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Management and Conservation

Comparing Traditional Ecological Knowledge and Western Science Woodland Caribou Habitat Models

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ABSTRACT Negotiating the complexities of wildlife management increasingly requires new approaches, especially where data may be limited. A robust combination of traditional ecological knowledge (TEK) and western science has the potential to improve management decisions and enhance the validity of ecological inferences. We examined the strengths and weaknesses of predicting woodland caribou (*Rangifer tarandus caribou*) habitat selection with resource selection functions (RSF) based on western science and TEK-based models within the territory of the Taku River Tlingit First Nation of northern British Columbia. We developed seasonal RSF models with data from 10 global positioning system collared caribou. We generated TEK-based habitat suitability index models from interviews with Taku River Tlingit members. We tested the ability of both habitat models to spatially predict the occurrence of collared caribou locations. To portray differences between the models, we statistically and visually compared the spatial predictions of TEK and RSF modeling approaches using Kappa statistics and *k*-fold cross validation. Kappa statistics of habitat ranks from the models showed substantial agreement during summer ($K = 0.649$) and fair agreement during winter ($K = 0.337$). We found that both TEK and RSF models predicted independent caribou locations (Spearman's rank correlations from *k*-fold cross-validation ranged from 0.612 to 0.997). Differences in model performance were a result of RSF models predicting more relatively high quality habitat than TEK models. Given the widespread declines of woodland caribou across the boreal forest of Canada, and the requirement of the Canadian Species at Risk Act to incorporate both traditional and western science approaches into recovery planning, our results demonstrate that TEK-based habitat models can effectively inform recovery planning for this imperiled species.

KEY WORDS critical habitat, habitat suitability index models, local ecological knowledge, *Rangifer tarandus*, recovery planning, resource selection functions, Species at Risk Act, traditional ecological knowledge.

The value of using traditional ecological knowledge (TEK) in contemporary wildlife management, policy, and conservation is growing (Schmidt and Stricker 2010, Huntington 2011). People who spend significant time on the land have intimate knowledge of wildlife distributions, behavior, movements, body conditions, and habitat relationships (Lyver and Łutsël K'é Dene First Nation 2005, Kendrick and Manseau 2008). TEK often emerges over long temporal scales and includes population-level inferences about wildlife that can offer complementary insights to shorter-term and smaller-scale scientific studies (Moller et al. 2004, Rist et al. 2010). For example, TEK has been successful in providing novel insights into species ecology (Ramstad et al. 2007), identifying baseline conditions (Nichols et al. 2004), describing historical species distributions (Ferguson and Messier 2000, Santomauro et al. 2012), and resolving land management issues (Sandström et al. 2003). Recent studies demonstrate that when TEK is brought into play early in a wildlife management process, the combination with scientific data can lead to more efficient and effective wildlife management decisions (Kendrick and Manseau 2008, O'Flaherty et al. 2008). Finding collaborative opportunities to include TEK in modern wildlife management is a priority for management agencies, conservation organizations, and indigenous people. This is especially true in northern North America where management is often explicitly required to include TEK.

TEK is often defined as an understanding of the environment that comes from a historical continuity in resource use in a particular place (Berkes 1999). In this context, the term traditional implies knowledge handed

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down through generations in the form of oral history, in contrast to local ecological knowledge (LEK) that is based on direct experiences (Anadón et al. 2009). However, because LEK is regularly embedded within cultural practices, distinguishing LEK from TEK can be difficult, especially when referring to knowledge of indigenous peoples. Thus, TEK and LEK can both represent a significant source of high quality information about ecological relationships. Though fundamental differences between TEK, LEK, and western science exist, all are empirical knowledge systems established through observation and experience (Berkes et al. 2000). All have the ability to test predictions, interpret results within a cultural framework, and adjust expectations when presented with new data (Davis and Ruddle 2010). As a result, TEK and western science often have related questions, predictions, and goals in relation to the management of natural resources.

The conservation and recovery of woodland caribou (*Rangifer tarandus caribou*) is an endangered species priority that directly intersects with the needs, interests, and knowledge of indigenous people throughout northern North America (Vors and Boyce 2009, Festa-Bianchet et al. 2011). Across Canada, boreal and southern mountain woodland caribou are listed as threatened under the Canadian Species at Risk Act (SARA) because of habitat loss associated with oil, gas, mining, and forestry extraction (Wittmer et al. 2005*a*, Apps and McLellan 2006, Schaefer and Mahoney 2007). Human development has also altered predator-prey relationships causing widespread population declines (Vors and Boyce 2009) and recently, extirpation of some herds (Wittmer et al. 2005*b*, Hebblewhite et al. 2010). Recovery planning for woodland caribou is challenged by the spatial scales associated with identifying critical habitat at a national level, factious politics of endangered species regulation, and the legal requirement under SARA to explicitly include TEK in the recovery process (Government of Canada 2002). Prominence of TEK in woodland caribou recovery planning is perhaps unprecedented among world endangered species legislation, reflecting the importance of this species to indigenous people and the legal treaty rights to the lands in which caribou exist. Although potentially beneficial as a conservation strategy, few examples demonstrate how to use TEK to guide endangered species recovery.

