishers were captured in or near the Bear Fen unit. The 654-ha Glen Meadow management unit contained lower-quality fisher habitat due to the dominance of younger stands, reduced understory, and open landscape and was scheduled for fuel treatment in 2010. Despite extensive effort, no animals were captured in this unit though collared animals were periodically located within and adjacent to it. Both units were slightly smaller than an average female fisher home range in the Southern Sierra but within the local range of variability ($\bar{x}$: 1,170 ha, range: 462- to 2,689-ha), and they were representative of the typical size of management units on the Sierra National Forest.

Fishers select habitat based on availability of forest structure (Zielinski et al. 2004*a*, Purcell et al. 2009), and we defined forest structure in terms of composition and configuration. Although much has been published regarding the influence of forest composition on fisher habitat selection, little is available addressing the influence of configuration or the spatial arrangement of high-quality habitat patches. We selected composition variables (density of large trees and snags, canopy cover, basal area) based on local knowledge as well as a review of pertinent technical literature. We selected configuration variables to reflect the spatial distribution of high-quality fisher habitat across the landscape based on a review of pertinent forest carnivore literature (Zielinski et al. 2006, Cushman and McGarigal 2007, Davis et al. 2007, Kirk 2007; Table 1). We defined habitat quality using the California Wildlife Habitat Relationships (CWHR) database, a matrix-based wildlife habitat relationships model developed from technical literature and scientific opinion for each species of terrestrial vertebrate in California (California Department of Fish and Game, 2008). The CWHR model ranks habitat from 0 (unsuitable) to 4 (highest quality) for reproduction, cover, and feeding. Because we wanted to identify patches of high-quality habitat for female fishers, we used the CWHR definition for high-quality reproductive habitat, characterized by dense, structurally complex conifer or montane-hardwood forest with average tree diameter at breast height >28-cm and canopy cover >60%. We used FRAGSTATS (McGarigal and Marks 1994) to analyze the configuration of these high-quality patches.

Data Projection: Future Conditions

We used the Forest Vegetation Simulator (FVS) program (Dixon 2002) to project the outcomes of fuel treatments on the 2 management units at 5-yr intervals (S. Parks and R. Rojas, unpublished data; Fig. 2). The FVS program is an individual-tree, distance-independent growth and yield

Table 1. Landscape metrics used to characterize the composition and configuration of fisher habitat in 2007 on the Kings River Administrative Area within the Sierra National Forest, California, USA. For the configuration metrics, _L indicates landscape-level metrics concerned with all habitat types whereas _C identifies metrics that focus solely on the distribution of high quality (California Wildlife Habitat Relationship (CWHR) database, class 4) habitat.

	Definition
Composition variable	
TPA	Trees per acre in 5 dbh categories (0–25-cm, 25–51-cm, 51–76-cm, 76–89-cm, >89-cm)
SPA	Snags per acre in 4 dbh categories (13–38-cm, 38–61-cm, 61–89-cm, >89-cm)
PERCC	Area-weighted % canopy cover
BA	Area-weighted basal area (m^2/ha)
Configuration variable	
ED_L	Amount of habitat edge in a home range (m/ha)
CONTAG_L	Tendency of cells of similar class type to be aggregated, indicating overall landscape clumpiness
COHESION_L	Landscape cohesion index represents the average physical connectedness of CWHR habitat types (landscape connectivity)
SHDI_L	Shannon's diversity index, evaluating how diverse the landscape is
PLAND_C	Percent of landscape covered by CWHR class 4 habitat
COHESION_C	Patch cohesion index measures the physical connectedness of the CWHR class 4 habitat type (class connectivity)

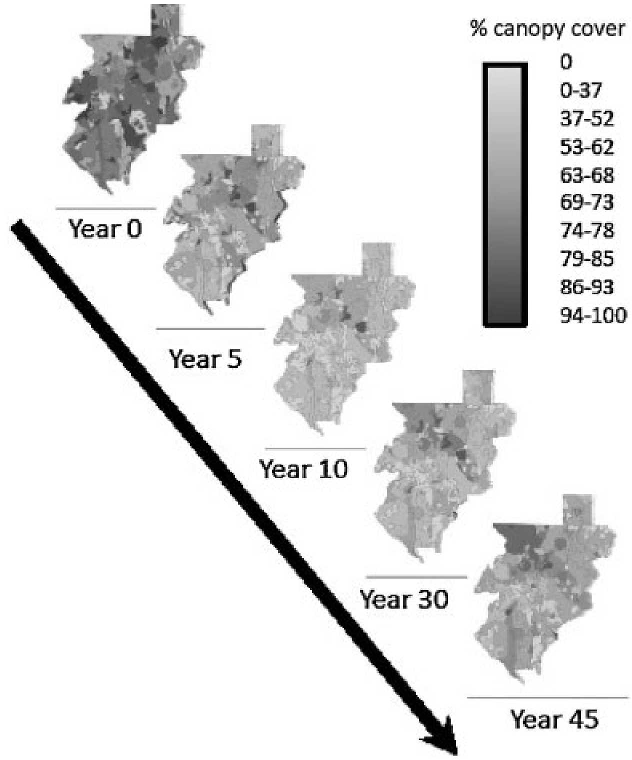

Figure 2. Projected canopy cover for the Bear Fen management unit following one fuel reduction scenario: thinning from below with an 89-cm maximum dbh cut (conducted in year 2) followed by a large, naturally occurring fire in year 8. Projections show the loss in canopy cover following thinning (year 5), additional loss following a simulated wildfire (year 10), and gradually recovery over the subsequent 35-yr.

model used widely throughout the United States Forest Service to simulate forest succession. Model variants are available for geographic areas that reflect local species and site conditions, and we used the variant designed for the western slope of the Sierra Nevada.

We modeled 2 management scenarios: no treatment and thinning from below with an 89-cm (35-inch) maximum dbh (89-cm cut). We modeled each scenario twice, once with and once without a large simulated fire. Simulations began in year 0 and ran for 45 yr, with fires simulated in year 8 using the Fire and Fuels Extension to FVS (Reinhardt et al. 2007). We simulated fires as one natural ignition, with the spread and intensity defined by forest conditions and the western Sierra Nevada FVS variant. It is important to note that we did not select the silvicultural and disturbance scenarios with the goal of providing guidance to the managers of the Sierra National Forest. Instead, these are simply examples to demonstrate how landscape trajectory analysis could be used to evaluate the effects of management choices on a wildlife species of interest.

