The following supplements accompany the article

Validation and improvement of species distribution models for structure-forming invertebrates in the eastern Bering Sea with an independent survey

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Supplement 1. Stereo drop camera description

The two stereo drop camera systems were comprised of two machine-vision cameras spaced approximately 30 cm apart in underwater housings that were connected via ethernet cables to a computer also in an underwater housing. On the first drop-camera system, one of the paired cameras recorded monochromatic still images sized at 1.45 megapixels (JAI, CM-140GE), while the other camera collected 1.73 megapixel color still images (JAI, AB-201GE). On the second drop-camera system, one of the paired cameras recorded monochromatic still images sized at 1.45 megapixels (JAI, CM-140GE), while the other camera collected 2.82 megapixel color still images (Prosilica GX 1920C). Lighting was provided by four strobe lights constructed of four Bridgelux® BXRA LED arrays capable of producing 1,300 lumens at 10.4 W. The computer, cameras, and lights were powered by a 28 V NiMH battery pack. Synchronous images were collected and recorded from each of the cameras at a frequency of one image per second. Each of the systems was enclosed in an aluminum cage to protect the components from damage. Additionally, a 1/4 inch diameter coaxial cable provided a connection from the drop-camera system to the winch at the surface, allowing images from the monochrome camera were viewed in real time at a rate of four images per second. This allowed the height of the camera to be actively controlled to keep it just above the seafloor using a quick response electric winch.

Supplement 2. Distribution modeling of structure forming invertebrates and cross-validation using bottom trawl survey and camera survey data

Bottom trawl survey models

The initial distribution modeling was carried out using bottom trawl survey data collected on the NOAA Fisheries, Alaska Fisheries Science Center, eastern Bering Sea outer shelf and slope surveys from 2002 to 2012 and was reported in Sigler et al. (2015). Briefly, the invertebrate distributions were predicted using generalized additive models (GAM) to determine the relationships between environmental variables (latitude*longitude, depth, slope, long-term average bottom temperature, ocean color, mean current speed, maximum tidal current speed, sediment grain size and sediment sorting which is the standard deviation of grain size) and observations of presence in bottom trawl survey catches for each structure-forming invertebrate group. All modeling was carried out in R software using the mgcv package (Wood 2006) and diagnostics were performed using the PresenceAbsence package. A binomial distribution was used to model presence or absence data and backwards term selection was employed so that the full model including all variables was fit first and the least significant variable was eliminated in stepwise fashion until no further gain in the unbiased risk estimator (UBRE) criterion was achieved (Wood 2006). The grid size of all models presented here was 1 hectare (100 m by 100 m). Spatial analyses and mapping were also carried out in R software using the spatial analyses packages: raster, gstat, rgdal, rgeos and sp.

Model validation was conducted by comparing the predictions of probability of structure-forming invertebrate presence or absence from the bottom trawl survey models to the observations of structure-forming invertebrate presence or absence from the camera survey. Since model predictions were made on a map, the camera survey transects were overlaid on each of the prediction maps and the underlying predictions were extracted. Because each camera transect may have viewed multiple grid cells on the prediction map, the maximum probability value underlying each camera survey drop was extracted and then compared to the observation of presence or absence from image analysis at that site.

The area under the receiver operating curve (AUC) was used to evaluate the fit of the trawl survey model to the camera drop observations performance (DeLong et al. 1988, Hosmer and Lemeshow 2005). The AUC measures the goodness-of-fit of presence-absence models by comparing the probability associated with randomly selected presence sites to randomly selected absence sites to determine if the probability of presence is higher at sites with observed presence than at sites with observed absence. The AUC can range from 0 to 1 and a value of 0.5 indicates model predictions are only as good as a random guess. A high AUC value indicates the model fits the observations better. The Spearman's rank correlation between the observations and predictions was also calculated.

As a secondary test of the model fit, a threshold probability was calculated where the rate of false positives (prediction of presence where absence was observed) was equal to the rate of false negatives (prediction of absence where presence was observed). This threshold probability was applied to all the camera survey sites to produce a matrix indicating the percent correctly predicted.

All of the model evaluations were carried out on the three taxonomic groups of structure-forming invertebrates (corals, sponges, and sea whips). All the analyses, modeling and mapping were carried out using R software (R Core Development Team 2013).

