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Both forest composition and configuration influence landscape-scale habitat selection by fishers (*Pekania pennanti*) in mixed coniferous forests of the Northern Rocky Mountains

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ABSTRACT

Informed forest management and effective conservation planning require an understanding of how forest patterns influence wildlife species. The fisher (*Pekania pennanti*) is a wide-ranging, mesocarnivore species that occurs at low population densities and uses large tracts of forested lands in the western USA. Loss and fragmentation of forested habitats are considered primary threats to fisher populations, however, these factors influence two different components of landscape pattern: composition and configuration. We used data from 18 fishers fitted with Argos satellite transmitter collars to evaluate habitat selection at the landscape scale (i.e., 50–100 km^2) in north-central Idaho. We developed a set of *a priori* models about how fishers might respond to forest pattern and tested the hypothesis that both forest composition and configuration influence habitat selection by fishers at broad spatial scales. Model selection results indicated that a model incorporating metrics of both forest configuration and forest composition performed significantly better those that with either alone. Fishers selected landscapes for home ranges with larger, more contiguous patches of mature forest and reduced amounts of open areas. Landscapes that had $\geqslant$50% mature forest arranged in connected, complex shapes with few isolated patches, and open areas comprising $\leqslant$5% of the landscape characterized a forest pattern selected by fishers in our study. To evaluate how well different forest management histories in our study region might provide habitat for fishers, we compared metrics of forest composition and configuration within fisher home ranges with metrics from forests managed under three distinct management histories. Landscapes managed primarily for timber production and lands managed as roadless/wilderness had significantly more open areas, less mature forest, and reduced proximity of mature forest patches than occupied fisher home ranges. These results can be used to facilitate effective conservation of fishers through informed forest management planning.

1. Introduction

Incorporating habitat needs of wildlife into forest management plans requires an understanding of how forest patterns influence the ecology and behavior of species. Forest patterns can be split into two major components: forest composition and forest configuration (Neel et al., 2004). Metrics such as patch area or the proportion of a landscape in a specific habitat type describe the composition of a forest. In contrast, forest configuration is inherently spatial and examines the arrangement of patches across a landscape (Gustafson, 1998). Common metrics of configuration include the average distance among patches of the same type, measures of average patch shape, and measures of patch aggregation. Ecologists have debated the relative importance of composition versus configuration in eliciting species responses to landscapes (e.g. Andren, 1994; Kareiva and Wennergren, 1995; Fahrig, 1997; Ewers and Didham, 2006). Although habitat loss and fragmentation are often inextricably intertwined, habitat loss, which is principally a change in composition, is generally believed to have a greater influence on wildlife (Flather and Bevers, 2002; Fahrig, 2003; St-Laurent et al., 2009) than habitat fragmentation, which is a change in configuration. However, other researchers argue that such a generalized conclusion might not be possible because of species-specific or guild-specific responses to changes in landscape pattern (Bender et al., 1998; Mazerolle and Villard, 1999; Betts et al., 2006; Wilson et al., 2009; Magrach et al., 2011). Ewers and Didham (2006) concluded that animal responses to habitat fragmentation, and thus habitat configuration, are governed by species-specific traits and that species with large body

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size, intermediate mobility, high tropic level, high habitat specialization, and low pre-fragmentation abundance are most likely to be strongly influenced by changes in habitat configuration.

One species that meets most of these criteria is the fisher (*Pekania pennanti*; formerly *Martes pennanti*, see Sato et al., 2012), which is a wide-ranging mesocarnivore that occurs at low population densities and uses large tracts of forested land. Historically, fishers were well distributed throughout the northern forests of North America (Powell and Zielinski, 1994); however, their current distribution is markedly reduced (Lewis et al., 2012). In the contiguous United States, the distribution is split into three general population segments: the Eastern (multiple states of the northeastern US), the West Coast (California, Oregon, and Washington), and the Northern Rockies (Idaho and Montana). The Eastern population is generally considered to be stable or expanding (Gibilisco, 1994). However, both the Northern Rockies and West Coast populations have been the focus of recent petitions for listing under the Endangered Species Act (U.S. Fish and Wildlife Service, 2011, 2004). In both petitions, loss and fragmentation of forested habitats was cited as a primary threat to fisher populations. Indeed, the response of fishers to changes in forest pattern has been identified as a high priority for research (Proulx et al., 2004).

Because habitat selection is a hierarchal process (Johnson, 1980), research has focused on evaluating habitat selection by fishers at multiple spatial scales (Lofroth et al., 2011; Raley et al., 2012). At fine spatial scales, selection of resting sites has been particularly well studied; dense overhead cover, abundant coarse woody debris, and large trees are consistently selected for resting sites across a wide range of latitudes and study areas (Aubry et al., 2013). Although these types of microsites are critical for reproduction and survival (Raley et al., 2012), most forest management occurs at larger spatial scales than the microsite, often at the stand, drainage, or landscape scales. However, research on how fishers select habitat at these scales is sparse; but what has been done suggests that factors operating at the extent of the home range scale and larger likely influence space use and habitat selection by fishers. Carroll et al. (1999) documented that landscape-scale estimates of canopy cover were better predictors of fisher occurrences than fine-scale habitat variables. Similarly, Davis et al. (2007) reported that GIS-derived estimates of dense forest canopy cover were as good or better than field based vegetation data for predicting fisher presence at the landscape level. Weir and Corbould (2010) concluded that the abundance of open areas within a landscape was the most important variable in predicting landscape occupancy by fishers. Zielinski et al. (2010) built a landscape-scale habitat suitability model that identified canopy cover, large trees, structurally complex forest, and the abundance of hardwoods as important biotic variables predicting the presence of fishers. These results suggest that conservation and management planning for fishers might be possible at landscape scales, even in the absence of fine-scale vegetation data. However, much of this work has approached habitat selection from a forest composition perspective. Explicit incorporation of forest configuration into models of habitat selection might improve their ability to predict habitat use by fishers and provide forest managers with more accurate information about potential occurrence of fishers and effects of proposed management actions.

