Wildlife Society Bulletin 43(3):414–424; 2019; DOI: 10.1002/wsb.1005

Emerging Issues

Incorporating Local Ecological Knowledge to Explore Wolverine Distribution in Alberta, Canada

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ABSTRACT Wolverines (*Gulo gulo*) occur at low densities in remote areas that are typically difficult to access, which has resulted in a lack of baseline data and uncertain status across parts of their range. We surveyed trappers in 2012 to gather information on local ecological knowledge of wolverine occurrence across a range of latitudes (49–59°N) in Alberta, Canada. We received questionnaires from 164 trapping areas in the Boreal Forest, Foothills, and Rocky Mountains. Similar to results from other methods of data collection, trapper observations of wolverines were associated with cooler climates and less anthropogenic disturbance. When we included data from all regions, the best model that explained recent wolverine observations included percent intact forest within the surrounding area. The odds ratio suggested that each increase of 1% in the amount of intact forest increased the odds of a trapper observing wolverine sign by 4%. In the Boreal Forest, the top model indicated that wolverines were more likely to be found in areas that had a cooler climate and more intact forest. Insights from trappers provided valuable baseline data on a sensitive species that is complementary to other research findings, and stimulated hypotheses that wolverines are linked to cooler climates and less disturbed environments.

KEY WORDS Canada, climate, furbearers, *Gulo gulo*, habitat relationships, human disturbance, local knowledge, stakeholder, trapper, wolverine.

We considered local ecological knowledge (LEK) to be the insight gained from spending extensive time observing an area or a species (Huntington 2000, Parry and Peres 2015). Incorporating LEK into research has important social and biological effects of broadening the knowledge base, identifying gaps in expert assumptions, and increasing trust and understanding between scientists and stakeholders (Corburn 2003, Hartley and Robertson 2006). The gathering of LEK has been a valuable tool for addressing complex environmental problems, community-based fisheries management, and monitoring wildlife over large spatial scales (Corburn 2003, Gilchrist et al. 2005, Hartley and Robertson 2006, Parry and Peres 2015). Although using LEK in ecological research has increased over time (1980–2004; Brook and McLachlan 2008), its use remains challenging and somewhat controversial, in part because of the difficulty in obtaining local knowledge and the multidisciplinary approach necessary for bridging the social and biological sciences (Huntington 2000). When there are limited data on rare species that occur in remote areas, LEK could be particularly beneficial for establishing baseline information and monitoring status over time (Gilchrist et al. 2005). Studies show that trappers are experienced, credible, and more knowledgeable than the general public about wildlife (Kellert 1984, Webb and Boyce 2008). By spending years, often on the same piece of land, trappers have gained detailed local knowledge about the ecology of many wildlife species (Pybus 2005, White et al. 2015). A challenge for wildlife professionals is how to effectively use local knowledge and apply these observations toward resource management (Riley et al. 2002).

Wolverines (*Gulo gulo*) are valuable furbearers, particularly in western Canada where approximately 1,000 wolverines are harvested annually (Banci 1994, COSEWIC 2014). However, wolverines are a conservation conundrum because they occur at low densities, have low reproductive rates, and

Received: 24 April 2018; Accepted: 20 March 2019

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occupy large home ranges in remote areas (COSEWIC 2014). The status of wolverines in Alberta, Canada, is uncertain (i.e., Data Deficient) and there are concerns that wolverines may be declining in some areas (COSEWIC 2014). Wolverines are allowed to be trapped (Nov–Jan), but they are managed as a sensitive furbearer with a quota to limit harvest to 1 wolverine/trapping area/year (Government of Alberta 2017).

Historically, the distribution of wolverines and other furbearers in Alberta was largely derived from fur trapping records, trapper questionnaires, and anecdotal information. A trapper opinion survey suggested that the wolverine population may have been declining by the mid-1980s and a later fur harvest analysis also showed reduced distribution over time (1977–1999; Skinner and Todd 1988, Poole and Mowat 2001). However, more recent fur harvest analyses indicated that the mean wolverine harvest density increased from the 1990s to the 2000s, particularly in the northwestern Boreal Forest region (Webb et al. 2016). Although long-term fur harvests were useful for mapping wolverine occurrences, we still do not understand the potential landscape factors that limit their distribution, which are important for clarifying their status and planning for habitat conservation.

Recent field studies found that wolverine distribution, behavior, and abundance may be limited by anthropogenic disturbance in the Foothills and Rocky Mountains (Fisher et al. 2013, Fisher and Bradbury 2014, Whittington et al. 2014, Stewart et al. 2016, Heim et al. 2017). Few wolverines were detected on cameras in heavily modified landscapes, and those wolverines were hesitant to climb baited trees and spent less time at sites compared with wolverines detected in protected or less developed landscapes (Stewart et al. 2016). Anthropogenic disturbance may also affect species negatively through increased interspecific competition (Heim et al. 2017, Scrafford et al. 2017). However, wolverines can be attracted to some disturbances that likely create good foraging opportunities, such as borrow pits, regenerating seismic lines, and cutblock edges (Scrafford et al. 2017). Wolverines have not been studied equally across their range and applying findings from the mountains to other areas may not be appropriate given the broad landscape conditions they occupy.

Prior to our study, the best data on wolverine distribution in Alberta were from long-term fur harvest records (Poole and Mowat 2001, Webb et al. 2016). Although fur harvests provided information on where wolverines had been harvested, we lacked data on where wolverines occurred but had never been harvested. To our knowledge, trappers had not been surveyed about the status of wildlife on their traplines since the 1980s, but many individual trappers indicated interest in contributing to research since then (Skinner and Todd 1988, Webb and Boyce 2008). Prior trapper surveys assessed the change in observed distribution, but did not associate observations with landscape features (Skinner and Todd 1988, Poole and Mowat 2001). Therefore, the primary objectives of our survey were to assess observations of wolverines across the province and examine the relationship between where trappers observed wolverine (direct sightings, harvest, or tracks) and landscape variables that could affect coarse-scale distribution in the future.

