

LANDSCAPE ECOLOGY OF FISHERS (*PEKANIA PENNANTI*) IN NORTH-CENTRAL IDAHO

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Abstract

The fisher (*Pekania pennanti*) is member of the mustelid family and is endemic to the northern forest of North America. It occurs at low densities, uses large landscapes, is generally associated with late-seral forest characteristics, and is of conservation concern. We examined space use and habitat selection by fishers across multiple scales in north-central Idaho with the goal of providing increased information for forest managers to map and integrate the habitat requirements of fishers into forest management plans. We used Argos satellite telemetry to monitor the movements of fishers and demonstrated that the locational accuracy and data collection rates of this telemetry technique are robust to the effects of varying topography and canopy cover. Overall, fishers selected landscapes for home ranges with larger, more contiguous patches of mature forest and reduced abundances of open forest. This result supports the hypotheses that both forest configuration and composition influence the distribution of fishers in north-central Idaho. Additionally, within home ranges, fishers selected areas for core use zones that had higher fine-scale habitat heterogeneity than peripheral use zones. This result supports the hypothesis that fishers establish home ranges that include a diverse array of forest conditions, thereby increasing their access to a greater diversity and abundance of prey species while still attaining access to habitat features that are important for reproduction and thermoregulation. Finally, and most importantly, we synthesized the results from our analyses at the landscape and intra-home range scales with a previously published study on the distribution of fishers across the Rocky Mountains of Idaho and Montana. In doing this, we produced an integrated, multi-scale habitat selection model that had improved predictive accuracy over the most detailed single-scale model available. Almost 80% of the predicted habitat for fishers in Idaho and Montana occurs on federally owned national forests, yet only 28% occurs in wilderness or roadless areas. Consequently, successful conservation of fishers will rely heavily on policy and management decisions made on landscapes managed under multiple-use principles as wilderness and roadless areas alone are unlikely to provide sufficient habitat or population reserves to ensure persistence of fishers in Idaho and Montana.

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Dedication

For fishers and for Idaho

Long may you both prosper

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Dissertation Introduction

The fisher (*Pekania pennanti*) is member of the mustelid family and is endemic to the northern forests of North America. It occurs at low densities, uses large landscapes, and is generally associated with late-seral forest characteristics (Raley et al. 2012). In the late 19th and early 20th centuries, fur trapping and habitat alteration caused the extirpation of fishers in many areas of the United States (Proulx et al. 2004). In the Rocky Mountains of Idaho and Montana, fishers were thought to have been extirpated by the 1920s (Williams 1962), although recent genetic analyses indicated that a remnant population persisted in the region, probably in the Selway-Bitterroot Wilderness (Vinkey et al. 2006). In the 1960s, the Idaho Department of Fish and Game translocated fishers from British Columbia to Idaho in an effort to re-establish a viable population in the State. Since that time, anecdotal observations of fishers have been on the increase, but formal investigations into the distribution of fishers and their habitat in Idaho have been limited.

For a long time, the work of Jones and Garton (1994) was the only study of habitat selection by fishers in Idaho. Although their work was seminal, they concluded that “we currently lack the information needed to develop a conservation plan for fishers in the Northern Rockies.” Since then, interest in and conservation concern for fishers has continued to grow. New genetic techniques and wide-spread, non-invasive hair sampling has allowed the distribution of fishers to be documented at a scale that was previously impossible to achieve (Schwartz et al. 2006, Olson et al. 2014). In 1996 and again in 2009, fishers were petitioned for listing under the Endangered Species Act; both of these petitions resulted in a “not warranted” ruling (USFWS 1996, 2011). However, as a consequence of the petition and review processes, it was concluded that fishers in Idaho and Montana were discrete (i.e., markedly separated from other fisher populations) and of genetic significance due to a unique haplotype present only in this population, making them a valid distinct population segment (DPS) that was eligible for listing in the future if population threats increased. Since then, fishers in Idaho and Montana have been petitioned for listing again (Center for Biological Diversity et al. 2013), but the outcome of that petition has not been determined at this time.

Understanding the habitat requirements of fishers is a key step towards identifying conservation priorities, threats, and opportunities. Because animals select and interact with habitats across a wide range of spatiotemporal scales (Kie et al. 2002, Graf et al. 2005, Boyce 2006) evaluations of habitat selection need to occur across the range of these scales to ensure all habitat requirements are met. Indeed, habitat selection is generally considered a hierarchical process in

which selection at finer scales is dependent on availability of and selection for habitat resources at broader scales (Johnson 1980, Meyer and Thuiller 2006, DeCesare et al. 2012).

The principal goal of our work was to advance understanding of fisher habitat selection across a range of scales to provide information for forest managers to map and integrate the habitat requirements of fishers into forest management plans. We deployed Argos satellite telemetry collars on fishers in north-central Idaho across a range of forest patterns. Argos telemetry is not as widely used as more traditional telemetry systems like VHF or GPS, and we evaluated its performance in our study. In chapter one, we present an analysis of the effects of topography and canopy cover on Argos telemetry performance and describe the strengths and weaknesses of this technique for wildlife telemetry studies. In chapter 2, we evaluated how habitat composition and configuration influenced where fishers located their home ranges within a landscape. We evaluated how landscape pattern varies across forest management strategies and explore the conservation implications of differing forest management strategies for fishers. In chapter 3, we examined habitat selection by fishers at the intra-home range scale by contrasting habitat patterns in core and peripheral use areas. We tested 2 hypotheses: 1) that similar to patterns of selection reported at other scales, fishers select core use areas based on abundant and contiguous mature forest, or 2) that heterogeneity and diversity of habitats are important to fishers at this scale, potentially to balance access to an array of habitat requirements. Finally, in chapter 4, we synthesized the results of chapters 2 and 3 with those of Olson et al. (2014) who evaluated the distribution of fishers across the Rocky Mountains of Idaho and Montana. We tested whether an integrated, multi-scale model of habitat selection improved predictive accuracy of fisher occurrences relative to the most detailed single-scale model currently available. We applied our multi-scale model across northern Idaho and western Montana to gain new insights into the abundance and distribution of predicted fisher habitat across the region. With this work, we fill some of the information gaps identified by Jones and Garton (1994) 20 years ago to facilitate informed forest management and effective conservation planning for fishers in Idaho and Montana.

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Chapter 1: Influence of Topography and Canopy Cover on Argos Satellite Telemetry Performance

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ABSTRACT

Environmental variables can affect performance of global positioning system (GPS) telemetry; however, similar assessments have not been reported for Argos satellite telemetry. We used a stratified random design and linear mixed-effects models to evaluate the influence of 2 environmental variables (canopy cover and topographic obstruction) on 2 metrics of Argos satellite telemetry performance, observation rate and mean location error. Our results indicated that an Argos transmitter moving from minimal (i.e., 20%) to maximal (i.e., 95%) topographic obstruction and canopy cover would experience, on average, only a 12.4% decrease in observation rate (approx. 1.3 fixes/24 hr of operation), and mean location error would decrease by 3.4% (7.8 m). We concluded that these environmental variables have little practical effect on Argos telemetry performance, a finding that markedly contrasts similar evaluations of GPS telemetry. We documented a substantial increase in the number of high-quality locations compared with values reported previously in the literature; this is likely due to recent improvements in satellite and transmitter technology. Although Argos telemetry location errors continue to exceed those reported for GPS telemetry, the system should be considered as a telemetry tool when avoiding data bias associated with missed fixes is more important than location accuracy.

INTRODUCTION

Automated telemetry techniques, particularly Global Positioning Systems (GPS) and Argos satellite Platform Transmitter Terminals (PTT), have substantially advanced the study of animal movements and space use. Unlike traditional very high frequency telemetry, both GPS and Argos telemetry rely on orbiting satellites for data collection, which can have both positive and negative aspects. The amount of location data that can be collected often is increased by one or more orders of magnitude

(Kie et al. 2010) compared with very high frequency telemetry, and the automated nature of these telemetry systems facilitates data collection under difficult conditions (e.g., at night, in wilderness areas, during winter or periods of inclement weather). In addition, as a function of cost per location, Argos and GPS telemetry are generally less expensive than aerial or ground-based telemetry (Thompson et al. 2012). Furthermore, customized programming allows researchers flexibility to maximize efficient use of battery resources, and biometric sensors can collect additional information (e.g., activity, temp, heart rate; Kie et al. 2010). Nevertheless, these benefits are not without tradeoffs. Performance of satellite-based telemetry systems can be markedly influenced by environmental conditions. Both canopy cover and topographic obstruction can negatively affect the quantity and quality of location data (D'Eon et al. 2002, Hebblewhite et al. 2007, Lewis et al. 2007, Sager-Fradkin et al. 2007). In some cases, animal behavior also can interact with environmental characteristics to further reduce telemetry system performance (Sager-Fradkin et al. 2007, Heard et al. 2008). Other factors that affect performance include manufacturer (Hebblewhite et al. 2007), miniaturization (Blackie 2010), programmed fix interval (Cain et al. 2005), elevation (Sager-Fradkin et al. 2007), and aspect (D'Eon and Delparte 2005). Other variables, such as satellite configuration and radiometric interference, also play a role in automated telemetry error (Moen et al. 1997).

Argos satellite telemetry functions differently than does GPS telemetry in several important ways that might influence how its performance is affected by the environment. GPS telemetry units simultaneously receive radio signals at 1575.42 MHz and 1227.60 MHz from multiple satellites and internally triangulate a location. Argos PTTs broadcast a signal at 406.65 MHz that is detected multiple times by individual polar-orbiting satellites. These signals are relayed to a ground-based processing station, which calculates a location using the Doppler shift principle (see Fancy et al. 1988 and CLS-America 2011 for more details). Topography and vegetation are known to diffract and diffuse radio waves, and such interactions with habitat are influenced by the radio wave frequency (Sizun 2004). The differences in both radio frequencies and methods for calculating locations suggest that environmental variables will affect Argos and GPS telemetry differently.

Although research into performance of early Argos telemetry systems documented moderate location accuracy and sparse data (Britten et al. 1999, Hays et al. 2001), recent system upgrades and technological developments (D. Stakem, CLS America, personal communication) might enhance use of the system for a wider range of wildlife applications. Earlier studies concluded that moderate levels of accuracy made the Argos system suitable only for studies of species that moved long distances (Harris et al. 1990, Keating et al. 1991, Britten et al. 1999). Accordingly, wildlife

research that has employed Argos telemetry has focused on large-scale movements, particularly of birds (Higuchi et al. 1998, Soutullo et al. 2006), marine mammals (Blix and Nordoy 2007), and large terrestrial mammals (Walton et al. 2001, Mauritzen et al. 2002, Ito et al. 2006). More recent evaluations of Argos telemetry suggest that it can be suitable for mid-scale analyses of space use and habitat selection by species that do not move large distances (Moser and Garton 2007). However, some geographic regions (e.g., Southern Russian and the Mediterranean) might not be suitable for Argos telemetry (Dubinin et al. 2010). Performance assessments of Argos telemetry in marine ecosystems has received recent attention (White and Sjoberg 2002, Freitas et al. 2008), but detailed evaluations of the influence of environmental variables in terrestrial systems are lacking in the published literature.

We evaluated the performance of current Argos satellite telemetry using PTTs that were designed for a mid-sized, forest-dwelling mammal. We quantified 2 performance metrics: observation rate (i.e., the no. of locations collected/24 hr of operation) and location error (i.e., the distance between the true and recorded locations) in relation to canopy cover and topographic obstruction. These variables were selected because they can degrade the performance of GPS telemetry systems (D'eon et al. 2002, Frair et al. 2004, Hebblewhite et al. 2007, Sager-Fradkin et al. 2007). Our work provides a similar quantitative assessment of the relationship between habitat features and performance of Argos satellite telemetry.

STUDY AREA

The study area spanned approximately 110 km² of the upper Lolo Creek drainage, located in the Clearwater Mountains of north-central Idaho, USA (46.425°N, -115.646°W). The topography was mountainous, with few open valleys and meadows, and with some areas of steep, rugged terrain. Elevation ranged from 1,000 m to 1,850 m, and annual precipitation ranged from 106 cm to 174 cm (Natural Resource Conservation Service 2010). The climate was Pacific maritime with cold, snowy winters and short, warm summers. The cover type was primarily mixed coniferous forest on the mountain slopes, with narrow riparian areas along streams and few open meadows. At low to mid-elevations, the forest was composed primarily of Douglas fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), grand fir (*Abies grandis*), and western red cedar (*Thuja plicata*); at higher elevations, the forest transitioned to subalpine fir (*A. lasiocarpa*), Engelmann spruce (*Picea engelmannii*), mountain hemlock (*Tsuga mertensiana*), and lodgepole pine (*Pinus contorta*). The study area spanned part of the Clearwater National Forest, which was managed for multiple uses.

The history of timber harvest had created a varied matrix of stand structures and canopy covers, ranging from open clearcuts, shrub fields, and regenerating forest to mature forest and old-growth stands.