Landscape pattern can be strongly influenced by land ownership and management history (Spies et al., 1994; Cohen et al., 2002; Kennedy et al., 2012). Publicly owned forests often are managed for multiple uses, and managers strive to balance the needs for timber production with those of wildlife, recreation, and other land uses (Multiple-Use and Sustained Yield Act, 1960). Generally, privately owned forests managed for timber production (hereafter called industrial forests) have increased rates of harvest in comparison with publicly owned forests. This difference in management objectives results in variation in abundances of seral stages, stand patch sizes, and spatial distribution of stands (Cohen et al., 2002). Wilderness and roadless areas, which are primarily passively managed by foresters, are generally believed to have more “natural” forest patterns that are commonly perceived as good wildlife habitat, particularly for forest carnivores (Noss et al., 1996; Carroll et al., 2001; Crist et al., 2005). However, many of these areas were not chosen *a -priori* for their wildlife habitat value; instead scenic beauty and the inability to efficiently harvest timber motivated their designation (Scott et al., 2001). Understanding how management histories influence forest patterns is needed to evaluate how management might also influence viability of wildlife populations.

We evaluated habitat selection by fishers at the landscape scale in relation to forest pattern to test the hypothesis that both forest composition and configuration shape patterns of space use and habitat selection by fishers. We conducted this work in north-central Idaho in the Northern Rockies fisher population, where the fisher often is classified as a sensitive species that requires special consideration when developing forest management plans or actions. To explore how different forest management histories might influence use of landscapes by fishers, we compared landscape characteristics within occupied fisher home ranges in our study area with landscape metrics from forests managed under three distinct management histories (i.e., industrial, multiple use, and roadless/wilderness) in the surrounding area. Our work advances understanding of habitat selection by fishers at the landscape scale, highlights the importance of forest configuration and composition, and demonstrates how this information could be used to assess how general forest management histories might influence landscape characteristics selected by fishers in the Northern Rockies region.

2. Material and methods

2.1. Study area

The study area spanned the Clearwater Mountains of north-central Idaho, USA (46.425°N, −115.646°W), including portions of the Clearwater and St. Joe National Forests, as well as industrial forests lands owned by Potlatch Timber Corporation and Hancock Timber Resource Group (Fig. 1). This area had been previously surveyed for fishers using non-invasive hair snaring techniques (N. Albrect, Coeur d’Alene Indian Tribe, unpublished data). The topography is mountainous with areas of steep, rugged terrain and few open valleys and meadows. Elevation ranges from 1000 to 1850 m, and annual precipitation ranges from 1060 to 1740 mm (Natural Resources Conservation Service, 2010). The climate is Pacific maritime with cold, snowy winters and short, warm summers. The vegetation is primarily mixed coniferous forest on the mountain slopes with narrow or no riparian areas along streams. Deciduous trees species reaching sizes necessary to form cavities are rare on the landscape. At low to mid-elevations, the forest is comprised primarily of Douglas-fir (*Pseutotsuga menziesii*), western larch (*Larix occidentalis*), grand fir (*Abies grandis*), and western redcedar (*Thuja plicata*); at higher elevations the forest transitions to subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), mountain hemlock (*Tsuga mertensiana*), and lodgepole pine (*Pinus contorta*) with an increasing incidence of mixed shrub fields (*Alnus* spp., *Salix* spp, *Ceanothus* spp., *Physocarpus* spp., *Sorbus* spp.) and mountain meadows.

Within the study area, land ownership, silviculture treatments, and overall intensity of management have evolved over decades. Generally speaking, private and state owned lands (i.e. industrial lands) have been consistently managed for fiscal return from

