Disrupting traditions of science: Indigenous Knowledge to model species habitat use

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While Indigenous Knowledge (IK) contains a wealth of information on the behaviour and habitat use of species, it is rarely included in the species-habitat models frequently used for conservation and management decisions. Exclusion of IK can negatively impact species and communities. We developed methods that relies solely on IK to identify species habitat use and important areas. We apply the method to ringed seals (*natchiq* in Iñupiat) in Alaskan waters, for which the designated critical habitat has been legally debated in part due to minimal inclusion of IK. This work was completed in partnership with Iñupiat hunters. Our work demonstrates how IK of species habitat use and important areas can be presented in a way that can be easily and meaningfully considered

for species management.

"Agencies have a traditional way they do science and including Indigenous Knowledge is less traditional." - Taqulik Hepa, Director, North Slope Borough Department of Wildlife Management

Species conservation frequently lies within a colonial context (*1–3*). Its focus on "Western" science and management practices often leads to superficial or a lack of consultation with Indigenous peoples (*4*), and limited inclusion of, and respect for, Indigenous Knowledge (IK) (*5, 6*). Exclusion of Indigenous management practices, knowledge, and leadership has led to, for example, poor fisheries management (*7*) and hunting bans that can impact the health, well-being, and livelihood of communities (*8*). Efforts to equalize conservation management to include IK and IK systems (*9, 10*) and to practice co-management (*11–13*) are increasing, as is Indigenous-led conservation (*14*) and the recognition of the importance of knowledge co-production (*15, 16*).

Although increases in the equitable inclusion of Indigenous peoples in conservation practices are encouraging, co-management often remains within colonial systems. For example, in the United States, the Ice Seal Committee (ISC) has a co-management agreement in place between subsistence communities in Alaska and the National Marine Fisheries Service (NMFS) (*17*), but final decisions regarding the listing and critical habitat designation of ice-associated seals still lie with NMFS (*18*). Although the best solution would be the full consideration of Indigenous management and understanding on its own terms (*5*), current co-management practices often create the need to convert IK into a form that fits paradigms of western management methods. The method we propose in this paper is developed within this context. It reflects the desire for IK to be more readily included into western conservation management.

Conservation management of endangered or listed species often relies on characterizing habitat use and identifying critical habitat using statistical tools such as resource selection or

habitat selection functions (HSFs) (*19*). These tools are used to estimate how the occurrence of a species varies across space, and are developed from animal occupancy or movement data (e.g., satellite telemetry data). Habitat suitability analysis has informed 40% of critical habitat definitions for Canadian vertebrate species at risk, providing information on species-habitat relationships (*20*). Indigenous Knowledge contains information on species habitat use and can be used to inform the identification of critical habitat. Indigenous Knowledge can be defined as "Knowledge created and/or mobilized by Indigenous Peoples that may include Traditional Knowledge and scientific knowledge." (*21, pg. 719*). As noted by co-author B. Adams, knowledge gained by hunters over time can have a better understanding of species habitat use and behavior than approaches that just use satellite tagged animals. In fact, IK has been included in previous studies of habitat use (*22–25*), but those studies do not directly characterize or estimate the relationships between species and habitat covariates. Expanding on these methods will provide additional approaches to better inform species management and conservation. Here, we show how IK can be the sole source of information (i.e., no other species observation data) to estimate species habitat selection. This method produces outputs similar to the selection coefficients for environmental covariates estimated by traditional HSFs and can be used to map spatial variation in species presence and identify important areas.

This study and the conversion and use of IK for habitat use models was initiated through discussions with the North Slope Borough Department of Wildlife Management (DWM), an agency of the regional municipal government representing eight subsistence communities in Northern Alaska. Additionally, this project was presented to the ISC for review, input, and approval. Both the DWM and the ISC have mandates to manage ice-associated seals considering both Indigenous Knowledge and 'standard' scientific knowledge (*26, 27*). Indigenous Knowledge of ringed seal habitat use was documented as part of a collaborative research project with Iñupiat hunters in Utqiaġvik, Alaska (Figure 1), and all examples of IK in this study and the

resulting maps were reviewed by six of the IK holders who participated in the IK documentation conducted by R. Gryba *et al.* (*28*). Additionally, five of the IK holders are co-authors (B. Adams, B. Frantz, J. Gatten, Q. Harcharek, and R. Sarren), while the other hunter chose to remain anonymous for this publication. The other authors are not Indigenous: R. Gryba is a PhD candidate at the University of British Columbia, M. Auger-Méthé and G. Henry are professors at the University of British Columbia, A. Von Duyke is a researcher at the DWM, and H. Huntington is an independent social scientist.

