**Supplemental Materials**

*Additional Sampling and Survey Details*

The Gulf of Alaska (GOA) study area extends from 131°W longitude to 165°W longitude, and covers depths up to 1000 m [(Zimmermann et al., 2019)](https://www.zotero.org/google-docs/?JmyKj0). Surveys were conducted in 1993 and 1996, and then biennially from 1999 to 2019. Stations are selected using a stratified random sampling design, and extensive information on survey data and how it was used in this study are available in Pirtle et al. (2023).

The Aleutian Islands (AI) are a chain of volcanic islands stretching from southwest Alaska across the North Pacific, separating the western GOA from the Bering Sea.The study area extends from Unimak Pass at 165°W to Stalemate Bank at 171°E, and covers depths up to 500 m. Surveys were conducted in 1991, 1994, and then biennially from 1997 to 2018. Data used to model the AI includes some stations sampled during GOA survey years. Stations are selected using a stratified random sampling design, and extensive information on survey data and how it was used in this study are available in Harris et al. (2023).

The Bering Sea area in this study includes the northern Bering Sea, eastern Bering Sea (EBS), and Bering Sea slope. The EBS has been surveyed annually since 1982, whereas the northern Bering Sea was sampled in 2010, 2017, and 2019, and the Bering Sea slope in 2002, 2004, 2008, 2010, 2012, and 2016. The northern and eastern Bering Sea are surveyed to a depth of 200 m, while the Bering Sea slope is surveyed to a depth of 1200 m. Stations in the northern and eastern Bering Sea use a systematic sampling design whereas the Bering Sea slope uses a stratified random design. Full details are available in Laman et al. (2023).

**Table S1**: Covariates used for species distribution models. The “response function used in GAMs” column describes the function specified to transform the covariate when estimating the linear predictor, where “2D smooth” refers to a Duchon spline [(Duchon, 1977)](https://www.zotero.org/google-docs/?Snsk2z) with a 1st order smoothing penalty, and “1D smooth” may refer to either a univariate thin-plate spline with a 2nd-order smoothing penalty or a cubic regression spline [(Wood, 2003)](https://www.zotero.org/google-docs/?3lhoGK).  Data source describes the method that was used to obtain each covariate.

|  |  |  |  |
| --- | --- | --- | --- |
| **Covariate** | **Units** | **Response function used in GAMs** | **Data source** |
| Geographic position (Latitude & Longitude)† | -- | 2D smooth | Taken from the midpoint of the path of each haul |
| Bottom current vector | m/s | 2D smooth | NEP5 ROMS (Regional Ocean Modeling System) pooled average 1991-2018 (AI and GOA) or 1982-2019 (EBS) [(Hermann et al., 2013, 2016; Kearney et al., 2020)](https://www.zotero.org/google-docs/?U4UG69) |
| Bottom current vector Variation | m/s | 2D smooth |
| Bottom depth | m | 1D smooth | Recorded from each trawl station |
| Slope | ° | 1D smooth | Bathymetry maps post-processed using ArcGIS 10.7 Benthic Terrain Modeler [(Walbridge et al., 2018; Wright et al., 2012)](https://www.zotero.org/google-docs/?Jzoytw). |
| Aspect (North & East) | -- | 1D smooth |
| Curvature | -- | 1D smooth |
| Bathymetric position index (BPI) | -- | 1D smooth |
| Bottom temperature | °C | 1D smooth | Recorded during each trawl |
| Tidal current Maximum | cm/s | 1D smooth | Tidal inversion program [(Egbert & Erofeeva, 2002)](https://www.zotero.org/google-docs/?WvpOIs) |
| Sediment size\* | -log(mm) | 1D smooth | EBSSED  [(eastern Bering Sea sediment database; Richwine et al., 2018)](https://www.zotero.org/google-docs/?uiXsDM)  |
| Terrain rockiness\* | % | 1D smooth | Smooth sheets [(Zimmermann et al., 2013b)](https://www.zotero.org/google-docs/?jZPhfD), EBSSED-2 (Richwine et al. 2018), and  trawlable seafloor models [(J. L. Pirtle et al., 2015)](https://www.zotero.org/google-docs/?rtWyRI) |
| Coral presence | -- | Factor | Modeled distribution from Rooper et al. [(2017)](https://www.zotero.org/google-docs/?fBeKUL) |
| Sponge presence | -- | Factor |
| Pennatulacean presence | -- | Factor |

\* Sediment Size is used only in the EBS, while Terrain Rockiness is used in the AI and GOA

† Not included in MaxEnt models

*Additional Modeling Details*

Maximum Entropy

Maximum entropy (MaxEnt) models were fit using the *maxnet* package in R (Phillips et al, 2017). This type of model takes opportunistic or “presence-only” data and uses a combination of mathematical functions or “features” to model how the probability of suitable habitat responds to environmental covariates. We used the default settings for the feature set, which included linear, quadratic, and product interaction features. Hinge features were included in all models with 80 or more presence records. MaxEnt models fit using this package differ somewhat from traditional versions, in that they are fit as a inhomogenous Poisson process, which allows the latent Poisson abundance to be approximated from the model outputs [(Phillips et al., 2017)](https://www.zotero.org/google-docs/?ByvI0i).