Data Analysis

We evaluated differences between the condition of landscapes successfully used by female fishers and the projected future condition of a management unit using combinations of univariate and multivariate techniques. Univariate techniques involved evaluating changes in a particular metric over time and calculating both the displacement and divergence of that metric across the landscape (Cushman and McGarigal 2007). Displacement refers to the overall change in a metric following a treatment scenario after a predetermined number of years. We calculated displacement for each metric for each treatment scenario after 45-yr, the longest timeframe under which comparable simulation data was available for both units. Divergence refers to the separation between projected landscape values and the average values taken from known, occupied fisher home ranges. Maximum separation can occur at any time step during simulation, and represents the period of greatest departure from known habitat conditions.

Interpreting dozens of univariate metrics is tedious and ignores the covariance structure among variables. To capture the full complexity of the dataset and to account for redundancy in composition and configuration metrics, we performed a principal components analysis (PCA) on the female fisher home range data to identify the major, uncorrelated axes defining occupied female fisher home ranges and proposed management units (Cushman and McGarigal 2007). This multivariate analysis provided an integrated and complete characterization of the variables that describe female fisher home ranges and these same variables measured at current and future simulated management units. Principal components analysis simplifies the complexity that arises when a response variable is affected by the covariance structure of multiple independent variables (McGarigal et al. 2000). We applied the resulting model to the landscapes generated by treatment simulations to determine how these landscapes compared to the landscapes selected by female fishers for their home ranges. In multidimensional space, one can imagine a cluster of points that represents individual female fisher home ranges. The centroid of that cluster therefore represents an average female fisher home range for that area. This multidimensional space represents a more comprehensive target for managers; if the trajectory of a treated landscape remains within that cluster over time or does not diverge far from that centroid, it is safe to assume the landscape is suitable for occupancy, at least with respect to the variables analyzed. Conversely, the further the trajectory of a treated landscape takes it outside that space or from that centroid, the less likely it is that the landscape will remain conducive to occupancy by female fishers and the greater the risk associated with that particular management approach.

RESULTS

Current Habitat Conditions

We generated 95% fixed kernel home ranges for 16 adult female fishers, which averaged 1,170-ha (SD: 594-ha, range: 462- to 2,689-ha). Within those home ranges, canopy cover averaged 63% (SD: 3.2%) and basal area averaged 37.3-m^2/ha (162.5-ft^2/acre) and SD: 5.3-m^2/ha (23.3-ft^2/acre) (Table 2). We estimated home ranges to include approximately 1 large snag (>89-cm dbh) and 5 large trees (>89-cm dbh) for every 0.81-ha (2 acres). Home ranges were characterized by high landscape-level cohesion, small yet connected

Table 2. Current (2007) landscape conditions for 16 female fisher home ranges and 2 management units in the Sierra National Forest, California, USA.

Variable[a]	Female fisher territories		Bear Fen Management Unit	Glen Meadow Management Unit
	$\bar{x}$	SD	Year 0	Year 0
% canopy cover	62.98	3.23	67.74	53.23
Basal area	162.46	23.29	178.08	173.64
Snags/acre: 12–38-cm dbh	6.44	1.66	8.00	4.35
Snags/acre: 38–61-cm dbh	2.02	0.54	2.50	2.08
Snags/acre: 61–89-cm dbh	0.84	0.24	1.27	0.60
Snags/acre: >89-cm dbh	0.44	0.21	0.59	0.50
Trees/acre: 0–25-cm dbh	604.08	248.36	786.53	405.68
Trees/acre: 25–51-cm dbh	50.13	6.23	58.01	38.09
Trees/acre: 51–76-cm dbh	12.71	3.55	13.10	17.73
Trees/acre: 76–89-cm dbh	2.39	0.76	2.05	3.7
Trees/acre: >89-cm dbh	2.77	0.97	3.37	3.42
ED_L	49.91	14.62	42.80	34.93
CONTAG_L	56.91	4.93	52.23	53.20
COHENSION_L	96.43	1.08	97.55	97.66
SHDI_L	1.91	0.21	1.11	1.08
PLAND_C	17.08	8.75	22.28	5.23
COHESION_C	94.04	2.09	96.22	85.56

[a] See Table 1 for definitions.

amounts of CWHR class 4 habitat and moderate amounts of edge (Table 2).

Based on these attributes, the current status of the Bear Fen management unit is similar to occupied fisher home ranges and can therefore be described as most likely representing functional fisher habitat. Current conditions for 66% of the variables on the Bear Fen management unit fell within 1 SD of the mean of the same variable as measured from the occupied fisher home ranges (Table 2). Conditions that fell outside this range (canopy cover was 5% higher on the Bear fen unit, there were more 61- to 89-cm (24- to 35-inch) dbh snags/acre, more 25- to 51-cm (10- to 20-inch) trees/acre, and higher cohesion at both the landscape and class levels) are all attributes typically related to higher-quality fisher habitat. The Bear Fen unit also included more CWHR class 4 habitat (PLAND_C) than the occupied territories, and the habitat was more connected (COHESION_C).

Comparatively, only 41% (7 of 17) of variables measured in the Glen Meadow unit fell within 1 SD of the mean of occupied fisher home ranges (Table 2). Canopy cover was lower than both the Bear Fen unit and the average occupied home ranges. The Glen Meadow unit had fewer large snags and small trees per acre, yet more large trees per acre than the Bear Fen unit. The Glen Meadow unit contained only 5% CWHR class 4 habitat and it was more fragmented. Both units contained less landscape-level heterogeneity and edge habitat than occupied home ranges (Table 2).

Future Habitat Conditions

Univariate analysis.—On the Bear Fen unit, either the no action or no action with fire scenario resulted in the maximum landscape displacement after 45-yr for 15 of 17 habitat variables (Table 3, Fig. 3). The only exceptions were landscape level cohesion, which showed the greatest displacement under the 89-cm cut scenario, and the number of 0- to 25-cm dbh trees per acre, which showed the greatest displacement under the 89-cm cut with fire scenario. Displacement was minimized under the 89-cm cut with fire scenario, which resulted in the minimum displacement for 7 of 17 variables (Table 3). The no action and no action with fire scenarios also resulted in the maximum landscape divergence for 16 of 17 variables, whereas the 89-cm cut scenario resulted in the minimum landscape divergence for the most variables (7).

On the Glen Meadow unit, maximum displacement occurred under the no action or no action with fire scenario for 15 of the 17 variables (Table 3, Fig. 4). The only exceptions were edge density and the number of snags >89-cm dbh, which showed the greatest displacement under the 89-cm cut with fire scenario. However the number of large snags per acre was nearly identical between the 89-cm cut with fire and the no action with fire scenarios. Minimum landscape displacement was distributed between 2 scenarios: the no action and 89-cm cut scenarios resulted in the least landscape displacement (6 and 9 out of 17 variables, respectively; Table 3). Combined, the no action and no action with fire scenario resulted in the maximum landscape divergence for 14 of 17 variables. The exceptions included trees per acre >89-cm diameter at breast height (increase) and landscape level contagion (decrease), both of which were maximized under the 89-cm cut scenario, and the cohesion of CWHR class 4 habitat which achieved the maximum divergence under the 89-cm cut with fire scenario (decrease).