Endangered species legislation prioritizes the conservation of critical habitat, a legal concept that can be challenging to define (Mooers et al. 2010). The first step is to understand habitat selection by relating the species selection of resource units to environmental variables (Boyce et al. 2002). Resource selection functions (RSF) use a statistical approach to measure habitat selection by examining use or avoidance of a resource relative to its availability (Manly et al. 2002). However, RSFs are limited by the spatio-temporal scales of animal location data, which are often collected for only a few animals (relative to the entire population) and over a short-time frame. Habitat suitability index (HSI) models, alternatively, predict habitat quality based on expert opinion (U.S. Fish and Wildlife Service 1981). Thus, the basis of HSI modeling is consistent with TEK and LEK. Using TEK and LEK to develop HSI models is particularly useful when statistical limitations result from nonexistent, incomplete, or biased empirical data (Johnson and Gillingham 2004, Doswald et al. 2007, Perera et al. 2012). In an era of inadequate funding and time for animal-based field studies, the value of TEK should be recognized, particularly in areas where intensive scientific studies are unrealistic. A challenge to the effective use of TEK has been how to explicitly use TEK and ensure that it meets rigorous quality standards. For example, managers must examine how well models that are informed by TEK (e.g., HSI models) predict animal locations, especially for endangered or threatened species (Nielsen et al. 2003, Doswald et al. 2007).

The goal of our study was to examine how alternative modeling approaches and information sources can be used in conjunction to inform endangered species recovery. Our first objective was to develop and test independent TEK and western science woodland caribou habitat models. Second, we statistically and visually compared the spatial predictions of TEK and western science models using *k*-fold cross-validation and spatial Kappa statistics. We conclude by making recommendations for the use of TEK in wildlife management and endangered species recovery planning.

STUDY AREA

We focused on an 11,594-km^2 home range area of the Atlin northern mountain woodland caribou herd that intersects the 48,000-km^2 traditional territory of the Taku River Tlingit First Nation (TRTFN) in northwest British Columbia (Fig. 1). Mountain ranges with high peaks, broad plateaus, and wide valleys characterize the study area. Elevations range from 660 m to 2,000 m. Lower elevation boreal forests included open lodgepole pine (*Pinus contorta latifolia*), subalpine fir (*Abies lasiocarpa*), and white spruce (*Picea glauca*). Mid-elevations transition into krummholz where willow (*Salix* spp.) and dwarf birch (*Betula glandulosa*) dominate. Alpine habitats consist of herbs, bryophytes, sedges (*Carex* spp.), and altai fescue (*Festuca altaica*) tundra. Trembling aspen (*Populus tremuloides*), black cottonwood (*Populus balsamifera trichocarpa*), and willow dominate valley bottoms. More details of the study area can be found in Polfus et al. (2011).

The northern mountain woodland caribou ecotype occurs throughout the Yukon Territory, Northwest Territories, and northwestern British Columbia and includes the traditional territory boundaries of 33 First Nations (Environment Canada 2012*a*). Northern mountain woodland caribou were listed under SARA as a species of special concern in 2004 in response to population declines resulting from habitat loss and fragmentation, human-induced changes to predator–prey dynamics, overharvest, and proliferation of human development (Environment Canada 2012*a*). Historically, tens of thousands of Tlingit maintained camps and villages from Â Tlèn (Atlin Lake) to T'àkhú (the Taku River) near Juneau, Alaska (McClellan 1981). Woodland caribou have always been a culturally important source of meat and other animal products for the TRTFN. In the early 1990s, concerns for population

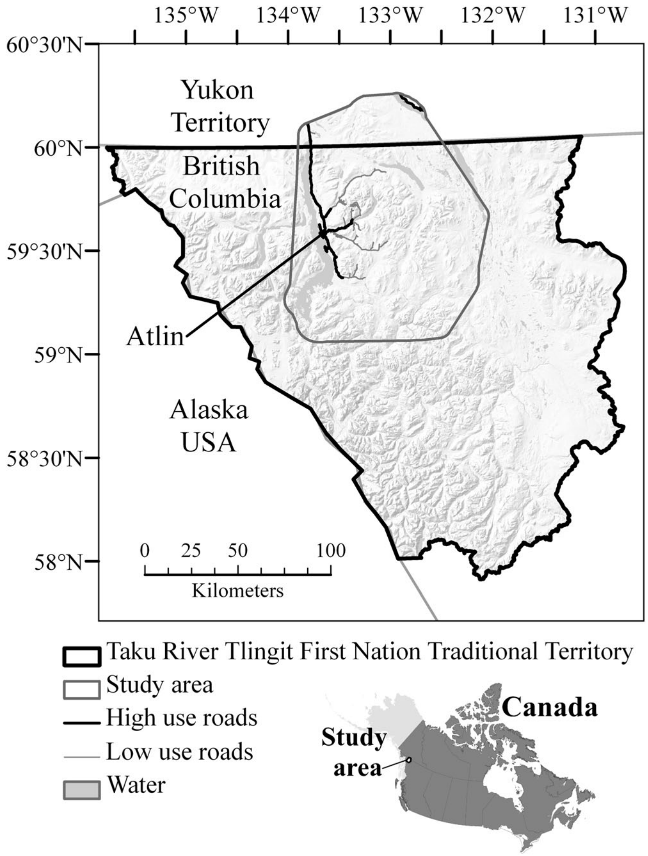

Figure 1. The home range area of the Atlin northern mountain woodland caribou herd that intersects the traditional territory of the Taku River Tlingit First Nation in North America on the border of the Yukon Territory and British Columbia, Canada.