Habitat selection functions often have two sequential goals: 1) quantifying the relationship between a species presence and environmental covariates, and 2) using these estimated relationships to predict how species occurrence varies spatially (*29*). Here, we use a similar two-step approach. We first use IK, documented via semi-directed interviews, to characterize the relationship with each covariate (Figure 2), and then combine these relationships to create maps that display the spatially-varying probability of a species presence (Figure 3). Knowledge documented via semi-directed interviews comes in many forms (e.g., maps of where animals are observed, types of habitat animals are associated with; Figure 2A, B). We classify the IK shared into three types: quantitative, qualitative, and spatial (Figure 2B). To quantify these relationships, we assume that the proportion of knowledge holders interviewed who share information specific to a habitat covariate value is equivalent to the probability of species presence associated with that covariate value. This assumption aligns with the feedback from hunters, who acknowledged that less common behaviours may not be observed by all (*28*). For qualitative and spatial types of IK, the relationships are characterized by setting the values of the covariate and the IK probability of species presence (Figure 2B-D). For the quantitative type of IK, the relationship between species presence and a covariate can be estimated using beta regression (Figure 3A-D). All variables can then be mapped and reviewed by the knowledge holders originally interviewed and edited as needed (Figure 3E). The second step of the approach com-

bines the relationship with each covariate into a single model that is used to predict the overall spatially-varying probability of a seal presence (Figure 3F-G). The supplementary material provides detailed instructions on how to apply the method.

We applied the methods to four environmental covariates that IK indicated as influencing the habitat selection of ringed seals in summer in the waters around Utqiaġvik, Alaska (Figure 1): distance from shore, ice concentration, currents, and spatial regions. The relationships between ringed seals and the environmental covariates defined here were based on IK documented in Gryba *et al.* (*28*), although some adjustments were made during review of the maps with the hunters. Knowledge of distance from shore, a qualitative type of IK, indicated a higher probability of ringed seal association with nearshore compared to offshore habitat (*28*), which we characterized as a simple linear relationship (Figure 4A, Table 1). During the review of the probability of ringed seal presence maps, one hunter noted that the region of Admiralty Bay should have lower probability of presence, a spatial type of IK. The probability of presence within the specified region was decreased accordingly (Figure 4B, Table 1). Ice concentration was treated as a quantitative type of IK, and ringed seal presence was quantified for a set of ice concentration bins (i.e.,0%, 10-20%, 30-40%, 50-60%, 70-80%, 90%, 100%) (*28*). While reviewing the IK probability maps that included a large area of ice (i.e., July 2015, Figure S1), the knowledge holders indicated that numerous seals would be present in areas of high ice concentrations. As such, the probabilities in high ice concentration were increased (Figure 4C). The knowledge holders indicated that these increases better reflected their observations. We used a quadratic beta regression to quantify this relationship (Table 1). Hunters indicated areas of currents used by ringed seals in summer (*28*), a spatial type of IK. The identified areas were given a probability of presence of 0.11 reflecting that each region was identified by one hunter (i.e., 1 hunter out of 9 hunters). Areas 10-20 km around these regions were given probabilities of 0.08 (Figure 4D, Table 1). The seal habitat use was predicted by combining into a single equation

(using Supplementary Materials equation 5) all of the variables and the estimated coefficients characterizing their relationship with seal presence (Figure 4E).

Table 1. IK based coefficient values ($\hat{\beta}$ and σ^2) for each habitat type.

Model	Habitat type	$\hat{\beta}$	σ
Quantitative	Intercept	0.12	0.86
	Ice concentration	1.51	0.50
	Ice concentration^2	4.48	0.77
Qualitative	At shore (intercept)	0.88	–
	Distance from shore	-0.16	–
Spatial	Current regions - outter (intercept)	0	–
	Current regions - near (10-20 km)	0.08	–
	Current regions - main	0.11	–
	Admiralty Bay region - inside (intercept)	0	–
	Admiralty Bay region - outside	0.89	–

"Showing IK in this way is a useful step to get buy-in and show the value of IK for agencies, and for them to see the wealth and depth of IK. It shows the value of IK and the importance of IK as a data set." - Taqulik Hepa, Director, North Slope Borough Department of Wildlife Management

Our method provides an approach to convert quantitative, spatial, and qualitative IK into probabilities which can subsequently be modelled and used to estimate habitat coefficients and species habitat use with IK as a sole data source. Our application of beta regressions in this context leans towards elicitation methods associated with 'expert knowledge' (*30,31*), as IK can certainly be classified. Beta regression provides an opportunity to directly model proportions with clear applications to ecology (*32,33*), and in our case an approach to model IK probabilities of presence to quantify species-habitat relationships.