METHODS

We employed a stratified random design to evaluate effects of canopy cover and topographic obstruction on Argos telemetry performance. Canopy cover estimates were derived from light detection and ranging data collected during the autumn of 2006 (Watershed Sciences 2006). Because performance might be influenced by canopy cover both directly above and at oblique angles to the transmitter, we averaged the estimated canopy cover within 15 m of the true transmitter location. We used the VISIBILITY function in ArcINFO as described by D'Eon et al. (2002) to quantify topographic obstructions at all locations within the study area, creating a topographic obstruction variable. This variable is more useful in the evaluation of topographic influences on telemetry performance than are single variables such as slope, elevation, or particular topographic features, because it combines all of these into one metric (D'Eon et al. 2002). To capture the heterogeneity of the study area, we stratified the continuous estimates of topographic obstruction and canopy cover into 4 categorical levels for the purpose of site selection. Topographic obstruction was categorized by quartiles, while canopy cover was categorized into the following intervals: <10%, 10% to <25%, 25% to <60%, and $\geq 60\%$. We randomly selected 3 sample locations within each of the 16 possible combinations of topographic obstruction and canopy cover, which created 48 sample sites. We required sample sites to be ≥ 50 m from abrupt changes in forest structure to minimize the potential confounding effect of edges. Three additional nonrandom locations were selected as reference sites; these sites were located on mountain tops without any canopy cover or topographic obstruction.

We deployed Sirtrack Kiwistat202 0.5 watt Argos satellite PTTs (Sirtrack, Havelock North, New Zealand) at each sample site for 48 hours to 120 hours between 5 August and 19 September 2007. These units, approximately 120 g in weight, were programmed to transmit a signal every 45 seconds when activated. With the exception of the on-off cycle, these transmitters were identical to units designed for deployment on fishers (*Martes pennanti*). We attached transmitters to water bottles filled with a saturated salt solution to mimic the capacitive coupling of an animal's neck (E. Levine, Merlin Systems Inc., personal communication) and suspended so they could pivot and swing freely 1 m above the ground and >1 m from the trunk of any tree. The true location of each

transmitter was recorded using a Trimble GeoExplorer GPS unit (Trimble Navigation Limited, Sunnyvale, CA), with a post-processed average error ≤ 6 m.

To calculate a location of a PTT, an Argos satellite must receive ≥ 4 messages from a transmitter during a single satellite pass. When this occurs, a location is calculated using the Doppler shift principle and an estimate of accuracy (called a location class, LC) is assigned. Location classes range from 3 (the most accurate) to 0 (the least accurate). An estimated 68% of LC-3 records are expected to have an error radius ≤ 250 m; those radii increase to ≤ 500 m for LC-2, $\leq 1,500$ m for LC-1, and $\geq 1,500$ m for LC-0 (CLS-America 2011). If fewer than 4 messages are received by a satellite during one pass, a location might be calculated but will have an unknown accuracy. Those types of locations are assigned to LCs of A, B, or Z, depending on the number of messages and the outcome of multiple plausibility tests (CLS-America 2011).

Evaluation of GPS telemetry performance has focused on fix rate and location error (D'eon et al. 2002, Hebblewhite et al. 2007, Lewis et al. 2007, Sager-Fradkin et al. 2007). Fix rate does not have an equivalent metric in the Argos system. Because the calculation of an Argos location is a function of a satellite being available and not a function of a pre-programmed acquisition schedule as in GPS telemetry, calculating a fix rate is impossible for Argos telemetry. Instead, we calculated the number of positions per 24 hours of transmitter operation (the 'observation rate') as a performance metric. To evaluate location error, we calculated the median Euclidean distance between the all locations reported by Argos and the known location of test transmitters, by LC, at each of our test locations.

We evaluated the relationship between Argos telemetry performance metrics and the continuous variables of topographic obstruction and canopy cover with a linear mixed-effect modeling approach in Program R (Program R, Version 10.2.0, www.r-project.org) using a linear and nonlinear mixed-effects model package (Pinheiro et al. 2010). We included transmitter test sites as a random effect because we were interested in the population-level effects of canopy cover and topographic obstruction, not the site effects. We included LC as a fixed effect because it is an a priori proxy for location accuracy derived from the number, strength, and geometry of detected transmitter signals (CLS-America 2011). Using LC as an explanatory variable allowed us to ask the simple question: does canopy cover or topographic obstruction affect Argos telemetry performance in concert with, or in addition to, the effects explained by LC? We log-transformed median location error and used a weighted variance parameter for LC to meet assumptions of normality and homoscedasticity of the residuals. We focused our analysis on LC-3, 2, and 1 points as the location accuracies, because these classes of points are most likely to be of use in wildlife telemetry

applications. We used Akaike's information criterion corrected for small sample size (AIC_c) and Akaike's weights to evaluate support for a suite of a priori models composed of plausible combinations of our environmental variables of interest (Burnham and Anderson 2002). We averaged the top models that composed $\geq 90\%$ of the Akaike's weights to predict potential transmitter performance in real situations. We used an estimate of R^2 based on a likelihood ratio test to examine the amount of variance explained by the fixed effects in our models (Kramer 2005).

RESULTS

In 3,571 hours of PTT operation, we collected 3,593 data records. Location class 3 records were the most common, followed by LC-2 and LC-ABZ (Table 1). True location errors at the 68th percentile (Table 2) were smaller than expected location errors defined by CLS-America (2011). Across all LCs, magnitude of errors in the east–west direction were greater than in the north–south direction (ANOVA, $df = 5,509$, $F = 67.572$, $P < 0.001$), with an east-to-north error ratio of 1.38:1.

Retrospectively, we identified that our stratification did not adequately sample sites with the lowest levels of canopy cover and topographic obstruction, and thus we constrained our analysis to values within the range of 20–95%.

Transmitters placed at reference sites on mountain tops performed differently than transmitters located at test sites with varying canopy cover and topographic obstruction. For the 3 reference sites, transmitters averaged 32.5 locations per 24 hours (range = 30.0–34.9) in LC-3, LC-2, and LC-1 combined. In contrast, transmitters placed at 48 test sites averaged 17.7 locations per 24 hours of operation (range = 11.5–23.4) for the same LCs. Contrary to expectations, reference sites had larger location errors than test sites across all LCs and across all percentile categories (Table 2).

For observation rate, the best supported model of transmitter performance (i.e., lowest AIC_c) included LC and topographic obstruction, with no interaction terms (Table 3). However, there was relatively high uncertainty among the top models because the 90% confidence model set included 4 models that differed widely in parameterization but were within ΔAIC_c of 2.09. Among the models in the 90% confidence set, all parameter estimates for canopy cover and topographic obstruction were negative, but small enough that 95% confidence intervals included zero. The R^2 values for these 4 models ranged from 0.79 to 0.80, which suggests that parameterization it had little effect on the amount of variance explained by the models. The LC variable had the highest relative importance weight, being 2.0 times as plausible as topographic obstruction and 3.5 times as plausible as canopy cover in explaining the rate at which transmitter locations were collected. Using model-averaged

parameter estimates (Table 4) from the 90% confidence model set, a transmitter located in 20% canopy cover and 20% topographic obstruction would be expected to average 10.5 LC-3 points per 24 hours of operation (95% prediction interval = 8.4–12.6), while a transmitter located in 95% canopy cover and 95% topographic obstruction would be expected to average 9.2 LC-3 points per 24 hours of operation (95% prediction interval = 6.6–11.7).

For median location error, the best supported model (i.e., lowest AIC_c) included LC and canopy cover (Table 3). This model was well-supported because the next best performing model had a ΔAIC_c of 2.73. The models in the 90% confidence set included additional variables of topographic obstruction and an interaction between canopy cover and topographic obstruction, although these extra parameters had weak effects on the amount of variance explained, because R^2 values ranged only from 0.55 to 0.56. Among the models in the 90% confidence model set, parameter estimates for LC and canopy cover were consistently negative and 95% confidence intervals did not overlap zero. In contrast, confidence intervals for estimates of topographic obstruction and the interaction between canopy cover and topographic obstruction always included zero. Relative importance weights for LC and canopy cover were identical because both variables were included in all models in the 90% confidence model set. Both of these variables were 3.9 times as plausible as topographic obstruction and 15.5 times as plausible as the interaction between canopy cover and topographic obstruction in explaining the median error distance in transmitter locations. Using model-averaged parameter estimates (Table 4), a LC-3 location from a transmitter located in 20% canopy cover and 20% topographic obstruction would be expected to have a median location error of 227.6 m (95% prediction interval = 114.5 m to 450.6 m), while a LC-3 location from a transmitter located in 95% canopy cover and 95% topographic obstruction would be expected to have a median location error that is only slightly smaller (219.8 m; 95% prediction interval = 65.7–734.7 m).

DISCUSSION

Our results indicate that Argos telemetry performance is robust to variation in canopy cover and topographic obstruction across a wide range of conditions likely to be experienced by a transmitter deployed on a mid-sized, forest-dwelling animal. An Argos transmitter moving from minimal (i.e., 20%) to maximal (i.e., 95%) topographic obstruction and canopy cover would experience, on average, a 12.4% decrease in location observation rate (approx. 1.3 fixes/24 hr of operation), and location accuracy would be expected to increase by 3.4% (approx. 7.8 m). This level of change represents a small practical effect of environmental variables on Argos telemetry performance.

These results differ markedly from results of similar tests of environmental variables on GPS telemetry receivers. Frair et al. (2004) demonstrated declines (10–40%) in GPS fix rate due to topography, forest cover (ranging from <50% to >80%), and collar brand. D'Eon et al. (2002) reported that canopy cover (0–100%) and topographic obstruction (10–75%) interacted to reduce fix rate by up to 30%. Hebblewhite et al. (2007) recorded declines (3–19%) in GPS fix rate due to cover type and topography. Sager-Fradkin et al. (2007) reported that GPS collar fix rates declined by 21% when canopy cover increased from <40% to >70%, and obstructed satellite visibility resulted in up to a 51% decline in fix rate. Most evaluations of GPS telemetry performance have been conducted with collars sized for wolves (*Canis lupus*), elk (*Cervus elaphus*), and black bears (*Ursus americanus*). Compared with full-size collars, Blackie (2010) reported reduced performance and high failure rates in miniaturized GPS units that were comparable in size to our Argos collars. Previous research has shown that biased fix rates are more problematic than inflated location errors for data analysis because the biases result in missing or lost information, whereas inflated location errors simply make the location information less precise (Cain et al. 2005, D'Eon and Delparte 2005). Our data suggest that across wide ranges of canopy cover and topographic obstruction, Argos telemetry is more robust to bias in observation rate and location error than is GPS telemetry.

Although performance of GPS telemetry systems is more strongly affected than Argos telemetry systems by environmental variables, GPS telemetry continues to provide greater location accuracy than Argos telemetry. Although Argos transmitters at our test sites exhibited smaller than expected location errors (Table 2), Argos telemetry yields larger location errors than does GPS telemetry. Lewis et al. (2007) reported that 95% of 3-D and 2-D GPS locations had location errors of ≤ 69 m and ≤ 253 m, respectively, while Sager-Fradkin (2007) reported location errors of ≤ 18 m and ≤ 265 m for 3-D and 2-D errors, respectively. Thus, the continued moderate location accuracies of Argos telemetry make it unsuitable for fine-scale analyses that require small location errors (Montgomery et al. 2010).

The trend for Argos location error to decline with increasing canopy was not an expected result and was more apparent in comparisons between our reference and test sites (Table 2) where location error dropped by 30% and observation rate dropped by 46%. This non-intuitive pattern is most likely an example of a screening effect described by Harris et al. (1990). They reported that when the position of an Argos satellite was $\leq 20^\circ$ or $\geq 70^\circ$ above the horizon, location errors were markedly increased. Thus, although our reference transmitters located at mountain-top sites had 'perfect visibility' (i.e., no topographic obstruction or canopy cover), they would be detected more

frequently by satellites at low angles, resulting in more locations with larger errors. Canopy cover and topographic obstruction effectively screen out satellites that are at low positions above the horizon, which results in fewer recorded locations, but an overall improvement in location accuracy. Our data support this screening effect phenomenon. However, the majority of the screening effect appeared to occur over a narrow range of canopy cover and topographic obstruction. Between our reference and test sites, observation rate dropped by 46% and location error dropped by 30%. But across our test sites, which spanned 20%–95% canopy cover and topographic obstruction, our recorded observation rate did not drop substantially (12.4% or approx. 1.3 locations/24 hr) and there was only a subtle improvement in location error (3.4% or approx. 7.8 m).

Our data show an improvement in Argos telemetry performance relative to previously published evaluations (i.e., Britten et al. 1999, Hays et al. 2001). Although absolute accuracy remains relatively unchanged, the percentages of LC-3 and LC-2 points collected during this study were substantially greater than those reported previously (Table 1). The existence of an easting versus northing error bias is consistent with previous work (Fancy et al. 1988, Keating et al. 1991) and is an inherent function of the polar orbit of Argos satellites. It is unclear, however, whether the difference between our ratio of easting to northing error of 1.38:1 and a previously reported ratio of 1.94:1 (Vincent et al. 2002) can be attributed to improvements to the Argos system or latitudinal differences between study sites.

The increase in LC-3 and LC-2 points in this study is likely attributable to multiple factors. At the time of the work of Britten et al. (1999) and Hays et al. (2001), ≤ 5 Argos satellites were in operation. In contrast, during our work, 6 satellites were operating. This increase means that there were simply more satellites available to detect transmitters. But more importantly, older satellites have been replaced with newer ones carrying new instruments that improve performance, including increased number of data receivers, increased bandwidth reception, and higher sensitivity (D. Stakem, personal communication). In practical terms, these changes mean that the current set of Argos satellites have the ability to detect more signals simultaneously, on a wider range of frequencies that are weaker in strength, as compared with satellites used ≥ 10 years ago. Additionally, the data processing algorithms that are employed to calculate locations have been improved over time (D. Stakem, personal communication). The most substantial improvement was the incorporation of digital elevation models into location calculations in 2005, addressing a major source of error described by Keating et al. (1991). Improvements in transmitter technology have aided Argos telemetry performance, as well. Temperature-compensated crystal oscillators and super

capacitors that stabilize output power are now commonly used to improve the strength of signals from transmitters (K. Lay, Sirtrack, personal communication). Overall these modifications permit a larger volume of data to be collected, and a significantly greater proportion of that data is of higher quality.