declines of the Atlin, Carcross-Squanga, and Ibex caribou herds caused many First Nation hunters to reduce or eliminate their harvest of caribou (Farnell 2009). Recent aerial surveys indicated that the Carcross-Squanga and Ibex herds have increasing population sizes with sustainable recruitment, whereas the Atlin herd consistently exhibits stable or decreasing recruitment indices indicative of population declines (Taku River Tlingit First Nation and British Columbia 2010).

METHODS

The Ministry of Water, Land, and Air Protection of British Columbia monitored caribou in the Atlin herd with global positioning system (GPS) collars (GPS 2000, LOTEK, Aurora, Ontario, Canada) between January 2000 and January 2002 and very high frequency (VHF) collars from December 1999 to March 2003 as part of an ungulate monitoring program (Polfus 2010). Caribou were captured by helicopter net-gun and physically restrained during collaring (Resource Inventory Committee 1998; procedures were part of a study plan approved by the Ministry of Water, Land, and Air Protection). Locations were recorded by GPS collars every 4 hr. Fix-rates were >90%; therefore, we assumed no significant habitat-induced fix-rate bias (Frair et al. 2010). Seasonal VHF locations (which were used only for model validation) were collected from fixed-wing aircraft 1–2 times/month. The GPS locations used for RSF modeling had locational accuracy of approximately 31 m (e.g., Hebblewhite 2006). We did not explicitly account for telemetry error because a primary focus of the study was on evaluating caribou response to human activity, and continuous covariates such as distance to human activity are known to be less affected by positional error than categorical covariates (Montgomery et al. 2011).

Model Variables

We included resource variables previously identified as influential predictors of northern woodland caribou habitat selection. Northern woodland caribou forage on terrestrial lichen in winter in forested and alpine windswept areas (Johnson et al. 2000, Gustine and Parker 2008, Farnell 2009). We used a 13-class land cover classification that was derived from Landsat TM satellite imagery (30-m resolution, minimum map unit was 900 m^2; Polfus 2010). We extracted elevation (m), slope (degrees), aspect (degrees), and hillshade from the Terrain Resource Information Management digital elevation model (30-m resolution) using ArcGIS 9.3.1 (Environmental Systems Research Institute, Redlands, CA). High hillshade values represent western slopes with high sun exposure, low values are indicative of shaded slopes. Snow affects caribou resource selection (Johnson et al. 2000); thus, we generated percent snow cover by averaging all 8-day composites of maximum snow extent maps in both winter and summer separately at 500-m resolution from Moderate Resolution Imaging Spectroradiometer (MODIS) satellites (Hall et al. 2000). To represent alpine areas where residual snow patches were likely to persist, we divided the number of days snow occupied a MODIS cell by the number of days in the May–June period to generate spatial models of percent snow cover for May and June. The RSF models also incorporated an index of primary productivity that was produced by averaging all 16-day MODIS composites of the normalized difference vegetation index (NDVI) in winter and summer at a 250-m resolution (Pettorelli et al. 2005). Caribou avoid recent burns because fire destroys slow growing lichen (Gustine and Parker 2008). Though fires are rare in the study area, we extracted burned lodgepole (stands that had burned since 1950) from the lodgepole pine land cover class with data from provincial fire history. More information about derivation of the habitat covariates can be found in Polfus et al. (2011).

Resource Selection Functions

We developed RSF models with a use-availability design (Manly et al. 2002) by comparing covariates at caribou GPS locations to random available locations within pooled 99% fixed-kernel seasonal ranges (for detailed methods, see Polfus et al. 2011). We generated available points using a 1:1 ratio of used to available locations. We developed models at the second-order (landscape) scale (Johnson 1980) during winter (15 Nov–15 May) and summer (16 May–14 Nov). We defined seasons based on elevational shifts in caribou locations (sensu DeCesare et al. 2012). We evaluated habitat selection with generalized linear mixed-models with a random intercept for each animal to account for sample size and autocorrelation (Gillies et al. 2006, Fieberg et al. 2010). We included human covariates in the models as a cumulative zone of influence (ZOI; Gunn et al. 2011). The distance the ZOI extended around human covariates varied by development type and season, and represented the area around developments avoided by caribou (Polfus et al. 2011). We spatially mapped the RSFs in ArcGIS 9.3.1 and divided the probability of selection into 10 equal-ranked bins (based on the number of pixels) from 1 (low quality habitat) to 10 (high quality habitat).