Camera survey models

Using only the camera survey data, a model was developed for presence or absence of structure-forming invertebrates. A generalized additive modeling framework (GAM; Wood 2006) was used with some of the same explanatory variables (latitude, depth, bottom temperature, slope, mean current speed, maximum tidal current speed, ocean color, grain size and sediment sorting) as the bottom trawl survey model, to predict presence or absence of the camera survey data. In both the bottom trawl survey and camera survey models sediment characteristics were taken from the EBSSED database (Smith and McConnaughey 1999). Longitude was not included in the camera survey model, as based on previous results (Sigler et al. 2015), latitude and depth were expected to be the most important variables driving community patterns on the eastern Bering Sea slope. Removing longitude also minimized the number of model parameters that had to be used in the smaller camera survey data set.

The camera survey model was evaluated using the same methods as were used for evaluating the bottom trawl survey model. AUC and correlation were calculated, a threshold probability was estimated that balanced the false positive and false negative error rates, and the percent classified correctly was also computed. These same diagnostics were computed comparing the bottom trawl survey observations to the camera survey model. These camera survey models were developed independently for coral, sponges, and sea whips. The camera survey models were validated using the bottom trawl survey data from Sigler et al. (2015).

Bottom trawl survey validation results

The model based on bottom trawl survey data predicted the distribution of presence or absence of coral in the camera survey data very well. The AUC was 0.73 (standard deviation; SD = 0.05) and the Spearman rank correlation was highly significant ($r = 0.27$, $p < 0.0001$) indicating model predictions were well correlated to observations and predicted correctly in 72% of cases (Table S1). The model based on bottom trawl survey data predicted the distribution of presence or absence of sponge in the camera survey data less well. The AUC was 0.63 (standard deviation = 0.04), although the Spearman correlation was highly significant ($r = 0.23$, $p = 0.0003$) indicating model predictions were well correlated to observations, although only about 60% of cases were predicted correctly at a threshold probability of 0.70 (Table S1). The AUC was 0.69 (SD = 0.03), although the Spearman correlation was highly significant ($r = 0.32$, $p < 0.0001$) indicating model predictions were well correlated to observations (Table S1). Sea whip presence or absence was predicted correctly in ~65% of cases with a threshold probability of 0.06.

Camera survey model validation results

The best-fitting model of coral presence or absence based on the camera survey data contained four significant terms, with depth and latitude being the most important (Table S2). Probability of coral presence increased sharply with increasing depth to about 300 m and then leveled off with further increase in probability of presence below 600 m (Figure S1). The model predicted higher probabilities of presence in the middle latitudes of the eastern Bering Sea slope. Probability of presence of coral increased slightly with increasing tidal currents and increased sediment sorting (Figure S1). The model explained about 51% of the deviance in the camera observations (AUC = 0.95, SD = 0.01) with 87% of the stations correctly predicted (Table S1). The predictions from the camera-based model (Figure S2) were similar to the predictions of the trawl survey-based model (Sigler et al. 2015).

The best-fitting model of sponge presence or absence based on the camera survey data contained seven significant terms (Table S2). Probability of sponge presence increased to a peak at a depth of ~300 m and then decreased at deeper depths (Figure S1). Probability of sponge presence decreased with increasing long-term average temperature and was highest at the large and small extremes of sediment sorting. There were increases in sponge probability of presence related to slope and sediment size and there was a dome-shaped relationship between sponge presence and ocean color (Figure S1). The model explained only about 16% of the deviance in the camera observations of sponge presence or absence (AUC = 0.80, SD = 0.03) with 73% of the stations predicted correctly (Table S1). The predictions from the camera-based model (Figure S2) were similar to the predictions of the trawl survey-based model (Sigler et al. 2015), although the bottom trawl survey model predicted a wider range of high probability sponge areas along the outer shelf, and the camera-based model predicted a higher probability of presence in the northeastern outer shelf. The camera-based predictions on the northeastern outer shelf were undoubtedly spurious, as no camera sampling was conducted here. The camera and trawl survey models did agree that sponge occurs in most areas of the outer shelf and slope.