STUDY AREA

On public land in Alberta, trapping was restricted to individuals that have been granted the exclusive right to trap over a defined area, referred to as a registered fur-management area. We chose these areas as our sampling unit because they have boundaries that have remained consistent over time and were managed by a single senior license holder. These tenures regularly spanned multiple decades, which allowed trappers to acquire in-depth knowledge of a specific area. We hereafter refer to these areas as traplines, because this is the colloquial term used by participants in our study; but, readers should keep in mind that these are polygons, for which a variety of landscape variables can be calculated.

Traplines in our study overlapped the Rocky Mountains, Foothills, and Boreal Forest natural regions (49–59°N, 110–118°W; Fig. 1). The Rocky Mountains was located along the western provincial border and consisted of montane, subalpine, and alpine subregions, with elevations ranging from 1,000 to 3,700 m (Natural Regions Committee [NRC] 2006). The Rocky Mountains were dominated by coniferous forests at lower elevations and rock, snow, and ice at higher elevations, with limited industrial development and motorized access, but popular recreational use in certain areas. The Foothills bordered the mountains and had a mix of coniferous, mixed, and deciduous forest with multiple, overlapping land uses (e.g., timber harvest, oil and gas development, coal mines, cattle grazing, and motorized and nonmotorized recreation), and elevations from 700 m to 1,700 m (NRC 2006). The Boreal Forest was located north of the Foothills and Rocky Mountains and represented 58% of the land base, yet >80% of the provincial wolverine harvest came from the Boreal region (Webb et al. 2013). Extensive wetlands mixed with coniferous, mixed-wood, and deciduous forests were prevalent in the Boreal, with elevations from 150 m to 1,100 m (NRC 2006). Industrial development and resource extraction (i.e., forestry and petroleum) were ubiquitous in the Boreal, but traplines were much more remote and located further from large urban centers (i.e., Calgary, Edmonton). In general, summers were short and warm and winters were long and cold in the Boreal Forest and Foothills; summers were short and cool and the winters were long and cold in the Rocky Mountains (NRC 2006).

METHODS

We developed survey questions in consultation with the Alberta Trappers' Association (ATA), the primary trapping organization that represented approximately 60% of trappers in the province (J. Mitchell, Alberta Trappers' Association, personal communication.). A list of trapper names and addresses were not available, so we promoted and distributed the voluntary questionnaire (Supporting

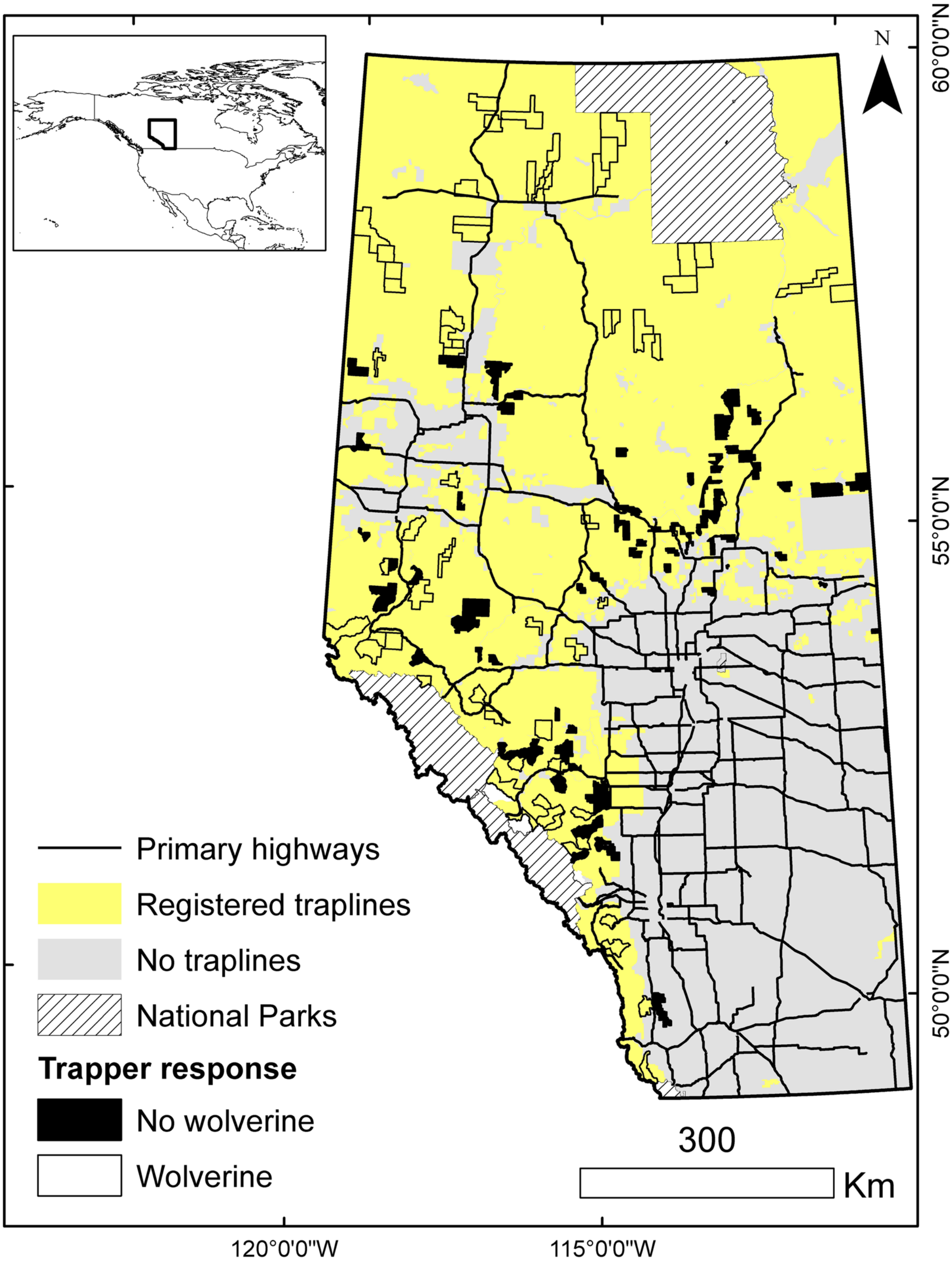

Figure 1. Distribution of where trappers observed wolverines recently (2009–2012) on traplines in Alberta, Canada.