TEK Habitat Suitability Index Models

The TRTFN and Round River Conservation Studies staff conducted interviews with 8 TRTFN members in the winter and spring of 2000 and 2001 to develop a regional conservation area design as part of landuse planning, and to develop HSI models for caribou. Interviews were conducted with permission from and in long-term collaboration with the TRTFN. All interviews were conducted in English. Participants were regarded as expert hunters, gatherers, and community elders and were selected by band members from the approximately 100 TRTFN members that reside in the Atlin area (Department of Indian Affairs and Northern Development 2001). All interviewees had >40 years of experience living, hunting, and subsisting in the study area. The knowledge represented information likely obtained by individuals through a combination of direct experience, shared information, and childhood education and tutelage by elders and parents. Thus, cultural learning, stories, and teachings (TEK) were inextricably intertwined with information collected over a lifetime of living and working on the land (LEK).

Questions about cultural practices and knowledge specific to numerous animal species were used to guide individual semi-directive interviews (Huntington 1998, Lyver and Łutsël K'é Dene First Nation 2005). Interview length depended on the knowledge of the participant, varying from an hour to several days. Questions about seasonal use and food resources for key wildlife species were explored during interviews. Participants drew important areas and animal locations on maps. All interviews were voice recorded and later transcribed. The TRTFN retained copies of all the recordings and hold intellectual property rights to the research materials. We analyzed information from interviews on caribou habitat requirements (i.e., land cover types, habitat associations, seasonal foraging strategies, and other resources that were associated with caribou during different times of the year) and summarized this information.

The process used to develop the TEK-HSI models is similar to other HSI modeling efforts (Johnson and Gillingham 2004) that include expert data (literature or expert opinion) and is interpretive and highly contextual. The HSI values represent the relative value of different environmental features (such as land cover type, availability of water, etc.) to caribou habitat use. We linked the habitat descriptions described in interviews with the same spatial resource covariates that we used to generate the RSF models (Table 1). We subsequently used these variables to create rule-based HSI models for summer (Jun–Nov) and winter (Dec–May) to match seasonal periods of the RSFs. Habitat

Table 1. Seasonal caribou (β) coefficients and standard errors for covariates from generalized linear mixed models with a random intercept predicting relative selection at the second-order scale (Johnson 1980) for the Atlin herd of northern mountain woodland caribou in northern British Columbia, 2000–2002.

	Summer				Winter			
Covariate	Selectivity β	SE	95% CI		Selectivity β	SE	95% CI	
LP[a]-lichen	−0.733	0.1465	−1.020	−0.445	0.569	0.0624	0.447	0.691
Mixed conifer	−0.857	0.0920	−1.037	−0.676				
Krummholz	0.329	0.1131	0.107	0.550	−0.919	0.1399	−1.193	−0.645
Burn LP					−0.866	0.1684	−1.196	−0.536
Spruce-fir					0.232	0.0625	0.110	0.355
Low valley willow					0.687	0.0937	0.503	0.870
Alpine shrub	0.495	0.1031	0.293	0.697				
Alpine tundra	0.596	0.1117	0.377	0.815	−0.699	0.1634	−1.019	−0.379
Rock	0.298	0.1388	0.026	0.570	−1.659	0.6140	−2.862	−0.456
Water	−3.198	0.3123	−3.810	−2.586	−0.827	0.1519	−1.125	−0.529
Elevation	0.012	0.0012	0.010	0.014	0.017	0.0012	0.015	0.019
Elevation^2	−4.44E−06	4.540E−07	−5.33E−06	−3.55E−06	−7.23E−06	5.640E−07	−8.34E−06	−6.13E−06
Slope	0.037	0.0078	0.022	0.053	−0.050	0.0034	−0.057	−0.044
Slope^2	−0.002	0.0002	−0.003	−0.002				
Hillshade	0.004	0.0006	0.002	0.005	0.006	0.0009	0.005	0.008
NDVI[b] summer	−2.71E−04	1.660E−05	−3.04E−04	−2.39E−04	0.003	0.0003	0.003	0.004
NDVI summer^2					−2.83E−07	2.310E−08	−3.29E−07	−2.38E−07
Percent snow winter	8.212	0.3753	7.48	8.95	9.552	0.6575	8.264	10.841
Percent snow winter^2					−7.655	0.4531	−8.543	−6.766
Human ZOI[c] summer	−0.478	0.0608	−0.598	−0.359				
Human ZOI winter					−0.954	0.0739	−1.099	−0.809
Constant	−14.990	0.6986	−16.360	−13.621	−22.795	1.1244	−24.999	−20.591

[a] Lodgepole pine.
[b] Normalized difference vegetation index.
[c] Zone of influence.

Table 2. Winter resource covariates used to generate a habitat suitability index model for the Atlin herd of northern mountain woodland caribou from interviews with members of the Taku River Tlingit First Nation in northern British Columbia, Canada, 2000–2002. Rank corresponds to the habitat value in the model.