Since the collection of our data, the Argos system has had 2 improvements. In 2009, an older Argos satellite was replaced with a newer one to maintain 6 operating satellites. In 2011, a Kalman filtering algorithm was instituted, which uses measurements from the current satellite pass, as well as information from previous satellite passes, to provide improved estimates of location errors (CLS-America 2011). Because these changes relate to logistical improvements and processing techniques, and not the underlying mechanism of location calculation based on the Doppler shift principle, we expect the changes to yield increased percentages of higher quality locations (i.e., LC-3 and LC-2), but not to affect the location accuracy of Argos telemetry. The relative difference in location accuracy between Argos and GPS telemetry and the relationship between Argos telemetry performance and environmental variables should remain unchanged.

MANAGEMENT IMPLICATIONS

Automated telemetry systems are important tools for wildlife biologists to monitor animal movement and habitat selection. Choosing an appropriate telemetry technique depends heavily on project objectives, logistical considerations, and the species being studied. Our study demonstrated that the Argos telemetry system is robust to negative effects of canopy cover and topographic obstruction on both observation rate and location error. This finding stands in contrast to results from previous GPS telemetry research and suggests that Argos telemetry should be considered as an option when dense vegetation or rough topography is likely to substantially reduce the performance of GPS telemetry. Availability of lighter weight telemetry units (PTT vs. GPS) and the ability to track movements almost in real time are additional benefits of the Argos system. However, the continued moderate location accuracies of Argos telemetry will limit its use for some types of fine-scale analyses. Nevertheless, when avoiding location bias is more important than location accuracy, Argos telemetry can be a useful tool in the study of animal movements.

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Table 1.1 Percent of total locations by location class for Argos platform terminal transmitters placed at 48 sites in the upper Lolo Creek drainage, Idaho, USA, during August and September 2007 and similar previously published data.

Location class ^a	Sauder et al. (this study)	Hays et al. 2001 ^b	Britten et al. 1999 ^c
3	44.6%	26.6%	1.3%
2	20.2%	19.6	1.3%
1	12.4%	13.3%	6.8%
0	3.5%	6.3%	14.9%
A, B, Z	19.2%	28.0%	75.7%

^a Argos-predicted location errors for location classes 3, 2, 1 and 0 at the 68th percentile are ≤ 250 m, ≤ 500 m, $\leq 1,500$ m, and $>1,500$ m, respectively. No error estimates exist for other classes.

^b Hays et al. (2001) placed transmitters at fixed locations with no canopy cover and relatively low topographic obstruction.

^c Britten et al. (1999) tested transmitters on caged rock doves (*Columba livia*) in a relatively open suburban backyard.

Table 1.2. Mean Argos telemetry errors (m) by location class at the 50th, 68th, and 90th percentiles from transmitters placed at reference ($n = 3$) and test ($n = 48$) sites in the upper Lolo Creek drainage, Idaho, USA, during August and September 2007.

Site	Location class	N^a	Percentile		
			50th	68th ^b	90th
Reference	3	137	215	310	516
	2	86	507	662	1079
	1	50	1,028	1,268	2,178
Test	3	1,589	162	216	358
	2	722	353	494	870
	1	445	702	991	1648

^a No. of recorded data points.

^b Argos-predicted total errors for LC-3, 2, and 1 at the 68th percentile are ≤ 250 m, ≤ 500 m, and $\leq 1,500$ m, respectively.

Table 1.3. Competing models of Argos telemetry performance metrics (i.e., observation rate and location error) as a function of location class (LC), canopy cover (CC), and topographic obstruction (TO) with associated Akaike's information criterion corrected for small sample size (AIC_c), ΔAIC_c , AIC_c weights, and R^2 . Transmitters were placed at 48 sites spanning a wide range of canopy cover and topographic obstruction in the upper Lolo Creek drainage, Idaho, USA, during August and September 2007.

Response	Model parameters	K	AIC	AIC_c	ΔAIC_c	AIC_c wt	R^2
Observation rate	LC + TO	6	505.88	508.21	0	0.36	0.80
	LC	5	506.80	508.42	0.21	0.33	0.79
	LC + CC	6	507.61	509.94	1.73	0.15	0.79
	LC + CC + TO	7	507.10	510.30	2.09	0.13	0.80
	LC + CC \times TO	8	509.08	513.31	5.10	0.03	0.80
	(LC + CC + TO) ^{2a}	12	515.62	526.02	17.80	<0.01	0.80
	(LC + CC + TO) ^{3b}	14	516.63	531.63	23.41	<0.01	0.80
	1	3	698.15	698.77	190.55	<0.01	<0.01
	CC + TO	5	701.41	703.03	194.81	<0.01	0.01
Location error ^c	LC + CC	6	144.35	146.68	0	0.69	0.55
	LC + CC + TO	7	146.22	149.42	2.73	0.18	0.55
	LC + CC \times TO	8	147.31	151.54	4.86	0.06	0.56
	(LC + CC + TO) ^{2b}	12	141.34	151.74	5.06	0.06	0.60
	(LC + CC + TO) ^{3c}	14	139.55	154.55	7.87	0.01	0.62
	LC	5	157.59	159.21	12.53	<0.01	0.50
	LC + TO	6	158.85	161.18	14.50	<0.01	0.50
	CC + TO	5	235.50	237.12	90.43	<0.01	0.06
	1	3	239.11	239.73	93.04	<0.01	<0.01

^a Complete 2-way interaction model.

^b Complete 3-way interaction model.

^c Location errors were log-transformed.

Table 1.4. Averaged model coefficients of the 90% confidence set of models for observation rate and location error for Argos transmitters as a function of location class (LC), canopy cover (CC), and topographic obstruction (TO) placed at 48 test sites in the upper Lolo Creek drainage, Idaho, USA, during August and September 2007.

Response	Parameter	Coeff.	SE	95% Prediction interval	
				Upper	Lower
Observation rate	Intercept	3.4386	0.6496	4.7052	2.1719
	LC2	1.4740	0.3685	2.1925	0.7553
	LC3	7.3948	0.3685	8.1134	6.6761
	CC	-0.0070	0.0021	-0.0029	-0.0110
	TO	-0.0106	0.0009	-0.0089	-0.0123
Location error ^a	Intercept	6.8135	0.1844	7.1731	6.4539
	LC2	-0.5965	0.0969	-0.40745	-0.7854
	LC3	-1.2363	0.1052	-1.0311	-1.4415
	CC	-0.0072	0.0021	-0.0030	-0.0111
	TO	-0.0020	0.0009	-0.0003	-0.0037
	CC*TO	0.0001	<0.0001	0.0001	<0.0001

^a Location errors were log transformed.

Chapter 2: 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., 50-100km²) 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 than 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 $\geq 50\%$ mature forest arranged in connected, complex shapes with few isolated patches, and open areas comprising $\leq 5\%$ 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.

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, Magrath et al. 2011). Ewers and Dindham (2006) concluded that animal responses to habitat fragmentation, and thus habitat configuration, are governed by species-specific traits and that species with large body size, intermediate mobility, high trophic 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 (Gibilsco 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 hierarchical 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.

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 (Figure 1). This area had been previously surveyed for fishers using non-invasive hair snaring techniques (N. Albrecht, 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 1,000 to 1,850 m, and annual precipitation ranges from 1060 to 1740 mm (Natural Resource 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 (*Pseudotsuga 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 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.

METHODS

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 0.6mm 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, sagittal 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 <120g and were less than 5% of the average weight of female fishers in our study area. The transmitters were programmed to cycle through three hour periods “on” followed by three hours “off” for 24 hours and then remain off for 48 hours, 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).

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 163m and 353m, respectively and are robust to topographic and vegetative obstruction (Sauder et al. 2012). We used only one location from each three hour “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 (Borger 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., ≥ 9 months) in our analyses without biasing results. We did

this by iteratively truncating long data streams into shorter ones (2 to 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).

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 tassell-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, 0-4.9m, 5-9.9m, 10-24.9m, and 25-50m; we assumed that trees in the 25-50m canopy height category represented mature forest from a fisher's perspective.

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 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 2000m, based on the average size of the home range for a female fisher (Powell and Zielinski 1994). We restricted our models to ≤ 2 independent variables because of relatively small event-to-variable ratios (Peduzzi et al. 1996, Vittinghoff et al. 2007), and screened metrics for high collinearity (Pearson's correlation coefficient ≥ 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 >100m 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. Albrecht, 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 Core Development Team 2005).

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.

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 ≥ 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 km² (SD = 41.2 km², n = 9), whereas average size of female home ranges was 49.3 km² (SD = 26.7 km², 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). 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 probability 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% (Figure 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 than the amount of mature forest.

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 ≤ 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 (Figure 1).

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 al. (2002), was more effective at identifying landscapes used versus 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 (*Uroditellus* 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 $\leq 5.0\%$ 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 (Allan 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. Albrecht, 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 25-50m 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 25-50m 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.

MANGAMENT IMPLICATIONS

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 $\geq 50\%$ mature forest arranged in contiguous, complex shapes with few isolated patches, and open areas comprising $\leq 5\%$ 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, 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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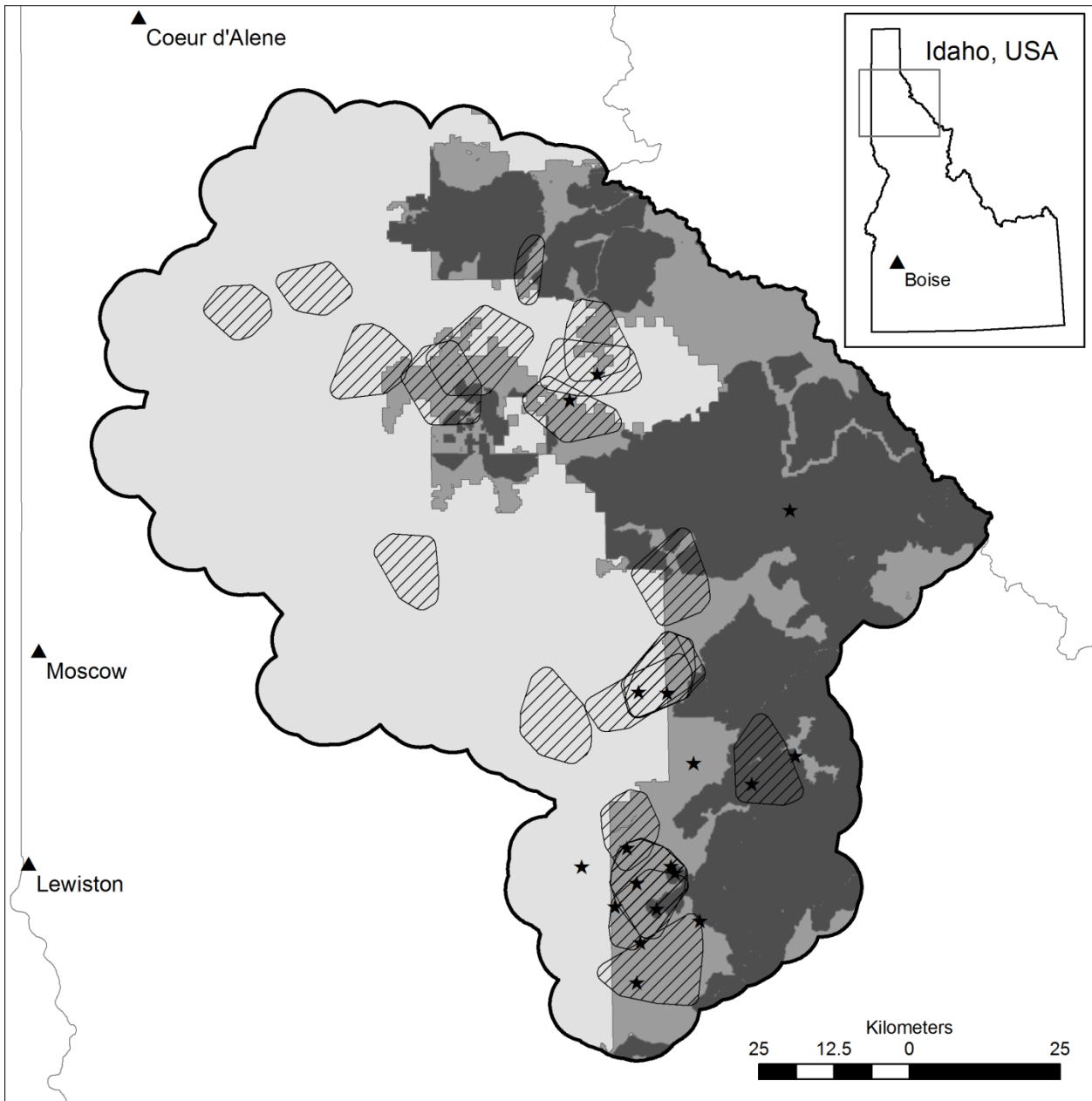


Figure 2.1. The study area in north-central Idaho. Industrial forest, multiple use forest, and roadless/wilderness areas shown in light, medium, and dark gray, respectively. Cross-hatched areas mark trapping grid locations and black stars mark centroids of fisher home ranges.