Information) opportunistically through the ATA website, monthly trapping meetings, annual trapper rendezvous, and trapping magazine; we also mailed the survey to all 20 local ATA chapters active in the province. Government of Alberta staff distributed the questionnaire when trappers renewed their trapping license at regional fish and wildlife offices in the summer–autumn of 2012. We communicated the value of receiving questionnaires from traplines with and without wolverines and accepted trapper completed questionnaires from January to December 2012.

Trappers were asked to provide information about observations of wolverine sign, harvest history, and opinions about population trend (Supporting Information); the focus of our analysis was on reports of wolverine occurrence. We compared the number of traplines where wolverines were observed versus where wolverines had been harvested in the past to determine how well fur harvest data related to trapper observations. We summarized the general status of wolverines based on trapper response: 1) Common—"It's common to observe wolverine sign on my trapline"; 2) Occasional—"I have observed wolverine sign in the past" or "Past trapping records indicate wolverine on my trapline"; and 3) No wolverine—"I haven't seen and have no knowledge of wolverine being on my trapline". We omitted responses that indicated the trapper had not observed wolverine sign if the trapline was new to them (≤5 yr). For the response variable in our models (recent wolverine occurrence), we quantified whether trappers had observed wolverine (direct sightings, harvest, or tracks) in ≥1 of the 3 previous years (2009–2012).

We used natural regions to group the responses into landscapes with similar climate, soil, topography, and vegetation (NRC 2006). Each trapline was assigned to a region based on the greatest proportion of a natural region that it overlapped and in accordance with the Fur Management Zones (e.g., west-central/foothills, NE Boreal, NW Boreal; Webb et al. 2016, Government of Alberta 2017). We used a Geographic Information System to quantify covariates within each trapline polygon. For the predictor covariates, we considered variables that have been associated with wolverine ecology, such as food, climate, refuge, and human disturbance (Banci 1994, Copeland et al. 2010, Fisher et al. 2013). We estimated the capability of the land to support ungulates by way of pre-existing data sources that made use of soil, aspect, elevation, and other environmental factors that are relatively constant over time (Environment Canada 1972). The land capability index indicated ungulate species the land could theoretically support and was ranked into 7 classes, with the top 3 classes being good, better, and best habitat capability with few limitations for ungulate production. We selected the top 3 classes and considered these areas to have the greatest productivity for ungulates; we excluded the remaining 4 classes because they had moderate to severe limitations and lower probability of ungulates. We did not have a good spatial layer to describe smaller prey items, such as beaver (*Castor canadensis*) and snowshoe hare (*Lepus americanus*), so we used land cover that best approximated habitats where they are generally found. We used conifer forests for snowshoe hares (Hodges 2000, Castilla et al. 2014) and wetland areas (i.e., fen, bog, and open water) using Alberta Merged Wetland Inventory (Alberta Environment and Sustainable Resource Development 2015) for beavers; the wetland inventory was only available for the Boreal Forest.

For climate, we used mapped areas where snow was expected to persist into spring (hereafter, called spring snow coverage), because it was correlated with the circumpolar distribution of wolverines (Copeland et al. 2010). We calculated percent spring snow coverage for each trapline and distance from trapline centroid to nearest spring snow coverage. We also created a temperature index that predicted cooler temperatures as you go higher in elevation and go north in latitude (Jump et al. 2009). We downloaded Canadian digital elevation models (GeoGratis, Sherbrooke, QC, Canada) and calculated the mean elevation of each township (1 township = 10 km × 10 km). Then we compared the centroid northing and mean elevation of a township to mean northing and elevation of all townships in the province to create relative indices that increased with northing (10-km increments) and elevation (10-m increments). We calculated the composite temperature index by summing these indices (i.e., Northing Index + Elevation Index) and determined the mean temperature index value of overlapping townships within each trapline. We predicted cooler temperatures with increasing index values and warmer temperatures with decreasing index values (i.e., larger numbers indicate increase in elevation and/or latitude, smaller numbers indicate decrease in elevation and/or latitude). To test the validity of the temperature index, we measured the relationship between the temperature index values and actual temperatures. We downloaded annual monthly means for August temperatures (°C; 2003–2012) for all weather stations in Alberta (Government of Canada 2017). We determined mean August temperature for each weather station, intersected these locations with the temperature index values of the corresponding township, and calculated the correlation between mean August temperature and temperature index by region.

In the Boreal Forest, we estimated snow depth for each trapline based on interpolated data from the Canadian Meteorological Centre (Brown and Brasnett 2010). Snow depths were derived using interpolation models that incorporated actual daily snow measurements from weather stations, meteorological aviation reports, and special aviation reports from the World Meteorological Organization information system (Brasnett 1999). We calculated the mean winter snow depth (cm; Dec–Mar; 1998–2014) for each trapline based on monthly snow depths of overlapping weather stations.

We considered intact forest as a metric for refuge because they were large (≥1,000 ha), contiguous pieces of land that had not been developed, as visible on Landsat satellite imagery *circa* 2010 (Lee et al. 2010). We measured percent intact forest and distance from trapline centroid to nearest intact forest. We used linear features as a surrogate to the amount of human disturbance in an area. We included all road types (truck trail, unimproved, winter, gravel, and paved roads), seismic–cutlines (strips of land originally cleared for oil and gas exploration that vary in width ~2–8 m), and oil and gas well sites (each well site is ~1 ha of cleared land) mapped to 2013, because these are ubiquitous features of industrial development on the landscape (Schneider 2002). We also included urban population centers (towns ≥ 1,000 people) from Canada Census and measured nearest distance to town from each trapline centroid.

To examine the nonresponse bias, we calculated summary statistics (e.g., mean, standard deviation, min., max.) for a subset of landscape variables on traplines in each region (NW Boreal, NE Boreal, Foothills, and Rocky Mountains). We used a nonparametric Wilcoxon Rank Sum (Mann–Whitney) test to compare covariates on traplines that were and were not surveyed, as well as to compare traplines with and without wolverines based on trapper responses. For wolverine comparisons, we grouped response data from NE–NW Boreal and Foothills–Rocky Mountains because of close proximity to increase sample size.