Interview description	Land cover type	Elevation (m)	Aspect	Rank
Low elevation lakes	Lake	<1,150	All	2
High in mountains	Alpine tundra	>1,150	All	2
Open, high elevation windswept slopes	Alpine tundra, rock, snow	>1,150	90°–180°	3
Low elevation forest	Spruce-fir, mixed conifer, mixedwood	<1,150	All	4
Eat caribou moss (lichen)	LP[a]-lichen	>1,150	All	5
Low elevation river valleys	Alpine shrub, low valley willow	<1,150	All	5
Low elevation forest near LP forest	Spruce-fir, mixed conifer, mixedwood <500 m from LP-lichen	<1,150	All	7
Low elevation LP forest	LP-lichen	<1,150	All	9
Lakes as escape terrain	Low elevation forests (LP-lichen, spruce-fir, mixed conifer, mixedwood <1,150 m) and low elevation valleys (alpine shrub, low valley willow <1,150 m) <1 km from a lake		All	Add 1[b]

[a] Lodgepole pine.
[b] A value of 1 is added to the current value of the land cover types listed when they occur <1 km from a lake.

quality was based both on the number of respondents (0–8) and the consistency of interviewee responses relative to each potential habitat characteristic. We scaled the HSI models from 10 (highest value) to 1 (lowest value) to match the RSF scale. We gave variables associated with a high number of respondents reporting similar observations the highest ranks (rank column in Tables 2 and 3). For example, if ≥75% of participants were in agreement about caribou associations with a specific seasonal habitat type, that variable received the highest rank (Table 2; e.g., low elevation lodgepole pine forests received a 9). If <75% of participants reported caribou associations with a habitat variable that variable received a lower rank (Table 2; e.g., low elevation river valleys received a 5). When <25% of participants identified a habitat variable, it received one of the lowest ranks (Table 2; e.g., low elevation lakes received a 2). We built models by applying the values (rank columns in Tables 2 and 3) to the combinations of ecological conditions for land cover type, elevation, and aspect in ArcGIS 9.3.1. In this way, we built models additively by overlaying all values as raster layers in ArcGIS 9.3.1 until all information (from all respondents) was included in one map layer. We could not incorporate human developments into the prediction of habitat quality in the HSI models because the original interviews had been designed to gather baseline habitat relationships in the absence of human impacts.

Model Evaluations and Comparisons

The utility of habitat models, whether they are RSF or HSI, depends on their ability to predict animal locations (Roloff and Kernohan 1999, Wiens et al. 2008). We used independent VHF data to assess if the RSF and TEK models predicted caribou use. In addition, we also used the GPS data (that was used to build the RSF models) to assess if the TEK models predicted caribou use. For each evaluation, we calculated the number of locations that occurred within

Table 3. Summer resource covariates used to generate a habitat suitability index model for the Atlin herd of northern mountain woodland caribou from interviews with members of the Taku River Tlingit First Nation in northern British Columbia, Canada, 2000–2002. Rank corresponds to the habitat value in the model.

Interview description	Land cover type	Elevation (m)	Aspect	Rank
Below treeline, wide-ranging	LP[a]-lichen	<1,150	All	2
Mountain sides and slopes, wide ranging	Krummholz, low valley willow, alpine shrub	<1,150	All	3
Mountain sides and slopes, eat grass and lichen	Alpine tundra	<1,150	All	4
Snow to escape insects	Snow	<1,150	All	4
Below treeline, mountain sides and slopes, wide ranging	Low valley willow, LP-lichen, spruce-fir, mixed conifer, mixedwood	>1,150	All	Add 1
High in mountains, graze on grass and other vegetation	Alpine tundra, alpine shrub, krummholz, rock, snow	>1,150	All	Add 3
North facing slopes to escape insects on snow patches	Alpine tundra, alpine shrub, krummholz, rock, snow	>1,150	315°–135°	Add 2[b]
Use last of snow to escape insects	Alpine tundra, alpine shrub, krummholz, rock, snow in area with >50% snow cover May and June (MODIS[c] snow cover data)	All	All	Add 1

[a] Lodgepole pine.
[b] A value of 2 is added to the current value of the land cover types listed in this row when the land cover types fall above 1,150 m and between the aspects of 315°–135°.
[c] Moderate resolution imaging spectroradiometer satellite.

the 10 habitat rank classes normalized by the area of that class (Boyce et al. 2002, Johnson and Gillingham 2005). We used Spearman's rank correlation (r_s) to test the correlation between predicted habitat quality and the frequency of caribou locations, with the expectation that a greater frequency of locations would occur in high quality habitat (Boyce et al. 2002). To visually examine where spatial discrepancies occurred between models, we subtracted the spatial predictions of the TEK models from the RSF models and mapped the difference between ranks in each cell. To statistically compare spatial predictions of habitat quality between the RSF and TEK models, we simplified the number of habitat ranks from 10 to 3 which represented high, medium, and low quality habitat to simplify decision making for managers (Johnson and Gillingham 2005). We used a weighted Kappa statistic to evaluate the agreement in the distribution of the 10,000 random points in habitat quality ranks (Monserud and Leemans 1992). A Kappa index value of 1 indicates perfect agreement, whereas a value of 0 indicates that the observed agreement was approximately equal to what would be expected by chance (Monserud and Leemans 1992).