Multivariate analysis.—The first 2 principal component axes accounted for 55% of the variation in occupied fisher habitat. The third and fourth axes added 13% and 12%, respectively, increasing the total explained variance to 80% (Table 4). Axis one represents availability of older forest habitat, with strong positive loadings on large trees, large snags, basal area, and both the total percentage and cohesion of high-quality breeding habitat (Table 4). In addition, the low landscape contagion and high-diversity index loadings indicate that this older habitat is located within a diverse matrix of forest age and condition. On one end of the gradient is a landscape with numerous patches of connected older forest surrounded by a diverse matrix. On the other end

Table 3. Landscape displacement at 45-yr following 4 simulated fuel treatment scenarios on the Bear Fen and Glen Meadow management units, Sierra National Forest, California, USA. Positive values indicate an increase in a particular variable, whereas negative values indicate a decrease. Tpa refers to trees per acre, spa refers to snags per acre.

Management Unit Variable[a]	89-cm cut	89-cm cut w/fire	No action	No action w/fire
Bear Fen				
% canopy cover	−9.24	−14.82	18.54	−19.36
Basal area	39.52	9.50	110.23	−92.00
Trees/acre: 0–25-cm dbh	−573.18	−586.50	−153.92	−583.65
Trees/acre: 25–51-cm dbh	−23.60	−32.01	−6.40	−33.09
Trees/acre: 51–76-cm dbh	10.52	8.32	15.41	−7.91
Trees/acre: 76–89-cm dbh	2.06	1.68	2.50	−1.28
Trees/acre: >89-cm dbh	1.75	1.47	1.89	−2.30
Snags/acre: 12–38-cm dbh	−2.73	−5.75	17.21	−6.18
Snags/acre: 38–61-cm dbh	0.21	−0.16	3.70	−0.07
Snags/acre: 61–89-cm dbh	−0.14	0.34	0.31	2.26
Snags/acre: >89-cm dbh	0.08	0.34	0.09	1.93
ED_L	8.08	7.65	−20.13	−19.24
CONTAG _L	−12.27	−9.81	18.08	18.99
COHESION_L	−1.89	−1.04	1.43	1.58
SHDI_L	0.30	0.25	−0.40	−0.43
PLAND_C	4.88	−1.39	54.22	−13.85
COHESION_C	0.87	1.56	3.63	−3.93
Glen Meadow				
PERCC	2.13	−51.34	21.97	−57.82
BA	42.06	−172.52	106.73	−188.29
Trees/acre: 0–25-cm dbh	−226.43	−281.11	−45.90	−397.07
Trees/acre: 25–51-cm dbh	9.18	−34.37	44.77	−37.32
Trees/acre: 51–76-cm dbh	1.87	−17.45	7.36	−19.34
Trees/acre: 76–89-cm dbh	0.37	−3.75	0.43	−4.21
Trees/acre: >89-cm dbh	1.27	−3.90	1.23	−3.92
Snags/acre: 12–38-cm dbh	3.84	−4.06	41.10	−4.90
Snags/acre: 38–61-cm dbh	0.70	−2.07	3.87	−2.32
Snags/acre: 61–89-cm dbh	0.82	−0.66	1.39	−0.71
Snags/acre: >89-cm dbh	0.12	−0.50	0.15	−0.50
ED_L	13.06	−45.38	1.19	−35.65
CONTAG _L	−8.07	−50.35	0.51	−51.58
COHESION_L	−0.50	−97.51	0.29	−97.64
SHDI_L	0.15	−1.11	−0.03	−1.12
PLAND_C	49.06	−3.73	57.34	−5.64
COHESION_C	13.50	−81.26	13.76	−84.96

[a] See Table 1 for definitions.

is a landscape dominated by younger, regenerating stands. The second axis represents a gradient in landscape heterogeneity, with negative loadings on CWHR class 4 percent landscape and cohesion and a positive loading on the number of medium-sized snags (Table 4). The third and fourth axes represent gradients in the availability of mid and early seral forest, respectively (Table 4).

DISCUSSION

Our analysis of the Bear Fen management unit indicates that it is currently functional habitat for female fishers, yet is at risk of severe habitat loss should a large fire occur (Fig. 5). The 89-cm cut scenario dramatically reduced this risk, yet the impact of the treatment on habitat quality was mixed. Under this prescription, the number of individual large trees and snags remained at or above levels found in occupied home ranges, whereas the percent canopy cover fell below the target range (Table 3, Fig. 3). Once a particular risk (e.g., loss of canopy cover) is identified, it is possible to modify the prescription and repeat the simulations, thereby refining the prescription. Comparatively, the Glen Meadow unit is less similar to occupied female fisher habitat yet is also at risk from severe fire. Like the Bear Fen unit, a large fire will cause the treated landscape to further diverge from occupied habitat, but recovery is predicted to occur within 30-yr (Fig. 6). If left untreated and a fire occurs, the Glen Meadow unit is not predicted to recover even after 45-yr. Unlike the Bear Fen unit, treatment under the 89-cm cut prescription does not result in a reduction in any variables dropping below target levels (Fig. 4). Instead, treatment delays forest succession such that the Glen Meadow unit does not develop into suitable female fisher habitat for an additional 5- to 10-yr. On this unit, modifications to the prescription that would speed up development of high-quality habitat could result in increased habitat quality for fishers.

Under the no action scenario and without a large fire, both units will likely continue to be functional habitat for female fishers for approximately 30- to 35-yr (Fig. 6). After that, the utility of those units comes into question due to the gradual domination of older forest and the loss of the heterogeneous matrix. Whereas this change may or may not result in a reduction of habitat quality, it represents a deviation from currently occupied home ranges. Although most fisher habitat suitability models would predict the loss of heterogeneity