We built *a priori* candidate models based on competing hypotheses (i.e., food, climate, refuge, disturbance) for examining factors that could affect the distribution of wolverines. To avoid collinearity, we calculated Pearson's correlation coefficient (r) for all pairs of predictor variables by region and did not include variables with high correlations in the same model (i.e., where $|r| \geq 0.7$). We used conditional (fixed-effects) logistic regression to generate models with a fixed variable for region so that we could account for regional effects. Then, we used logistic regression to fit candidate models to investigate the pattern of wolverine observations in the Boreal Forest separately, where we could include additional explanatory variables only available for that region (i.e., wetlands and snow depth). We used an information-theoretic approach to rank models and determine the strength of support for top models; Akaike's Information Criterion (AIC_c) was used because of our small sample size (Burnham and Anderson 2002). We considered models with ΔAIC_c values between 0 and 2 to have substantial support and calculated a weight of evidence (w_i) to determine how likely each model was the best given these data; values range between zero and one with larger values indicating more support. We examined evidence ratios based on the ratio of Akaike weights (e.g., w_1/w_2) to compare level of support of the top models. We also calculated odds ratios to examine the effect that changes in important predictor variables might have on trappers observing wolverines. All spatial and statistical analyses were conducted in ArcMap (Environmental Systems Research Institute, Inc., Redlands, CA, USA) and STATA (StataCorp, College Station, TX, USA).

Table 1. Comparison of mean and standard deviation of landscape variables[a] on surveyed ($n = 164$) and nonsurveyed ($n = 1{,}391$) traplines in Alberta, Canada, during 2009–2012.

	Surveyed traplines			Nonsurveyed traplines		
Variable by region	$\bar{x}$	SD	n	$\bar{x}$	SD	n
NE Boreal						
Trapline size	182.59	180.14	50	181.69	142.56	453
Roads	0.20	0.23	50	0.22	0.25	453
Intact forest	10.97	23.19	50	15.71	29.53	453
Temp index[b]	−10.82	10.04	50	−11.45	10.71	453
Spring snow*	0.98	2.97	50	0.93	2.16	453
NW Boreal						
Trapline size*	368.06	223.06	41	290.65	300.69	463
Roads	0.16	0.18	41	0.19	0.23	463
Intact forest	19.51	23.96	41	20.59	26.1	463
Temp index[b]	10.26	18.5	41	4.96	14.45	463
Spring snow*	6.93	16.89	41	3.99	12.54	463
Foothills						
Trapline size	214.91	160.15	45	162.47	105.74	388
Roads	0.56	0.31	45	0.56	0.37	388
Intact forest	2.51	7.99	45	3.33	10.68	388
Temp index[b,*]	8.08	15.76	45	3.21	15.53	388
Spring snow*	13.98	20.01	45	8.84	17.26	388
Rocky Mountains						
Trapline size	306.64	196.53	28	254.79	176.69	87
Roads*	0.25	0.27	28	0.38	0.29	87
Intact forest	55.70	33.53	28	41.62	33.46	87
Temp index[b]	60.86	26.01	28	52.75	22.92	87
Spring snow	60.18	32.06	28	56.41	28.67	87

[a] Variables: Trapline size (km^2); Density of roads (km/km^2); % Intact forest; Temperature index[b]; % Spring snow coverage.
[b] Temp index is the inverse of Temperature because it is based on latitude and elevation.
* Significant Wilcoxon Rank Sum results ($P \leq 0.05$).

RESULTS

Trapline Responses

We received questionnaires from 164 traplines (Fig. 1). Trappers in our study had been trapping the same area for many years ($\bar{x} = 19 \pm 14$ [SD] yr, range = 1–66 yr, $n = 159$ traplines); few trappers had been trapping for ≤5 years ($n = 10$). Responses consisted of traplines in the Boreal Forest ($n = 91$), Foothills ($n = 45$), and Rocky Mountains ($n = 28$) and represented 9% of the Boreal Forest, 10% of the Foothills, and 23% of the Rocky Mountain traplines available; however, the status and number of inactive traplines (i.e., allocated but no longer trapped) was unknown during our study.

The landscape composition of traplines differed by region and tended to be larger and have more percent intact forest in the NW Boreal and Rocky Mountains, as compared with the NE Boreal and Foothills (Table 1). Access density was greatest in the Foothills and lowest in the NW Boreal. Climate also varied across the regions, with cooler climates and greater percent spring snow coverage in the Rocky Mountains and Foothills. Mean August temperatures (2003–2012) were cooler in the Rocky Mountains ($\bar{x} = 10.83 \pm 4.63$ [SD]° C, $n = 82$) and warmer in the NW Boreal ($\bar{x} = 12.73 \pm 2.01$ [SD]° C, $n = 83$), Foothills ($\bar{x} = 12.74 \pm 3.14$ [SD]° C, $n = 107$), and NE Boreal ($\bar{x} = 13.33 \pm 3.1$ [SD]° C, $n = 68$). The temperature index was correlated with mean August temperatures in the NW Boreal ($r_{81} = -0.46$, $P < 0.001$), Foothills ($r_{105} = -0.34$, $P < 0.001$), NE Boreal ($r_{66} = -0.30$, $P = 0.01$), and Rocky Mountains ($r_{80} = -0.29$, $P = 0.01$). As temperature index values increased (as a result of an increase in elevation and/or latitude), actual temperatures were cooler and vice versa. The high correlations ($r \geq 0.78$) between the temperature index and spring snow coverage in the NW Boreal, Foothills, and Rocky Mountains also provided further evidence that the temperature index was indicative of local climates.