One of the main motivations for this study was to create estimates of species habitat use that fully consider IK. This was partially in response to the listing of ringed seals and bearded seals as threatened under the US Endangered Species Act, and subsequent designation of critical habitats (*34, 35*). The use of IK as a data source in critical habitat predictions provides an

opportunity to reduce scientific uncertainty or lack of data for species that are limited in terms of western science approaches (*36, 37*). For example, satellite telemetry data of ringed seals is limited in summer in the waters near Utqiaġvik, Alaska as most individuals tagged move farther offshore, west into the northern Chukchi Sea, or east into the eastern Beaufort Sea (*38*). As such, telemetry data may not capture the habitat use of the ringed seals that remain in waters near Utqiaġvik. In contrast, IK provides information on the seals that remain in the region and is not limited by the small sample size associated with many telemetry studies. The ringed seal critical habitat designation is based on essential features that include sea ice suitable for whelping, nursing, and basking in waters deeper then 3 m (*34*), information that is primarily based on satellite telemetry and aerial survey data. The critical habitat was also assessed to sufficiently represent areas of ringed seal primary prey. The habitat use identified in this study indicates high use of ringed seals in nearshore habitat that is not included in the current critical habitat designation. Although the critical habitat is not intended to include all areas of ringed seal presence, consideration of IK on ringed seal use of the waters near Utqiaġvik, Alaska may reflect information not available in 'standard' science data sources. Additionally, the IK not only highlights areas of high use but also identifies areas important for foraging (*28*).

The quantification of IK in this study can provide an additional approach for IK to be a sole data source in habitat use modelling. This approach inherently considers a small portion of what IK embodies as the links between species, people, and place are not included (*39*). Although only a portion of IK is considered in these types of methods, the approach can provide opportunities for co-management bodies, such as the ISC, to clearly show the extent of species-habitat relationships that are part of IK and that standard scientific data need not be the only data source considered in habitat modelling approaches. The efforts of organizations such as the ISC to center IK in management can move forward the decolonization of current management paradigms (*40*). This is particularly important considering the relationships that Indigenous

peoples have with species (*21, 39*) and the need to consider cultural and traditional practices and move forward with true reconciliation and restoration (*40*).

Translation of IK into forms such as habitat use may serve to provide an opportunity for IK to be considered in new ways in many of the current conservation management frameworks. The approach, if initiated and guided by Indigenous Knowledge holders and communities, can provide opportunities for knowledge co-production that can help to communicate the extent of IK and also the relationships between Indigenous peoples, their land, and species (*1, 15*). Additionally, the recognition and inclusion of IK as an integral data source can help solve many of the issues we are facing when attempting to manage species in a changing world (*7, 15*).

"One isn't better than the other [IK and 'western' data] and all are equally valuable and both can give a broader understanding. This approach helps to show the depth of understanding in IK and there is a need to help grow the understanding of IK for management use." - Taqulik Hepa, Director, North Slope Borough Department of Wildlife Management

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Supplementary materials

Materials and Methods

Fig. S1

References *(29-43)*

Fig. 1. Study area around Utqiaġvik, Alaska (shown in the yellow triangle).