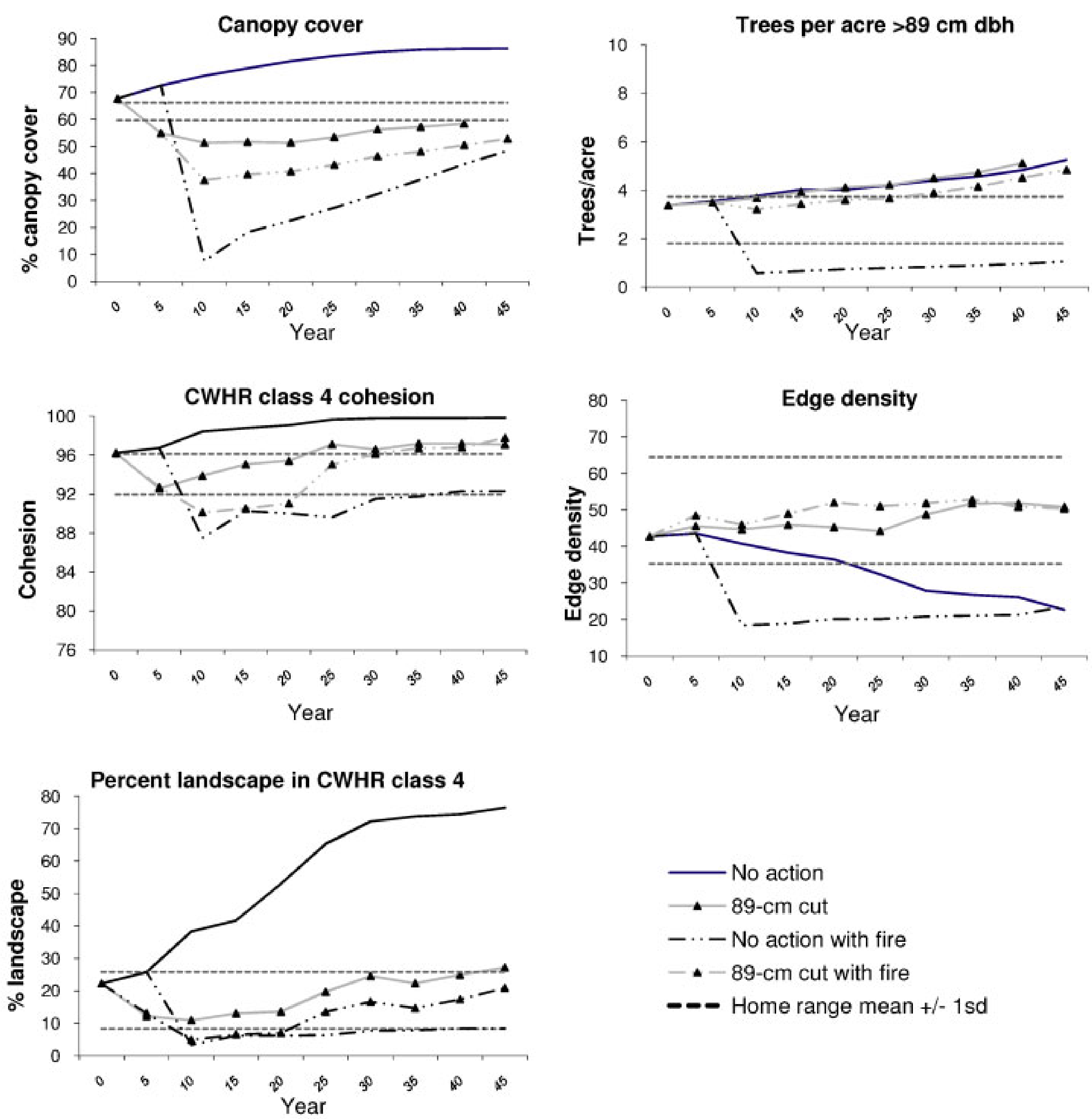

Figure 3. Projected habitat conditions on the Bear Fen management unit in the Sierra National Forest, California, USA, following 4 fuel treatment scenarios. Horizontal dashed lines indicate the range of variability ($\bar{x} \pm 1$ SD) on landscapes currently selected and used by adult female fishers. Simulated fires occurred in year 8 for relevant scenarios.

due to unchecked forest succession to represent an increase in habitat quality, the true effects are unknown. It is equally plausible that forest homogenization (as gaps are closed in and young stands age) could result in a loss of foraging opportunities for Sierra fisher, who rely on a diverse prey base representing various forest habitats (Zielinski et al. 1999; C. Thompson and K. Purcell, unpublished data). Conversely, on both units the no action with fire scenario represents the most catastrophic loss of fisher habitat with respect to CWHR class 4 habitat availability, connectivity, and matrix heterogeneity (Figs. 4 and 5). The landscape is homogenized into a younger, regenerating stand which gradually, but slowly, recovers.

A species' habitat is described by a particular range of conditions, and coupling data on this range with forest simulation models facilitates a detailed assessment of the potential risks of proposed management actions (Cyr et al. 2009). Such an approach has recently been successfully applied to Chinook salmon (*Oncorhynchus tshawytscha*) restoration (Bartz et al. 2006) and spotted owl (*Strix occidentalis*) conservation (Lee and Irwin 2005). We extended the methods proposed by Lee and Irwin (2005) into a form of environmental risk assessment; quantitatively evaluating the potential impacts of management actions on a species of concern using multiple landscape variables and providing a platform with which management scenarios can be modified and more appropriate alternatives generated.

Fishers in the Sierra Nevada are a prime example of the perceived conflicts between ecosystem restoration and species conservation. In a recent assessment of the role of science in national fire policy, Franklin and Agee (2003:6) state that Sierra Nevada forests in particular are "likely to experience

