Round River Conservation Studies

Use of aerial surveys to monitor backcountry winter recreation and predict associated wolverine habitat use

Final Report to Idaho Department of Fish and Game

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Executive Summary

Backcountry winter recreation is growing in popularity and technical capability, with access to increasingly remote landscapes by snowmobile, ski, heli-ski and other forms of motorized and non-motorized transportation. Some of these backcountry areas are also important habitats for wolverine during winter and reproductive denning and kit rearing seasons. Documented effects of winter recreation on wolverine include increasing avoidance as off-road recreation intensity increases and changes in movement rates. In previous research, we have highlighted the lack of baseline information on backcountry recreation use, and the difficulty of effectively documenting and monitoring recreation use at the landscape scales required for effective management of recreation and conservation of wolverines. In the present research, we focused on evaluating and refining the aerial survey methodology to more powerfully capture the relative intensity of backcountry winter recreation. Our goals in this effort were to:

- Provide improved protocols for systematic aerial surveys of backcountry winter recreation
- Assess the ability of the aerial survey information to reflect relative intensity and use of areas by backcountry winter recreationists
- Assess the ability of the aerial survey information to predict wolverine responses to winter recreation
- Provide on-going monitoring of winter recreation in the study area

We developed and implemented aerial (fixed wing) surveys in February 2018 on portions of the Payette and Boise National Forests where extensive prior monitoring of wolverines and recreation provides a solid baseline of information for testing new protocols and data. Winter recreation was surveyed based upon a standardized grid of 2.25 km^2 cells with alternate boundaries serving as transects spaced 3km apart. Observers collected winter recreation data in cells out each of the left and right sides of the plane, allowing two grid cells to be surveyed simultaneously. We systematically sampled winter recreation along the transect at 20 second intervals, recording winter recreation attributes including recreation type, recreation track age, pattern and local footprint. We also established infra-red trail use counters at primary access points to estimate total recreation visits.

We found that multiple aerial survey metrics correlated with the original recreation intensity mapping based on GPS tracking of recreationists. Of these metrics, a combination of the local footprint and recreation pattern was most predictive of female wolverine responses using wolverine GPS locations from 2010-2015. This combined Footprint+Pattern classified covariate was used to replace the original recreation intensity metric in a habitat model for female wolverines. The predicted responses were similar

to the original habitat model, and validated well using 10-fold cross validation. The higher recreation intensity classes showed stronger avoidance coefficients and were the most important predictors of female wolverine presence in the model. Movement rate analyses also suggested the strongest wolverine responses at higher recreation intensity classes.

This study provided an improved approach to monitoring backcountry winter recreation, including the identification of data that can characterize recreation intensity in a manner that is meaningful to understanding the potential responses of wolverines and identifying potential thresholds in relative intensity of winter recreation leading to measurable wolverine responses. There are limitations to the analyses we have undertaken, including the gap between when the original GPS recreation information and GPS wolverine data were obtained and the current survey was conducted. Still, the strength of the results, despite the time gap, suggests the patterns we have identified are robust. Thus, while the results we have presented should be interpreted cautiously, we believe they provide significant new advancements in our ability to monitor backcountry winter recreation and its potential effect on wolverine habitat use.

Introduction

The growing popularity of winter backcountry recreation combined with improved technology, equipment and opportunities to access increasingly remote landscapes for winter recreation activities has resulted in winter recreation expanding across previously undisturbed public lands. Advances in snowmobile technology provide skilled riders access to nearly any topography and the opportunity and challenge of accessing rugged and remote terrain. Increasingly, backcountry skiers are also using snowmobiles to reach remote areas and have skis built to allow easier trail-breaking and off-trail activities. In addition, guided access to remote areas for skiing using helicopters (heli-skiing) or tracked vehicle (cat-skiing) is growing in popularity.

Some areas now being accessed by backcountry winter recreations are also habitats used by wolverines during winter and reproductive denning and kit rearing seasons. The potential effects of winter recreation on wolverine behavior and habitat use were the focus of a 6-year research project in central Idaho and the western Yellowstone region. In this research we GPS-collared 24 individual wolverines and acquired >54,000 GPS locations over 39 animal-years. Simultaneously, we monitored winter recreation through voluntary GPS tracking, aerial surveys and remote trail use counts. We collected ~6,000 GPS tracks from backcountry winter recreationists representing ~200,000km of recreation activity. We combined the GPS tracks with trail use counts and aerial-based recreation surveys to map the extent and relative intensity of motorized and non-motorized recreation. We modeled habitat selection and assessed the potential for indirect habitat loss from winter recreation. The research found that motorized recreation occurred at higher intensity across a larger footprint than non-motorized recreation in most wolverine home ranges. Wolverines avoided areas of both motorized and non-motorized winter recreation and off-road recreation elicited a stronger response than road-based recreation. Female wolverines exhibited strong avoidance of off-road motorized recreation and experienced higher indirect habitat loss than male wolverines. The research conclusions suggest indirect habitat loss, particularly to females, could be of concern in areas with higher recreation levels.

The research effort documented higher levels and larger recreation footprints than was previously assumed by most local managers (Heinemeyer et al. 2019), highlighted the lack of baseline information on backcountry recreation use, and the difficulty of effectively documenting and monitoring recreation use at the required landscape scales. We speculated that the potential for backcountry winter recreation to affect wolverines may increase under climate change because of a “funnel-effect,” whereby reduced snow pack and snow season might concentrate winter recreationists and wolverines spatially and temporally in the areas of persistent snow cover. White et al. (2016) identifies the possibility in local areas retaining adequate snow, though overall they predict the effect of climate change will reduce participation in non-motorized snow recreation due to lack of adequate snow by 2030. It seems safe to assume the high elevation habitats of wolverines would offer snow after lower elevation areas lose adequate snow cover. This further motivates the need to develop standardized approaches to monitoring backcountry winter recreation across space and time to inform management decisions.

During the wolverine-winter recreation research, we developed an approach for systematically surveying and mapping winter recreation through aerial surveys and used the aerial survey data to validate recreation maps based on our more intensive ground-based GPS tracking. The aerial survey approach was based upon systematic sampling using a transect sampling approach for repeated presence-absence point observations that were then used to score grid cells based on the proportion of positive observations. The surveys also recorded the type of recreation, so that separate relative intensity indexes could be calculated for backcountry skiing and for backcountry snowmobiling. The grid cell size used in these surveys was 25km^2 and based upon prior helicopter grid-based recreation surveys completed as a reconnaissance survey for the wolverine-winter recreation research project. We analyzed the data based on cell quadrats, thus effectively looking at 6.25km^2 analysis units. While this is still quite coarse relative to the GPS recreation track data, we found a significant correlation between these aerial surveys and the GPS track density maps (Heinemeyer et al. 2019).