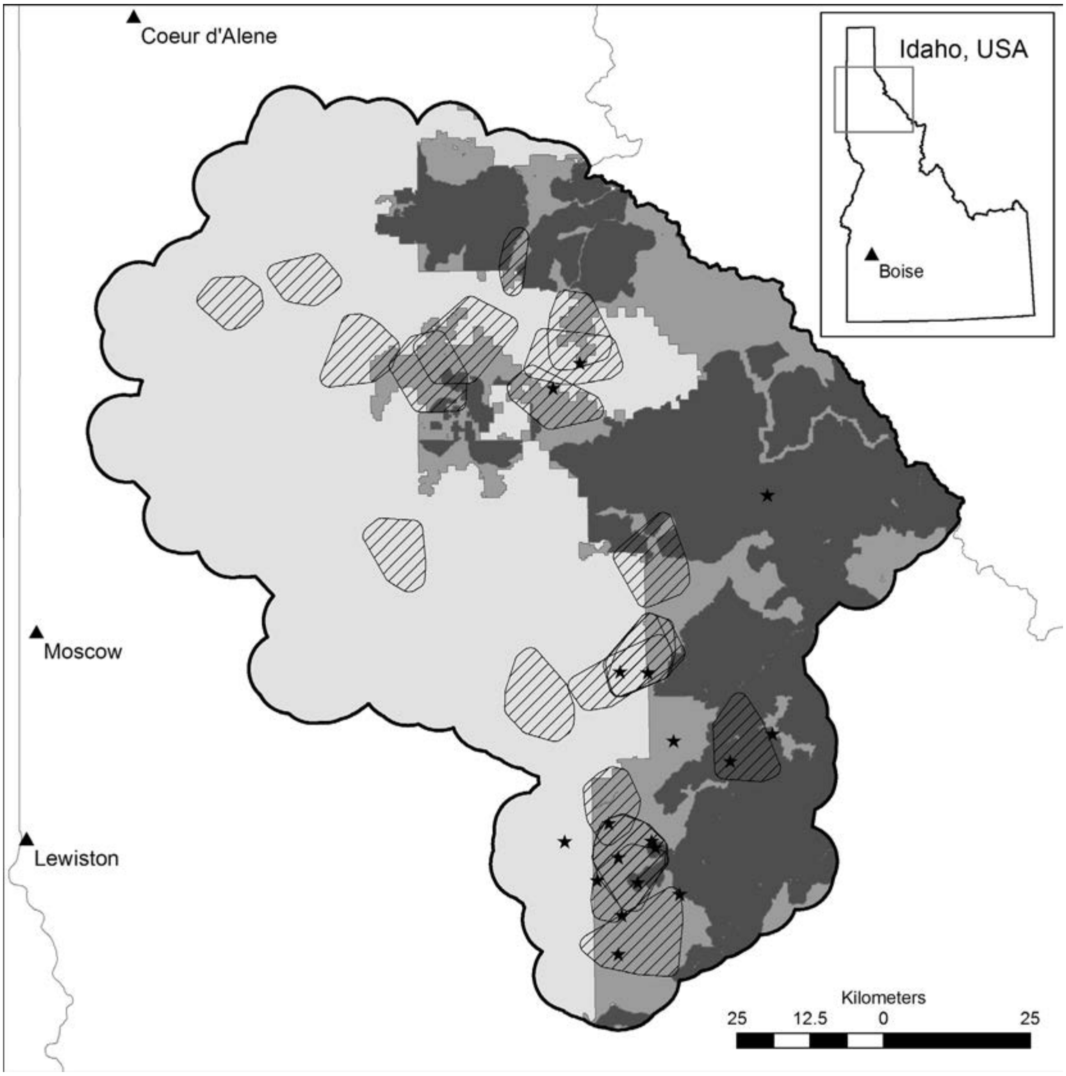

Fig. 1. The study area in north-central Idaho. Industrial forest, multiple use forest, and roadless/wilderness areas shown in light, medium, and dark gray, respectively. Cross-hatched areas mark trapping grid locations and black stars mark centroids of fisher home ranges.

timber production, with a secondary, but minor emphasis on grazing. However, in multiple use landscapes, emphasis has transitioned from a larger to smaller focus on timber production with increased emphasis placed on wildlife, recreation, and other uses. In addition, fire management on these lands has changed from aggressive suppression to more frequently allowing fires to burn with moderate or no suppression. This varied history of management has created a mixed pattern of stand structures and canopy covers, ranging from open clearcuts, shrub fields, and regenerating forest to mature forest and old growth stands.

2.2. Animal capture

We captured, radio-tagged, and tracked fishers on our study area to delineate home ranges and evaluate habitat selection. We trapped in a wide variety of landscape configurations and across three general forest management histories. To maximize trapping success, most live trapping was conducted in landscapes where fishers had recently been documented to occur. When setting up a trapping grid, we attempted to place traps in likely habitat within every square mile along roads and trails. Trapping normally lasted 1–2 weeks at a site with 25–30 traps being operated at one time. We used large Havahart collapsible traps (Woodstream Corp, Litiz, PA, USA) fitted with 0.6 mm black plastic sleeves and covered with conifer bows to create a cubby-type trap. Beaver (*Castor canadensis*) castor was used as a scent lure in the traps, which were baited with meat from road-killed animals, mainly white-tailed deer (*Odocoileus virginianus*) and elk (*Cervus canadensis*). In addition, pure skunk scent (Family Mephitidae) was applied to a carpet pad above the traps to create a broadcast olfactory signal. Captured fishers were anesthetized using 25 mg/kg Ketamine (Drew, 2010); morphometric data were collected and individuals were aged as juvenile or adult using tooth wear, sagitial crest development, and weight criteria. Individuals were fitted with Sirtrack Kiwistat202 0.5 watt Argos satellite platform terminal transmitters (PTTs; Sirtrack, Havelock North, New Zealand) that weighed <120 g and were less than 5% of the average weight of female fishers in our study area. The transmitters were programmed to cycle through 3 h periods "on" followed by 3 h "off" for 24 h and then remain off for 48 h, which extended the projected battery life to approximately 12 months. Field methods were approved by the University of Idaho Institutional Animal Care and Use Committee (Protocol 2007-5) and the Idaho Department of Fish and Game (Scientific Collecting Permit #010813) and were in accordance with guidelines for use of wild mammals in research published by the American Society of Mammalogists (Sikes and Gannon, 2011).

2.3. Data processing

To prepare our telemetry data for analysis, we filtered location data for accuracy, temporal autocorrelation, and outliers. We retained telemetry locations with location accuracy classes of 3 or 2 (CLS America, 2011), which we documented to have median location errors of 163 m and 353 m, respectively and are robust to topographic and vegetative obstruction (Sauder et al., 2012). We used only one location from each 3 h "on" block for each animal in our analyses to reduced temporal dependence among locations. During the breeding season, fishers can roam over long distances outside of the range they use during the remainder of the year (Powell, 1993), which can result in inflation of the bandwidths when using a fixed-kernel home range estimator. We tested for outliers using 3 *a priori* criteria: (1) The location was collected during the breeding season (i.e., March or April); (2) the location was >3 standard deviations from the geometric center of all points collected for that animal; and (3) the individual did not return to that region again outside of the breeding season. Points that met these criteria were considered outliers and were removed from the data set.