We have no way of knowing whether the returned surveys exhibited sampling bias regarding the class distribution of wolverine present versus no wolverine present in the overall population of traplines (Oommen et al. 2011). As a surrogate for this, we tested for bias in the landscape characteristics of sampled traplines by comparing values of a suite of variables measured for traplines that did and did not respond to our survey. We found that surveyed traplines 1) had more spring snow coverage in the NE Boreal ($P = 0.02$), although the mean spring snow coverage on surveyed traplines was low (<1%); 2) were larger in size ($P < 0.001$) and had more spring snow coverage ($P < 0.001$) in the NW Boreal; 3) had a cooler temperature index ($P = 0.02$) and more spring snow coverage ($P = 0.05$) in the Foothills; and 4) had lower density of roads ($P = 0.03$) in the Rocky Mountains, as compared with nonsurveyed traplines (Table 1). However, most of the comparisons showed no significant difference (14 of 20; Table 1). Samples were not collected randomly and some of the variables were significantly different for the sampled traplines; therefore, we assume that there may also have been some class-distribution sampling bias. This does not preclude the use of logistic regression for such data, but does affect interpretation and application of results, allowing for the identification of important habitat variables associated with the pattern of observation, but preventing the calculation of probability of use for individual traplines (Keating and Cherry 2004, Oommen et al. 2011). As such, our focus was on variables found to be significant in separating the classes (observed vs. not observed; Oommen et al. 2011) and odds ratios associated with those variables included in the top models (Keating and Cherry 2004).

Wolverine Observations

Thirty-three percent of traplines in our survey harvested a wolverine on their trapline at some point in the past, whereas 16% of traplines indicated that they caught a wolverine every 1–2 years ($n = 164$ traplines). Wolverine sign was variable depending on region, but 41% of surveyed traplines responded that it was common to observe wolverines in the northern Boreal (>55°N, $n = 69$ traplines), as compared with 31% in the Rocky Mountains ($n = 28$ traplines), 14% in west-central–Foothills ($n = 45$ traplines), and 0% in the southern Boreal (<55°N, $n = 22$ traplines; Fig. 2).

We excluded 20 responses from our modelling analysis because it was unclear whether trappers had observed wolverines recently or the trapline was new to them (≤5 yr). Forty-seven percent of responses ($n = 144$ traplines) indicated they had observed wolverine sign recently on their trapline in ≥1 of the past 3 years (2009–2012). In the NE Boreal, correlations were found between temperature index and snow depth ($r_{13} = 0.73$, $P < 0.001$), snow depth and percent intact forest ($r_{12} = 0.89$, $P < 0.001$), and temperature index and distance to town ($r_{48} = 0.75$, $P < 0.001$). In the NW Boreal, percent spring snow coverage and temperature index were correlated ($r_{39} = 0.79$, $P < 0.001$). In the Foothills, correlations were found between percent spring snow coverage and the temperature index ($r_{43} = 0.78$, $P < 0.001$) and percent conifer forest and the temperature index ($r_{43} = 0.76$, $P < 0.001$). In the Rocky Mountains, there were correlations between most of the covariates. We did not find a significant correlation between percent conifer forest and intact forest.

When we included data from all regions ($n = 144$ traplines), the best model included percent intact forest ($\beta = 0.041$, $SE = 0.01$, $P \leq 0.001$, $w_i = 0.76$; Table 2). Percent intact forest explained 15% of the variation in the reports of wolverine occurrence. The odds ratio suggested that each increase of 1% in the amount of intact forest increased the odds of a trapper observing wolverine sign by 4%. As intact forest increased, the proportion of traplines where wolverines were observed also increased (Fig. 3). A lower proportion of traplines reported wolverine observations when intact forest was <50% of the trapline area. There was also evidence ($\Delta AIC < 4$) that the temperature index ($\beta = 0.038$,

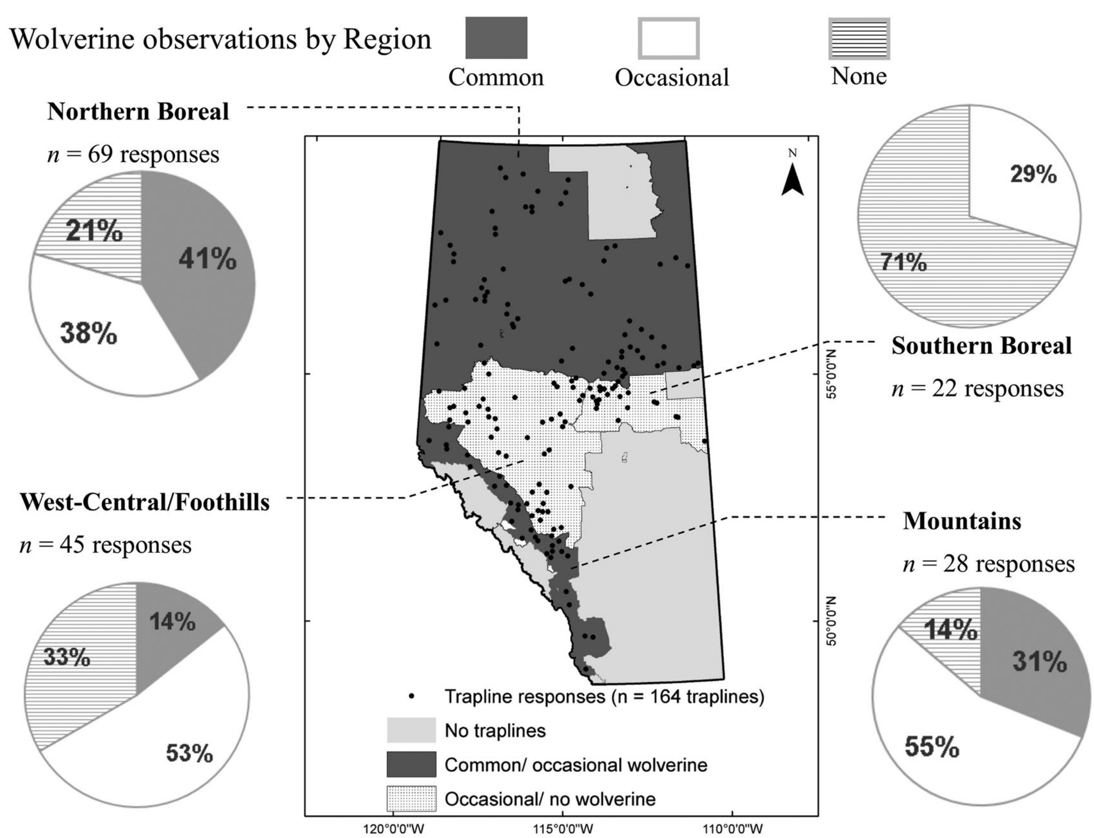

Figure 2. Comparison of wolverine sign (i.e., common, occasional, none) observed by trappers (2009–2012) in Alberta, Canada.