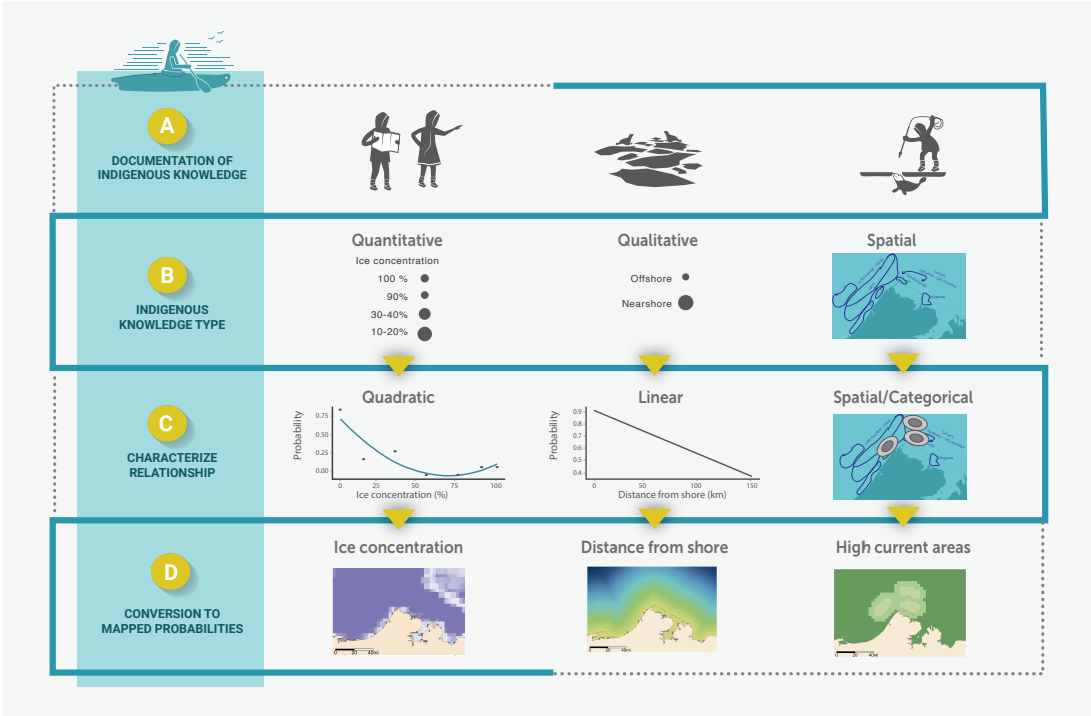
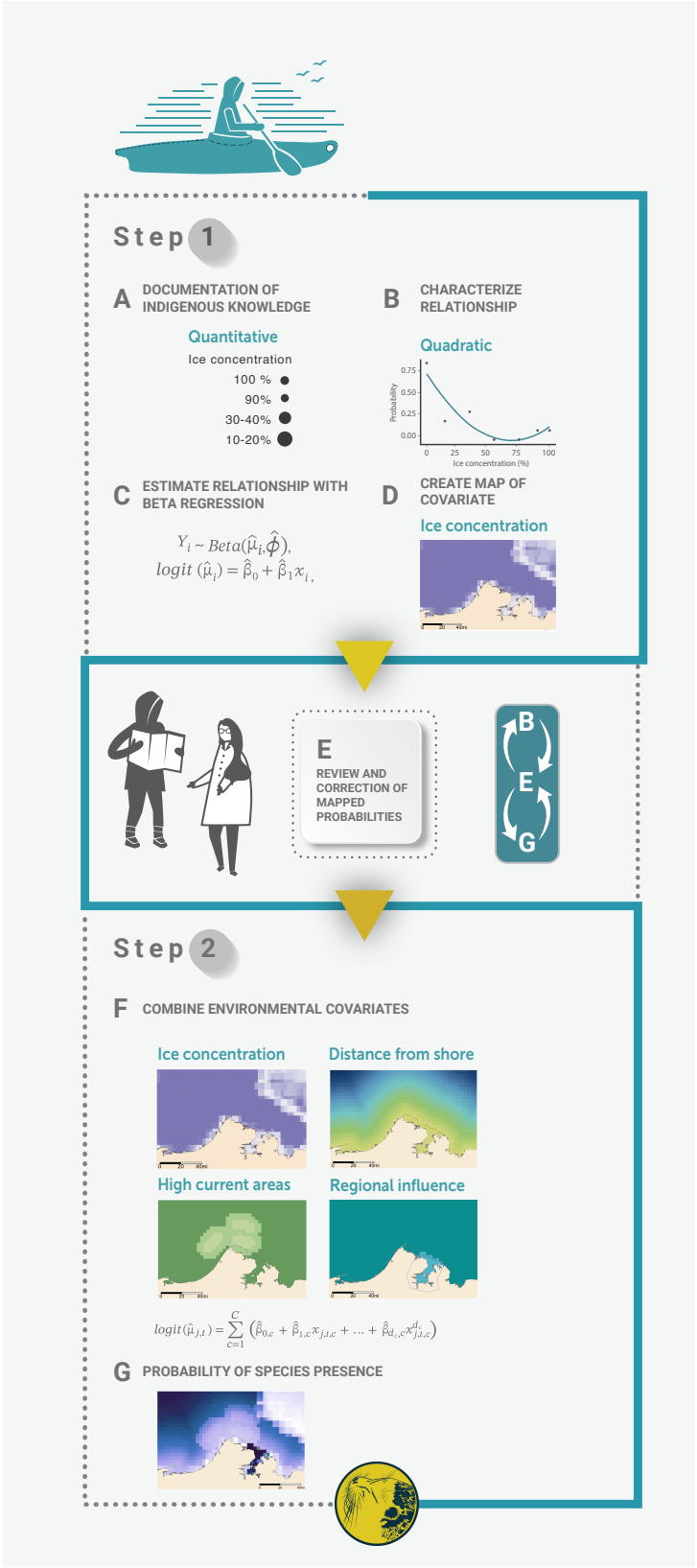