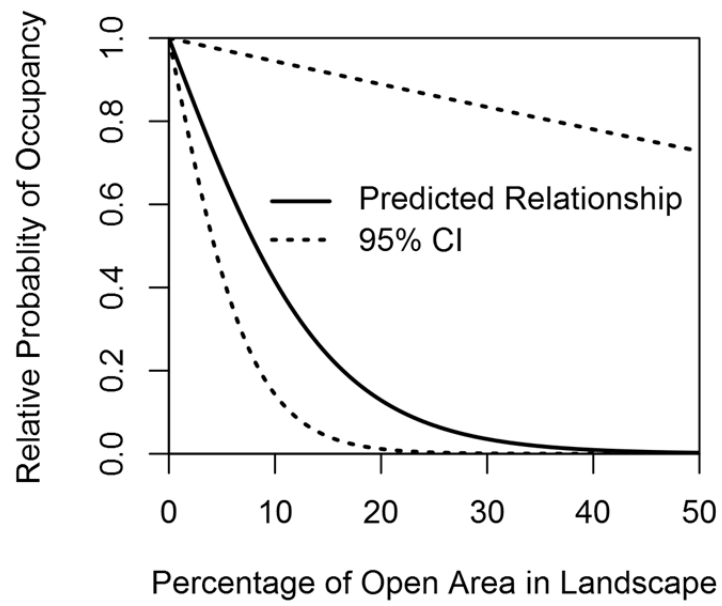


Figure 2.2. The effect of open area (%) within a landscape on the relative probability of occupancy by fishers in mixed coniferous forests of north-central Idaho.

Table 2.1. *A priori* suite of candidate models evaluated using landscape composition¹ and configuration² 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 & 10 combined		
#12	Models 7 & 10 combined		
#13	Models 8 & 9 combined		
#14	Models 8 & 6 combined		

Table 2.2. 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 (AICc), 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 2.3. 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	Landscape Type			
	Occupied Fisher Home Range	Industrial Forest	Multiple Use Forest	Roadless Forest
Proximity Index among mature forest patches ¹	2821.2 (547.7 – 4834.1)	431.2 ⁴ (172.6 - 816.0)	1597.8 (817.3 – 3481.1)	260.5 ⁴ (134.7 – 1062.3)
Percentage of landscape composed of open area ²	5.4 (4.5 – 8.2)	17.4 ⁴ (10.3 - 25.5)	5.7 (3.89 – 7.4)	11.2 ⁴ (7.4 – 15.5)
Percentage of landscape composed of mature forest ³	55.8 (39.5 – 64.8)	31.3 ⁴ (24.0 – 41.4)	43.0 (34.8 – 52.4)	21.4 ⁴ (14.0 – 38.4)

¹- global Kruskal-Wallis chi-squared = 31.1121, df = 3, p-value = 8.051e-07

²- global Kruskal-Wallis chi-squared = 69.3949, df = 3, p-value = 5.752e-15

³- global Kruskal-Wallis chi-squared = 29.4443, df = 3, p-value = 1.806e-06

⁴- Differs significantly from occupied fisher home ranges (multiple comparison tests after global Kruskal-Wallis test, $p \leq 0.01$).

Table 2.4. 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)

Chapter 3: Fine-scale heterogeneity influences habitat selection by fishers (*Pekania pennanti*) within home ranges

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ABSTRACT

Habitat selection by animals occurs across a wide range of spatial and temporal scales. Information about habitat requirements across scales is needed to develop effective habitat management strategies that promote wildlife conservation. The fisher (*Pekania pennanti*) is a wide ranging mesocarnivore that occurs at low population densities, uses large tracts of forested land, and has been repeatedly petitioned for listing under the Endangered Species Act, primarily due to habitat loss. Although habitat selection by fishers at fine and broad spatial scales has been widely studied, selection at intermediate scales is poorly reported in the literature. We used data from 18 fishers fitted with Argos satellite telemetry collars to evaluate two competing hypotheses about habitat selection by fishers at the intra-home range scale: fishers select core use areas based on 1) abundant and contiguous mature forest, or 2) heterogeneity and diversity of habitats. We identified core and peripheral use areas within home ranges using an optimal isopleth analysis, and we evaluated a suite of *a priori* models that described how forest composition and configuration might influence habitat selection for core areas. Model selection results indicated that core use areas were composed of intermediate amounts of both landscape edge and high canopy cover forest, which indicates that core use areas had more abundant habitat with fine-scale habitat heterogeneity than peripheral use areas, potentially facilitating access to diverse array of resources. Overall, our results supported the hypothesis that fishers select core use areas based on habitat heterogeneity and diversity. Because most forest management occurs at intermediate spatial scales, these results contribute to a better understanding about how forest management strategies can facilitate persistence of fishers in managed forest landscapes.

INTRODUCTION

Understanding relationships between wildlife populations and their habitats is fundamental to sound, science-based wildlife conservation. Informed forest management and effective conservation planning must incorporate an understanding of how species select and use forested

habitats. However, habitat selection by animals occurs across a wide range of spatial and temporal scales and can differ markedly across scales (Kie et al. 2002, Graf et al. 2005, Boyce 2006). In addition, habitat selection is considered to be a hierarchical process in which selection at finer scales is dependent on availability of habitat resources at broader scales (Johnson 1980, Meyer and Thuiller 2006, DeCesare et al. 2012). Consequently, it is important that managers of forests have information about how wildlife species select and use habitat resources across a spectrum of spatiotemporal scales. Johnson (1980) identified 4 scales or orders of habitat selection that have provided a useful framework for organizing habitat studies and identifying information gaps in our understanding of habitat requirements. In this framework, 1st order selection encompasses the geographic extent of the species, 2nd order reflects selection of a home range within a larger landscape, 3rd order evaluates selection of specific areas or resources within the home range, and finally, 4th order represents selection of particular sites or structures. A comprehensive understanding of habitat requirements across all scales is necessary to help shape effective habitat management for conservation of wildlife species.

The fisher (*Pekania pennanti*) is a forest-dwelling mesocarnivore that naturally occurs at low population densities and is generally associated with late-seral forest characteristics (Raley et al. 2012). Fishers live in both eastern and western forests in the United States, but population trends in these regions differ markedly (Gibilisco 1994). Studies of habitat selection by fishers from 27 study areas across the western United States and Canada were summarized by Lofroth et al. (2011). The majority of studies (22 of 27) reported results at the site or structure scale (i.e., 4th order selection). Similarly, 21 studies reported results at home range and larger spatial extents (i.e., 1st or 2nd order). However, only 10 reported results at the stand scale, which would be comparable to 3rd order selection of habitats within home ranges, and most of those studies were unpublished reports.

At fine spatial scales (i.e., 4th order), selection of resting sites and structures by fishers has been particularly well studied. Rest sites used by fishers are often located in areas with relatively steep slopes, cool microclimates, dense overhead cover, large log volume, and high prevalence of large trees and snags (Aubry et al. 2013). At broad spatial scales (i.e., 1st and 2nd order), avoidance of open areas by fishers and selection for dense canopy cover or mature forest has been regularly reported (Raley et al. 2012). In addition to avoiding open areas, fishers in central Idaho selected landscapes with abundant large trees (Schwartz et al. 2013, Olson et al. 2014) and mature forest arranged in contiguous, complex shapes with few isolated patches (Sauder and Rachlow 2014).

Information about habitat use and selection by fishers at intermediate scales (i.e., 3rd order) is relatively limited and results are inconsistent. At this scale, fishers selected for moderate values of most forest structural attributes in British Columbia (Weir and Harestad 2003), but selection differed between the sexes. Behavior also likely influences habitat selection at this scale; fishers are thought to use sapling and young forest vegetation for hunting while preferentially using mature forests for resting (Jones and Garton 1994), however, a review by Raley et al. (2012) failed to discover strong overarching patterns of habitat use or selection by active fishers (i.e., while traveling or foraging) at any scale. Similarly, Lofroth et al. (2011) reported widely varying patterns of habit selection at intermediate scales, with some studies reporting selection for high canopy cover and mature trees, and others detecting no strong patterns. Overall, habitat selection by fishers at intermediate spatial scales is poorly understood.

Because of the strong and consistent association of fishers with large trees, dense canopy cover, and abundant mature forests at both fine and broad spatial scales, one hypothesis is that these associations also are present at intermediate scales. If this is true, then one would expect that locations of regular and repeated use by fishers would have high values of these characteristics and relatively low habitat heterogeneity. However, an alternative hypothesis is that fishers might establish home ranges in areas with a heterogeneous array of forest conditions to increase their access to a greater diversity and abundance of prey species while still retaining access to habitat features that are important to reproduction and thermoregulation (Raley et al. 2012). Because heterogeneity influences availability and distribution of a wide variety of resources, selecting for increased heterogeneity at intermediate spatial scales could allow wildlife species to meet their habitat needs on daily, seasonal, or annual bases (Turner 1989). For example, landscape heterogeneity explained a substantial portion of the variation in home range sizes of mule deer (*Odocoileus hemionus*), such that deer used larger home ranges in more homogenous habitats, presumably because they traveled more widely to acquire forage or locate escape cover (Kie et al. 2002). Even among forest-dwelling species such as the northern spotted owl (*Strix occidentalis caurina*) that are closely associated with a single habitat type (i.e., old growth forest), landscape heterogeneity can promote fitness by increasing reproductive output (Franklin et al. 2000). Thus, if habitat heterogeneity does influence habitat selection by fishers at the intra-home range scale, areas used most intensively by fishers should have relatively high habitat diversity and heterogeneity.

We tested these two competing hypotheses of habitat selection with the goal of obtaining a more complete understanding of habitat requirements of fishers at intermediate scales. We delineated core and peripheral use areas within individual home ranges and evaluated support for a suite of resource selection models using a variety of habitat metrics that described forest composition and configuration. We conducted this work in north-central Idaho in the Northern Rockies fisher population, where the species has been petitioned multiple times to be listed by the United States Fish and Wildlife Service (USFWS) under the Endangered Species Act (USFWS 2004, USFWS 2011, Center for Biological Diversity et al. 2013). Petitioners have argued that habitat loss from logging and fires threatens the preferred habitat of fishers in the Rocky Mountains. The USFWS (2011) ruled that the Northern Rockies fisher population was a distinct population segment, eligible for listing, but that habitat loss and other threats were not of a magnitude to warrant listing at that time. Our results advance the understanding of habitat selection by fishers at intermediate spatial scales and can facilitate integration of their habitat needs into forest plans by providing information at scales that are relevant to forest management.

STUDY AREA

Our study was conducted in the Clearwater Mountains of north-central Idaho, USA (46.425° N, -115.646° W). The study area included portions of the Clearwater and St. Joe National Forests, as well as industrial forest lands owned by Potlatch Timber Corporation and Hancock Timber Resource Group. The area is generally mountainous, with few areas of very steep, rugged terrain and few open valleys and meadows. Elevation ranges from 1,000 to 1,850 m, and annual precipitation ranges from 1060 to 1740 mm (Natural Resource 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 tree 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 (*Pseudotsuga 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 changed over time. In general, private and state owned forested lands have been managed consistently for fiscal return from timber production, with a secondary, but minor emphasis on providing forage for livestock grazing. On federally managed forests, with a mandate to manage for multiple uses, emphasis has transitioned from a larger to smaller focus on timber production with increased emphasis placed on wildlife habitat, recreation, and other land uses. In addition, fire management on these lands has changed from consistent aggressive suppression to more frequent use of a “let burn” policy. 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.

METHODS

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; to maximize trapping success, live trapping was conducted in landscapes where fishers had previously been documented to be present using non-invasive hair snaring techniques (N. Albrecht, Coeur d’Alene Indian Tribe, unpublished data). When setting up a trapping grid, we attempted to place traps in likely habitat within every square mile along roads and trails. Trapping typically 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 0.6mm 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, sagittal 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 <120g and were less than 5% of the average weight of female fishers in our study area. The transmitters were programmed to cycle through three hour periods “on” followed by three hours “off” for 24 hours and then remain off for 48 hours, 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).

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 163m and 353m, respectively (Sauder et al. 2012). We used only one location from each three hour “on” block for each animal in our analyses to reduce 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 point 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 restricted our analysis to animals that were tracked for ≥ 4 months, a threshold that we identified to minimize bias in home range analyses (Sauder and Rachlow 2014).

Habitat resource layers (canopy cover and canopy height) from the LANDFIRE dataset (2006) 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 tassal-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 hectare to reduce the influence of image speckle on landscape metrics. We collapsed the number of categories in the LANDFIRE dataset 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, 0-4.9m, 5-9.9m, 10-24.9m, and 25-50m; we assumed that trees in the 25-50m canopy height category represented mature forest from a fisher’s perspective.

To identify areas that fishers regularly and repeatedly used, we delineated core and peripheral use areas within home ranges. Core use areas have traditionally been defined by the 50% density isopleth from kernel density estimates (Laver and Kelly 2008). However, this arbitrary choice

is problematic because it defines a core area even if one does not actually exist, and the method is not based on animal space-use patterns or biological justification (Powell 2000). Instead, we used the methods of Wilson et al. (2010) to identify an optimal isopleth that split home ranges into core and peripheral use areas within which the pattern of telemetry points were homogenous. To characterize habitat within the core and peripheral areas, we generated 50 random points within both use zones delineated for each individual. Using this approach instead of raw telemetry locations prevented points potentially used for finer scale attributes (e.g., a snag with a cavity, a scavenged carcass, etc.) from biasing our evaluation of habitat selection at the intra-home range scale.