The best-fitting model of sea whip presence or absence based on the camera survey data also contained seven significant terms, with sediment grain size being the most important (Table S2). Probability of sea whip presence increased sharply with increasing grain size to a value of ~4 (which corresponds to very fine sand) and then decreased (Figure S1). The model predicted higher probabilities of presence in the middle latitudes of the eastern Bering Sea slope. Probability of presence of sea whips had a dome-shaped relationship with depth, peaking at about 450 m. There was generally a nonlinear increase in sea whip probability of presence with increasing temperature, slope and tidal currents and a linear increase in probability of presence with current speed. The model explained only about 26% of the deviance in the camera observations (AUC = 0.83, SD = 0.03), with the model predicting 76% of the stations correctly (Table S1). The predictions from the camera-based model (Figure S1) were different from the predictions of the trawl survey-based model (Sigler et al. 2015), in that the camera model predicted a much wider depth range for sea whips and a much broader distribution on the outer shelf. Similar to the case for the sponges, the high probability of presence in the northeastern outer shelf and also in the southeastern outer shelf were outside the area of sampling for the camera survey and should be viewed with caution.

Cross-validation of average predictions

The results of cross-validation of the average predictions with the bottom trawl and camera survey observations with are shown in Table S1. It should be noted that in this case, the observations are not truly independent from the average predictions, as they form the basis for the two sets of model predictions that were averaged. However, the results show that the average predictions performed well across all taxa and data sets, with AUC values > 0.71 in all cases. The average predictions also predicted the percent correct for both presences and absences greater than 70% of the time. It is important to note that the prevalence of the positive values was different for each of these data sets. For example, there were corals observed at only 6.2% of the bottom trawl survey sites used in the modeling, whereas corals were observed at 12.8% of the camera survey transects. The rate of positive occurrences and the overall probability of presence in each dataset can greatly impact the threshold values chosen to infer presence and thus threshold values for presence are generally not transferable across data sets (Manel et al. 2001). A separate threshold value was set for each dataset (bottom trawl survey or camera survey) during evaluation to account for potential biases. In further analyses to model density and height distributions, only camera survey data was available, so the average predictions and the threshold specific to the camera survey were used to derive presence levels for each structure forming invertebrate taxa.

LITERATURE CITED

DeLong ER, DeLong DM, Clarke-Pearson DL (1988) Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics 44:837–845

Hosmer DW, Lemeshow S (2005) Applied logistic regression, 2nd edn. John Wiley & Sons, Hoboken, NJ

Manel S, Williams HC, Ormerod SJ (2001) Evaluating presence-absence models in ecology: the need to account for prevalence. J Appl Ecol 38:921–931

R Development Core Team (2013) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.www.r-project.org

Sigler MF, Rooper CN, Hoff GR, Stone RP, McConnaughey RA, Wilderbuer TK (2015) Faunal features of submarine canyons on the eastern Bering Sea slope. Mar Ecol Prog Ser 526:21–40

Smith KR, McConnaughey RA (1999) Surficial sediments of the eastern Bering Sea continental shelf: EBSSED database documentation. NOAA Tech Memo NMFS-AFSC-104. US Department of Commerce, Seattle, WA

Wood SN (2006) Generalized additive models: an introduction with R. Chapman & Hall, Boca Raton, FL

Table S1. Summary of generalized additive model fits and AUC for model validation (trawl model vs. camera observations and camera model vs. trawl observations) and for cross-validation of the average of both model predictions.

Taxonomic group	Data	AUC	Spearman correlation	Percent correct - Presence	Percent correct - Absence	Threshold
			Bottom trawl survey model			
Corals	Bottom trawl	0.92 (0.01)	0.35	0.82	0.80	0.08
	Camera	0.73 (0.05)	0.27	0.72	0.72	0.19
Sponges	Bottom trawl	0.83 (0.01)	0.56	0.74	0.74	0.53
	Camera	0.63 (0.04)	0.23	0.58	0.59	0.70
Sea whips	Bottom trawl	0.89 (0.01)	0.42	0.81	0.79	0.13
	Camera	0.69 (0.03)	0.32	0.66	0.64	0.06
			Camera survey model			
Corals	Camera	0.95 (0.01)	0.52	0.88	0.87	0.21
	Bottom trawl	0.73 (0.04)	0.01	0.67	0.78	0.19
Sponges	Camera	0.80 (0.03)	0.515	0.72	0.74	0.44
	Bottom trawl	0.54 (0.02)	-0.07	0.50	0.49	0.56
Sea whips	Camera	0.83 (0.03)	0.56	0.75	0.76	0.44
	Bottom trawl	0.57 (0.02)	0.08	0.55	0.55	0.72
			Average prediction			
Corals	Bottom trawl	0.85 (0.03)	0.27	0.74	0.81	0.01
	Camera	0.90 (0.02)	0.47	0.81	0.82	0.11
Sponges	Bottom trawl	0.71 (0.01)	0.46	0.70	0.71	0.59
	Camera	0.76 (0.03)	0.44	0.71	0.71	0.60
Sea whips	Bottom trawl	0.85 (0.02)	0.35	0.72	0.72	0.40
	Camera	0.74 (0.03)	0.41	0.7	0.7	0.16

Table S2. Best-fitting generalized additive models predicting presence or absence of corals, sponges and sea whips using data from the 2014 camera survey of the eastern Bering Sea slope and outer shelf. Model terms are listed in order of importance in the models, estimated degrees of freedom (edf) for each of the variables are also given.