We quantified patterns of space use by the fishers throughout the year using a fixed-kernel home range estimator. We used likelihood cross-validation (*CVh*; Horne and Garton, 2006) to calculate the bandwidths for fixed-kernel density estimates of annual home ranges, and we used Home Range Tools (Rodgers et al., 2007) using 90% isopleths to define annual home ranges (Börger et al., 2006). Location data were collected between 2006 and 2010. Because data streams from the collared individuals varied in duration, we tested our ability to include shorter data streams (i.e., <9 months) and longer data streams (i.e., $\geqslant 9$ months) in our analyses without biasing results. We did this by iteratively truncating long data streams into shorter ones (2–9 months), calculating home range estimates, and then comparing the estimated home range sizes from the experimentally shortened data streams with estimates derived from the complete data sets using a metric of percent relative bias (Seaman et al., 1999).

2.4. Environmental predictor variables

Habitat resource layers (canopy cover and canopy height) from the nationally available LANDFIRE dataset (2006) produced by the United States Departments of the Interior and Agriculture for landscape scale vegetation analyses were used to evaluate habitat selection by fishers. Because of recent timber harvest (typically clearcuts) on industrial forest lands, we updated the LANDFIRE layers by identifying and reclassifying areas with strong increases in soil reflectance values. This was done using a tassel-cap soil transformation (Healey et al., 2005) of paired LANDSAT Thematic Mapper images in the DeltaCue extension to ERDAS Imagine (Intergraph Inc., Norcross, GA, USA). We resampled habitat layers and applied a minimum mapping unit of 1 ha to reduce the influence of image speckle on landscape metrics. We collapsed the number of categories in the LANDFIRE data due to sparse data in some categories. Canopy cover categories were 0–9.9% (hereafter called open areas), 10–39.9%, 40–69.9%, and 70–100%. Canopy height categories were nonforested/open, 0–4.9 m, 5–9.9 m, 10–24.9 m, and 25–50 m; we assumed that trees in the 25–50 m canopy height category represented mature forest from a fisher's perspective.

2.5. Modeling approach and statistical analysis

We drew from key findings from previously published work on habitat selection by fishers and general principles of landscape ecology to develop hypotheses about how fishers respond to forest pattern. We built a suite of *a priori* univariate conceptual models of landscape-scale habitat selection that included metrics that characterized either forest composition or forest configuration. We combined specific univariate models to form plausible bivariate combination models that described how fishers might be selecting simultaneously for or against multiple factors (Table 1). We identified landscape metrics that best captured the conceptual models, focusing on metrics with high universality and consistency (Cushman et al., 2008), and used program FRAGSTATS 3.3 (McGarigal et al., 2002) and FragStatsBatch (Mitchell, 2008) to calculate the landscape metrics. We required cells having adjoining

Table 1
A priori suite of candidate models evaluated using landscape composition[1] and configuration[2] metrics to explain habitat selection by fishers at the landscape scale in north-central Idaho.

Model	The probability of fishers occupying a landscape is related to…	Landscape metric and hypothesized relationship	Reference
Univariate models			
#1 – Null	Nothing, there is no selection	None	
#2 – Anthropogenic influences: A	The density of roads	Road density (−)[1]	
#3 – Anthropogenic influences: B	The degree which anthropogenic influences have shaped landscape pattern	Landscape fractal dimension (+)[2]	
#4 – Landscape fragmentation	The degree to which the landscape is broken smaller patches and intermixed	Landscape contagion (−)[2]	Weir and Harestad (1997, 2003)
#5 – Landscape diversity	A diverse array of habitats, evenly arranged on the landscape	Shannon's diversity index (+)[1]	Jones and Garton (1994)
#6 – Security obligate	The prevalence of areas with open canopy cover	% of landscape with canopy cover $<10\%$ (−)[1]	Weir and Corbould (2010)
#7 – Canopy cover obligate	The prevalence of areas with high canopy cover	% of landscape with canopy cover $>70\%$ (+)[1]	Carroll et al. (1999)
#8 – Mature forest obligate	The prevalence of mature forest areas	% of landscape in mature forest (+)[1]	Powell and Zielinski (1994)
#9 – Mature forest fragmentation	The degree to which mature forest is fragmented in smaller patches	Clumpiness index of mature forest (−)[2]	Weir and Harestad (1997, 2003)
#10 – Mature forest connectivity	The connectedness of mature forest patches within a landscape	Proximity index among mature forest patches (+)[2]	Jones and Garton (1994)
Bivariate models			
#11	Models 6 and 10 combined		
#12	Models 7 and 10 combined		
#13	Models 8 and 9 combined		
#14	Models 8 and 6 combined		

edges to be considered a contiguous patch (i.e., the "4-cell rule") to minimize landscape percolation effects on metric behavior (Hargis et al., 1997). For the proximity index, a user-specified search radius must be provided; we set it at 2000 m, based on the average size of the home range for a female fisher (Powell and Zielinski, 1994). We restricted our models to $\leqslant 2$ independent variables because of relatively small event-to-variable ratios (Peduzzi et al., 1996; Vittinghoff and McCulloch, 2007), and screened metrics for high colinearity (Pearson's correlation coefficient $\geqslant 0.60$).