Fig. 2. Methods process map of (A) the documentation of Indigeneous Knowledge (IK), (B) identification of IK type, (C) characterization of relationship between IK probability of species presence and habitat covariates, (D) mapping of IK probability of species presence. The size of the circles in (B) represent the proportion of hunters that indicated that species-habitat association and inform the probability values in (C).

Fig. 3. Methods process map of (A) the documentation of IK, (B) characterization of relationship between IK probability of species presence and habitat covariates, (C) application of beta regression to quantitative covariates, (D) mapping of IK probability of presence for review, (E) review and correction of the IK probabilities of presence, (F) using β estimates in a logistic regression equation to estimate (G) the final probability of species presence, and reviewing the final estimate of probability of species presence for any needed corrections. The size of the circles in (A) represent the proportion of hunters that indicated that species-habitat association and inform the probability values in (B).


Step 1
A DOCUMENTATION OF INDIGENOUS KNOWLEDGE
Quantitative
Ice concentration
100 %
90%
30-40%
10-20%
B CHARACTERIZE RELATIONSHIP
Quadratic
Probability
0.75
0.50
0.25
0.00
0
25
50
75
100
Ice concentration (%)
C ESTIMATE RELATIONSHIP WITH BETA REGRESSION
$Y_i \sim Beta(\hat{\mu}_i, \hat{\phi}),$
$logit\,(\hat{\mu}_i) = \hat{\beta}_0 + \hat{\beta}_1 x_i,$
D CREATE MAP OF COVARIATE
Ice concentration
E
REVIEW AND CORRECTION OF MAPPED PROBABILITIES
B
E
G
Step 2
F COMBINE ENVIRONMENTAL COVARIATES
Ice concentration
Distance from shore
High current areas
Regional influence
$logit(\hat{\mu}_{j,t}) = \sum_{c=1}^{C} \left(\hat{\beta}_{0,c} + \hat{\beta}_{1,c} x_{j,t,c} + \ldots + \hat{\beta}_{d_c,c} x_{j,t,c}^{d_c}\right)$
G PROBABILITY OF SPECIES PRESENCE