We buffered the points in the core and peripheral use areas by 1000m and calculated habitat metrics for our models of habitat selection. We tested for differences in habitat configuration and composition between core and peripheral use areas using a mixed-effect logistic regression. We drew from key findings from previously published work on habitat selection by fishers and general principles of landscape ecology to develop models relating to our two competing hypotheses about how fishers use habitats at the intra-home range scale (i.e., concentrated use of mature forest versus heterogeneous habitats). We focused on models and habitat metrics that are relevant to forest management (Table 1). We used FRAGSTATS 4.2 (McGarigal et al. 2012) to calculate habitat metrics. We required cells have adjoining 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).

We calculated 2 categories of habitat metrics: class and landscape. Class level metrics represent habitat composition and configuration relative to each cover type. Thus, in the context of our hypotheses, if fishers selected for mature forest characteristics at intermediate scales, metrics that described the abundance and configuration of mature or high canopy cover forest should be highly supported. Alternatively, metrics calculated at the landscape level (i.e., across all habitat class types) generally represent the overall diversity and heterogeneity of the landscape (McGarigal et al. 2001). If fishers are selecting core use areas based on the availability of a diverse array of forest conditions, metrics like edge density and cohesion calculated at a landscape level should be highly supported.

Using 2 habitat resource layers and 6 habitat metrics, we built a suite of *a priori* univariate models ($n = 15$) of habitat selection (Table 1). We combined the most supported univariate models to build a small suite of ecologically plausible bivariate models ($n = 5$). Due to our modest sample size, we did not combine models further. We screened for metrics with high collinearity (Pearson’s

correlation coefficient ≥ 0.60) and used Akaike's information criterion corrected for small sample sizes (AIC_c) and Akaike's weights (w_i) to evaluate support for our *a priori* models of habitat selection (Burnham and Anderson 2002). Evaluation of model residuals indicated that a quadratic term was required for some variables, so we incorporated these transformations *post hoc*. We evaluated the fit of our best supported models using the area under the curve (AUC) of a receiver operating characteristic curve plot. Using a threshold criterion that maximized the sum of model specificity and sensitivity (Freeman and Moisen 2008), we calculated the amount of preferred habitat within core and peripheral use areas for each fisher. All analyses were performed in Program R (R Core Development Team 2005).

RESULTS

We collared and tracked 18 fishers (9 males, 9 females) for ≥ 4 months, with an average of 135 locations per animal ($SD = 92$). The optimal isopleth analysis indicated that 15 of the 18 animals showed strong evidence of core use areas within their home ranges with the optimal isopleth for delineating core versus peripheral use areas ranging widely. For males, the optimal isopleth ranged from 51 to 71% (mean = 60%, $SD = 6.5$), and for females, it ranged from 38 to 61% (mean = 52%, $SD = 7.0$). We detected no correlation between the number of telemetry points and the optimal isopleth ($r = -0.06$), however, 3 individuals (2 males and 1 female) with < 60 telemetry points did not exhibit well-defined core use areas, and we excluded them from the analyses of habitat selection. For 2 of the 15 animals with well-defined core areas, it was necessary to use 2 isopleths to divide the telemetry locations into three homogeneous, spatially random, point processes. For these individuals, we pooled the outer two zones together because our interest was in exploring habitat differences between the zone with the greatest amount of use with the remainder of the home range.

The average size of core use areas for male and female fishers was 27.5km^2 ($SD = 9.9\text{km}^2$) and 18.6km^2 ($SD = 21.0\text{km}^2$), respectively (Table 1). Likewise, peripheral use areas averaged 82.8km^2 ($SD = 26.9\text{km}^2$) and 51.4km^2 ($SD = 31.4\text{km}^2$) for males and females, respectively. Female fishers showed moderately strong correlation between the sizes of peripheral use and core use areas ($r = 0.68$), while males did not ($r < 0.01$), suggesting that different criteria influence size of core use areas between the sexes. Fishers with adjacent home ranges showed moderate to low levels of overlap within sexes. Overall, female pairs with adjoining ranges ($n = 4$) overlapped on average 21.3% ($SD = 14.0\%$) of their home range area, while overlap between core use areas ($n = 2$) was 8.1% ($SD = 7.0\%$).

For pairs of males ($n = 8$), average home range overlap was 15.3% (SD = 10.5%), while overlap between core use areas ($n = 3$) was 3.3% (SD = 3.5%).

We modeled differences in habitat between core and peripheral use zones of fisher home ranges using metrics that characterized both forest composition and configuration. Overall, models describing fine-scale habitat heterogeneity and diversity had considerably more support than models describing the abundance or configuration of mature or open areas. Our best supported model included selection for intermediate abundance of high canopy cover areas and intermediate landscape edge densities (Tables 2 & 3). This model had the lowest AIC_c and 86% of the Akaike weight. The second best supported model, which rounds out the 95% confidence set, included selection for intermediate abundances of high canopy cover areas and intermediate abundances of mature forest edge density. This model had a ΔAIC_c of 3.6 and 13% of the Akaike weight, making it 6.05 times less likely to be the best performing model. All other models were not well supported with $\Delta AIC_c > 10$ and Akaike weights < 0.01 . For our best performing model, the AUC was 0.68, indicating a moderate ability to discriminate differences in habitat between core and peripheral use areas of fisher home ranges.

Intensity of use within home ranges of fishers was associated with heterogeneous habitats. Overall, core use areas were composed of 16.6% (SD = 15.2%) high canopy cover forest, and averaged 73.7m/ha (SD = 23.7m/ha) of landscape edge. Generally, landscape pattern within male and female fisher home ranges was similar (Table 1). Overall, these two habitat variables were more variable within peripheral use zones than core areas, reflecting selection for intermediate abundances of high canopy cover areas and landscape edge densities in core use areas. Using a threshold criterion that maximized the sum of specificity and sensitivity of our best model for habitat selection for core areas (0.498), we estimated that, on average, 77% of fisher core use areas were composed of habitat with fine-scale heterogeneity (i.e., intermediate abundances of high canopy forest and landscape edge density), while an average of 59% of the peripheral use areas were composed of such habitats. These percentages of heterogeneous habitats differed significantly between core and peripheral areas (paired t-test, $p = 0.03$, $t = 2.403$, d.f. = 14), which supports the hypothesis that fishers selected more strongly for forest heterogeneity than mature forest structure at intermediate spatial scales.

DISCUSSION

Our study provided a quantitative assessment of resource selection by fishers at a poorly understood, intermediate scale. Although mature forest structure appears to strongly influence habitat selection by fishers at both landscape and micro-site scales, core use areas within fisher home ranges were consistently composed of moderate amounts of both high canopy cover forest and moderate landscape edge density. These results support the hypothesis that fine-scale habitat heterogeneity and diversity are important to fishers at the intra-home range scale. Because decisions about forest management occur most often at intermediate spatial scales, these results can help guide forest management aimed at promoting persistence of fishers within managed forest landscapes.

The optimal isopleth for core area delineation in our study varied substantially among fishers, ranging from 38 to 71%, suggesting that some individuals concentrated use within their home range, while others used resources spread across larger areas. This variability would not have been detected using the traditional rule of thumb of the 50% isopleth to delineate core use areas. This illustrates the importance of using objective methods for estimating core use areas (Wilson et al. 2010, Fieberg and Borger 2012). While it was beyond the scope of our work to identify the reasons for this variability, differences in prey densities, habitat quality, or social structure could influence patterns of space use within home ranges. However, we did detect moderate correlation between the size of core use and peripheral use zones for female fishers but not for males, which suggests that different factors influence choices about how the sexes use habitats within their home ranges. This is not unexpected given the marked differences in reproductive strategies and body size between the sexes (Powell and Zielinski 1994).

Although it has long been recognized that high canopy cover forests are important to fishers across multiple scales of habitat selection (Jones and Garton 1994, Powell and Zielinski 1994, Proulx et al. 2004, Lofroth et al. 2011, Raley et al. 2012), at intermediate scales, our research suggests that habitat heterogeneity is an important structural characteristic. Habitat selection by fishers at intermediate scales has been sparsely reported in the literature. Most studies have focused on resource selection at fine spatial scales, documenting selection of resting sites, or at broad spatial scales, examining selection at landscape or larger scales (Lofroth et al. 2011). Aubry et al. (2013) reported consistent and strong selection for high canopy cover at rest sites across multiple populations of fishers throughout western North America. Even within forested stands that had high canopy cover, individual rest trees selected by fishers in California had higher canopy cover than

surrounding areas (Zielinski et al. 2004). At a regional extent, a linear relationship has been suggested between the probability of occurrence and high canopy cover (Carroll et al. 1999, Zielinski et al. 2010). However, between these 2 extremes, at intermediate spatial scales, our results indicated that fishers more intensively used areas of moderate abundance of high canopy cover. These results are consistent with those of Weir and Harestad (2003), who reported that fishers selected for moderate values of most forest structural attributes at the intra-home range scale. In that study in central British Columbia, fishers preferentially used forested stands with conifer canopy closure between 21% and 60%. The authors also reported that fishers selected patches within high canopy cover stands that were relatively low in canopy cover, preferring patches with 41-60% canopy cover.

Our results indicated that edge density, measured at the landscape level (i.e., any edge formed by 2 habitat types being adjacent to each other) also is important to fishers when selecting habitats to use within their home ranges. Core use areas tended to be composed of a moderate amount of landscape edge, while locations with lower or higher densities of habitat edge occurred more often in peripheral use areas. Landscape edge density has not been previously reported as influencing habitat selection by fishers, but this may be due to previous studies focusing primarily on metrics of forest composition and not configuration. Yet, Sauder and Rachlow (2014) reported that mature forest arranged in larger, more contiguous patches strongly influenced habitat use by fishers at the landscape level. Landscape edge density was well supported in our best model and was 6 times more plausible in explaining fisher habitat selection than mature forest edge density. Although edge density at the individual class level (e.g., mature forest, open areas, etc.) is generally considered to be a measure of fragmentation, edge density at the landscape represents fine-scale habitat heterogeneity and configuration (McGarigal et al. 2001). Landscape edge density is low when a landscape is comprised of large and/or regular, compactly shaped patches and increases with decreasing mean patch size and as patch shape becomes more irregular. In our study, fishers appeared to use areas with greater heterogeneity more intensively within their home ranges.

Our analysis of habitat selection did not support the hypothesis that composition or configuration of mature forest or open areas influenced habitat selection by fishers at the intra-home range scale. We believe that this is due to the hierarchical nature of habitat selection (Johnson 1980, Meyer and Thuiller 2006, DeCesare et al. 2012). Selection at the intra-home range scale is influenced by prior choices made at larger scales (i.e., the landscape). We previously documented that mature forest arranged in larger, more contiguous patches and low abundance of open forest

were the best predictors of habitat selection by fishers at the landscape level in our study area (Sauder and Rachlow 2014). For the fishers collared in this study, the median home range was comprised of abundant mature forest (55.8%) with few open areas (5.4%; Sauder and Rachlow 2014), so it is not surprising that we did not detect selection for these variables at the intra-home range scale because they had been previously selected for and against, respectively, at a broader spatial scale.

Early research hypothesized that fishers in western North America might require old-growth conifer forests for survival (Buskirk and Powell 1994). However, recent research suggests fishers are more appropriately considered to be associated with late-seral forest characteristics (Raley et al. 2012), but are not old growth obligates. Our results are consistent with this current understanding. Although selection for characteristics of late-seral forests (i.e., large trees, complex vertical and horizontal structure) at fine and broad scales is well documented (Raley et al. 2012), at intermediate scales, fishers in our study area appeared to use a wider array of forest types and configurations. The potential reasons for this are manifold. Weir and Harestad (2003) hypothesized that selection for moderate forest structural attributes might strike a balance between the competing needs of fishers. Canopy cover is thought to provide security from potential predators like coyotes (*Canis latrans*) and bobcats (*Lynx rufus*) as well as thermal refugia (Raley et al. 2012). Additionally, fishers avoid areas with soft snow during winter (Leonard 1981, Raine 1981), and canopy cover promotes snowpack consolidation, permitting more efficient locomotion. However, very dense forest potentially can hinder hunting success or might not support high prey 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). 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 saplings and medium sized trees support relatively high densities of hares (Lewis et al. 2011). Jones and Garton (1994) reported that fishers in Idaho used sapling and young forests for hunting, 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 individuals might travel and hunt at least occasionally in young, non-forested or sparsely forested habitats where those species typically occur. Core areas of fisher home ranges had higher fine-scale habitat heterogeneity than peripheral use areas, which potentially facilitates access to rest sites, protection from predators, higher prey densities, and efficient travel. We hypothesize that future investigations of habitat selection will support the contention that fishers select for a diverse array of

habitats at intermediate scales, and that selection for late-seral forest characteristics will be weaker at this scale than at broad or fine spatial scales.