Table 2. Models considered for full data set (all regions) where response variable was whether or not wolverine sign was recently observed (2009–2012) on a trapline in Alberta, Canada ($n = 144$).

Model	Variables[a]	AIC_c^b	ΔAIC_c^c	w_i^d
Refuge	Intact forest	134.52	0.00	0.76
Climate + Disturb	Temp index[e] + Roads	137.15	2.63	0.20
Climate	Temp index[e]	141.82	7.30	0.02
Refuge	Dist to town	142.83	8.30	0.01
Disturb	Roads	144.51	9.99	0.01
Refuge	Dist to intact forest	145.54	11.02	0.00
Climate	Spring snow	148.38	13.86	0.00
Food	Conifer + Ungulates	157.61	23.09	0.00
Climate	Dist to Spring snow	158.91	24.39	0.00

[a] Variables: % Ungulates; % Conifer forest; Density of roads (km/km^2); Nearest distance to town (km); % Intact forest; Nearest distance to intact forest (km); Temperature index[e]; % Spring snow coverage; Nearest distance to spring snow coverage (km).
[b] Akaike's Information Criterion (AIC_c).
[c] ΔAIC_c ($AIC_{ci} - AIC_{cmin}$).
[d] Weight of evidence (w_i).
[e] Temp index is the inverse of Temperature because it is based on latitude and elevation.

SE = 0.013, $P = 0.002$) and road density ($\beta = -2.474$, SE = 0.949, $P = 0.009$) predicted reports of wolverine occurrence, although this model had lower weight of evidence ($w_i = 0.2$) and an evidence ratio of 3.80. There was no support for spring snow coverage, conifer forest, or ungulate covariates in our provincial models.

When we considered responses from only the Boreal Forest ($n = 81$ traplines), wolverines were observed in areas that were further from towns, had more percent intact forest, in closer proximity to intact forest, had cooler temperature index values, had deeper snow depths, and more percent spring snow coverage (Table 3). We had a distinct increase in wolverine observations with increasing latitude and westerly longitude; latitude explained 44% and longitude explained 15% of the variation in wolverine observations in the Boreal Forest. The models indicated that the temperature index was a strong predictor, explaining 31% of the variation in wolverine observations. Although spring snow coverage was greater on surveyed traplines and traplines that reported wolverines, mean amounts were low (7% with wolverines vs. 1% no wolverines), and there was little support for spring snow coverage among our competing models ($w_i \leq 0.001$); spring snow coverage explained approximately 5% of the variation in wolverine observations. Cooler climates and lack of human disturbance appeared to be important covariates associated with trappers observing wolverine. The top model had a high weight of evidence ($w_i = 0.79$) and indicated that wolverine observations were more likely to be in areas that had cooler predicted temperatures ($\beta = 0.095$, SE = 0.025, $P \leq 0.001$) and more percent intact forest ($\beta = 0.03$, SE = 0.015, $P = 0.046$; Table 4). The odds ratio suggested that the odds of a trapper observing recent wolverine sign increased 10% with each increase of either 10 km further north or 10 m of elevation gain across their trapline. The odds ratio also showed that the odds of a trapper observing wolverine increased 3% with each 1% increase of intact forest within their trapline area. There was weak evidence that food covariates differed on traplines where trappers did and did not report wolverines (Tables 3 and 4).

DISCUSSION

We combined local ecological knowledge of experienced trappers and landscape features to explore the variation in the distribution of wolverines across the province of Alberta. Traplines covered diverse latitudes (49–59°N) and landscapes with wide ranges in the land cover, climate, and human footprint, allowing us to investigate potential habitat associations of wolverines at a coarse scale. Insights from trappers provided valuable baseline data on a sensitive species that are complementary to other research findings, and stimulated hypotheses about the relationships among wolverine distribution, climate, and human disturbance. Based on our findings, we hypothesize that 1) wolverines in Alberta's boreal forest are associated with areas of cooler climate, but they are not limited by the distribution of late spring snow coverage; and 2) the overall distribution of wolverines in Alberta is influenced by anthropogenic disturbance more so than climate.

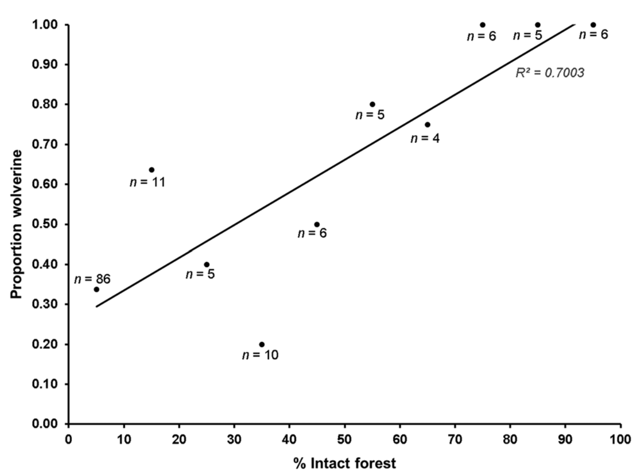

Figure 3. Scatterplot of percent intact forest midpoint (x) and proportion of trapline responses where trappers observed wolverines recently (2009–2012; y) in Alberta, Canada.

Table 3. Summary statistics of landscape variables[a] measured on traplines where wolverines were and were not recently observed (2009–2012) by trappers in the Boreal Forest of Alberta, Canada.