RESULTS

GPS collars were placed on 8 female and 2 male caribou and VHF collars were placed on a separate sample of 13 female and 4 male caribou. We obtained 16,270 GPS locations and 661 VHF locations. Mean group size of the Atlin herd was 14 individuals, though congregations of up to 200 animals occur (K. Diemert, British Columbia Ministry of Forests, Land, and Natural Resource Operations, unpublished report and data). We assumed that a sample of 27 collared caribou captured in separate groups represented the Atlin herd because caribou are social. Further, beta coefficients for resource selection stabilized and standard errors reached an asymptote when we included 8–10 caribou in the models (see Figs. S1 and S2, available online at www.onlinelibrary.wiley.com). We pooled males and females as resource use did not differ between the sexes (χ^2 test, winter $P = 0.455$, summer $P = 0.816$; Polfus et al. 2011).

Resource Selection Function Models

At the landscape scale, caribou showed significant avoidance of summer and winter ZOIs (Polfus et al. 2011). In winter, caribou selected intermediate elevations (1,179 m) and lichen-lodgepole pine complexes, spruce-fir forests, and low elevation willow (Table 1). Caribou avoided krummholz, alpine environments, steep slopes, burned lodgepole pine, rock, and water in winter. In summer, caribou habitat selection shifted to higher elevations (1,363 m) and caribou displayed strong selection for krummholz, alpine shrub and tundra, rock, slopes with greater sun exposure, and areas that had high percent snow cover in winter. Caribou selection was negatively associated with lodgepole pine, mixed conifer forests, water, and steep slopes (Table 1).

TEK Habitat Suitability Index Models

The 8 TRTFN members were generally in agreement about caribou habitat use (i.e., individuals did not contradict each other). The TRTFN members indicated that in winter caribou used low elevation forests, especially mature lodgepole pine with lichen groundcover (Table 2). They also indicated that caribou used low elevation valleys in river bottoms and open windswept slopes in alpine areas depending on snow conditions. Low elevation lakes were also identified as predator escape terrain and were thought to be used by caribou in winter as mineral licks (Table 2). Participants reported that in summer caribou used predominately high elevation alpine environments during the entire period and could often be found on remnant snow patches to escape insects. They also indicated that caribou were wide-ranging and used mountainsides and slopes where they foraged on grass, willow, and lichen (Table 3).

Model Comparison and Evaluation

Correlations between the summer and winter RSF models and frequency of withheld caribou locations were high ($r_s = 0.994$ and 0.997, respectively). The TEK-based HSI models also had high predictive performance when evaluated with caribou location data. Output from the summer TEK model was highly correlated with the frequency of caribou GPS locations ($r_s = 0.910$), though the correlation was lesser for VHF locations ($r_s = 0.612$). Output from the winter TEK model was more highly correlated with frequency of VHF caribou locations ($r_s = 0.806$) compared to GPS locations ($r_s = 0.750$).

Visual inspection of the differences between the 10 habitat class RSF and TEK maps indicated that most spatial discrepancies were a result of the RSF models predicting more high quality habitat than the TEK models (Fig. 2). In winter, discrepancies were most apparent on north and west slopes, on small lakes, and within a large historical burn in the northern part of the study area (see Fig. S3, available online at www.onlinelibrary.wiley.com). The winter TEK model predicted more high quality habitat in and around the town of Atlin than the RSF model. In summer, areas of low elevation were given higher rank by the RSF than by the TEK model (see Fig. S4, available online at www.onlinelibrary.wiley.com). Reducing the number of rank classes from 10 to 3 standardized the amount of area in each habitat class; high (30%), medium (30%), and low (40%) and facilitated statistical comparison between the 2 models. The Kappa value for the summer TEK and RSF models was 0.649 (SE = 0.008) and indicated substantial spatial agreement (0.61–0.80), whereas the Kappa value for the winter TEK and RSF model was 0.337 (SE = 0.008), which represented fair agreement (0.21–0.40).

DISCUSSION

Our study is the first to quantitatively compare TEK-based caribou habitat models with habitat models developed using western science approaches. The high predictive ability of the models and correlations between HSI and RSF model outputs demonstrates that TEK can be an effective tool for wildlife management and recovery planning. Specifically, both modeling approaches predicted that caribou selected low elevation lodgepole pine forests in winter, which is