In the present research, we focus on evaluating and refining the aerial survey methodology to more powerfully capture the winter recreation characteristics that emerged in the research as predictive of wolverine responses. This current work focuses on metrics that aim to characterize the intensity and repeated use of an area by backcountry recreationists. We also decreased the size of the survey grid to provide a comprehensive survey of winter recreation activities. We maintained several components of the original survey effort that have proven both effective and efficient, including the use of fixed-wing aircraft, linear transects and systematic sampling approaches. In addition to the aerial surveys, we also deployed remote trail use counters, which provide an estimate of total visitation to an area. Our goals in this effort are to:

- Provide improved protocols for systematic aerial surveys of backcountry winter recreation
- Assess the ability of the aerial survey information to reflect relative intensity and use of areas by backcountry winter recreationists
- Assess the ability of the aerial survey information to predict wolverine responses to winter recreation
- Provide on-going monitoring of winter recreation in the study area

Field Data Collection Methods

Remote Trail Use Counts

To estimate the number of recreationist visits into the study area, we installed infra-red trail counters (Trafx Research Ltd, Canmore, Alberta, Canada) at major trailheads for backcountry snowmobile and ski/snowboard (see Heinemeyer et al. 2019). Trail use counters were established across a subset of the sites monitored in 2010-2015, allowing comparisons over time of visitation rates at these primary access points. Trail counters were established in mid-January and checked periodically until they were removed in late March/early April.

Winter Recreation Aerial Surveys

Winter recreation aerial surveys covered 4,329 km^2 that includes portions of the Payette and Boise National Forests in central Idaho. Surveys were organized on a grid of 2.25km^2 (1.5km x 1.5km) cells (Figure 1). The survey was completed using fixed wing aircraft (Cessna 206) along east-west linear transects that represented boundaries between every other row grid cells and so were spaced 3km apart. The team consisted of the pilot, a survey leader in front with the pilot and two observers in the back. The pilot attempted to fly the survey at consistent air speed of ~90 mph and approximately 500-800 ft above the ground but modified this as needed for topography and safety. The pilot used a handheld tablet (Samsung Galaxy X) with the Avenza Maps® mobile map app that provided live tracking of the plane to support flight lines on the transect. The survey leader assisted the pilot in monitoring the survey progress and flight line, and took a GPS location when s/he prompted the observers to record data. Each observer was responsible for recording winter recreation observations from their side (left or right) of the plane at the signal from the survey leader: writing these observations on a standardized data sheet along with the spatial identifier of the waypoint number provided by the survey leader. Along the transect, the survey leader signaled the observers to look out their respective windows at 20-second intervals which were timed to allow, on average, for a new field of view between observations (Figure 2). The 3km transect spacing is closer than the original 5km spacing used previously and represents an increase in effort to more effectively search each grid cell for recreation activity. At each prompt, the observers scanned for recreation activity in the form of snowmobile, skier or other human tracks and, if present, recorded the following information:

- Recreation type: In our study area, the dominant forms of winter recreation are primarily snowmobile and backcountry skier but additional forms of recreation would also be included if observed, e.g., snowshoe, snowbike and such rare occasions would be noted in the Comments section of the observation.

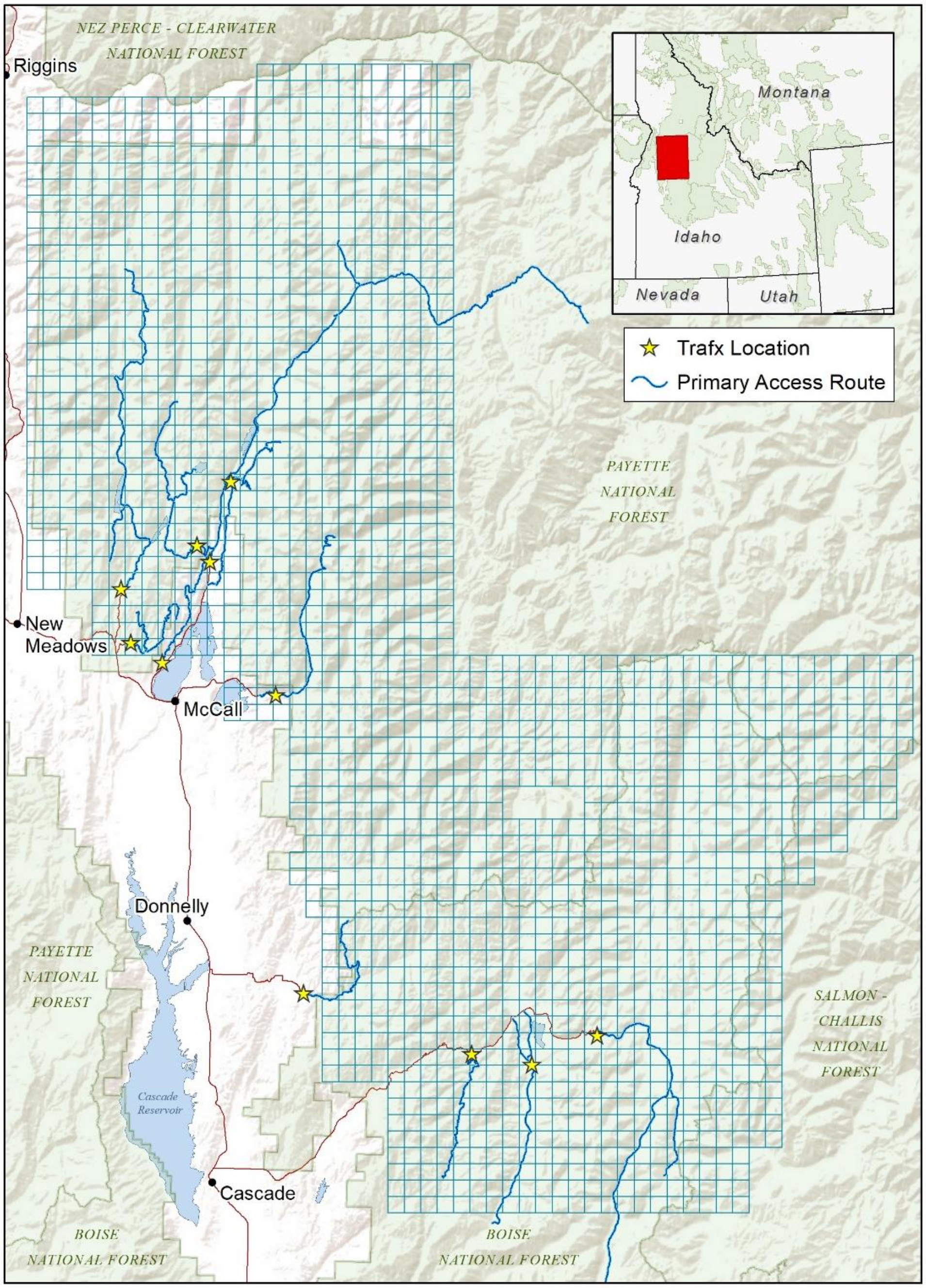

Figure 1. The study area includes portions of the Payette and Boise National Forests in central Idaho, where we used a grid of 2.25km² cells to for collecting information on recreation type and intensity through aerial surveys.