Variable	Wolverine			No wolverine			P
	$\bar{x}$	SD	Range	$\bar{x}$	SD	Range	
Ungulate	32.30	34.11	0.00–100.00	18.04	25.71	0.00–100.00	0.11
Conifer	33.22	21.00	1.00–81.75	33.12	24.47	0.11–90.34	0.70
Wetland	0.31	0.20	0.01–0.76	0.34	0.21	0.004–0.88	0.63
Roads	0.13	0.14	0.00–0.60	0.23	0.25	0.00–0.98	0.12
Wellsites	0.03	0.06	0.00–0.28	0.15	0.35	0.00–1.84	0.06
Cutlines	1.87	1.21	0.12–4.64	1.99	0.78	0.82–3.86	0.31
Dist to town	88.56	49.51	13.26–170.82	57.57	31.10	13.05–119.12	0.003
Intact forest	25.38	29.48	0.00–93.37	7.17	14.45	0.00–50.47	≤0.001
Dist to intact forest	9.25	12.44	0.00–35.92	21.28	19.39	0.00–81.76	≤0.001
Temp index[b]	10.98	20.37	−20.09–53.37	−8.49	10.92	−29.67–37.99	≤0.001
Snow depth	23.22	7.17	12.84–37.16	17.30	3.48	11.61–30.43	≤0.001
Spring snow	6.95	16.32	0.00–64.00	1.22	6.04	0.00–42.00	0.01
Dist to spring snow	15.55	14.45	0.00–47.44	11.29	7.92	0.51–30.9	0.49

[a] Variables: % Ungulates; % Conifer forest; Wetland (proportion); Density of roads (km/km^2); Density of wellsites (wells/km^2); Density of cutlines (km/km^2); Nearest distance to town (km); % Intact forest; Nearest distance to intact forest (km); Temperature index[b]; Mean snow depth (cm); % Spring snow coverage; Nearest distance to spring snow coverage (km).
[b] Temp index is the inverse of Temperature because it is based on latitude and elevation.

Our assessment of patterns in wolverine observations among trappers had many similarities to previous fur harvest and trapper survey results. Fur harvest records provide a useful starting place to gather background information on where species are trapped, but likely underestimates the species' distribution at finer scales. Local knowledge provides opportunity to gather more specific information on species occurrence and directly engages trappers in research. We were surprised that far more trappers reported observing wolverines than trapping wolverines. This demonstrates a trapper survey can add value to harvest distribution maps that are constrained by trapper effort (i.e., actively trapped areas; Webb and Boyce 2008).

Fur harvest trends suggest wolverines were more common in the northern Boreal (>55°N) and mountains, and infrequently caught in the Foothills (Webb et al. 2016). We found that 39% of the traplines in the Foothills reported seeing wolverine sign recently, despite low occupancy documented by other researchers in the Foothills (Fisher et al. 2013, Heim et al. 2017). This discrepancy could be related to trappers spending years in the same trapping area and having greater opportunity to encounter animals, whereas research studies offer a seasonal snapshot over a small area and may miss animals (Pybus 2005). However, wolverines have large home ranges and the same wolverine's tracks could be observed by multiple trappers when traplines are smaller, as they tend to be in the Foothills. The previous trapper survey indicated that the wolverine distribution was a mix of widespread, moderate, and sparse in the Foothills, and our results support that variation (Skinner and Todd 1988).

Based on wolverine harvest density and spring snow coverage, we expected wolverine sign to be considered common more frequently in the mountains and were surprised that a similar percent of trappers observed wolverines occasionally in the mountains and adjacent west-central–foothills areas (Copeland et al. 2010, Webb et al. 2016). Although trappers reported wolverine distribution to be mostly widespread in

Table 4. Boreal Forest models considered where response variable was whether or not wolverine sign was recently observed (2009–2012) on a trapline in Alberta, Canada ($n = 81$).

Model	Variables[a]	AIC$_c^{b}$	ΔAIC$_c^{c}$	w_i^{d}
Climate + Refuge	Temp index[e] + Intact forest	95.12	0.00	0.79
Climate + Disturb	Temp index[e] + Roads	97.93	2.81	0.19
Climate	Snow depth	102.94	7.82	0.02
Refuge	Dist to town + Intact forest	108.24	13.12	0.00
Refuge + Climate	Dist to intact forest + Dist to spring snow	113.14	18.02	0.00
Climate	Spring snow	120.61	25.49	0.00
Disturb	Roads + Wellsites + Cutlines	122.17	27.05	0.00
Food	Ungulates + Wetlands + Conifer forest	125.23	30.11	0.00

[a] Variables: % Ungulates; % Conifer forest; Proportion wetland; Density of roads (km/km^2); Density of wellsites (wells/km^2); Density of cutlines (km/km^2); Nearest distance to town (km); % Intact forest; Nearest distance to intact forest (km); Temperature index[e]; Mean snow depth (cm); % Spring snow coverage; Nearest distance to spring snow coverage (km).
[b] Akaike's Information Criterion (AIC$_c$).
[c] ΔAIC$_c$ (AIC$_{ci}$ − AIC$_{cmin}$).
[d] Weight of evidence (w_i).
[e] Temp index is the inverse of Temperature because it is based on latitude and elevation.

the mountains in the 1980s, they still considered their relative abundance to be sparse, which concurs with our findings (Skinner and Todd 1988). Similarly, our results concur with an earlier study where trappers reported that the wolverine distribution was widespread and had greater relative abundance in the northern Boreal, as compared with other areas of the province (Skinner and Todd 1988). Our results suggesting wolverines are uncommon in the southern Boreal also support what trappers reported in the 1980s, although the authors indicated they had insufficient data in that area (Skinner and Todd 1988). It is interesting that the overall distribution of wolverines appears to be similar to the 1980s trapper survey, despite increasing anthropogenic development, changes in trapping effort (e.g., declining number of trappers, low pelt prices, improved off-road vehicles), and fluctuations in fur harvests (Poole and Mowat 2001, Schneider 2002, Webb et al. 2016).