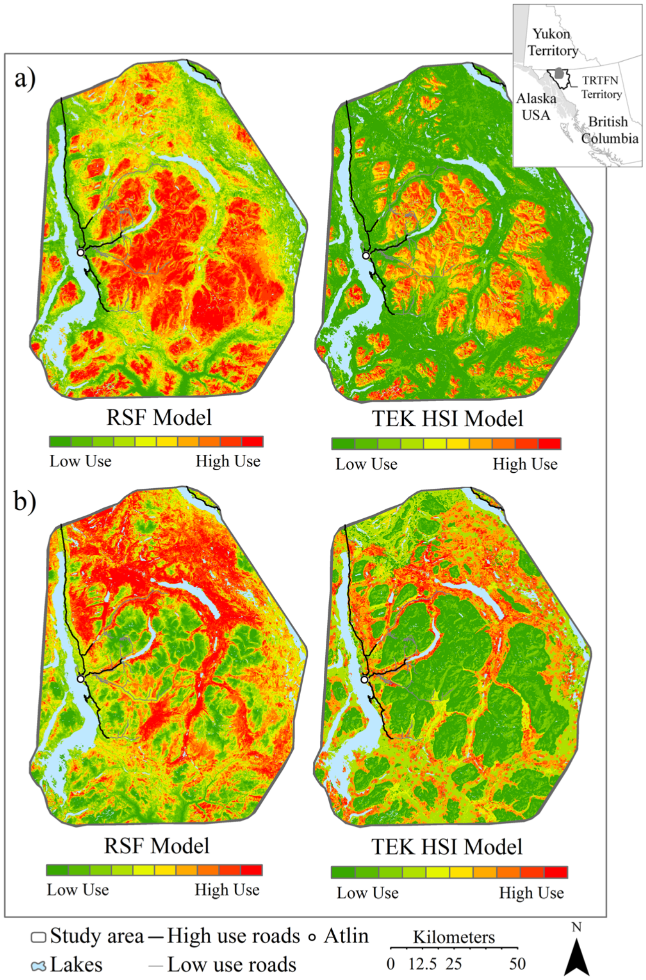

Figure 2. Second-order resource selection function (RSF) maps generated with global positioning system collar locations (left column) and habitat suitability index (HSI) model maps generated with the traditional ecological knowledge (TEK) of the Taku River Tlingit First Nation (TRTFN, right column) for summer (a) and winter (b) habitat use of the Atlin herd of northern woodland caribou, northern British Columbia, Canada, 2000–2002. The relative probability of selection in the RSF models is scaled between low (green) and high (red).

typical of northern mountain populations (Poole et al. 2000, Florkiewicz et al. 2007, Gustine and Parker 2008). During summer, both models predicted caribou use of alpine habitats, which is likely a result of selection for high quality forage and relief from insect harassment (Ion and Kershaw 1989). Our results support the growing recognition of TEK approaches in conservation initiatives around the world (Berkes 2004).

Comparisons between different modeling approaches can reveal assumptions about modeling processes, potential biases, and differences in scales of inference. For example, Johnson and Gillingham (2005) found that an HSI model of caribou habitat in British Columbia was a poor predictor of caribou distribution when compared to RSF and species niche models. However, the HSI model was not developed with local expert knowledge, which may have limited performance. In our case, despite high overall agreement between approaches, we found several informative differences between TEK and RSF models. First, the RSF models predicted a greater area of habitat in RSF ranks 8–10 (winter 3,475 km^2) than occurred in the corresponding habitat ranks of the TEK models (winter 1,705 km^2) because the habitat classes in the TEK models did not have equal areas. Thus, to facilitate statistical comparison, we reduced the number of habitat classes so the areas of the resulting 3 classes (high, medium, and low) were similar between the RSF and TEK models (i.e., high quality habitat in the TEK models included ranks 7–10; 3,242 km^2). Further, RSF models allow remote sensing covariates such as slope, aspect, hillshade, and NDVI to be simultaneously incorporated in the model; all of which are challenging to match with TEK because people do not often discuss this type of variable. Thus, the RSF's ability to incorporate remote sensing covariates likely resulted in some of the spatial discrepancies between models (see Fig. S3, available online at www.onlinelibrary.wiley.com). In summer, the TEK and RSF models had relatively high spatial agreement. Most discrepancies occurred in valley bottoms, which were often considered medium quality habitat in the RSF models but low quality habitat in the TEK-HSI models because of an elevational cut-off used to indicate caribou preferred alpine habitats.

TEK can also provide unique perspectives and suggest new avenues for scientific exploration (Ramstad et al. 2007). For example, local resident knowledge of jaguar (*Panthera onca*) occurrence in Nicaragua overlapped with a GIS-based least-cost corridor analysis by only 33%, a result that affirmed the importance of examining alternate data sources and the value of local knowledge in guiding conservation planning (Zeller et al. 2011). In our study, respondents described lakes as escape terrain in winter. Caribou are also highly visible on frozen lakes and commonly dig through the snow to lick the ice and feed on vegetation in muskrat (*Ondatra zibethicus*) push-ups (J. Williams, M. Connor, TRTFN, personal communication). However, the RSF models indicated that caribou avoided lakes in winter. Resource selection analyses may emphasize behaviors with high residency times in a land cover type, and underestimate importance of land cover types used for movement (Cleveland et al. 2012). Additionally, in the RSF models, caribou avoidance of large lakes may have masked selection for small lakes because all lakes were classified as a single land cover type. Caribou likely differentiated between large and small lakes. Frozen lakes provide an example where TEK suggests the need for additional information gathering around a potentially important but otherwise overlooked habitat type.