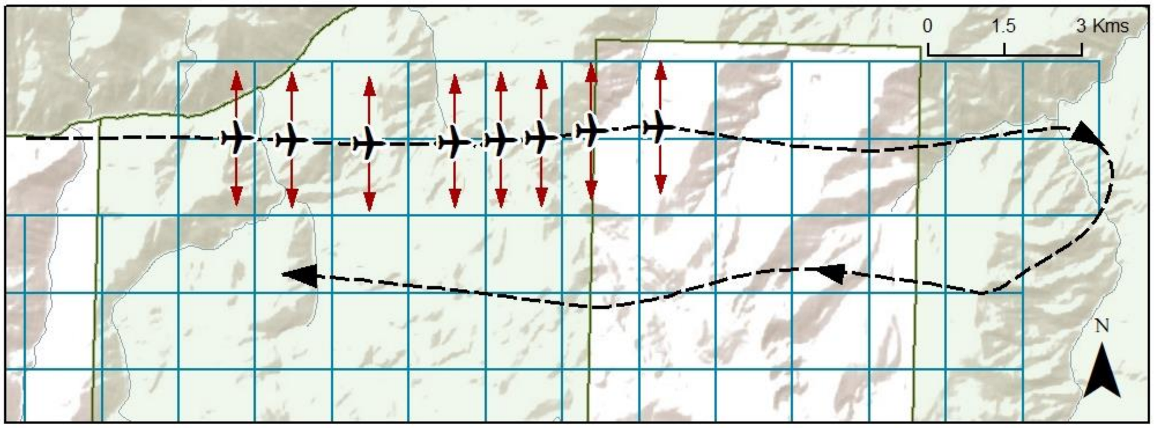

Figure 2. Surveys were flown along every other cell boundary of the overlain grid, so the boundary served as the transect lines 3km apart and observations were taken systematically with observers looking out the left and right sides of the plane to record recreation activity in the cells immediately north and south of the transect line.

- <u>Track Age:</u> The analyses of wolverine responses to winter recreation suggests that areas that receive repeated recreation use or higher intensity recreation use are more strongly avoided than those of lower use or frequency of use. Thus, this metric attempts to identify, as feasible, if tracks of multiple ages are present. Attributes collected are: "Fresh" if tracks laid down after last snowfall, "Old" if tracks are covered in recent snow, or "Both" if there were tracks that were both fresh and old.
- <u>Recreation Pattern</u>: This attribute attempts to quantify the relative intensity of use through characterizing the pattern of use. "Trail" is noted if the tracks are clearly linear following a travel route (existing road, groomed route or well-used pathway);
  "Play" is noted if the pattern of tracks indicated concentrated play type of recreation activity such as high-marking by snowmobilers, or repeated downhill runs by skiers; in general, "play" track patterns are looping, crossing over one another and fairly concentrated in space; "Dispersed" tracks are characterized as not following a linear path, nor exhibiting the looping and concentration of use characterizing a play area; these tracks typically were seen weaving through trees or trail breaking in lower use areas. Observers could note as many of these patterns as they observed at each sample point.
- <u>Recreation Footprint</u>: Finally, observers noted the spatial extent of the recreation within that observation window. This is a challenging metric to standardize and we requested observers imagine polygons around the outer edges of clusters of recreation (e.g., along

the edges of a trail or along the outer boundaries of a play area) and we defined the footprint categories broadly to reflect this: <10% or a small or trace amount of recreation seen; 10-50% if a substantive portion of the observation window shows evidence of recreation or >50% if the majority of the observation window has evidence of recreation. Another scoring approach that was useful was to break the window into 4 quadrats and count the number of quadrats with recreation present to assist in deciding between the mid and upper class where these were possibly close.

Training Flights. We flew 3.5 hours of training flights to explore potential recreation characteristics, notepad tracking, and overall survey design, as well as standardize our data collection across team members. With training, the team was able to consistently classify the different metrics of recreation.

Data processing. Following the completion of the surveys, the grid cells were attributed with the survey data, which required 're-flying' the survey using GIS to identify the cells to the left and to the right of each waypoint.

Aerial Survey Data Analysis Methods

We explored our ability to use the aerial recreation data to map backcountry recreation patterns and wolverine responses to backcountry recreation as an alternative to ground-based GPS tracking of recreationists.

Characterizing winter recreation based on aerial recreation survey metrics

We compared our observed variables or combinations of them to the relative intensity or density of winter recreation GPS tracks collected during the wolverine-winter recreation study in 2010 and 2011. While winter recreation in 2018 would not be expected to be a mirror of recreation in 2010 and 2011, the general patterns of recreation remained similar given that new roads or trails have not been developed nor other major management changes have fundamentally changed the area available for winter recreation. Thus, at the scale of our 2.25km^2 grid cells, we expect generally that recreation would be similar in the two time periods and we confirmed this visually by comparing prior aerial survey maps to the 2018 survey results. During the wolverine-winter recreation research, we found that aerial recreation surveys can characterize winter recreation, as indicated by the correlation found between the GPS tracking and concurrent winter recreation surveys (Heinemeyer et al. 2019). Therefore, we looked at correlations between the 2018 aerial survey data and the prior GPS tracking intensities.

Each 2018 grid cell had 1-4 observations, with 1-2 observations most commonly completed. We calculated grid cell scores based on weighting rules for each of the winter recreation characteristics observed during the aerial surveys. We explored both linear and exponential weighting scales and found that exponential weighting did not improve results so selected the simpler linear weighting rules. Resulting scores were scaled to represent the proportion of the maximum score possible for each metric for each grid cell, as follows:

Track Age Score: Fresh only = 1, Old only= 1; Fresh + Old = 2 = max score possible during a single observation; The Track Age Score of each grid cell is calculated as

$$\text{Track Age Score} = \frac{\sum_{i=1}^{n}(Fresh+Old)}{2n}$$

where *Fresh* and *Old* are the number of times each was indicated for a cell across all observations *i* = 1 observation to *n*, and *n* is the total number of observations in the cell. For example, assume there are two observations in a cell with: Observation 1: Fresh and Old; Observation 2: Fresh only. The sum of the observed is 1+1+1=3; the maximum possible score is 2n or =4. In this example, the score would be ¾ = 0.75.