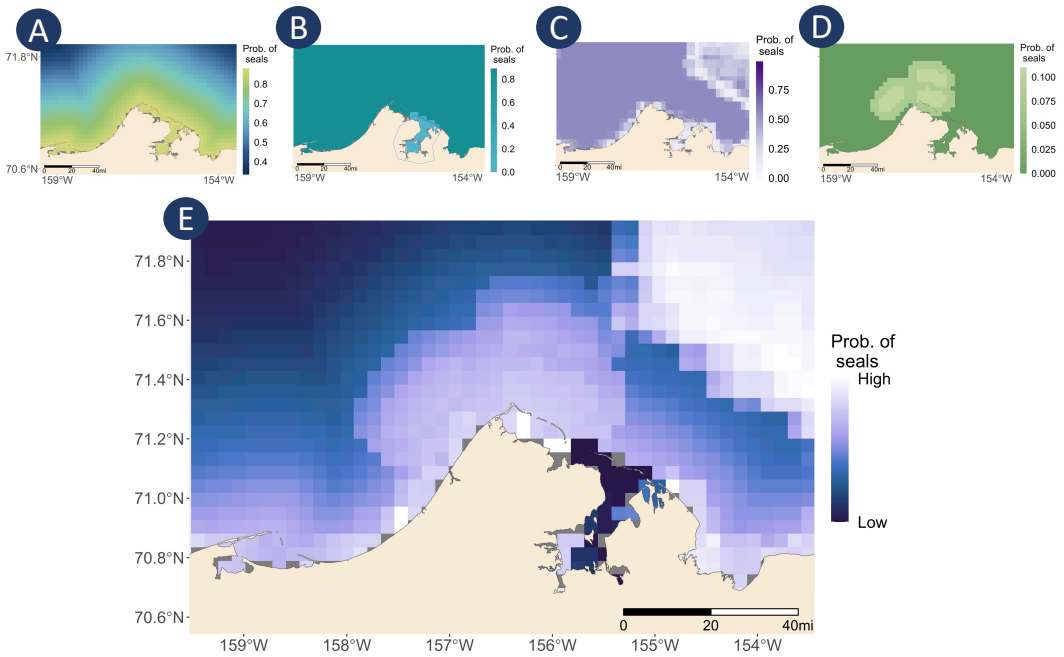


Fig. 4. IK probability of ringed seal presence associated with habitat covariates and final predicted habitat selection. (A) IK probability of ringed seals presence associated with distance from shore. Yellow indicates high probability of presence and blue indicates low probability of presence. (B) IK probability of ringed seal presence associated with distance from shore with decreased probability within Admiralty Bay. Dark blue indicates high probability of presence areas, light blue indicates low probability of presence, Admiralty Bay is enclosed by the polygon shown in blue. (C) IK probability of ringed seal presence associated with ice concentration for July 15, 2015. White indicates low probability of presence and dark purple indicates high probability of presence. (D) IK probability of ringed seal presence associated with currents. Light green indicates areas of higher probability of presence, dark green indicates areas of lower probability of presence. (E) Final IK probability of ringed seal presence for July 15, 2015. White indicates areas of high probability of presence, dark blue indicates ares of low probability of presence.

Supplementary Materials: Materials and Methods

Habitat selection functions often have two sequential goals: 1) quantifying the relationship between a species presence and environmental covariates, and 2) using these estimated relationships to predict how the species occurrence vary spatially (*29*). Here, we use a similar two-step approach. We first use Indigenous Knowledge (IK) to characterize the relationship with each covariate, and then combine these relationships to create maps that display the spatially-varying probability of a species presence.

Step 1: Using IK to characterize the species relationship with each environmental covariate

The first step of the approach requires quantifying the relationship between the probability of species presence and each environmental covariate. To quantify these relationships using IK, we assume that the proportion of knowledge holders interviewed who share information specific to a habitat covariate value is equivalent to the probability of species presence associated with that covariate value. For example, if only one of the n hunters interviewed declare that seals are present in areas with currents, the probability of seal being present at those areas is set to $1/n$. This assumption aligns with the feedback given during semi-directed interviews in Gryba *et al.* (*28*), where hunters acknowledged that others have different experience and that less common behaviours may not be observed by all.

Knowledge documented via semi-directed interviews comes in many forms (e.g., maps of where animals are observed, types of habitat animals are associated with; Figure 2A, B), which affects how the relationship with a given covariate is characterized. We classify the documentation methods into three types: quantitative, qualitative, and spatial (Figure 2B). For the quantitative type of IK, the relationship between species presence and a covariate can be estimated using beta regression (Figure 3A-C). Beta regression is a distributional regression that can be

used to model a continuous response variable Y within the interval (0,1), such as probability of presence or proportion (*32, 41*). A beta regression model can be defined in several ways, we used the following parametrization:

$$\begin{aligned} Y_i &\sim Beta(\hat{\mu}_i, \hat{\phi}), \\ logit(\hat{\mu}_i) &= \hat{\beta}_0 + \hat{\beta}_1 x_i, \end{aligned} \tag{1}$$

where Y_i is probability of species presence for a specific covariate value i, $\hat{\mu}_i$ is the estimated expected mean value of Y_i associated with the value of the covariate, and $\hat{\phi}$ is the precision, x_i is the covariate value, and $\hat{\beta}_1$ is the estimated regression coefficient that characterizes the relationship between the covariate and the IK-informed probabilities of species presence Y_i, and $\hat{\beta}_0$ is the estimated intercept. The two β coefficients are estimated, and are the main parameters of interest in this step of our approach. Beta regression can also be used to characterize quadratic relationships.