We also found habitat quality differences in the winter TEK and RSF models within a large burn that was considered low quality based on TEK but high quality in the RSF models. Few caribou locations occurred within the burn. The TEK captured a habitat relationship not quantified in the RSF model but one that likely has importance in understanding caribou habitat quality and distribution. Rather than use differences between models to determine which is more correct, managers must acknowledge that neither the RSF nor TEK models are necessarily better than the other and that objective comparison can increase insights into both methodological approaches (Ramstad et al. 2007).

Several studies have attributed long temporal but relatively small spatial scales to ecological information collected from TEK (Usher 2000, Moller et al. 2004, Fraser et al. 2006, Rist et al. 2010). In the Atlin area, our model comparisons indicate that predictions from the TEK models most closely resembled caribou habitat selection at the scale of the herd home range (Polfus 2010). Methods used to collect TEK may be adapted to compliment the scale of western scientific studies (Ramstad et al. 2007). For example, Gagnon and Berteaux (2009) reported that in Nunavut, Canada, TEK regarding arctic fox (*Vulpes lagopus*) populations provided information at a larger spatial scale than current scientific data (by describing an area up to 23,000 km^2), but that the scale of TEK on the distribution of molting locations and migrations of snow goose (*Chen caerulescens*) was similar to western scientific documentation. In Switzerland, lynx (*Lynx lynx*) habitat models developed with the local knowledge from game wardens performed better than models developed with knowledge from international lynx experts when validated against information from the local area (Doswald et al. 2007). However, the model derived from lynx experts was more transferable to other parts of Switzerland. New statistical approaches like scale-integrated RSFs, may allow managers to synthesize results across scales to predict species occurrence across a variety of extents (DeCesare et al. 2012).

The TEK HSI models did not include direct reference to the influence of human development on caribou habitat selection which contributed to some discrepancies. We found the winter TEK models predicted higher quality habitat closer to human disturbances than the RSF models. For these reasons, TEK may be useful for predicting the habitat quality in areas that are currently avoided by caribou because of human developments. Thus, TEK might be used to locate suitable sites for habitat restoration (Patthey et al. 2008), guide dynamic estimates of habitat quality (Nielsen et al. 2010), or produce population abundance targets (Serrouya et al. 2011). Because interview structure is flexible, managers may be able to design interview questions to include information about historical distributions that could aid in the identification of underlying habitat quality in areas that are avoided at present. Information about potential habitats that are currently unused is difficult to reveal with telemetry data. Knowledge of potential habitats could be especially important in areas of recent extirpation or in places that have experienced recent increases in human development.

Governments around the world are recognizing the importance of indigenous rights in wildlife management. Recently, the TRTFN and British Columbia signed a joint land use plan (Taku River Tlingit First Nation and Province of British Columbia 2011) that includes explicit direction for the management of land use activities, cumulative effects, and habitat loss that may affect the Atlin caribou herd. Managers must find new ways to incorporate TEK in natural resource management (Colchester 2004). Merely testing TEK with western science (Gilchrist et al. 2005, Anadón et al. 2009) fails to appreciate that western scientific approaches are not necessarily closer to truth than other approaches (Gratani et al. 2011). Instead, collaborative comparisons provide an avenue towards a more complete understanding of ecosystems and can lead to more effective management decisions. Using TEK requires respecting cultural differences, developing meaningful collaborations, and ensuring that knowledge is not taken out of context, misinterpreted, or misused (Usher 2000, Huntington 2011). Though obstacles may impede the translation of ideas and concepts between worldviews, our example clearly shows TEK-based habitat models have the potential to provide useful habitat identification and increase the ability of indigenous people to influence decisions that affect their community, culture, and lifestyle (Berkes 2004).

MANAGEMENT IMPLICATIONS

Our work demonstrates that TEK can be used by wildlife management organizations in response to the ongoing challenges of woodland caribou conservation and recovery planning across Canada (Festa-Bianchet et al. 2011). Recent court rulings upholding First Nations concerns and legal rights regarding boreal caribou declines emphasize the importance of increasing First Nation involvement in conservation strategies. Although the collection and incorporation of TEK in recovery planning is required under SARA, political controversy, inadequate guidelines, and weak policy direction have hindered the inclusion of TEK. Current approaches by the Canadian Government to collect TEK to inform SARA recovery planning for woodland caribou could benefit from adopting a collaborative community-based approach. Traditional knowledge holders may also gain confidence in co-management settings through a process of collaborative validation (Gratani et al. 2011). Quantitative TEK-based caribou habitat models, such as ours, are especially important in areas where western scientific data, such as telemetry data, are limited. For example, collecting western scientific data for the 57 local boreal woodland caribou populations that span 1.5 million km^2 will be difficult (Environment Canada 2012*b*). Managers need to accept, however, that although collaborative approaches can ultimately lead to more successful conservation decision making, they require a substantial time and financial commitment to be successful. Finally, our efforts demonstrate that TEK-based habitat models not only facilitate critical habitat identification, but offer an approach that can meaningfully incorporate knowledge held by First Nation people into a more complete understanding of caribou ecology and, ultimately, recovery planning.

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SUPPORTING INFORMATION

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