Response variable	Generalized additive model	Deviance explained	edf	R^2
Coral presence or absence	s(depth)+s(latitude)+s(tidal current)+s(sediment sorting)	51%	2.9; 2.3; 2.3 ; 1.9	0.43
Sponge presence or absence	s(slope)+s(sediment sorting)+s(depth)+s(latitude)+s(grain size)+s(temperature)+s(ocean color)	16%	2.9; 1.0; 2.8; 2.9; 2.0; 2.8; 2.2	0.22
Sea whip presence or absence	s(grain size)+s(temperature)+s(depth)+s(tidal current)+s(current speed)+s(latitude)+s(slope)	26%	2.5; 2.6; 2.7; 2.8; 1.0; 2.3; 2.2	0.26

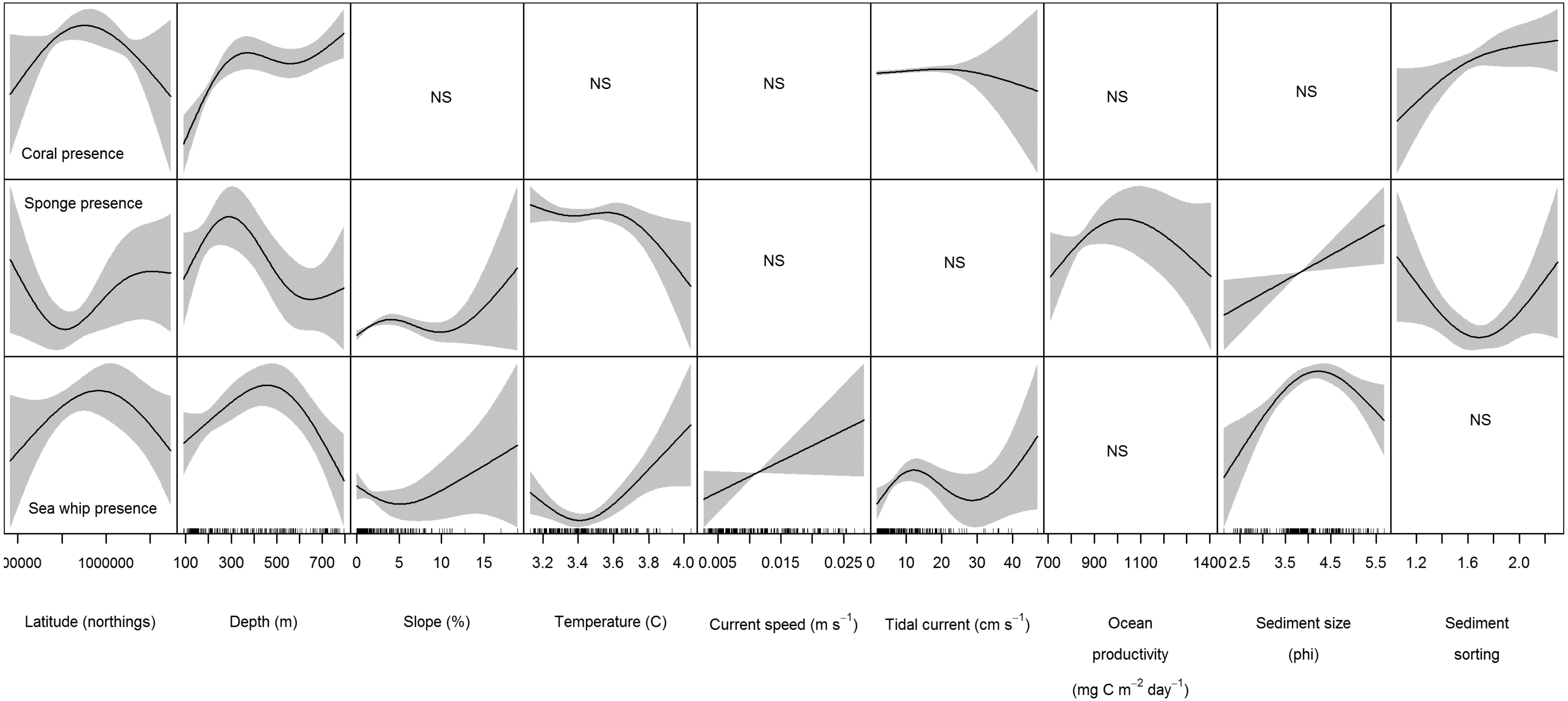