Recreation Pattern Score: In this case, we weighted higher intensity recreation patterns and de-emphasized trail use based on the lower avoidance of trail-based recreation document in the wolverine-winter recreation study. Thus:

- $W_{trail} = 1$
- $W_{dispersed} = 3$
- $W_{play} = 6$

It is possible for the observer to record all three types of recreation patterns, thus the maximum score per observation is ($W_{trail} + W_{dispersed} + W_{play}$) is 10. Similar to the Track Age Score, the Pattern Score of each grid cell is calculated as

$$\text{Pattern Score} = \frac{\sum_{i=1}^{n}(Wtrail + Wdispersed + Wplay)}{10n}$$

where the nominator is the sum of all the weighted pattern observations from $i = 1$ observation to n, and n is the total number of observations in the cell. The denominator is the maximum score possible in the grid cell.

Footprint Score: The observers only record a single value for footprint during each observation, but multiple observations still may occur within a grid cell. The footprint categories were weighted to reflect their relative intensity such that the Weighted Footprint (W_{FP}) is

- = 1 if Footprint is <10%
- = 3 if Footprint is 10-50%; and
- = 6 if Footprint is >50%.

Thus, the maximum score of any observation is 6, and the total grid score for footprint is

$$\text{Footprint Score} = \frac{\sum_{i=1}^{n}(WFP)}{6n}$$

where the nominator is the sum of all the weighted Footprint observations from $i = 1$ observation to n, and n is the total number of observations in the cell. The denominator is the maximum score possible in the grid cell.

We evaluated each Metric score and also combined the different metrics to capture the various qualities of winter recreation into a single variable including: Track Age Score + Track Pattern Score + Footprint Score and combinations of two metrics.

Additionally, we calculated the equivalent of the original wolverine-winter recreation aerial survey score (Heinemeyer et al. 2019): Percent positive observations (# of positive observations/total # observations).

Most tracks (98%) observed were of snowmobile recreation, and we chose not to distinguish between snowmobile and ski tracks given the limited sample size.

To compare the 2018 surveys to the GPS track data, we generated 192,400 random points across our study area, and attributed points with the 30m track intensity calculated from 2010-2011 data (Heinemeyer et al. 2019). Each 2018 grid cell was attributed with the average recreation track intensity of the random points that fell within the cell, and each cell was also attributed with the aerial survey scores as described above. We ranked the recreation metric score of grid cells 0 to 10 with 0 representing grid cells where no recreation was documented during the aerial recreation survey, and Classes 1 through 10 representing equal interval bins (i.e., Pattern Class 1 would include grid cells with Pattern Scores greater than 0 but less than 0.10 and Class 10 would include grid cells with Pattern Scores between 0.9 and 1). For each aerial survey metric or combined metric, Pearson correlations were calculated between the aerial survey metric ranks and the average GPS track density, following the approach used in Heinemeyer et al (2019) to compare aerial survey results to GPS track densities.

Assessing wolverine responses to aerial recreation survey attributes

We evaluated the strength of the aerial survey metrics to predict wolverine responses to winter recreation using the GPS collar data collected on wolverines during the wolverine-winter recreation study. Specifically, we used GPS collar locations (used sites) of female wolverines monitored during the wolverine-winter recreation study. We evaluated movement rates and habitat selection across areas with differing intensities of winter recreation. One female had a high concentration of locations at den sites in 2011 that fell within small portions of two grid cells with recreation use in 2018; because we do not know if there were active dens in these areas during 2018, we removed these locations from the analyses.

To evaluate habitat selection, we compared animal locations to random locations (available sites) within each female wolverine home range that overlapped our study area (see Heinemeyer et al. 2019). We evaluated habitat selection relative to winter recreation metrics using univariate and multivariate resource selection analyses. Resource selection functions (RSF) compare covariate characteristics at used GPS locations with random locations (putatively available) to identify covariates that are used disproportionately more (i.e., selected), less than (i.e., avoided) or in proportion to available (Manly et al. 2002). We used general linear models with a logit link function (GLM) in univariate examinations of the responses of female wolverines to different winter recreation metrics from the aerial survey. We compared AICs to identify the most predictive recreation metric, which then served as a covariate in a multivariate general linear mixed model (GLMM).

We developed three multivariate GLMM models using data from the six female wolverines monitored from 2010-2014 in our study area:

- Model 1 (Potential habitat): We used the environmental covariates important in predicted female habitat use identified in Heinemeyer et al (2019)
- Model 2: (Potential + GPS Recreation Covariates): Model 1 plus the GPS-based recreation covariates selected by Heinemeyer et al (2019) as the top performing model
- Model 3: (Potential + Aerial Recreation Survey Covariate): Model 1 plus most predictive aerial recreation covariate determined in univariate assessments.

To control for repeated sampling of individual wolverines, animal-year was included as a random effect (Gillies et al. 2006). We standardized the covariates so the relative strength of each covariate can be compared within a model. We evaluated the AICs across these models to assess the utility of using the aerial recreation covariate as a replacement for the GPS track-based covariates. We validated Model 3 through 10-fold cross validation (Boyce 2002).

We looked at patterns of behavioral responses of female wolverines to winter recreation based on changes in the average log movement rate across classes of our top winter recreation metrics, with overall significance assessed through contingency table analyses. We evaluated 95% confidence intervals around the average log(movement rate) for each metric 10 rank class to identify patterns of movement rates across metric classes. We identified metric classes with significantly higher movement rates than the baseline movement rate calculated for areas without documented winter recreation.

Results

Traffic Counter Visitation Estimates

Data were collected on trail use using remote trail counters from mid-January through the end of March 2018. These data were compared to similar data collected between 2010-2014 for the same trails. Trends in visitation over the monitoring period starting in 2010 varied by recreation access (Figure 3 and 4). The Warren Wagon and Upper Elevation parking lots continue to dominate the recreation access into the region (Figure 3). We see significant increase in the backcountry visitation counts from the Warren Wagon access points between 2015 and 2018, we assume coinciding with an increase in parking area. Recreation visitation has tended to increase over the 8 years of monitoring on both the Boise National Forest and Payette National Forest portions of the study area, while the Payette NF still consistently experiences more visitation (Figure 5).