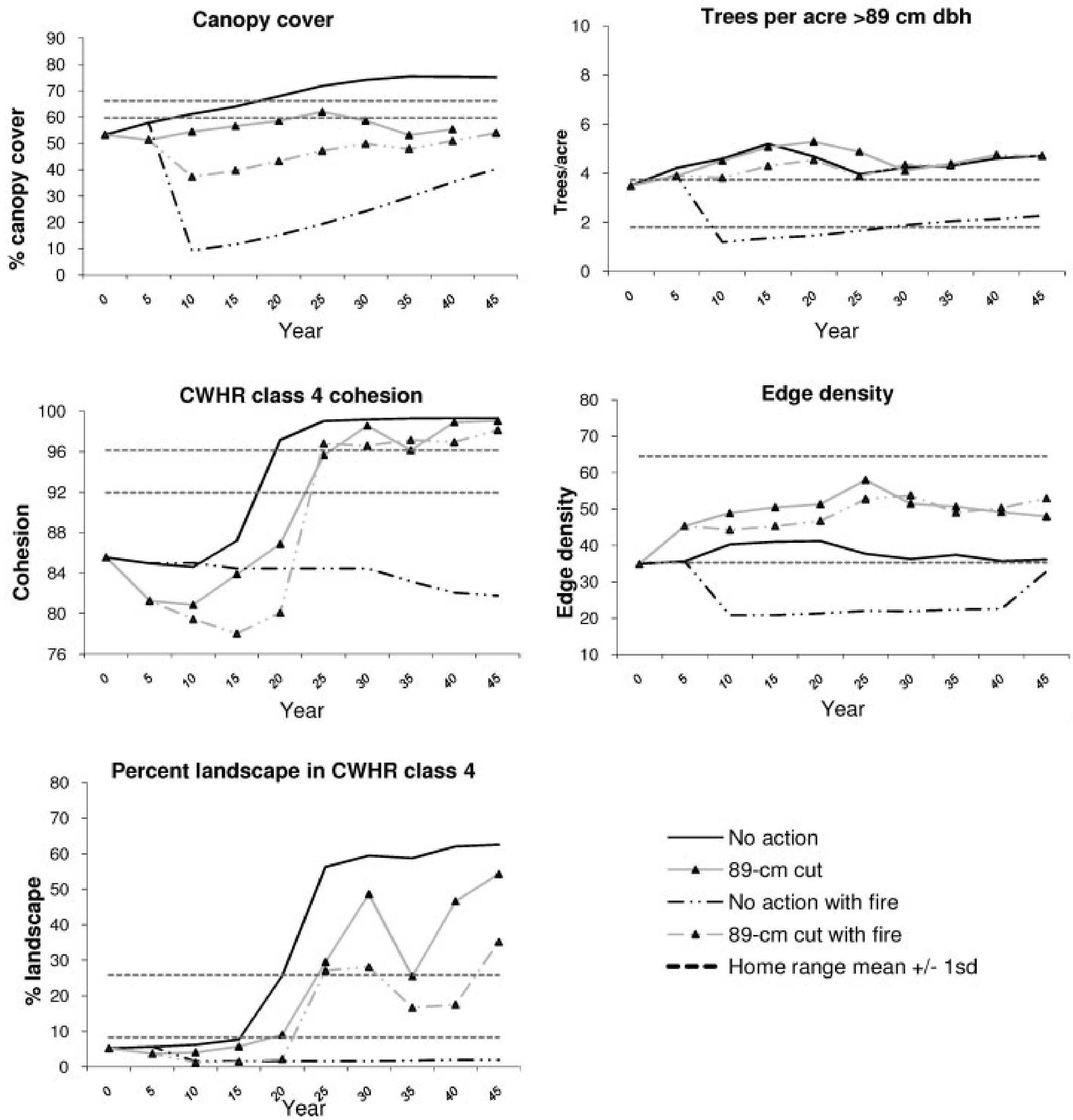

Figure 4. Projected habitat conditions on the Glen Meadow management unit in the Sierra National Forest, California, USA, following 4 fuel treatment scenarios. Horizontal dashed lines indicate the range of variability ($\bar{x} \pm 1$ SD) on landscapes currently selected and used by adult female fishers. Simulated fires occurred in year 8 for relevant scenarios.

uncharacteristic stand-replacing fires without active fuels treatments and prescribed burning programs, with the resulting loss of critical watershed and habitat." Fisher populations in the Sierra Nevada are in a precarious position due to the danger of catastrophic habitat loss due to wildfire (Zielinski 2004, Spencer et al. 2011). Increases in the size and severity of wildfires across the western United States have resulted in calls for an increase in the size and number of fuel treatments aimed at reducing unnaturally heavy fuel loads even though these treatments often conflict with species and habitat conservation goals (Allen et al. 2002, Della Sala et al. 2004, Lee and Irwin 2005, Noss et al. 2006). However, these conflicts are often more a matter of perception than reality (Noss et al. 1997, Prather et al. 2008), and a rigorous analysis of both the short- and long-term risks associated with management decisions is both necessary and possible (Lee and Irwin 2005). Our results indicated that female fishers used landscapes where availability of large trees and snags was higher and where patches of high-quality habitat were connected, yet where the matrix consisted of a heterogeneous mix of forest age and condition. Thus, some level of management to reduce fire risk may be consistent with the maintenance of landscapes attractive to fishers. The method we developed, however, can be used to verify that assumption and to determine acceptable levels.

Our analytical approach is limited in several respects. First, it relies heavily on the assumption that reference, or target, conditions can be defined based on current female fisher

Table 4. Loadings for the first 4 principal component axes (PCA1 through PCA4), reflecting the primary combinations of habitat factors characterizing female fisher home ranges in the Sierra National Forest, California, USA. "_L" indicates landscape-level variables; "_C" indicates variables focusing on California Wildlife Habitat Relationship (CWHR) class 4 habitat. Values under the axis headings (PCA1, PCA2, etc.) indicate the axis eigenvalue and the percentage of total variance in the data explained by each axis.

Variable[a]	PCA1 7.5–37.4%	PCA2 3.1–15.7%	PCA3 2.8–13.8%	PCA4 2.6–13.1%
% Canopy	−0.16	−0.18	−0.21	0.36
Basal area	0.30	0.11	0.27	0.14
Snags/acre: 12–38-cm dbh	0.23	0.08	−0.30	0.21
Snags/acre: 38–61-cm dbh	−0.01	0.47	0.12	0.14
Snags/acre: 61–89-cm dbh	0.03	0.42	−0.16	0.31
Snags/acre: >89-cm dbh	0.30	0.14	0.07	0.21
Trees/acre: 0–25-cm dbh	−0.29	0.18	−0.11	0.25
Trees/acre: 25–51-cm dbh	0.25	0.06	−0.07	0.30
Trees/acre: 51–76-cm dbh	0.23	0.07	0.38	−0.17
Trees/acre: 76–89-cm dbh	0.21	−0.08	0.42	−0.17
Trees/acre: >89-cm dbh	0.29	0.10	0.19	0.23
ED_L	0.09	0.22	−0.28	−0.28
CONTAG_L	−0.28	0.09	0.24	0.04
COHESION_L	−0.23	0.03	0.08	−0.15
SHDI_L	0.26	−0.18	−0.10	0.15
PLAND_C	0.28	−0.22	−0.27	−0.13
COHESION_C	0.27	−0.28	−0.14	−0.01

[a] See Table 1 for definitions.

habitat selection. This assumption is supported by the fact that female fishers are more selective than males and because survival of adult females is the most critical aspect of fisher population persistence (Zielinski et al. 2004*a*). However, fishers using a different set of landscape conditions may select a different collection of habitat choices, and therefore a different template would be applied. Our analysis is essentially a risk assessment given current landscape conditions and management goals. As such, using current female territories to define reference conditions is a safe assumption given the proven viability of the landscape. Second, landscape trajectory analysis as we applied it is limited to the home range scale and cannot be applied in isolation. Fisher habitat selection also occurs at the microhabitat scale with respect to forest elements such as resting and denning sites. Retention of these sites is critical to population persistence and therefore must be considered during development of fuel management prescriptions (Zielinski et al. 2004*a*, Purcell et al. 2009). And third, the question of how much risk is acceptable in pursuit of fire management objectives is open for debate. Divergence of a landscape from either the cluster of points that represents occupied habitat or from the centroid of that cluster can be quantified using multidimensional confidence intervals. We chose to simply calculate distance from the centroid because our objective was to compare treatment scenarios, not to evaluate the potential risk of a single treatment scenario.