MANAGEMENT IMPLICATIONS

Our results contribute to a broader understanding of how fishers respond to forest composition and structure at intermediate spatial scales (i.e., within home ranges), and they highlight the need for understanding habitat requirements across multiple scales. Selection for increased fine-scale heterogeneity at the intra-home range scale versus highly abundant or contiguous mature forest suggests that some disturbances that promote fine-scale heterogeneity are valuable. Windthrow, forest diseases or pest infestations, and wildfires that form landscape mosaics are all natural mechanisms that promote fine-scale heterogeneity and potentially benefit fishers when they occur at appropriate frequencies and extents. Some forest management activities that create edge and heterogeneity in stands of high canopy cover forest also might be beneficial or at least tolerated by fishers. However, a better understanding of what types of management actions, their scope, and arrangement within a landscape is needed. Future studies using GPS telemetry with finer temporal and spatial resolution should be conducted to address questions about responses of fishers to changes in forest habitats associated with anthropogenic factors. Long-term persistence of fishers will require such information to develop management strategies that meet both timber harvest and conservation objectives.

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Table 3.1. Average (\pm SD) size and habitat composition of fisher home ranges in north-central Idaho by sex and use zone.

	Males		Females	
	Core	Peripheral	Core	Peripheral
Average size	27.5km ² (9.9 km ²)	82.8 km ² (26.9 km ²)	18.6km ² (21.0 km ²)	51.4 km ² (31.4 km ²)
Average percent composed of high-canopy cover forest	15.9% (15.2%)	26.1% (22.9%)	17.1% (15.8%)	20.1 (21.3%)
Average amount of landscape edge	76.4m/ha (23.8m/ha)	68.5m/ha (29.0m/ha)	71.7m/ha (24.0m/ha)	68.5m/ha (28.6m/ha)

Table 3.2. *A priori* suite of candidate models evaluated to explain habitat selection within home ranges by fishers in north-central Idaho. Superscripts denote those variables requiring a quadratic term.

Model	The probability of a location being within the core use area of the home range is related to the ...	FragStats Metric
Univariate models		
1	abundance of high canopy cover forest ¹	PLAND
2	abundance of mature trees ¹	PLAND
3	abundance of open areas ¹	PLAND
4	density of high canopy cover forest edges ¹	ED
5	density of mature forest edges ¹	ED
6	density of edges across all class types ¹	ED
7	average size of high canopy cover forest patches	AREA_MN
8	average size of mature forest patches	AREA_MN
9	average size of open patches	AREA_MN
10	average size of patches across all class types	AREA_MN
11	connectedness of high canopy cover patches	PROX
12	connectedness of mature forest patches	PROX
13	degree to which high canopy cover forest is clumped or dispersed	CLUMPY
14	degree to which mature forest is clumped or dispersed	CLUMPY
15	degree to which all class types are clumped or dispersed	COHESION
Bivariate Models		
16	Models 1 and 6 combined	
17	Models 1 and 5 combined	
18	Models 1 and 2 combined	
19	Models 2 and 6 combined	
20	Models 2 and 5 combined	

Table 3.3. Ninety-five percent confidence set of models that explained habitat selection by fishers at the intra-home range 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). Superscripts denote those variables requiring a quadratic term.

Model #	Model Parameters	AIC_c	ΔAIC_c	w_i
16	Abundance of high canopy cover forest ¹ Density of edges across all class types ¹	1936.2	0.0	0.86
17	Abundance of high canopy cover forest ¹ Density of mature forest edge ¹	1939.8	3.6	0.13

Table 3.4. Habitat variables that comprised the best supported model (Model 16) of habitat selection within the home range by fishers in north-central Idaho, USA. This model had 86% of the AIC_c weight and was 6 times as likely as the next best performing model.

	Coefficient	SE	Z	P > Z	95% CI
Intercept	0.728	0.104	6.968	<0.0001	0.519 - 0.937
Density of edges from all patch types	0.141	0.062	2.277	0.0228	0.171 - 0.265
Density of edges from all patch types squared	-0.316	0.051	-6.196	<0.0001	-0.541 - -0.090
Abundance of high canopy cover forest	0.006	0.081	0.073	0.9415	-0.155 - 0.167
Abundance of high canopy cover forest squared	-0.479	0.070	6.863	<0.0001	-0.618 - -0.339

Chapter 4: Integrating habitat selection information across scales: mapping habitat for fishers (*Pekania pennanti*) across the Rocky Mountains of Idaho and Montana

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Abstract

Understanding the habitat requirements of wildlife is a key step towards identifying conservation priorities, threats, and opportunities. Because wildlife species select and interact with habitats across a wide range of spatiotemporal scales, enacting effective conservation requires integrating information about how species use habitats across scales. The fisher (*Pekania pennanti*) is a wide-ranging mesocarnivore that occurs at low population densities, uses large tracts of forested land, and is of conservation concern in Idaho and Montana. We combined 3 previously published, single-scale models of habitat selection by fishers using 2 different methods (ranked-boolean overlay and multiplication) to create an integrated multi-scale model of potential fisher habitat in the Rocky Mountains of Idaho and Montana. The integrated multi-scale models improved predictive accuracy of fisher occurrences relative to the most detailed single-scale model available. Using the best performing multi-scale model, we identified 3.5 million ha of probable habitat for fishers, with almost 80% occurring on 9 national forests across the Rocky Mountains of Idaho and Montana. However, only 28% of the probable habitat occurred within wilderness or roadless areas, suggesting that these areas alone will not be sufficient to ensure the persistence of fishers in Idaho and Montana and that policy and management decisions made on national forest lands managed under a multiple-use philosophy will be critical to the persistence of fishers in this region.

Introduction

Mapping the distribution of species and their habitats is a key step in identifying conservation opportunities, threats, and priorities. The ability of wildlife biologists and land

managers to enact effective conservation of species is facilitated by current and accurate maps of their habitats. Because animals select and interact with habitats across a wide range of spatial and temporal scales (Kie et al. 2002, Graf et al. 2005, Boyce 2006), maps with the highest predictive accuracy often incorporate information about how species use habitats across a range of scales (Meyer and Thuiller 2006). Indeed, habitat selection is generally considered a hierarchical process in which selection at finer scales is dependent on availability of and selection for resources at broader scales (Johnson 1980, Meyer and Thuiller 2006, DeCesare et al. 2012).

Yet, exactly how land managers should synthesize information about wildlife habitat relationships across scales to produce predictive habitat models and maps is uncertain. DeCesare et al. (2012) encouraged hierarchically nested sampling and analysis of use-availability data as a means of integrating wildlife-habitat relationships across differing scales. This solution explicitly addresses the conditional nature of probabilities of occurrence across scales; however, it requires sophisticated modeling that may not be feasible for some datasets or species. In addition, such an approach is not conducive to retrospective synthesis of existing datasets that have been collected using varying protocols, techniques, or study designs. One alternative approach employed by Johnson et al. (2004) is to multiply the relative probabilities of occurrence from separate, single-scale models of resource selection to produce a multi-scale map of relative probability. This “product map” essentially weights the relative probability of occurrence at fine scales by the probabilities of occurrence at broader scales. Boolean overlay techniques represent another approach to combining datasets, and although they have been used widely to evaluate biodiversity and identify priority conservation areas (Scott et al. 1993), they have not been used to our knowledge to build multi-scale habitat models.

The fisher (*Pekania pennanti*) is a North American mesocarnivore that occurs at low population densities and is generally associated with late-seral forest characteristics (Raley et al. 2012). Fishers live in both eastern and western forests in the United States, but population trends differ markedly between these regions (Gibilisco 1994). The population of fishers in north-central Idaho and western Montana has been petitioned multiple times for listing by the United States Fish and Wildlife Service (USFWS) under the Endangered Species Act (ESA; USFWS 1996, USFWS 2011). Petitioners have argued that habitat loss from logging and fires threatens the preferred habitat of fishers in this region. In 2011, the USFWS ruled that this fisher population qualified as a distinct population segment (DPS) due to its discreteness (i.e., marked separation from other fisher populations) and genetic significance (Vinkey et al. 2006), and thus was eligible for ESA listing. However, the USFWS review concluded that habitat loss and other threats were not of a magnitude

to warrant listing at that time. Recently, fishers in Idaho and Montana have been petitioned again for ESA listing (Center for Biological Diversity et al. 2013).

Several recently published studies have examined habitat selection by fishers at varying scales in Idaho and Montana. At the broadest extent (i.e., distribution scale), Olson et al. (2014) reported a variety of climate and vegetation characteristics that shaped the distribution of fishers in this region. Habitat parameters that contributed most strongly were the abundance of tall trees, riparian areas, moderate topographic relief (i.e., valley bottoms), and intermediate mean annual precipitation. At the landscape scale, mature forest arranged in larger, more contiguous patches, with less open area strongly influenced where fishers located their home ranges (Sauder and Rachlow 2014). At finer scales (i.e., within home ranges or at specific sites), fine-scale habitat heterogeneity (Sauder, ch.3) and large trees increased the probability that fishers used habitats, while dryer forest types (i.e., ponderosa pine, *Pinus ponderosa*) and those species that typically have small diameters (i.e., lodgepole pine, *Pinus contorta*) decreased the probability of use (Schwartz et al. 2013). Each of these studies provides important information that increases our understanding of how fishers select and use forested habitats. However, while Schwartz et al. (2013) and Olson et al. (2014) evaluated a few variables at more than one scale, overall these studies have primarily focused on single scales of habitat selection. This means they can only yield habitat predictions that are specific to a single spatial scale (Turner et al. 1989).

We combined single-scale models of habitat selection by fishers to create a comprehensive representation of potential habitat for this species in the Rocky Mountains of Idaho and Montana, and we tested whether an integrated, multi-scale model improved accuracy of predicted fisher occurrence relative to the most detailed single-scale model (Olson full model; Olson et al. 2014). We used 2 different techniques to combine models, and an independent dataset of fisher locations to evaluate and contrast performance of both multi-scale models. Finally, we assessed the abundance and distribution of predicted fisher habitat across the region to facilitate forest management planning. Our results advance understanding of habitat selection by fishers and provide increased information for forest managers to integrate the habitat requirements of fishers into forest management plans.

Methods

Single-scale models of habitat selection

Using a Maxent approach (Phillips et al. 2006, Phillips and Dudík 2008), Olson et al. (2014) evaluated the distribution of fishers across the Rocky Mountains of north-central Idaho and western Montana (Figure 1). For model training locations, they used 222 sites where fishers had been detected using non-invasive hair-snaring techniques, and they validated their models using an additional 104 independent sites. They produced 2 models: a climate-only distribution model that used only abiotic environmental variables and a full model that used both climate and vegetation variables. Six environmental variables were used in the climate-only model; 5 environmental and 13 vegetation variables were included in the full model (Table 1). Model performance was evaluated using the area under the curve (AUC) of a receiver operating characteristic (ROC) curve (Pearce and Ferrier 2000); reported values were 0.84 and 0.87 for the climate-only and full models, respectively (Olson et al. 2014). For our multi-scale modeling, we used the climate-only model to avoid high correlations of vegetation variables among different scales. However, we provide comparisons between their full model, which is the most detailed single-scale model available, and our multi-scale models.

At the landscape scale, habitat selection was evaluated using data from fishers fitted with Argos telemetry collars in north-central Idaho (Sauder and Rachlow 2014). That study used a case-control logistic regression framework to compare the composition and configuration of habitats within fisher home ranges to those available across the landscape. At this scale, low abundance of open areas and large patches of mature forest arranged in connected, complex shapes best modeled how fishers selected habitats. The AUC for the best-supported landscape model was 0.86 (Sauder and Rachlow 2014).

The same Argos telemetry data were used to evaluate habitat selection by fishers within their home ranges in north-central Idaho (Sauder, ch. 3). In that study, an optimal isopleth analysis (Wilson et al. 2010) was used to identify core and peripheral use areas within fisher home ranges, and a suite of *a priori* models were evaluated to explore how forest composition and configuration might influence habitat selection of core areas. Fine-scale habitat heterogeneity, as measured by intermediate amounts of both landscape edge and high canopy cover forest, influenced selection of core use areas with moderate predictive power (the AUC for the best-supported model was 0.68; Sauder, ch. 3).

Model integration and predictive ability

We used 2 methods to combine the 3 single-scale models of fisher habitat selection into a multi-scale model. First, we used a rankedboolean approach. We generated maps of the relative probability of fisher occurrence using the statistical habitat model for each scale of habitat selection. These relative probabilities of occurrence are proportional to actual probabilities (Boyce et al. 2002) and assumed to be related to habitat quality (Boyce and McDonald 1999), although that assumption is rarely tested. We identified a consistent threshold criterion to divide the scale-specific maps into “probable” and “not probable” fisher habitat. Appropriate methodologies for identifying thresholds depend on the application and the original data (Freeman and Moisen 2008). We chose to apply a user-specified level of model specificity. This approach involves calculating the highest model sensitivity (i.e., correctly predicting presence) possible while requiring model specificity (i.e., correctly predicting absence) to meet a user-specified level. For example, the user can specify that the probability of misidentifying non-habitat as habitat be $\leq 20\%$ (Freeman and Moisen 2008). Because the conservation consequences are potentially high for incorrectly predicting suitable habitat to be present when it is not, this method is particularly appropriate when predicting the availability of habitat for rare or threatened species (Freeman and Moisen 2008). We chose to use a minimum model specificity of 80%, meaning that the probability of incorrectly predicting fisher habitat to be present when it was not was $\leq 20\%$. Setting the threshold higher increases the probability that some areas that are actually used by fishers would be excluded. We believe that this threshold is a reasonable balance between model sensitivity and specificity for regional-level forest management applications.