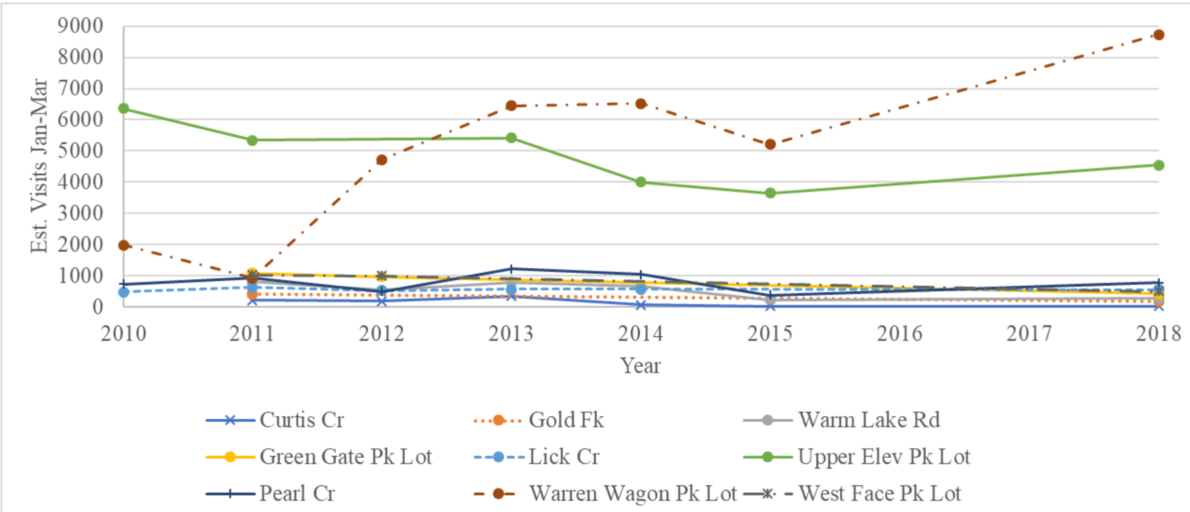

Figure 3. Annual remote trail use counter counts at monitored backcountry access points on the Payette and Boise National Forests from 2010 – 2018; gaps in monitoring indicated by a lack of a point in the year of the gap (e.g., Warren Wagon parking lot not monitored in 2016 and 2017).

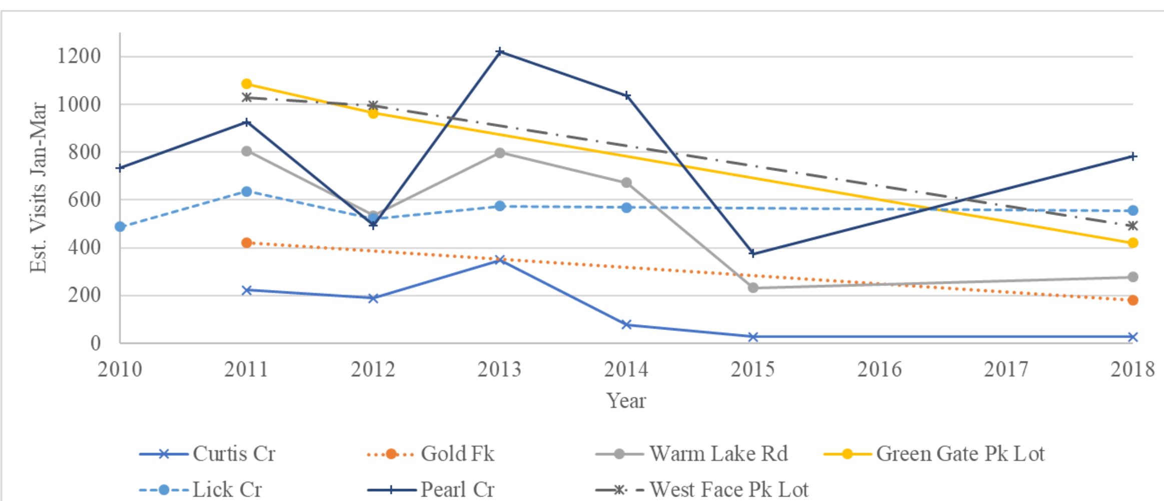

Figure 4. Two dominant access points (Warren Wagon and Upper Elevation Parking Lots) are removed from Figure 3 to allow a more useful visualization of the remaining backcountry visitation on the Payette and Boise National Forest (see Figure 3 for details).

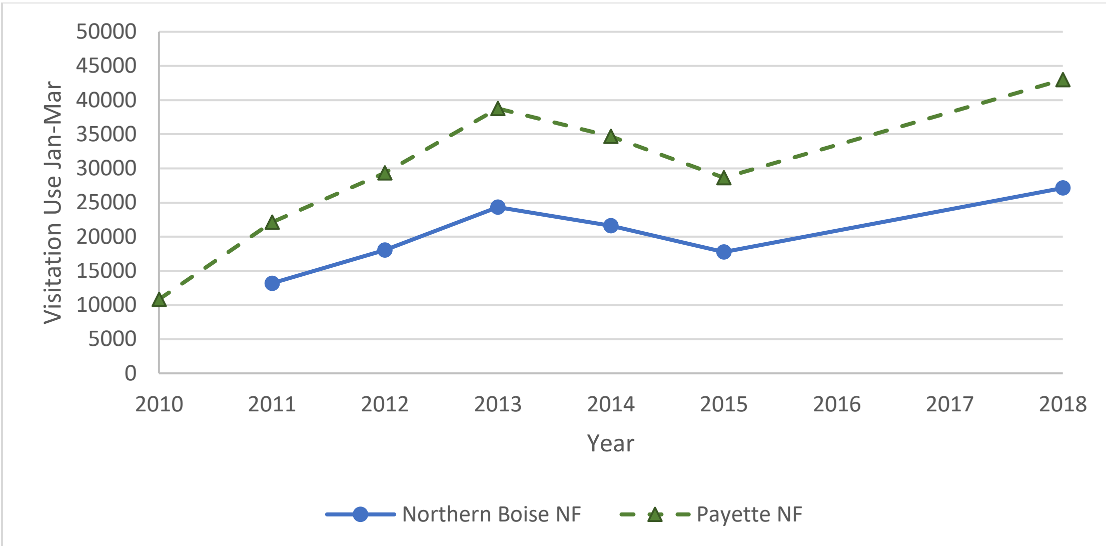

Figure 5. Total estimated visitation per year estimated from remote trail use counters at monitored backcountry winter recreation access sites on the Boise and Payette National Forests.

Aerial Survey Results

The aerial surveys for winter recreation were flown over an area covering 4,329 km^2 (1924 2.25km^2 grid cells) in 9 hours of surveying. The survey area included the majority (2,938 km^2, 1,306 grid cells) of the McCall study area for the wolverine-winter recreation study as well as areas that were outside of the 2010-2015 wolverine-winter recreation study area to expand the winter recreation base data in the area of the Stibnite Mine and proposed access road. Across this area, 20% of the grid cells were recorded to have winter recreation activity and all of this activity was within the 2010-2015 study area.

Comparison of Aerial Survey and GPS Tracking of Recreation

The 2010-2011 GPS track intensity and the various winter recreation metrics collected during the 2018 aerial surveys showed positive and significant correlations. The correlations between the track intensity and the Percent Positive, Footprint, and Track Age+Pattern+Footprint showed strongest correlations with all exceeding 0.90 (Table 1), and Footprint+Pattern also showed a high correlation at 0.89. Given the low number of replicate samples within any cell, the Percent

Positive metric has only 3 classes and therefore provides limited ability to assess variation in recreation across the landscape.