Figure S1. Smoothed relationships from the best-fitting GAM model between explanatory variables and the presence or absence of corals, sponges and sea whips from the camera survey. NS indicates the variable was not significant and – indicates the variable was not used in the modeling.

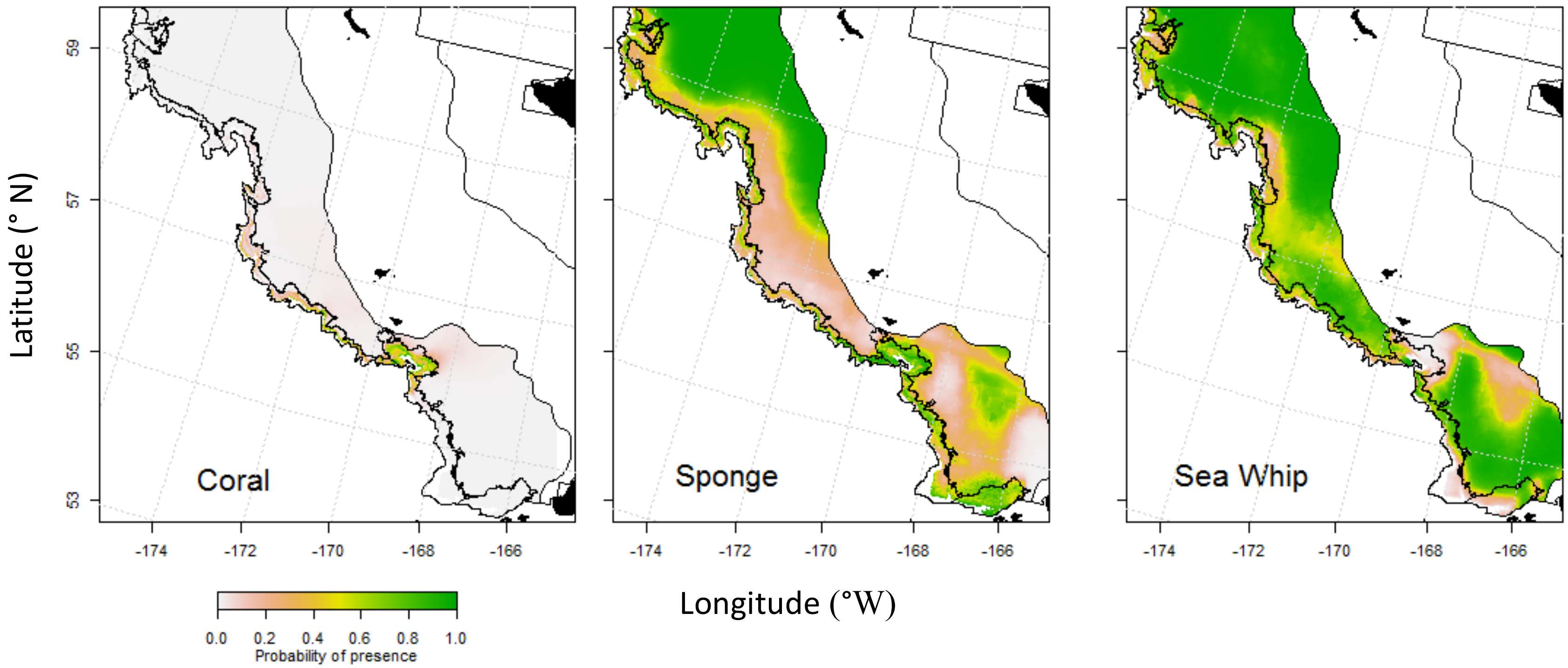

Figure S2. Predicted probability of structure-forming invertebrate presence predicted from the best fitting GAM model of presence or absence in the camera survey data. Panels represent coral, sponge and sea whips, predictions are made on a 100 m by 100 m grid.