Applying this threshold to the relative probability maps produced 3 boolean maps of probable fisher habitat based on each scale of habitat selection. We combined these maps and assigned a habitat quality ranking with 8 possible outcomes using 2 criteria: 1) the number of single-scale models indicating that fisher habitat was present, and 2) the predictive strength of the original models (as measured by AUC). For example, areas where all 3 models indicated that probable fisher habitat was present would receive the highest rank (i.e., 8), and areas where only the weakest model (i.e., the intra-home range scale model) predicted probable fisher habitat to be present would receive a habitat rank of 2. Those areas where all 3 models indicated that fisher habitat was not probable received the lowest ranking (i.e., 1).

The second method of combining the single-scale habitat models into a comprehensive model used the relative probabilities generated from each individual model and combined them

mathematically. We multiplied the relative probabilities of the original maps (*sensu* Johnson et al. 2004), producing a combined probability map (hereafter called the product model).

To evaluate the predictive capacity of both multi-scale models and the Olson full model, we used an independent dataset of fisher locations ($n = 146$; N. Albrecht, Coeur d'Alene Indian Tribe, unpublished data) collected across north-central Idaho and western Montana. We calculated the number of locations within each of 8 habitat quality ranks for the boolean multi-scale model (Boyce et al. 2002, Johnson and Gillingham 2005). For the product and full Olson models, we created similar habitat quality ranks by dividing the relative probability maps into 8 bins. We used the geometric interval function in ArcGIS 10.1 (ESRI 2012) to create the bins, tallied the frequency of fisher locations from the independent dataset in each bin, and normalized the number of fisher locations by bin area. This results in a measure of the density of validation locations, controlled for variation in the predicted area among habitat ranks (Johnson and Gillingham 2005). Models with greater predictive accuracy are expected to have a greater number of validation locations in higher-quality habitats (i.e., rank 8). We also calculated Spearman rank correlation coefficients between the 8 habitat classes and the area normalized occurrence of fisher locations for each model as recommended by Boyce et al. (2002). Additionally, we generated 146 random locations across north-central Idaho and western Montana that represented available habitat, and we used these with the independent validation set of fisher locations to calculate an AUC to evaluate model performance for the product and full Olson models. Finally, we used the Kappa statistic to evaluate classification agreement between our models; the Kappa statistic evaluates model agreement while adjusting for the degree of agreement expected by chance alone (Boyce et al. 2002).

Distribution and abundance of fisher habitat

To facilitate interpretation of the abundance and distribution of fisher habitat across the Rocky Mountains of Idaho and Montana, we applied two criteria to our best performing multi-scale model. First, as described for the single-scale models, we calculated the threshold at which the probability of incorrectly predicting fisher habitat to be present was $\leq 20\%$, and we eliminated those areas from further consideration. The remaining area was considered to be probable fisher habitat. To identify where the best fisher habitat occurred, we calculated a second threshold at which the probability of incorrectly predicting fisher habitat to be present was $\leq 5\%$. We consider areas above this threshold to be high-quality predicted habitat.

Results

Combining information about habitat selection by fishers across multiple scales markedly improved the predictive capacity of the model relative to even the most detailed single-scale model. Both multi-scale models (i.e., rankedboolean and product models) had greater predictive accuracy than the full model of Olson et al. (2014) across all habitat quality ranks, more so at moderate to high ranks (Figure 2). Spearman rank correlations were consistently large and similar across all 3 models ($r_s > 0.95$, $p < 0.01$), indicating strong correlation between the relative probability of fisher occurrence and habitat ranks for all models. The AUC for the multi-scale product model and single-scale full Olson models were similar (0.89 and 0.90, respectively). However, the Kappa statistic between the models was low, 0.20, which infers only fair agreement. Partial Kappa statistics were higher between the models for both poor quality habitats (i.e., rank 1, 0.26) and good quality habitats (i.e., rank 8, 0.49), indicating that the models were in better agreement about where the worst and best habitats were predicted to occur. In general, the product model predicted more contiguous and abundant fisher habitat in Idaho than the full Olson model (Figure 3). However, the full Olson model predicted more habitat across western Montana, although it was generally in disjunct and isolated patches.

The ranked-boolean model performed similarly to the product model across a wide range of habitat ranks, but had a lower predictive accuracy at the highest habitat quality rank (i.e., 8, Figure 2). Overall, the Kappa statistic was low, 0.29, between rankedboolean and product models. However, partial Kappa statistics were higher between the models for both poor habitats, (i.e., rank 1, 0.64) and good habitats (i.e., rank 8, 0.44). Overall, the ranked-boolean multi-scale model predicted a habitat pattern in between the product model and the full Olson model, with some dispersed habitat in Montana and more contiguous habitat in Idaho (Figure 3).

Because the multi-scale product model had the highest predictive accuracy, we used it to evaluate the abundance and distribution of predicted fisher habitat across various administrative and management boundaries (Table 2). Approximately 67% of the predicted fisher habitat occurs in Idaho, with 31% in Montana and the remainder in the extreme northeast corner of Washington. Most predicted fisher habitat is on federally owned lands (79%), but only 28% occurs in wilderness or roadless areas. Across Idaho and Montana, there are 9 national forests that contain $\geq 1\%$ of the predicted probable fisher habitat (Table 2); however, almost 40% of this area occurs within only 3 of those forests (i.e., Kootenai, Clearwater, and Nez Perce national forests). The predicted habitat that was higher in quality (i.e., those areas with $\leq 5\%$ probability of falsely predicting fisher habitat to be present when it is not) was widely dispersed across the region, with 5 national forests supporting

>10%. Based on our best multi-scale model, we estimated that there are approximately 3.5 million hectares of probable fisher habitat and 1.1 million hectares of high-quality habitat across north-central Idaho and Montana.

Discussion

Our research illustrated methods for and demonstrated the value of combining information about wildlife-habitat relationships across spatiotemporal scales to generate habitat maps for conservation purposes. The best multi-scale and single-scale models had similar AUCs (0.89 and 0.90, respectively), but using the AUC alone can be a misleading measure of model performance (Lobo et al. 2007). The multi-scale model predicted fisher occurrences more accurately across a wide range of habitat qualities than the single-scale model. As successful prediction is the most important consideration for evaluating resource selection models (Boyce et al. 2002), particularly for conservation planning, we conclude that the multi-scale product model provides a useful and improved tool to estimate of the abundance and distribution of fisher habitat across the Rocky Mountains of Idaho and Montana.

Because diverse spatiotemporal scales influence habitat selection by wildlife, integrating information across scales is important for effective conservation planning. Multi-scale models have been reported to be generally more predictive than models encompassing only single scales of habitat selection (Meyer and Thuiller 2006). The integrated, hierarchical modeling approach of DeCesare et al. (2012), while conceptually ideal and mathematically robust, may not be feasible for some datasets or for syntheses of previously published results. In our analysis, we took 3 previously published models of fisher habitat selection at single-scales and used 2 relatively simple techniques to integrate them. Both techniques (i.e., multiplicative product and ranked-boolean overlay) resulted in multi-scale habitat models that had increased predictive accuracy over the most comprehensive single-scale model. Multiplying the relative probabilities proved to have the highest predictive accuracy, and this approach has other desirable features, such as finer resolution habitat maps and application specific threshold criteria that can better facilitate setting of conservation priorities. Ultimately, the multi-scale product model that we produced can support management decisions based on predicted abundance and distribution of fisher habitat across the Rocky Mountains of Idaho and Montana.

We documented generally low classification agreement between our best performing multi-scale habitat model (i.e., the product model) and the most detailed single-scale model (i.e., the Olson

full model; Olson et al. 2014). A large proportion of the mismatch between the predictions of these models occurred in areas with moderate habitat quality ranks (i.e., ranks 2-7), particularly in western Montana. These mismatches were principally a result of integrating the landscape-scale selection model of Sauder and Rachlow (2014). That model identified abundant mature forest arranged in larger, more contiguous patches and sparse open areas across large landscapes as significant predictors of where fishers located their home ranges. In many areas of western Montana, the Olson full model predicted probable fisher habitat in disjunct and isolated patches (Figure 3b), however, such locations had lower probabilities of fisher occurrence in the multi-scale model because of fisher habitat selection patterns at the landscape scale. We recognize that the landscape and intra-home range selection models were based on a single telemetry dataset collected in north-central Idaho (Sauder and Rachlow 2014, Sauder, ch3), and consequently, it is possible that fishers in western Montana use and select forested habitats differently. Additional telemetry studies should be conducted to develop localized habitat selection information that could improve understanding of the abundance and quality of habitat for fishers in western Montana.

Although our multi-scale model of fisher habitat synthesized across 3 scales of selection, it did not incorporate information about site-specific habitat features that fishers select. Large log volume, cool microclimates, and large trees and snags with cavities for dens and rest sites are critically important to fishers (Weir et al. 2012, Aubry et al. 2013, Schwartz et al. 2013). Lack of, or variation in the abundance of, such features across a landscape will certainly influence the probability of fisher occurrence. However, because mapping such features across wide areas is exceedingly difficult, it is challenging to model how the abundance of these features influence fisher occurrence across large geographic areas. Nonetheless, because the multi-scale product model delivered the greatest predictive accuracy, we conclude that it provides the best available estimate of the abundance and distribution of fisher habitat in Idaho and Montana. Additional habitat use data from other areas and at finer spatial scales will be important to refine the model and ensure it represents how fishers across the entire region use forested habitats.

The distribution of the high-quality habitat largely reflects where fishers have been repeatedly detected via non-invasive hair snaring (N. Albrecht, unpublished data). One apparent anomaly, however, is in the Selkirk Mountains of the Kaniksu National Forest in northern Idaho (Figures 1 and 3). Although this area is predicted to have relatively abundant high-quality habitat, intensive hair-snaring efforts have resulted in few detections of fishers (M. Lucid, unpublished data). The Kootenai River Valley to the east of the Selkirk Mountains has been reported to act as a barrier

to dispersal by many wildlife species, including martens (*Martes americana*; Wasserman et al. 2010) and black bears (*Ursus americanus*; Schwartz et al. 2006). We suspect that this valley also acts as a barrier to movements of fishers, and that the near absence of fishers in the Selkirk Mountains might be due to low recolonization rates after widespread trapping extirpated fishers from most locations across Idaho in the early 1900s (Williams 1962, Vinkey et al. 2006).

Approximately two thirds of the probable fisher habitat we modeled occurs in Idaho, one third in Montana, and a trace amount in Washington. Furthermore, almost 80% of the probable habitat occurs on federally owned lands, principally national forest lands (Table 2). This distribution suggests that successful conservation of fisher habitat in the Rocky Mountains of Idaho and Montana will rely heavily on policy and management decisions made on national forest lands. In fact, almost two thirds of the predicted high-quality habitat for fishers occurs on 5 national forests (i.e., the Clearwater, Nez Perce, Coeur d'Alene, Kaniksu, and Kootenai). Incorporating the habitat requirements of fishers into the forest management plans for these 5 forests will be key for long-term conservation of fishers in this region. Overall, we estimated that there are approximately 3.5 million hectares of probable fisher habitat and 1.1 million hectares of high-quality habitat across north-central Idaho and Montana. Although these figures represent relatively large areas, taken in the context of the large forested landscapes that individual fishers require (male and female home ranges average 98.4km² and 49.3km², respectively; Sauder and Rachlow 2014), this does not constitute a surplus of habitat.

Sauder and Rachlow (2014) cautioned that roadless and wilderness areas should not be considered *de facto* high-quality habitat for fishers. The multi-scale product model supports this assertion. Less than one third of the probable fisher habitat and less than one quarter of the high-quality habitat we modeled occurs in wilderness or roadless areas (Table 2). A prime example of this is the eastern portions of the Nez Perce and Clearwater National Forests, where there are large expanses of roadless and wilderness areas, but probable fisher habitat is relatively uncommon. We stress that it is doubtful that the inherent management philosophy of wilderness and roadless itself (i.e., landscapes where natural processes operate freely) is at odds with the preferred habitat characteristics of fishers. More likely, it is the location of many wilderness and roadless areas that dictates the suitability of habitat for fishers. Areas designated as wilderness or roadless often receive such designations for reasons other than wildlife habitat quality and do not encompass a representative sample of all the habitats that wildlife species might need. Typically, wilderness and roadless areas in the northern Idaho and western Montana tend to be at higher elevations, a pattern

that has been noted across the coterminous United States (Scott et al. 2001). Landscapes at higher elevations often have less dense canopy cover, smaller trees, more snow, and more abundant open areas, all characteristics that are not conducive to fisher occurrence (Raley et al. 2012). Overall, our results support the contention that wilderness and roadless areas alone are unlikely to provide sufficient habitat to ensure the persistence of fishers in Idaho and Montana. Finally, we conclude that continuing to refine and improve our understanding of the distribution and abundance of fisher habitat is critical to developing forest plans and proposing habitat management actions that accommodate the habitat requirements of fishers.

Acknowledgements

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Table 4.1. Variables used in the full and climate-only models of Olson et al. (2014) predicting fisher habitat in northern Idaho and western Montana, USA. Vegetation variables describe the proportion of a 900m radius neighborhood composed of that vegetation type. Environmental variables were also calculated at a 900m radius neighborhood.