Our analysis quantified the central tendency and variation in female fisher home ranges on the Sierra National Forest and then coupled this with post-management landscape projections to help illuminate the risks associated with particular management scenarios, including no action. This approach could be applied to any species considered at risk from management actions, as long as questions of scale are properly addressed. Most forest growth and yield models operate at the stand level, and the results are therefore only applicable to species that select habitat at a roughly similar scale. One exception is the work by Zielinski et al. (2010) who created a similar tool, also using FVS, to evaluate the effects of forest management on fisher resting habitat at the

Table 5. Multivariate divergence values reflecting the landscape trajectory under different treatment scenarios for 2 management units on the Sierra National Forest, California, USA. Values represent how far, in multivariate principle component space, a landscape is from the centroid of occupied female fisher habitat at any given year under a particular treatment scenario. Simulated fires occurred in year 8 for relevant scenarios.

		Year									
Unit	Scenario	0	5	10	15	20	25	30	35	40	45
Bear Fen	No action	3.29	3.78	4.50	5.19	5.83	6.48	7.52	9.01	11.08	12.92
	No action with fire	3.29	3.78	49.01	36.55	29.27	23.77	18.61	14.94	12.23	9.53
	89-cm cut	3.29	3.69	3.77	2.33	2.90	2.90	3.52	4.04	4.93	—[a]
	89-cm cut with fire	3.29	3.67	12.32	7.64	6.05	4.45	3.66	3.10	3.17	3.41
Glen Meadow	No action	2.47	1.51	0.59	1.24	4.02	5.21	7.04	10.26	14.71	17.88
	No action with fire	2.47	1.61	45.64	36.87	31.09	26.31	21.91	18.12	14.98	11.15
	89-cm cut	2.47	2.77	1.77	0.64	1.21	5.24	5.07	4.82	5.45	—[a]
	89-cm cut with fire	2.47	2.77	10.14	7.16	5.63	5.47	5.71	4.52	4.87	6.01

[a] Simulation data on year 45 under the 89-cm cut scenario for both units was unavailable.

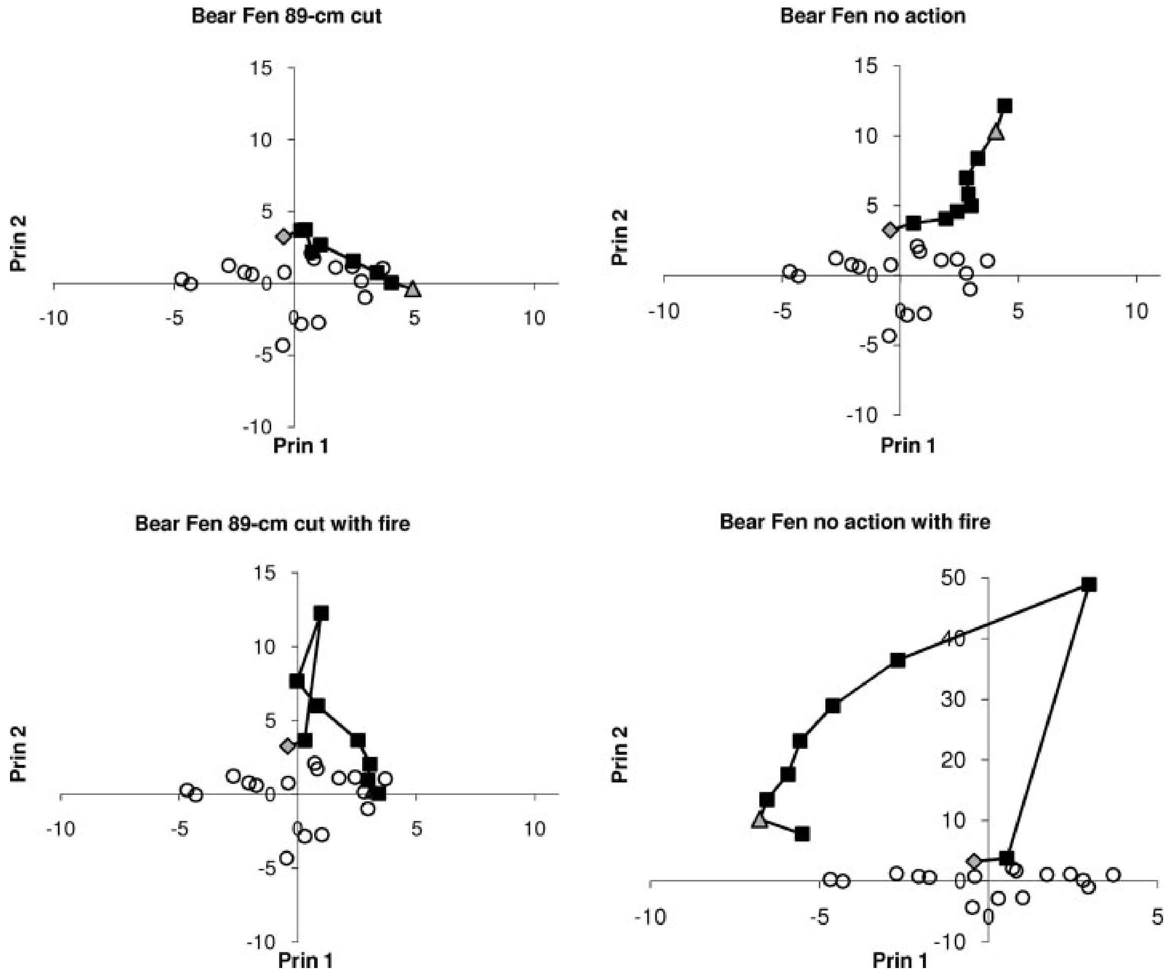

Figure 5. Landscape trajectory of the Bear Fen management unit on the Sierra National Forest, California, USA, following 4 fuel treatment scenarios. Axes represent the first 2 principal components (prin 1 and prin 2, respectively) generated by a principal components analysis of female fisher habitat. Open circles represent currently occupied landscape. Diamonds represent starting (2007) conditions and triangles represent final (2052) conditions, with closed squares representing 5-yr intervals. Note that the no action with fire scenario is scaled differently than the others. Simulated fires occurred in year 8 for relevant scenarios.

plot level. Regardless of the scale, it is critical that habitat selection, simulation results, and management actions are all assessed at roughly the same spatial scale.