Characterizing the qualitative and spatial types of IK (Figure 2C,D) does not require the Beta regression. Instead, the relationships are set based on the values of the covariate and the IK probability of species presence. For example, a linear relationship can be characterized by simply fitting a line and then calculating the slope and intercept of that line to define the relationship. Spatial IK (i.e., IK that was drawn on maps) can have regions that are higher or lower probability of species presence, based on a background value, with buffers to indicate change in probability of species presence (Figure 2C,D). The background value is the intercept (β_0) and is assumed to be 0, with the other β coefficients measuring the difference from the background value. If needed a transform can be applied to ensure that the probabilities remain between 0 and 1.

Once the β coefficients are estimated, they are used to predict the probability of species presence to a rasterized version of the covariate and mapped (Figure 3D). All of the maps are reviewed by the knowledge holders originally interviewed and can be edited as needed (Figure

3E).

Step 2: Combining the relationship with covariates to predict overall probability of use

The second step of the approach combines the relationship with each covariate into a single model that is used to predict the overall spatially-varying probability of a seal presence.

Simply, we can predict the probability of species presence in each cell j of our rasterized map using

$$logit(\hat{\mu}_j) = \sum_{c=1}^{C} \left(\hat{\beta}_{0,c} + \hat{\beta}_{1,c} x_{j,c} \right), \tag{2}$$

where C is the number of covariates in the analysis, $\hat{\mu}_j$ is the overall predicted probability of species presence at location j, $x_{j,c}$ is the value of the covariate c in cell j, and $\hat{\beta}_{0,c}$ and $\hat{\beta}_{1,c}$ are the regression coefficients estimated in step 1 of the approach which characterize the relationship between the covariate c and the IK-informed probabilities of presence $Y_{i,c}$.

If covariates with complex relationships (e.g., quadratic) are included we can estimate the final probabilities of species presence using

$$logit(\hat{\mu}_j) = \sum_{c=1}^{C} \left(\hat{\beta}_{0,c} + \hat{\beta}_{1,c} x_{j,c} + ... + \hat{\beta}_{d_c,c} x_{j,c}^{d_c} \right), \tag{3}$$

where d_c is the number of order for the polynomial for covariate c.

If time varying covariates are included we can estimate the final probabilities of species presence using,

$$logit(\hat{\mu}_{j,t}) = \sum_{c=1}^{C} \left(\hat{\beta}_{0,c} + \hat{\beta}_{1,c} x_{j,t,c} \right), \tag{4}$$

where t is time.

If all above scenarios are included in the analysis the final probabilities of species presence is estimated using,

$$logit(\hat{\mu}_{j,t}) = \sum_{c=1}^{C} \left(\hat{\beta}_{0,c} + \hat{\beta}_{1,c} x_{j,t,c} + ... + \hat{\beta}_{d_c,c} x_{j,t,c}^{d_c} \right) \tag{5}$$

The prediction is mapped and then presented to the knowledge holders, if there is any noted discrepancy, we go back to step 1.

Case Study Application

Indigenous Knowledge of ringed seal habitat use was documented as part of a collaborative research project with Iñupiat hunters in Utqiaġvik, Alaska (*28*)(Figure 1). We applied the methods to four important environmental covariates that influence the habitat selection of ringed seals in summer in the waters around Utqiaġvik as indicated by IK: distance from shore, ice concentration, currents, and spatial regions. Knowledge of distance from shore, a qualitative type of IK, was characterized as a simple linear relationship with a probability of 0.88 assigned to areas within 5 km of shore decreasing to probability of 0.33 120 km from shore (Figure 4A, Table 1). No transform was applied as we were not predicting beyond the range of the data and the probabilities were within 0 and 1. Ice concentration was treated as a quantitative type of IK, and ringed seal presence was quantified for a set of ice concentration bins (i.e.,0%, 10-20%, 30-40%, 50-60%, 70-80%, 90%, 100%) (*28*). To reflect the increased probability of ringed seal presence in areas of high ice concentrations (i.e., July 2015, fig. S1), the probabilities were increased from 0.11 in $\geq 90\%$ ice concentration (*28*) to 0.55 in 90% ice and 0.66 in 100% ice (Figure 4C). The knowledge holders indicated that these increases better reflected their observations. Distance from shore and ice concentration were treated as continuous variables in the analysis, and scaled prior to modeling. During the review of the probability of ringed seal presence maps, one hunter noted that the region of Admiralty Bay should have lower probability of