Variable	Percent contribution to full model	Percent contribution to climate-only model
Canopy height (25-50m)	19.7	
Montane riparian	16.3	
Topographic position index at 2000m scale	14.7	21.2
Mean annual precipitation	13.3	28.9
Mean temperature in coldest month	6.3	32.8
Canopy height (0-10m)	4.8	
Gross primary productivity	4.4	
Spruce/fir and lodgepole	4.2	
Annual potential solar radiation	2.9	3.9
Wetness	2.7	
Slope	2.3	12.9
Canopy cover (10-30%)	1.8	
Brightness	1.7	
Dry-mesic mixed conifer	1.1	
Canopy height (10-25m)	1.1	
Normalized Difference Vegetation Index	1.0	
Variation in canopy cover	1.0	
Variation in canopy height	0.6	
Persistent snow		0.4

Table 4.2. Abundance (%) and distribution of probable and predicted high-quality fisher habitat across Idaho and Montana, by ownership, and within the boundaries of 9 national forests that are located in the region.

	Probable Habitat	High-Quality Habitat
Total hectares:	3,556,688	1,084,093
States:		
Idaho	67.3	80.2
Montana	30.6	15.8
Washington	2.01	4.0
Land Ownership:		
State/Private	21.1	20.0
Federal	78.9	80.0
Wilderness/Roadless	27.8	22.6
National Forests:		
Kootenai	14.0	11.0
Bitterroot	0.6	-
Flathead	3.5	0.4
Nez Perce	10.4	11.6
Clearwater	12.3	14.7
St Joe	7.5	8.3
Coeur d'Alene	8.2	16.1
Kaniksu	7.6	11.4
Lolo	7.2	2.9

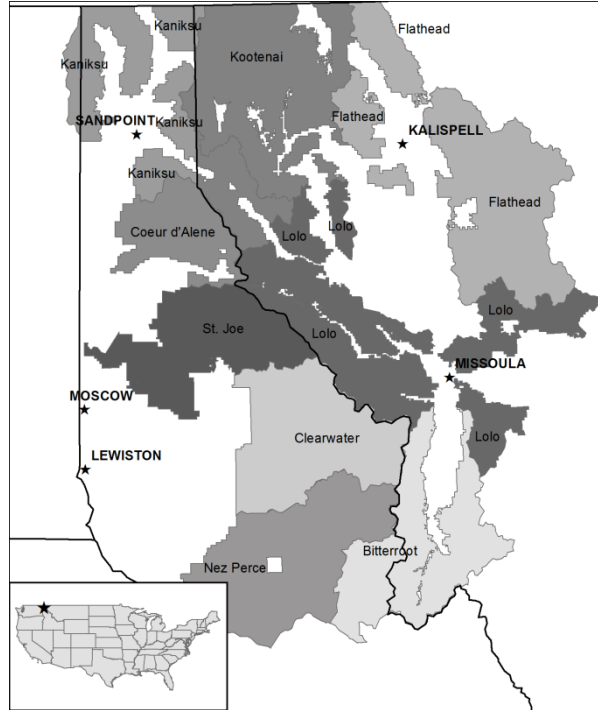


Figure 4.1. Boundaries for USDA national forests in northern Idaho and western Montana, USA, that have probable and predicted high-quality habitat for fishers. Predicted areas described in Table 4.2.

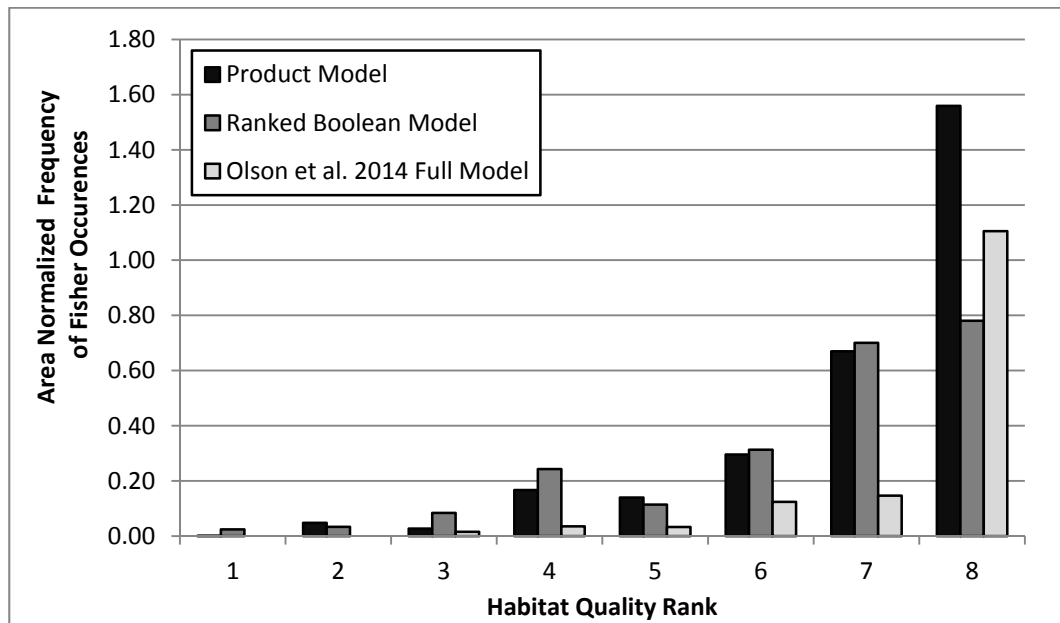


Figure 4.2. Predictive accuracy of 2 multi-scale models (product and ranked-boolean models) and 1 single-scale model (Olson full model) of fisher occurrences in Idaho and Montana, USA, across 8 habitat quality ranks.

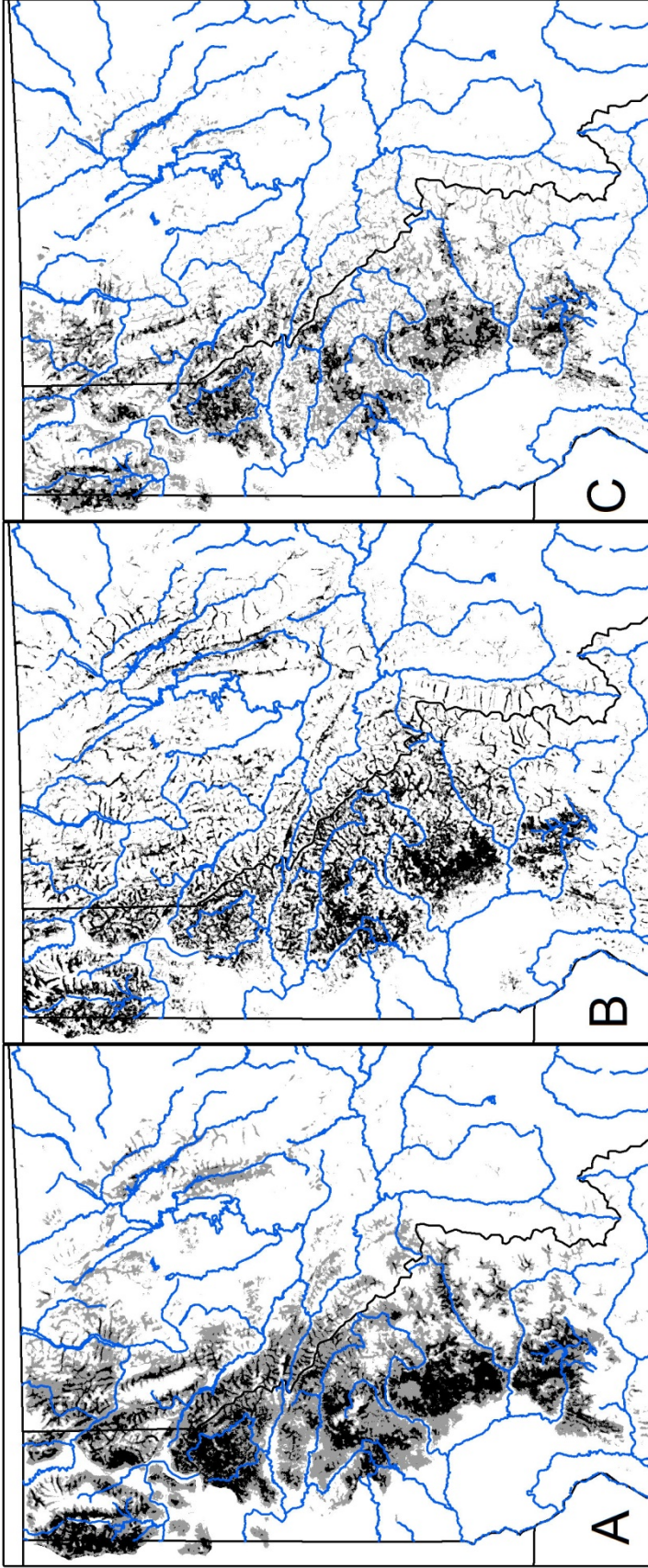


Figure 4.3. Probable (light gray) and predicted high-quality (dark gray) fisher habitat in northern Idaho and western Montana, USA, identified by 3 habitat models: a) multi-scale product model, b) single-scale full (climate and vegetation) model from Olson et al. (2014), and c) multi-scale ranked-boolean model.

Dissertation Conclusion

Understanding relationships between wildlife populations and their habitats is fundamental to sound, science-based wildlife conservation. However, wildlife species select and interact with habitats across a wide range of spatial and temporal scales (Kie et al. 2002, Graf et al. 2005, Boyce 2006). Habitat maps with the highest predictive accuracy often incorporate information about how species use habitats across a range of scales (Meyer and Thuiller 2006). This dissertation examined space use and habitat selection by fishers (*Pekania pennanti*) across multiple scales in north-central Idaho with the goal of providing increased information for forest managers to map and integrate the habitat requirements of fishers into forest management plans.

We employed satellite-tracked transmitters, a telemetry technique rarely used for mid-sized terrestrial wildlife, to successfully follow the movements of an uncommon and wide-ranging species that has proven difficult to study in the past. In doing so, we collected the first substantial telemetry dataset from fishers in Idaho in over 20 years. We showed that the locational accuracy and data collection rates of Argos satellite telemetry are robust to the effects of varying topography and canopy cover. This result differs markedly from what has been reported for GPS telemetry (Lewis et al. 2007) and provides researchers with yet another potential tool to use when studying the movements of wildlife.

We demonstrated that fishers showed strong habitat selection based on forest pattern. Fishers selected landscapes for home ranges with larger, more contiguous patches of mature forest and reduced abundances of open forest. This result supports the hypotheses that both forest configuration and composition influence the distribution of fishers in north-central Idaho. Additionally, we explored resource selection by fishers at the intra-home range level, a scale of habitat selection that has been poorly reported in the literature. We showed that metrics that described fine-scale habitat heterogeneity were more plausible in explaining habitat selection at this scale than measures of mature forest abundance. These results support the hypothesis that fishers establish home ranges that include a diverse array of forest conditions, thereby increasing their access to a greater diversity and abundance of prey species while still attaining access to habitat features that are important for reproduction and thermoregulation (Raley et al. 2012).

Finally, and most importantly, we synthesized the results from our analyses at the landscape and intra-home range scales with those of Olson et al. (2014), who studied the distribution of fishers across the Rocky Mountains of Idaho and Montana. In doing this, we produced an integrated, multi-

scale model of habitat selection that had improved predictive accuracy over the most detailed single-scale model available. We used this improved model to provide a comprehensive estimate of the abundance and distribution of fisher habitat across the Rocky Mountains of Idaho and Montana. Based on our model of predicted fisher habitat, we assert that wilderness and roadless areas alone are unlikely to provide sufficient habitat or population reserves to ensure persistence of fishers in Idaho and Montana. Finally, almost 80% of the predicted habitat for fishers occurs on federally owned national forests, and we conclude that successful conservation of fishers in the Rocky Mountains of Idaho and Montana will rely heavily on policy and management decisions made on these landscapes.

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Appendix A:

Animal Care and Use Permit

**University of Idaho
Animal Care and Use Committee**

Date: Friday, September 08, 2006
To: Janet Rachlow
From: University of Idaho
Re: Protocol 2007-5
Fisher Habitat Selection and Ecology in North-Central Idaho

Your animal care and use protocol for the project shown above was reviewed by the University of Idaho on Friday, September 08, 2006.

This protocol was originally submitted for review on: Wednesday, July 12, 2006
The original approval date for this protocol is: Friday, September 08, 2006
This approval will remain in affect until: Saturday, September 08, 2007
The protocol may be continued by annual updates until: Tuesday, September 08, 2009

1. The ACUC is now maintaining electronic copies of the final approved version of protocols. An electronic copy that includes any changes in the reviewed protocol above must be submitted to campusvet@uidaho.edu.

Federal laws and guidelines require that institutional animal care and use committees review ongoing projects annually. For the first two years after initial approval of the protocol you will be asked to submit an annual update form describing any changes in procedures or personnel. The committee may, at its discretion, extend approval for the project in yearly increments until the third anniversary of the original approval of the project. At that time, the protocol must be replaced by an entirely new submission.



IACUC Representative

Appendix B:

Copyright Letter from *Wildlife Society Bulletin* for Chapter 1.

Sauder,Joel

Subject: FW: Copyright

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[Influence of topography and canopy cover on argos satellite telemetry performance](#)

Wildlife Society Bulletin, Volume 36, Issue 4, December 2012, Pages: 813–819, Joel D. Sauder, Janet L. Rachlow and Michelle M. Wiest

Can you help me with this?

Thanks,

Joel Sauder

Appendix C:

Copyright Letter from *Forest Ecology and Management* for Chapter 2.

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Apr 01, 2014

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