Many of the forest growth and disturbance modeling frameworks (e.g., Forest Vegetation Simulator, Landscape Disturbance and Succession Model) and sampling protocols (e.g., Common Stand Exam, Forest Inventory and Analysis) currently used by silviculturists and land managers can be used to simulate land management scenarios and results linked to wildlife models (Millspaugh and Thompson 2009). Thus, in many cases, data are readily available and both the variables used and the results generated are already in a language familiar to managers, which addresses the often cited gap between science and management and allows land managers to easily implement new research results using current data collection protocols. Furthermore, once an initial model of the system is designed, repeated simulations can be used, for example, to evaluate or refine different prescription options, to assess the effect of reinstating a more natural fire regime, or to plan for stand maintenance or management reentry. Applying multivariate analytical techniques, such as ordination techniques, to these data facilitates the objective evaluation of complex landscape change and avoids using expert opinion to assess habitat quality.

Simulation modeling is a process of refining choices rather than a path to a single correct answer. Our approach is not intended to yield a recommendation about the value of fuels treatments or the value of one prescription over another; it is an approach to ecological risk assessment by which the relative risks of one suite of management actions can be compared to another. The utility of the approach rests on identifying an appropriate scale of habitat selection that is roughly equivalent to the scale of management actions and that there is not a one-size-fits-all approach. This is simply one facet of a necessarily multi-faceted conservation approach.

MANAGEMENT IMPLICATIONS

Addressing the explosion in the use of spatially explicit models, Kareiva and Wennergren (1995: pp. 302) wrote that "One critical test for ecological science will be whether it can profitably use the insights that spatially explicit models generate to solve practical problems." Reconciling competing

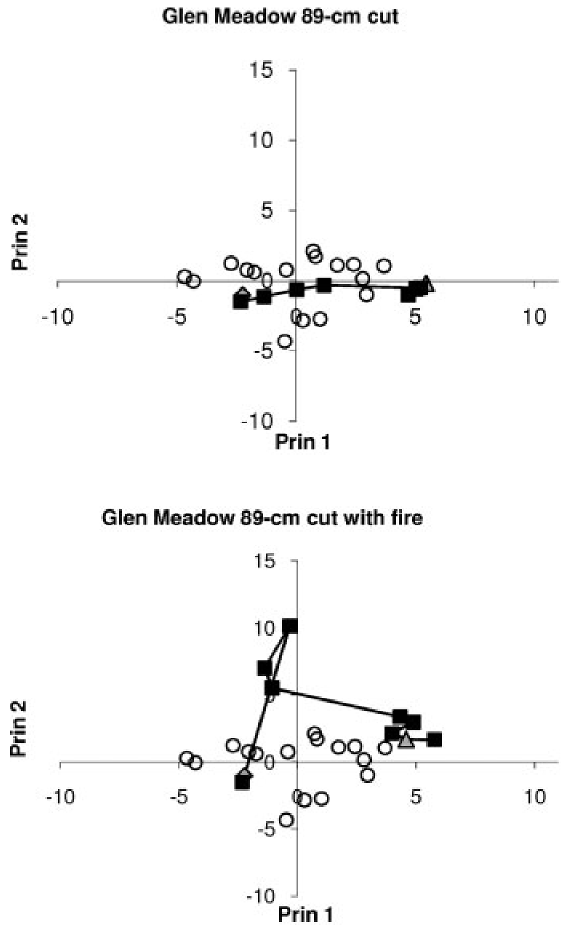

Figure 6. Landscape trajectory of the Glen Meadow management unit on the Sierra National Forest, California, USA, following 4 fuel treatment scenarios. Axes represent the first 2 principal components (prin 1 and prin 2, respectively) generated by a principal components analysis of female fisher habitat. Open circles represent currently occupied landscape. Diamonds represent starting (2007) conditions and triangles represent final (2052) conditions, with closed squares representing 5-yr intervals. Note that the no action with fire scenario is scaled differently than the others. Simulated fires occurred in year 8 for relevant scenarios.

interests and designing the most effective, most efficient, and least harmful management scenario is a practical problem facing land managers every day. Our results demonstrate that landscape trajectory analysis, coupled with carefully defined reference conditions, can provide a direct, intuitive method for interpreting the potential effects of management actions on species or processes of concern as well as estimating the time necessary for a disturbed landscape to recover to the point of providing suitable habitat. Depending on management objectives, alternative reference conditions can be defined based on the historic range of variability (Agee 2003, Nonaka and Spies 2005), biodiversity, or habitat suitability (Cushman and McGarigal 2007).

While the scope of inference of our results is limited to habitat needs of fishers in the Sierra National Forest, the applicability of the technique to help guide management decisions and facilitate necessary management actions is extensive. Reconciling fuel management and fisher conservation, or the conservation of any other species of interest, requires a rigorous evaluation of both short- and long-term risks associated with different management options as well as the risk of no action. Landscape trajectory analysis, coupled with a basic knowledge of species habitat selection, offers a simple, straightforward approach to ecological risk assessment. We recommend that whenever possible, this type of analysis accompany plans to implement fuels treatments, and other vegetation-altering management activities, in fisher habitat in the southern Sierra Nevada.

ACKNOWLEDGMENTS

A. Mazzoni and her field staff provided data on 6 female fishers monitored from 1999 to 2001. J. Banaszack, J. Garner, R. Green, B. Nichols, S. Rossler, T. Smith, G.W. Watts, and numerous volunteers collected additional data on female fisher habitat use. R. Rojas and S. Parks of the Sierra National Forest created and provided detailed vegetation data. J. Baldwin of the USFS Pacific Southwest Research Station provided statistical support. Funding for this work was provided by the USFS Region 5 and the Pacific Southwest Research Station Sierra Nevada Research Center.

LITERATURE CITED

Agee, J. K. 2003. Historical range of variability in eastern Cascades forests, Washington, USA. Landscape Ecology 18:725–740.

Allen, C. D., M. Savage, D. A. Falk, K. F. Suckling, T. W. Swetnam, T. Shulke, P. B. Stacey, P. Morgan, M. Hoffman, and J. T. Klingel. 2002.

Ecological restoration of southwestern ponderosa pine ecosystems: a broad perspective. Ecological Applications 12:1418–1433.

Aubry, K. B., and D. B. Houston. 1992. Distribution and status of the fisher (*Martes pennanti*) in Washington. Northwestern Naturalist 73:69–79.

Bartz, K. K., K. M. Lagueux, M. D. Scheuerell, T. Beechie, A. D. Haas, and M. H. Ruckelshaus. 2006. Translating restoration scenarios into habitat conditions: an initial step in evaluating recovery strategies for Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 63:1578–1595.

Buck, S., C. Mullis, and A. Mossmen. 1994. Habitat use by fishers in adjoining heavily and lightly harvested forest. Pages 368–375 *in* S. W. Buskirk, A. S. Harestad, M. G. Raphael, and R. A. Powell, editors. Martens, sables and fishers: biology and conservation. Cornell University Press, Ithaca, New York.

California Department of Fish and Game. 2008. California Interagency Wildlife Task Group. CWHR version 8.2 personal computer program. Sacramento, USA. <http://www.dfg.ca.gov/biogeodata/cwhr/>.