Wolverine responses to winter recreation characterized by aerial survey

The high correlation between winter recreation intensity calculated in 2010-2011 and aerial winter recreation intensity metrics calculated in 2018 justified using the 2018 winter recreation metrics to evaluate their utility in predicting wolverine responses to winter recreation based on wolverine GPS collar data collected during Heinemeyer et al (2019). Univariate analyses showed consistent patterns in wolverine responses to winter recreation with avoidance of higher scores while responses varied to some extent to lower scores. The combined Footprint+Pattern metric (Figure 6) had the most explanatory power with the lowest AIC across the metrics, followed by Pattern and Age+Footprint+Pattern (Table 1). In evaluating the univariate logistic regression of Footprint+Pattern, the most strongly avoided classes of Footprint+Pattern are classes 6 – 10, though avoidance was significant in other classes as well (Table 2).

The GLMM Model 3, which included environmental covariates and the Footprint+Pattern covariate, performed better than Model 1 (no recreation covariates) but not as well as Model 2, which contained the higher resolution GPS track-based recreation covariates (Table 3). There was an increasingly negative response to higher Footprint+Pattern classes in Model 3 similar to the pattern seen in the univariate evaluation (Table 4). Avoidance of Footprint+Pattern classes 6 and higher was strong and ranks as 4 of the top 5 covariates in strength. Mapping this habitat model (Figure 7) shows spatial patterns of avoidance similar to those shown in the original female realized habitat model from Heinemeyer et al (2019), including strong avoidance of areas where there were higher levels of winter recreation. Model 3 showed a strong validation with Pearson correlation rho = 0.87.

The average female log(movement rate) was significantly higher when locations fell within grid cells with Class 5 or higher Footprint+Pattern score. Due to low sample size in Class 9, we combined 9 and 10 (Figure 8).

Table 1. Evaluation of aerial survey winter recreation metrics: 1) GPS tracking-based winter recreation mapping: Pearson's correlation between the GPS track intensity of winter recreation recorded in 2010-2011 and the aerial survey winter recreation metric scores ranked into 10 classes with 10 indicating the highest score reflecting higher levels of winter recreation. 2) Univariate logistic regressions of animal use/availability by each metric were completed, and the AIC scores across metrics were compared; delta AIC of 0 indicates the best fit model.

Metric	1) Correlation	2) Delta AIC
Percent positive observations[1]	0.98	500
Footprint	0.96	286
Age+Pattern+Footprint	0.94	187
Pattern + Footprint	0.89	0
Pattern	0.71	78

[1] Percent positive observations only had 3 classes due to sampling limitations.

Table 2. Univariate logistic regression of female wolverine locations on the Footprint+Pattern score classified into 10 classes and based on aerial recreation survey data collected during winter of 2018.

Coefficient	Estimate	Std. Error	z value	Significance
(Intercept)	-0.61	0.012	-51.8	***
Class 1	-0.54	0.049	-11.1	***
Class 2	0.07	0.05	1.334	-
Class 3	-0.61	0.064	-9.51	***
Class 4	-0.47	0.062	-7.68	***
Class 5	0.31	0.055	5.701	***
Class 6	-1.08	0.089	-12.2	***
Class 7	-1.25	0.103	-12.1	***
Class 8	-0.51	0.073	-7.06	***
Class 9	-1.55	0.167	-9.25	***
Class 10	-1.04	0.093	-11.3	***

Table 3. Delta AIC scores of multivariate RSF models developed for female wolverines within the study area, with the lowest score indicating the most supported model.

Model	Delta AIC
Model 1: Environmental covariates only[1]	968
Model 2: Environmental covariates + GPS Recreation Track covariates[1]	0
Model 3: Environmental covariates + 'Footprint+Pattern' covariate	229

[1] As described in Heinemeyer et al. (2019) as the top performing model for female wolverines