To assess habitat selection by fishers, we contrasted forest characteristics within used home ranges to those available within the study area in a one-to-many matched case-control logistic regression framework (Hosmer and Lemeshow, 2000). Cases were 90% annual home ranges of fishers, and controls were "pseudo home ranges" that we generated by creating 20 copies of each actual home range. We located the pseudo home ranges randomly within the study area, rotated them to a random orientation, and estimated forest characteristics within both actual and pseudo home ranges. Cases and controls were matched by animal in the analysis to control for the unique effects of home range shape and size on landscape metrics (Katnik and Wielgus, 2005). We restricted placement of the pseudo home ranges so that they did not overlap major lakes or known fisher home ranges by >100 m and had >50% of their area within the study area boundary. If a randomly located pseudo home range did not meet these criteria, it was dropped and a new one generated. The true occupancy by fishers at our control sites (i.e., the pseudo home ranges) was unknown; however, within the study area, extensive hair snaring had been conducted to document the distribution of fishers (N. Albrect, unpublished data). This external dataset and our extensive live trapping efforts throughout the study area supported the assumption that the probability of occupancy at control sites by fishers was low. Under such circumstances, Keating and Cherry (2004) concluded that it is appropriate to interpret results as used-unused rather than used-available.

We used Akaike's information criterion corrected for small sample size (AIC_c) and Akaike's weights (w_i) to evaluate support for our suite of *a priori* landscape selection models (Burnham and Anderson, 2002). We evaluated the fit of our best supported models using a receiver operating characteristic (ROC) curve and calculated odds ratios to interpret the effects of landscape pattern on the probability of a landscape being occupied by fishers. All analyses were performed in Program R (R Development Core Team, 2005).

2.6. Applications to forest management

To evaluate the how forest management histories might influence probability of fisher occupancy on the landscape, we compared median values of the landscape metrics from the best supported models of fisher habitat selection across three common forest management histories in north-central Idaho: industrial forest (i.e., state, corporate, and privately owned forested lands managed primarily for timber production), roadless forest (i.e., federally owned and designated roadless or wilderness areas), and multiple use forest (i.e., the remainder of federally owned lands). We estimated the average home range size of our fishers and located 50 circular, hypothetical home ranges of that size within each of the three forest types. We characterized the landscape metrics in each and tested for differences in median values using a global Kruskal–Wallis test followed by multiple comparisons.

3. Results

Between November 2006 and March 2010, we captured 20 individual fishers, and fitted them with Argos satellite PTTs collars. Our iterative truncation of long data streams into shorter ones to test for an effect on estimates of home range size indicated that data stream length influenced estimates of home range size; longer data streams showed reduced percent relative bias in home range estimates. For our analysis, we retained data from individuals tracked for $\geqslant 4$ months, which resulted in a mean percent relative bias of 14.7% (SD = 2.7%). We believe this balanced the need to reduce potential bias and the realities of working with a low density species that is challenging to trap, collar, and track. Accordingly, data from two individuals were excluded from further analysis because their collars functioned for <4 months. After filtering the location data for outliers and temporally dependent locations, we retained an average of 15.8 locations per individual per month (SD = 5.2), resulting in an average of 135 locations per animal (SD = 92). Overall, transmitters functioned for an average of 8.5 months (SD = 3.5; range = 2.5–16.0 months).

Home range sizes differed between the sexes, with males ranging over areas that were approximately twice the size of female ranges. Annual 90% home ranges of male fishers estimated using fixed-kernel analyses averaged 98.4 km^2 (SD = 41.2 km^2, $n = 9$), whereas average size of female home ranges was 49.3 km^2 (SD = 26.7 km^2, $n = 9$).

Habitat selection by fishers at the landscape scale was best modeled using metrics characterizing both forest configuration and composition aspects of forest pattern. Of the 14 *a priori* models tested (Table 1), the best supported one included selection for large patches of mature forest in close proximity and selection against the percentage of the landscape classified as open area (Model #11, Table 2). This model was strongly supported with 83% of the AIC_c weight and was 9.0 times as likely as the next model (model #10), which had a ΔAIC_c of 4.40 and a AIC_c weight of 9%. A third model was included in the 95% confidence model set (Model #14), but it had a ΔAIC_c of 6.22 and an AIC_c weight of only 4%

Table 2
Ninety-five percent confidence set of models that explained habitat selection by fishers at the landscape scale in north-central Idaho with associated Akaike's information criterion corrected for small sample size (AIC_c), ΔAIC_c, and AIC weights (w_i). Models and landscape metrics are described in Table 1.

Model	Model parameters and parameter odds ratios	AIC_c	ΔAIC_c	w_i
#11	Proximity index among mature forest patches Odds ratio = 1.0005 (95% CI = 1.0002–1.0008) % of landscape composed of open areas Odds ratio = 0.875 (95% CI = 0.774–0.989)	74.38	0.00	0.83
#10	Proximity index among mature forest patches Odds ratio = 1.001 (95% CI = 1.000–1.001)	78.78	4.40	0.09
#14	% of landscape composed of mature forest Odds ratio = 1.0536 (95% CI = 1.0126–1.0962) % of landscape composed of open areas Odds ratio = 0.8554 (95% CI = 0.7523–0.9726)	80.60	6.22	0.04

(Table 2). A total of three metrics were included in 95% confidence model set (Table 2), one forest configuration metric and two forest composition metrics.

We evaluated the performance of our best supported model (Model #11) using a ROC curve; the area under the curve was 0.86, indicating that the model discriminated well between landscapes used and unused by fishers and performed substantially better than what would be expect at random (i.e., 0.5). From our model, the odds ratio for the effect of open area abundance on the probably of use by fishers was 0.875 (95% CI = 0.774–0.989, Table 2). Increasing the amount of open area from 5% to 10% within a landscape reduces the relative probability of occurrence by 39% (Fig. 2).