presence (as in) (*28*). The probability of presence within the specified region was set to 0 and the areas outside had a probability value of 0.89 (Figure 4B, Table 1). To characterize the spatial region IK a categorical variables was included with a value of zero for the region specified by the IK and a value of 0.89 applied the area outside. Similarly, currents were analyzed as spatial categorical variables: main current region, near the main current region, and far from the main area (outside current regions). Currents were considered a constant covariate as the IK indicated regions of high currents that are used by ringed seals through-out the summer. The locations of currents used by ringed seals in summer were based on areas indicated by hunters (*28*), a spatial IK. These areas were buffered to provide higher probability where the currents were identified and then decreasing probability 10-20 km from the main current areas (Figure 4D, Table 1). The region at the currents was given a probability of presence of 0.11 reflecting that each region was identified by one hunter (i.e., 1 hunter out of 9 hunters). The mapped probabilities were reviewed by the IK holders. The environmental variables used for mapping were projected to a 5 km x 5 km grid, Alaska Albers projection, with ice concentration from Spreen *et al.* (*42*).

To characterize the relationship between the probability of ringed seal presence with ice concentration, we applied a beta regression with a quadratic relationship to capture the higher probability of presence at low and high ice concentrations compared to medium values. The resulting estimate of probability of presence was mapped and reviewed by the IK holders (Figure 3D, E). The characterized relationships between the IK probability of presence and distance to shore, region, and areas of high currents were also mapped for review. All analysis was completed in R (R Core Team 2021) and beta regression was completed using a Bayesian approach and the R package brms (*43*), with flat priors over the entire real line. Model convergence was checked using the Gelman-Rubin statistic and by visual inspection of chain plots. The beta regressions were run for 10,000 iterations with a warm-up of 2,000 iterations. The final estimate of the probability of ringed seal presence included all four covariates in equation 5.

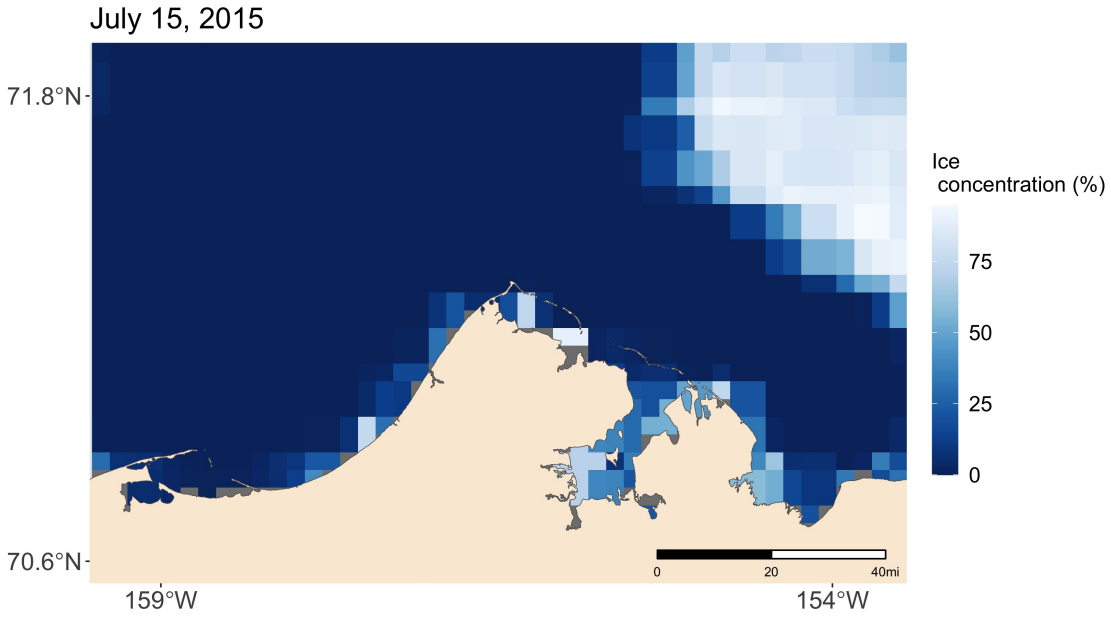


Fig. S1. Ice concentration (%) in the area near Utqiaġvik, Alaska on July 15, 2015 (*42*). White is high ice concentration, dark blue is low ice concentration.