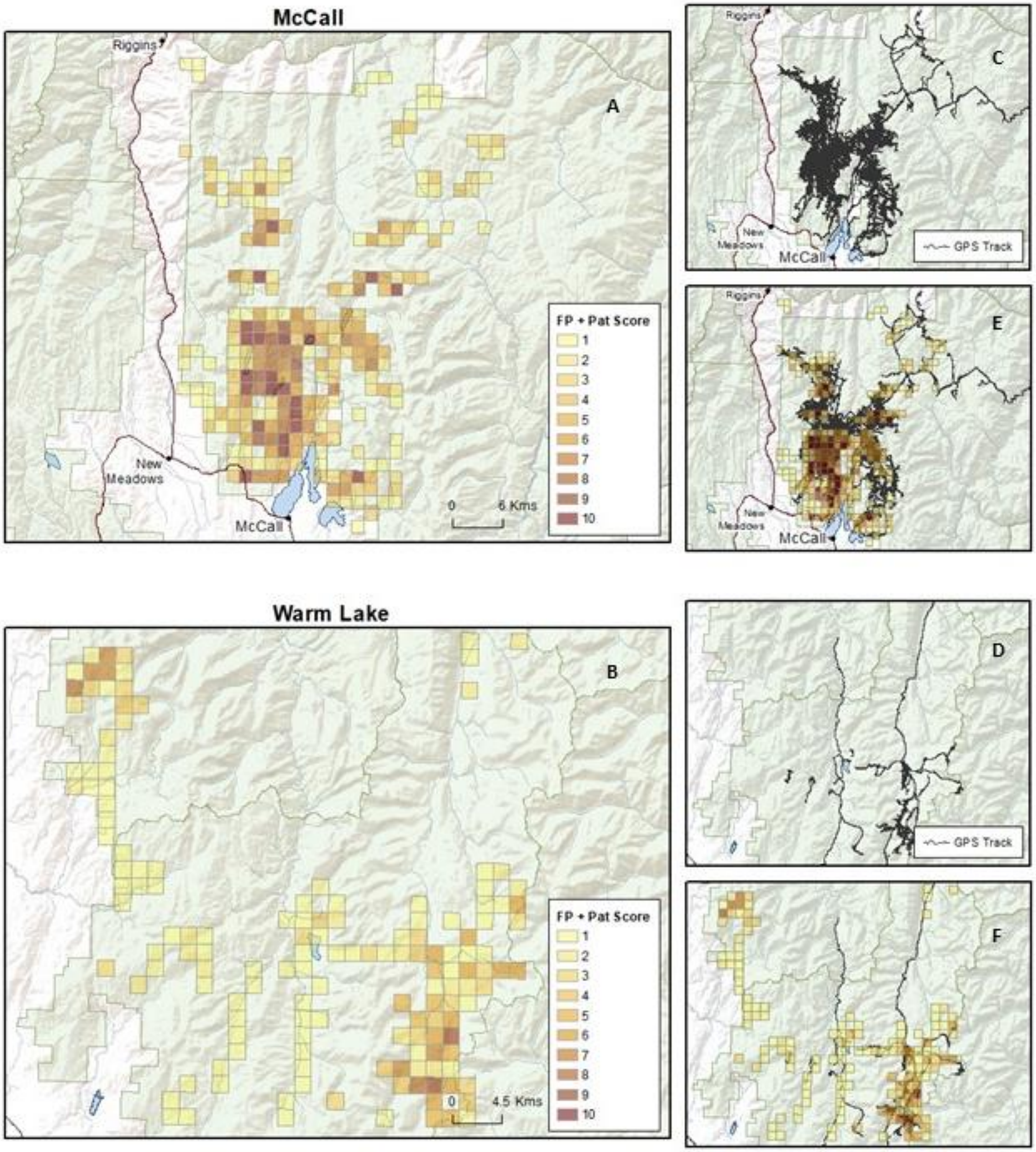

Figure 6. The combined Footprint+Pattern metric classes 1-10 in the McCall portion of the study area (A) and the Warm Lake portion of the study area (B). For each study area, the original GPS track grid is shown (C, D), and the GPS track grid on top of the Footprint+Pattern classes (E, F).

Table 4. Multivariate mixed model resource selection function model standardized coefficient estimates, standard errors, z-values, probability and covariate rank for environmental covariates and the 10-class Footprint+Pattern recreation metric input as a categorical factor.

	Estimate	Std. Error	z value	Probability	Covariate rank
Talus	0.32	0.01	21.46	<0.0001	11
Riparian	-0.04	0.01	-3.72	<0.0001	21
Shrub Grass	-0.13	0.02	-8.14	<0.0001	16
Terrain Ruggedmess	-0.43	0.01	-31.22	<0.0001	8
Solar Insolation	-0.08	0.01	-6.25	<0.0001	19
Slope	-0.27	0.02	-16.90	<0.0001	13
Slope^2	-0.19	0.01	-17.49	<0.0001	15
Snow Model	0.04	0.01	2.68	<0.0007	20
Edge Area Ratio	0.09	0.02	5.36	<0.0001	18
Dist. to Forest Edge	-0.32	0.02	-16.66	<0.0001	12
Fir Forest Types	-0.11	0.02	-6.01	<0.0001	17
FP+Pattern Class 1	-0.48	0.05	-9.28	<0.0001	7
FP+Pattern Class 2	0.26	0.06	4.71	<0.0001	14
FP+Pattern Class 3	-0.51	0.07	-7.68	<0.0001	6
FP+Pattern Class 4	-0.41	0.06	-6.31	<0.0001	10
FP+Pattern Class 5	0.54	0.06	8.99	<0.0001	5
FP+Pattern Class 6	-0.97	0.09	-10.54	<0.0001	4
FP+Pattern Class 7	-1.16	0.11	-10.92	<0.0001	2
FP+Pattern Class 8	-0.42	0.08	-5.42	<0.0001	9
FP+Pattern Class 9	-1.62	0.17	-9.48	<0.0001	1
FP+Pattern Class 10	-0.97	0.10	-9.99	<0.0001	3

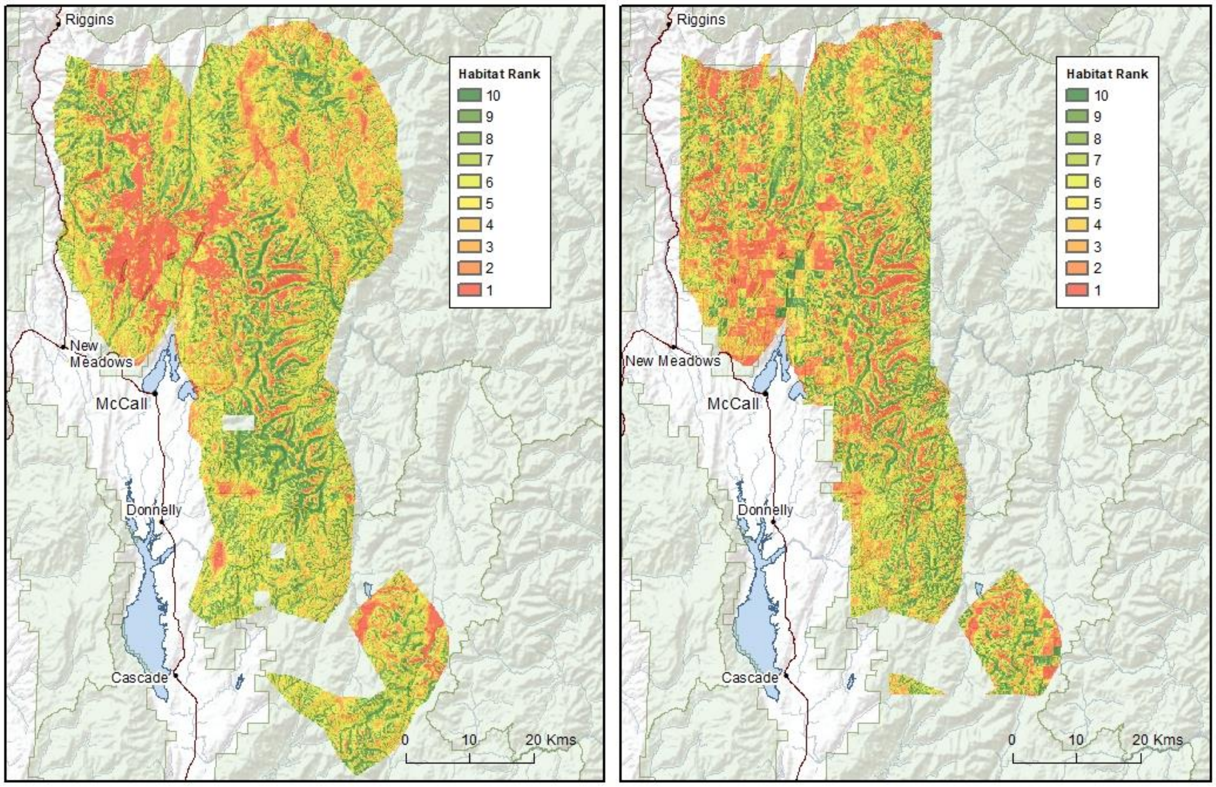

Figure 7. Female wolverine habitat models; right panel shows model using 10 class Footprint+Pattern covariate while the left panel shows the original female realized habitat model using recreation intensity covariate based on GPS track data.