Configuration of mature forest patches was the most supported habitat variable influencing habitat selection by fishers at the landscape level in our study. Among the univariate models (Models #1–10, Table 1), the proximity index of mature forest was the best supported variable. It had stronger support than any of the composition metrics that we examined: percentage of open area, $\Delta AIC_c = 7.4$; percentage of mature forest, $\Delta AIC_c = 8.0$; and percentage of high canopy cover forest, $\Delta AIC_c = 22.0$. The proximity index of mature forest was 40 times more plausible than the amount of open area as best explaining landscape-level habitat selection by fishers, and 56 times more the than amount of mature forest.

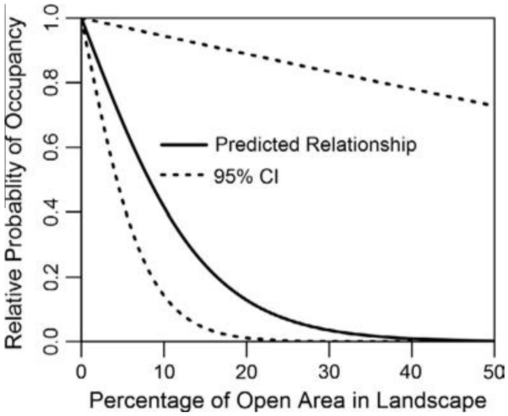

Fig. 2. The effect of open area (%) within a landscape on the relative probability of occupancy by fishers in mixed coniferous forests of north-central Idaho.

Metrics of forest pattern selected by fishers differed markedly among landscapes managed under different management histories. Forest patterns in two of the three general types of forest management histories that we examined (industrial and roadless forests) differed significantly from landscapes occupied by fishers in our study area (Table 3). In both of these types of landscapes, the amount of open area was greater, the amount of mature forest less, and the proximity mature forest patches was less than within occupied fisher home ranges (Table 3, multiple comparisons, all p-values $\leqslant 0.01$). Metrics from multiple use forests were similar to those from occupied fisher home ranges and did not differ significantly (Table 3). Based on our modeling results, the difference in open area abundance between multiple use forests (5.7%) and industrial use forests (17.4%) equals a 72% decrease in the relative probability of occurrence of fishers. This result is corroborated by our live trapping data. Overall, capture rates of fishers in industrial forest were half those in multiple use or roadless forests (Table 4), and despite substantial trapping effort, fishers were not caught on all trapping grids (Fig. 1).

4. Discussion

Our results demonstrated that fishers exhibited strong habitat selection at the landscape scale based on forest patterns. Fishers selected landscapes for home ranges with larger, more contiguous, patches of mature forest and reduced amounts of open areas. Selection for closer proximity of patches of mature forest and not strictly its abundance is a novel result for this species that supports the hypothesis that forest configuration as well as forest composition likely influences distribution of fishers across forests in our study area.

The association of fishers with mature forest and high canopy cover has long been recognized (Jones and Garton, 1994; Powell and Zielinski, 1994; Proulx et al., 2004; Lofroth et al., 2011; Raley et al., 2012). However, in our analysis, the percentage of mature forest within a landscape was not the best supported forest variable for predicting occupied versus unoccupied forests, nor was the abundance of forest with high canopy cover. Proximity among mature forest patches, as measured by the proximity index of Gustafson and Parker (1994) and modified by McGarigal et

Table 3
A comparison between landscape pattern metrics (with median and interquartile ranges) from 18 fisher home ranges in north-central Idaho and landscapes managed under three general forest management histories ($n = 50$ each).

Landscape metric	Occupied fisher home range	Landscape type		
		Industrial forest	Multiple use forest	Roadless forest
Proximity index among mature forest patches[a]	2821.2 (547.7–4834.1)	431.2[d] (172.6–816.0)	1597.8 (817.3–3481.1)	260.5[d] (134.7–1062.3)
Percentage of landscape composed of open area[b]	5.4 (4.5–8.2)	17.4[d] (10.3–25.5)	5.7 (3.89–7.4)	11.2[d] (7.4–15.5)
Percentage of landscape composed of mature forest[c]	55.8 (39.5–64.8)	31.3[d] (24.0–41.4)	43.0 (34.8–52.4)	21.4[d] (14.0–38.4)

[a] Global Kruskal–Wallis chi-squared = 31.1121, df = 3, p-value = 8.051e−07.
[b] Global Kruskal–Wallis chi-squared = 69.3949, df = 3, p-value = 5.752e−15.
[c] Global Kruskal–Wallis chi-squared = 29.4443, df = 3, p-value = 1.806e−06.
[d] Differs significantly from occupied fisher home ranges (multiple comparison tests after global Kruskal–Wallis test, $p \leqslant 0.01$).

Table 4
Data on catch per unit effort and distribution of collared fishers in north-central Idaho in forests managed under three general management histories.