Studies have associated the presence of wolverines with the absence of people and less developed landscapes (Banci 1994, Fisher et al. 2013, Fisher and Bradbury 2014, Stewart et al. 2016). Local ecological knowledge supports this theory—we found that undeveloped, intact forest further from large towns was commonly associated with where trappers observed wolverines, especially in northern Alberta. Fewer wolverines were observed in the Foothills, where industrial development and associated infrastructure is widespread, climate is milder, and predator assemblage is diverse (Fisher et al. 2013, Stewart et al. 2016, Webb et al. 2016, Heim et al. 2017). In our study, the Foothills traplines had at least double the density of roads compared with other regions and low amounts of intact forest. The places that tend to be further from people also tend to be more rugged in terrain, higher in elevation, and further north in latitude. Although our results highlight the importance of areas with low levels of human disturbance for wolverine observations, additional research is needed to understand underlying mechanisms (e.g., mortality risk, avoidance behavior, etc.) and correlated variables including cooler climates and landscape features (Fisher et al. 2013).

More recently, climate has been debated as a crucial component for the persistence of wolverines (Aubry et al. 2007, Copeland et al. 2010). Although there is evidence that wolverines live, move, and den in places where snow covers the ground into late spring (Aubry et al. 2007, Copeland et al. 2010, Magoun et al. 2017), we did not find strong support for the importance of spring snow coverage within Alberta. Instead, the temperature index, based on elevation and latitude, was the most important climate variable in our models. Wolverine observations generally increased with latitude, but we had some areas in northern Alberta (54–56°N) where trappers reported no wolverines. Warmer August temperatures in NE Boreal may be indicative of a less favorable climate and contribute to lower occurrence of wolverines there, but deserves more in-depth study because we had a small sample size of trapline responses from this area. Although large areas with spring snow coverage are mostly limited to the mountains in our study, our results support the fact that wolverines are adapted to cooler climates, where food resources and competition for them are likely limited (Copeland et al. 2010, Inman et al. 2012).

Although we did communicate the value of getting questionnaires from all traplines, regardless of wolverine occurrence, willingness to participate was likely greater for trappers that were familiar with wolverines, and therefore interested in the topic. Our study may have exhibited sampling bias regarding the class distribution of the response variable (wolverine recently observed or not). To address this, we have appropriately limited our interpretation to the identification of variables that help to explain the patterns in observations and the odds ratios associated with those variables included in the top models (Keating and Cherry, 2004, Oommen et al. 2011). Our results cannot be used to estimate the probability of observing wolverines on a specific trapline, but rather give a qualitative ranking of habitats based on geographic location and disturbance level in the surrounding forest. Although we developed questions with input from trappers, there was some reluctance to divulge potentially sensitive information, which trappers perceived could be used against them. These views could have been prompted by trapper concerns about recent proposals to list wolverine as a threatened species in the contiguous United States (USFWS 2013), reported wolverine declines in Alberta (COSEWIC 2014), and increasing antitrapping attitudes by the general public (White et al. 2015). Although trapper participation in research highlights an important contribution by stakeholders facing increasing scrutiny, low survey response rates can make the results difficult to interpret (Webb and Anderson 2016). Creative strategies need to be developed to increase response rates, particularly if trapper contact information is confidential and difficult to obtain. We recommend that researchers work closely with stakeholders when designing a questionnaire to better understand social considerations. Investing time to develop relationships may also help to ensure adequate participation and data quality. We suspect that we would have gotten better response rates if we had repeated the survey after having worked closely with the trapping community on a co-created citizen science project for multiple years (Webb and Anderson 2016).

Obtaining and interpreting trapping-related data are challenging, but collective knowledge of trappers represents a rich source of mutually beneficial information that can be used in conjunction with other data sources (Pacifici et al. 2017). In addition to engaging stakeholders in research, LEK is a valuable approach for developing a knowledge base of a species and generating hypotheses about habitat relationships that can supplement landscape use studies. Trapper engagement stimulated cooperative research to assess wolverine habitat selection and the relationship of female wolverines to spring snow cover (Webb et al. 2016, Scrafford et al. 2017). Our study reiterates that LEK from experienced observers is a valid approach to help examine the distribution of wildlife species over large areas and could be used to optimize survey design for future studies (Gilchrist et al. 2005, Parry and Peres 2015, Reich et al.

2018). Trappers are uniquely connected to the environment and often bring a long-term historical understanding of the wildlife that inhabit their trapping areas. We encourage researchers and managers to engage traditional users of the landscape, who have great potential to offer valuable insight into other systems (e.g., hunters, anglers) and can be vocal advocates for conserving wildlife into the future.

MANAGEMENT IMPLICATIONS

This study suggests wildlife managers can efficiently use LEK from trappers to evaluate trends in wolverine observations and link those trends to relevant climate and landscape features. Similarly, trappers may have insights about the distributions of other rare wildlife species. Experienced trappers revealed information about wolverine spatial patterns across large, often remote, areas that would have been difficult to quantify using more traditional research methods (e.g., camera, hair, or snow-track surveys). We recommend that wildlife managers conduct periodic surveys with trappers to assess the status and distribution of wolverines, as well as landscape features that may be associated with their occurrence. Engaging trappers in research may carry the ancillary benefit of promoting trust in the information among the trappers. Trappers who want to see wolverines persist over the long term may be motivated to engage with local government and industrial planning exercises by providing LEK. By doing so, they will be helping to manage resource development and conserving land for the benefit of wolverines and many other species that they value.

ACKNOWLEDGMENTS

We are grateful to the trappers who participated in this research. We thank J. Mitchell for providing input when developing the questionnaire, B. Taylor for Geographic Information System assistance, and J. P. Copeland for the spring snow coverage data. We appreciated K. Norstrom, G. Chapman, J. Gerwing, C. Wilson, D. Forsythe, and L. Berg for helping distribute questionnaires to trappers at regional fish and wildlife offices. We also thank J. Brammer, 2 anonymous reviewers, and the Associate Editor for comments to improve our paper. This study was supported by Alberta Conservation Association and Alberta Trappers' Association.

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Associate Editor: Peterson.

SUPPORTING INFORMATION

Additional supporting material may be found in the online version of this article at the publisher's website. The complete questionnaire includes all the questions and information collected from trappers who were surveyed. Trappers were asked to provide information about observations of wolverine sign, harvest history, and opinions about population trends.