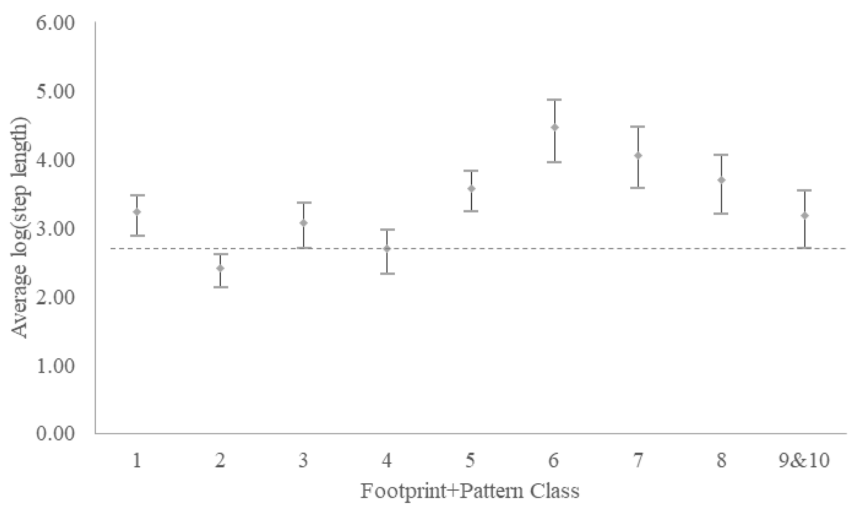

Figure 8. Average log(movement rate) of wolverines monitored in 2010-2015. Movement rates within each class of Footprint+Pattern score was calculated along with 95% confidence intervals. The dashed line indicates the upper confidence interval of the baseline log(movement rate): if the confidence interval of the movement rates is above this line then the movement rate in that class of recreation metric is significantly higher than the baseline movement rate in un-recreated portions of the study area.

Discussion

Our surveys in 2018 found winter recreation in many of the same areas as identified during 2010-15 and covered approximately 20% of the overall study area. This larger study area includes areas currently inaccessible or quite remote from recreation access. Within the core winter recreation areas documented in the earlier monitoring work, we generally found winter recreation spatial extent and relative intensity to be similar. Overall, the area has seen a steady increase in recreation activity, as documented by the remote trail use counters, particularly at an access point where improvements in parking area have occurred. The current work is a single aerial survey and significant on-going snowfall over the prior several days limited our ability to identifying only the most recent recreation activity. Still, we garnered enough information to test several potential new survey metrics and identify those that were most informative of winter recreation and wolverine responses to winter recreation, thus increasing the efficiency of even a single survey effort. From this survey, we were able to provide useful maps of winter recreation relative intensity, validate the patterns using previous recreation monitoring, and develop aerial survey-based metrics that predicted wolverine responses to winter recreation.

Wolverines have been previously shown to respond to increasing levels of winter recreation with increasing avoidance of those areas (Heinemeyer et al. 2019). Even at the coarser scale of aerial surveys, we captured important metrics of winter recreation that predicted this increasing avoidance response. A combination of the local footprint and the pattern type (Footprint+Pattern) most strongly predicted wolverine responses, including habitat avoidance and changes in movement rate. The Footprint+Pattern metric was the top performing metric in univariate tests of wolverine responses, performed reasonably well as a substitute for the GPS recreation track-based covariates originally used in female wolverine habitat RSF models, and substantially improved our ability to predict habitat use by female wolverines over the model without any recreation covariates. The increase in movement rates at higher classes of the Footprint+Pattern metric also suggests this metric captures important components of winter recreation that affect wolverine behavior. These multiple evaluations provide strong support for the utility of the Footprint+Pattern metric to collect, map and assess the winter recreation and its potential for affecting wolverine habitat use and behavior across large landscapes.

The Footprint+Pattern metric also had a high correlation with prior baseline data on recreation relative intensity. We suggest that future surveys focus on the local footprint and pattern of recreation as a priority, as well as documenting the type of winter recreation. We did not find the track age metric useful, possibly because our temporal window was limited by recent snowfall. Repeated surveys would effectively identify areas of repeated use, further making the track age metric potentially redundant. While we did not have enough information to look separately at motorized and non-motorized recreation, this would be possible for surveys that are of larger areas or are repeated through time.

Our analyses were founded on comparing the current survey to GPS track-based recreation intensity maps completed between 2010-2015 at a much finer resolution. The differences in spatial resolution challenge this comparison and were confounded by the fact that we expect winter recreation to be spatially and temporally dynamic. Still, the analyses showed that the aerial survey approach captured important patterns of winter recreation similar to conclusions reached in Heinemeyer et al. (2019) for concurrent aerial surveys and GPS tracking. The current work refined and increased the types of information collected during the survey to better capture the relative intensity of winter recreation. We expect that repeated surveys both within and across years will further improve our ability to capture and map the relative intensity of winter recreation and different types of winter recreation.

Monitoring backcountry winter recreation consistently across space and time is increasingly recognized as critical to maintenance and management of our public land values. The lack of monitoring to date is partly due to a lack of recognition of the extent of these human activities across the landscape, but also partly to the challenge of developing methods to do so that are effective and efficient. A key challenge is developing methods that are repeatable across space, time and observers. We believe the aerial survey approaches we have developed over the last several years provide a reasonable approach to monitoring backcountry winter recreation. The grid design, transect sampling and type of data collected standardize the effort. We have attempted to minimize the observer bias in assessing recreation intensity by breaking the data into distinct characteristics to be collected (e.g., age, pattern, footprint, type). Of these metrics, assessing the local footprint of the recreation at each observation likely has the most vulnerability to observer bias and will require on-going standardization across observers. Our team was quickly able to standardize among ourselves, and we recommend that training flights are required with any new team to ensure that all agree on the definition of the footprint as well as other metrics.

Translating winter recreation information into management recommendations is an on-going challenge. This study has provided an effective means to initiate winter recreation monitoring across large landscapes and to gather the types of data that are linked to effects on wolverine and potentially on other species. We found that female wolverines' responses were most strongly negative when the Footprint+Pattern class was ≥6, and we found that the relative intensity of winter recreation was the most important predictor of female wolverine habitat use. We also found that female wolverine increased their movement rates significantly in areas corresponding to Footprint+Pattern classes ≥5. If aerial surveys are completed, the information could be interpreted such that areas with Footprint+Pattern classes ≥5 or 6 identify winter recreation levels that most negatively impact female wolverines. We would caution that we measured negative responses to most levels of winter recreation Footprint+Pattern scores, and classes lower than 5 or 6 may still have negative effects on the habitat use or behavior of female wolverines. The appropriate management responses, if any, to balancing wolverine habitat conservation and providing opportunities for backcountry winter recreation require significant additional collaborations with managers, recreationists and scientists.

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