	Industrial	Multiple use	Roadless/wilderness
Trap nights	2983	4553	765
Capture events of fisher (per 100 trap nights)	0.40	0.86	0.92
N of fishers with >10% of home range in a forest type	7	15	7
Mean % of home range in forest type ($n = 18$)	22.1 (SD = 32.5)	50.7 (SD = 33.7)	27.6 (SD = 36.4)

al. (2002), was more effective at identifying landscapes used verses unused by fishers in our study area. The proximity index simultaneously evaluates aspects of both configuration and composition by using the size of and distance among all patches of a habitat type within a landscape to distinguish between landscapes with sparse distributions of small habitat patches and landscapes comprised of complex clusters of larger patches (McGarigal et al., 2002). Thus, the proximity index incorporates aspects of both isolation (i.e., distance between patches) and fragmentation (i.e., patch size). Our results demonstrated that fisher home ranges typically had high values for the proximity index (Table 3), and thus fishers in our study area selected landscapes that had large patches of mature forest that were arranged in complex, highly connected patterns. Because the proximity of mature forest more strongly predicted habitat selection than abundance of mature forest, our results imply that simply increasing the amount of mature forest would not necessarily enhance habitat suitability for fishers.

Although fisher home ranges are consistently characterized by moderate to high proportions of mid- and late seral forests, there are few overarching patterns of selection for particular seral conditions or species compositions. Raley et al. (2012) hypothesized that when fishers select home ranges, they benefit from including a diverse array of available forest conditions by increasing access to a greater diversity and abundance of prey species while still attaining habitat features important for reproduction and thermoregulation. Our results are consistent with this contention. A high proximity index implies that mature forest patches are well distributed throughout an individual's home range, suggesting that forest structures used for resting, denning, and predator avoidance would be available throughout the home range. In addition, other habitats are likely intermixed with mature forest, which might be conducive to finding prey at higher densities. The diets of fishers in the Northern Rockies are poorly studied, but snowshoe hares (*Lepus americanus*) are believed to make up a large portion of their diet (Jones, 1991). However, snowshoe hare densities are typically reduced in mature and old growth forests (Sullivan et al., 2012) whereas areas with high understory cover and high densities of sapling and medium sized trees have the highest densities (Lewis et al., 2011). Jones and Garton (1994) reported that fishers in Idaho used young forests in winter more than expected at random, and Jones (1991) documented evidence of microtines, yellow-bellied marmots (*Marmota flaviventris)* and ground squirrels (*Urocitellus* spp.) in the diets of Idaho fishers, suggesting that fishers might travel and hunt at least occasionally in young, nonforested, or sparsely forest habitats where those species typically occur. Our results confirmed that having a variety of habitat patches within a matrix of well-connected mature forest was a forest pattern favored by fishers in our study area.

Although fishers selected for the proximity of mature forest stands, they simultaneously selected against open areas. Previous work has consistently demonstrated a negative relationship between open areas and habitat use by fishers (Buskirk and Powell, 1994; Jones and Garton, 1994). Weir and Corbould (2010), who studied a population of fishers in British Columbia, reported that among a suite of univariate models of landscape selection, abundance of open areas best predicted occupancy by fishers. Our odds ratio for the effect of open area (0.875, 95% CI = 0.774–0.989) was similar to the odds ratio they reported (0.803, 95% CI = 0.663–0.973), suggesting that abundance of open areas might be a useful metric for evaluating habitat suitability for fishers across large landscapes, even those composed of differing forest habitat types. The median amount of open area in a home range in our study was 5.4%, which is consistent with results from California where fisher home ranges, on average, contained $\leqslant$5.0% open area (Raley et al., 2012). Both our results and those of Weir and Corbould (2010) suggested that even relatively small changes in the amount of open area in a landscape can have large effects on the probability of occupation by fishers. Our results predict an increase in the amount of open area from 5% to 10% reduces the relative probability of occupation by fishers by 39%. Based on the results of Weir and Corbould (2010), such a change reduces the relative probability of occupation by fishers by 60%.

We evaluated many of the landscape metrics that have been reported in the literature to be associated with the presence of fishers. One metric of particular interest was the abundance of forest with high canopy cover, which has been one of the strongest and most consistent predictors of fisher distribution and habitat use across studies (Raley et al., 2012). Although purported critical thresholds of canopy cover vary widely, canopy cover has been reported as an important metric for predicting the presence of fishers in California (Carroll et al., 1999; Zielinski et al., 2010) and evaluating habitat suitability range wide (Allen, 1983). However, in our analysis, abundance of high canopy cover habitat was not the most effective metric for identifying landscapes used by fishers (Model #7, $w_i < 0.0001$). The proximity index of mature forest, the abundance of open areas, and the abundance of mature forest were each significantly more plausible at explaining habitat selection by fishers in our study area than abundance of high canopy cover. Raley et al. (2012) pointed out that inconsistency in terminology and differences in methods of measuring canopy cover confuse comparisons of the effects of this variable across studies. In our analysis, we believe that the poor performance of high canopy cover in predicting habitat selection was due, in part, to the fact that high canopy cover can be achieved in multiple ways in a forest. Typically, patches of mature forest have high levels of canopy cover. But regenerating young forests with high stem densities, which frequently occur in industrial forests, also can have high levels of canopy cover. Yet, it is likely that fishers do not perceive such forest types as equivalent, even though estimates of canopy cover might be similar. Areas of regenerating young forest with high canopy cover might provide vertical escape cover from terrestrial predators and microclimates favorable for traveling and foraging (Raley et al., 2012), but these habitat types typically have fewer cavities and structural features (e.g., large trees, broken top snags, mistletoe shelves, etc.) that are critical resting and denning sites for fishers (Zielinski et al., 2004; Purcell et al., 2009; Aubry et al., 2013). We suggest that in areas such as ours, where industrial forest composes a significant portion of the landscape (56% in study area), high canopy cover is not the best metric to use in evaluating fisher habitat; the proximity index of mature forest, or even the abundance of mature forest would be more appropriate. If canopy cover must be used, we encourage forest managers to be aware of and explore potentially confounding issues associated with the metric.