Common Stand Exam. 2003. Common Stand Exam Users Guide Version 1.5.1. US Forest Service, Washington, D.C.

Crookston, N. L., M. Moeur, and D. Renner. 2002. Users guide to the Most Similar Neighbor Imputation Program Version 2. U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-96. Ogden, Utah, USA.

Cushman, S. A., and K. McGarigal. 2007. Multivariate landscape trajectory analysis: an example using simulation modeling of American marten habitat change under four timber harvest scenarios. Pages 119–140 *in* J. A. Bissonette and I. Storch, editors. Temporal dimensions of landscape ecology. Springer Science, New York, New York, USA.

Cyr, D., S. Gauthier, Y. Bergeron, and C. Carcaillet. 2009. Forest management is driving the eastern North American boreal forest outside its natural range of variability. Frontiers in Ecology and the Environment 7:519–524.

Davis, F. W., C. Seo, and W. J. Zielinski. 2007. Regional variation in home-range-scale habitat models for fisher (*Martes pennanti*) in California. Ecological Applications 17:2195–2213.

Della Sala, D. A., J. E. Williams, C. D. Williams, and J. F. Franklin. 2004. Beyond smoke and mirrors: a synthesis of fire policy and science. Conservation Biology 18:976–986.

Dixon, G. E. comp. 2002. Essential FVS: A user's guide to the Forest Vegetation Simulator. Internal Rep. U.S. Department of Agriculture, Forest Service, Forest, Management Service Center, Fort Collins, Colorado.

Franklin, J. F., and J. K. Agee. 2003. Forging a science-based forest fire policy. Issues in Science and Technology. Fall 20:59–66.

Kareiva, P., and U. Wennergren. 1995. Connecting landscape patterns to ecosystem and population processes. Nature 373:299–302.

Kirk, T. A. 2007. Landscape-scale habitat associations of the American marten (*Martes Americana*) in the Greater Southern Cascades region of California. Thesis, Humboldt State University, Arcata, California, USA.

Lee, D. C., and L. L. Irwin. 2005. Assessing risks to spotted owls from forest thinning in fire-adapted forests of the western United States. Forest Ecology and Management 211:191–209.

Mayer, K. E., and W. F. Laudenslayer, editors. 1989. A guide to wildlife habitats of California. California Department of Forestry, Sacramento, USA.

Mazzoni, A. K. 2002. Habitat use by fishers (*Martes pennanti)* in the southern Sierra Nevada, California. Thesis, California State University, Fresno, USA.

McGarigal, K., S. Cushman, and S. Stafford. 2000. Multivariate statistics for wildlife and ecology research. Springer-Verlag New York Inc, New York, USA.

McGarigal, K., and B. J. Marks. 1994. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. U.S. Department of Agriculture Forest Service, Northwest Forest Experiment Station General Technical Report PNW-351. Portland, Oregon, USA.

Millspaugh, J. J., and F. R. Thompson, III editors. 2009. Models for planning wildlife conservation in large landscapes. Elsevier Science, San Diego, California, USA.

Nonaka, E., and T. A. Spies. 2005. Historical range of variability in landscape structure: a simulation study in Oregon, USA. Ecological Applications 15:1727–1746.

Noss, R. F., P. Beier, W. W. Covington, R. E. Grumbine, D. B. Lindenmayer, J. W. Prather, F. Schmiegelow, T. D. Sisk, and D. J. Vosick. 2006. Recommendations for integrating restoration ecology and conservation biology in ponderosa pine forests of the southwestern United States. Restoration Ecology 14:4–10.

Noss, R. F., M. A. O'Connell, and D. D. Murphy. 1997. The science of conservation planning: habitat conservation under the Endangered Species Act. Island Press, Washington, D.C., USA.

Prather, J. W., R. F. Noss, and T. D. Sisk. 2008. Real versus perceived conflicts between restoration of ponderosa pine forests and conservation of the Mexican spotted owl. Forest Policy and Economics 10:140–150.

Purcell, K. L., A. K. Mazzoni, S. R. Mori, and B. B. Boroski. 2009. Resting structures and resting habitat of fishers in the southern Sierra Nevada, California. Forest Ecology and Management 258:2696–2706.

Reinhardt, E. D., N. L. Crookston, S. A. Rebain, Technical editors. 2007. The fire and fuels extension to the Forest Vegetation Simulator. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-116. Ogden, Utah.

Spencer, W., H. Rustigian-Romsos, J. Strittholt, R. Scheller, W. Zielinski, and R. Truex. 2011. Using occupancy and population models to assess habitat conservation opportunities for an isolated carnivore population. Biological Conservation 144:788–803.

U.S. Fish and Wildlife Service. 2004. Notice of 12-month finding for a petition to list the west coast distinct population segment of the fisher (*Martes pennanti*). Federal Register 69:18770–18792.

Zielinski, W. J. 2004. The status and conservation of mesocarnivores in the Sierra Nevada. Pages 185–193 *in* D. Murphy, and P. Stine, editors. Proceedings of the Sierra Nevada Science Symposium: Science for Management and Conservation. Pacific Southwest Research Station General Technical Report PSW-GTR-193. U.S. Department of Agriculture, Forest Service, Albany, California.

Zielinski, W. J., N. P. Duncan, E. C. Farmer, R. L. Truex, A. P. Clevenger, and R. H. Barrett. 1999. Diet of fishers (*Martes pennanti*) at the southernmost extent of their range. Journal of Mammalogy 80:961–971.

Zielinski, W. J., A. N. Gray, J. R. Dunk, J. W. Sherlock, and G. E. Dixon. 2010. Using forest inventory and analysis data and the forest vegetation simulator to predict and monitor fisher (*Martes pennanti*) resting habitat suitability. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station General Technical Report PSW-GTR-232. Albany, California.

Zielinski, W. J., R. L. Truex, J. R. Dunk, and T. Gaman. 2006. Using forest inventory data to assess fisher resting habitat suitability in California. Ecological Applications 16:1010–1025.

Zielinski, W. J., R. L. Truex, F. V. Schlexer, L. A. Campbell, and C. Carroll. 2005. Historical and contemporary distributions of carnivores in forests of the Sierra Nevada, California, USA. Journal of Biogeography 32:1385–1407.

Zielinski, W. J., R. L. Truex, G. A. Schmidt, F. V. Schlexer, K. N. Schmidt, and R. H. Barrett. 2004a. Resting habitat selection by fishers in California. Journal of Wildlife Management 68:475–492.

Zielinski, W. J., R. L. Truex, G. A. Schmidt, F. V. Schlexer, K. N. Schmidt, and R. H. Barrett. 2004b. Home range characteristics of fishers in California. Journal of Mammalogy 85:649–657.

Associate Editor: Bruce Thompson.