Our evaluation of landscape pattern across forests with three differing management histories revealed practical implications for conservation of fishers in the forests of the Northern Rockies. Forest configuration and composition within occupied fisher home ranges differed from both industrial and roadless forests, but not from multiple use forests in our study area (Table 3). Across industrial forest landscapes, the median abundance of open area was 17.4%, which was substantially more than the median of 5.4% within occupied fisher home ranges. Based on our modeling results, the difference in open area between multiple use forest (5.7%) and industrial (17.4%) equates to fishers being 3.6 times more likely to occur in multiple use forest verses industrial forest. Although our study did not explicitly evaluate the link between relative probability of occurrence and absolute probability of occurrence, qualitatively it is corroborated by extensive surveys using both hair snares (N. Albrect, unpublished data) and our live trapping data. Capture rates of fishers in industrial landscapes were less than half of those in multiple use forest (Table 4). The proximity index (which is best used as a comparative index because it is dimensionless; McGarigal et al., 2002) was significantly lower in industrial landscapes than within fisher home ranges suggesting that mature forest patches were more fragmented and isolated. Thus, while we documented fishers maintaining entire or significant portions of their annual home ranges in industrial forest (Table 4), it does not appear that industrial forests as a whole within our study area are in a configuration or composition pattern preferred by fishers. Additional research is warranted to better understand implications of this result. Understanding whether industrial forests are sub-optimal but adequate or are population sinks will be important to future conservation efforts (Baguette et al., 2012). Fine-scale information focused on how fishers move through landscapes avoiding or selecting individual patches and how residual structures left after harvest might facilitate use by fishers will be important for achieving both timber harvest and fisher conservation objectives. Finally, forest management strategies are not static and landscape patterns seen now are the product of multiple management actions spanning many decades. Studies that combine telemetry work with concurrent timber harvest or thinning would provide important data to evaluate the effects of specific management actions of fisher habitat selection.

The difference in forest pattern between occupied fisher home ranges and roadless forests was contrary to our expectations and has implications for the assumed value of roadless areas for conservation of fishers. In the Northern Rockies, roadless areas often are considered key landscapes for biodiversity conservation in general and carnivore conservation in particular (Noss et al., 1996; Carroll et al., 2001; Crist et al., 2005). In the past, roadless and wilderness areas have functioned as refugia from trapping pressure for fisher populations (Vinkey et al., 2006). However, in our study area, composition and configuration of roadless areas differed significantly from occupied fisher home ranges (Table 3), suggesting that roadless areas might not be preferred fisher habitat this region. The abundance of open areas was significantly higher and proximity of mature forest patches was significantly reduced in roadless landscapes relative to occupied fisher home ranges. We suspect that these differences arise for multiple reasons. First, roadless areas within our study area tended to occur at higher elevations than multiple use or industrial forests, a pattern that has been noted across the coterminous United States (Scott et al., 2001). At higher elevations, mountain meadows, shrub fields, and rock outcrops become more common, increasing the amount of the landscape classified as open area, which fishers avoid. Second, in our study area, lower to mid-elevations sites were dominated by Douglas-fir, western larch, grand fir, and western redcedar, all species that regularly grow tall enough to fall in the 25–50 m height category that we used to define mature forest patches from a fisher's perspective. However, as elevations increase, the conifer community transitions to include increasing abundances of lodgepole pine, mountain hemlock, Engelmann spruce, and subalpine fir. These species are generally shorter in height and thus are less likely to reach the 25–50 m height category. Consequently, estimates of proximity among mature forest patches are likely reduced. Davis et al. (2007) asserted that lodgepole pine and subalpine fir habitats are poorly suited for fishers. These smaller, higher elevation trees are probably less likely to form cavities, which are important features influencing habitat selection by this species (Aubry et al., 2013). Roadless and wilderness areas comprised a significant portion of our study area (>27%), so the importance of this forest type for fisher conservation and management could be substantial. We point out that although our live trapping success in roadless areas was high (Table 4), we believe that this result was influenced by particularly good fisher habitat in one low-elevation roadless area where we trapped. We believe that additional trapping in more typically configured roadless habitat would result in lower capture rates. Overall, based on our results, the assumption that roadless and wilderness areas are *de facto* good fisher habitat deserves further evaluation and perhaps site-specific consideration.

5. Conclusions

Understanding relationships between wildlife populations and their habitats is fundamental to sound, science-based wildlife conservation. Informed forest management and effective conservation planning must evaluate how forest pattern will influence a species. Our research demonstrated that models incorporating metrics quantifying both forest composition and forest configuration performed well in evaluating habitat selection by fishers at the landscape scale. Fishers in our study area located their home ranges in landscapes with abundant mature forest in large patches that were highly connected and in areas with relatively low amounts of open area. Landscapes that have ⩾50% mature forest arranged in contiguous, complex shapes with few isolated patches, and open areas comprising ⩽5% of the area appear to constitute a forest pattern occupied by fishers. Such a pattern can serve as a target for land managers seeking to maximize the probability of occupation by fishers in our region and similar habitats (i.e., low to mid elevation, mesic, and mixed conifer forest). Although we tracked fishers living and maintaining home ranges in landscapes managed under three distinctly different forest management histories, in general, the landscape patterns of industrial and roadless forests in our study area did not appear to closely match those occupied by fishers. The conservation implications of this result need to be explored further. Future research should examine how survival and reproductive success of fishers varies among forests with differing landscape patterns. Such information has implications for long-term population persistence and could improve our understanding of the respective roles that these forests potentially serve in conservation of fishers in the Northern Rockies population.

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