General Additive Models

Four types of general additive models (GAMS) were used in this study. Each GAM were fit using the *mgcv* package in R (Wood, 2011). The paGAM uses presence/absence data to fit a complementary log-log (cloglog) linked model with a binomial error distribution [(Barry & Welsh, 2002; Potts & Elith, 2006)](https://www.zotero.org/google-docs/?3kyQOK). Unlike a logit link, the cloglog link estimates the probability of observing zero or greater than zero events, meaning that it can approximate an underlying Poisson distribution. This approximation is made by applying the log function to the linear predictor from the cloglog model, and it is expected to be most accurate when predicting low abundances.

 The hurdle model (hGAM; a.k.a. delta-model) separates observed catches in the survey into a binomial (presence-absence) component for the probability that the species is caught in a given haul, and a “positive” component for the mean density given that the species is present. The presence-absence component is fit using a cloglog link and the density component is fit using a log link. These component models use a combined zero-adjusted Poisson distribution (Zuur, 2009). The estimate of numerical abundance is obtained by applying the inverse cloglog function to the linear predictor of the  probability component and the inverse log function to the linear predictor of the density component, and then multiplying these two values together.

The Poisson and negative-binomial GAMs (GAMP & GAMnb) both use a log link function and both directly estimate abundance. The GAMnb estimates an additional parameter that can help account for the overdispersion commonly observed in ecological count data [(McCullagh & Nelder, 1989)](https://www.zotero.org/google-docs/?ZDxFVA).

*Supplemental References*

[Barry, S. C., & Welsh, A. H. (2002). Generalized additive modeling and zero inflated count data. *Ecological Modeling*, *157*, 179–188.](https://www.zotero.org/google-docs/?VeCzQm)

[Danielson, S., Curchitser, E., Hedstrom, K., Weingartner, T., & Stabeno, P. (2011). On ocean and sea ice modes of variability in the Bering Sea. *J. Geophys. Res*, *116*. https://doi.org/10.1029/2011JC007389.](https://www.zotero.org/google-docs/?VeCzQm)

[Duchon, J. (1977). *Splines minimizing rotation-invariant semi-norms in Solobev spaces* (W. Shemp & K. Zeller, Eds.). Springer.](https://www.zotero.org/google-docs/?VeCzQm)

[Egbert, G. D., & Erofeeva, S. Y. (2002). Efficient inverse Modeling of barotropic ocean tides. *Journal of Atmospheric and Oceanic Technology*, *19*(2), 183–204. https://doi.org/10.1175/1520-0426(2002)019<0183:EIMOBO>2.0.CO;2](https://www.zotero.org/google-docs/?VeCzQm)

Harris, J., Laman, E. A., Pirtle, J., Siple, M. C., Rooper, C. N., Hurst, T., & Conrath, C. L. (2022). Advancing model-based essential fish habitat descriptions for North Pacific species in the Aleutian Islands. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-458, 406 p.

[Hermann, A. J., Gibson, G. A., Bond, N. A., Curchitser, E. N., Hedstrom, K., Cheng, W., Wang, M., Stabeno, P. J., Eisner, L., & Cieciel, K. D. (2013). A multivariate analysis of observed and modeled biophysical variability on the Bering Sea shelf: Multidecadal hindcasts (1970–2009) and forecasts (2010–2040). *Deep Sea Research Part II: Topical Studies in Oceanography*, *94*, 121–139.](https://www.zotero.org/google-docs/?VeCzQm) <https://doi.org/10.1016/j.dsr2.2013.04.007>

[Laman, E. A., Pirtle, J., Harris, J., Siple, M. C., Rooper, C. N., Hurst, T., & Conrath, C. L. (2022). Advancing Model-Based Essential Fish Habitat Descriptions for North Pacific Species in the Bering Sea](https://www.zotero.org/google-docs/?VeCzQm). U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-459, 538 p.

[Kearney, K., Hermann, A., Cheng, W., Ortiz, I., & Aydin, K. (2020). A coupled pelagic–benthic–sympagic biogeochemical model for the Bering Sea: Documentation and validation of the BESTNPZ model (v2019.08.23) within a high-resolution regional ocean model. *Geoscientific Model Development*, *13*(2), 597–650.](https://www.zotero.org/google-docs/?VeCzQm) <https://doi.org/10.5194/gmd-13-597-2020>

[McCullagh, P., & Nelder, J. A. (1989). *Generalized Linear Models* (2nd ed.). Chapman and Hall.](https://www.zotero.org/google-docs/?VeCzQm)

[Pirtle, J. L., Weber, T. C., Wilson, C. D., & Rooper, C. N. (2015). Assessment of trawlable and untrawlable seafloor using multibeam-derived metrics. *Methods Oceanogr*, *12*, 18–35.](https://www.zotero.org/google-docs/?VeCzQm)

[Pirtle, J., Laman, E. A., Harris, J., Siple, M. C., Rooper, C. N., Hurst, T., Conrath, C. L., & Gibson, G. (2023). Advancing Model-Based Essential Fish Habitat Descriptions for North Pacific Species in the Gulf of Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-468, 541 p.](https://www.zotero.org/google-docs/?VeCzQm)

[Potts, J., & Elith, J. (2006). Comparing species abundance models. *Ecol. Model*, *199*, 153–163.](https://www.zotero.org/google-docs/?VeCzQm)

[Richwine, K. A., Smith, K. R., & McConnaughey, R. A. (2018). *Surficial sediments of the eastern Bering Sea continental shelf: EBSSED-2 database documentation. U.S* (p. 377, 48).](https://www.zotero.org/google-docs/?VeCzQm)

[Rooper, C. N., Wilborn, R., Goddard, P., Williams, K., Towler, R., & Hoff, G. R. (2017). Validation of deep-sea coral and sponge distribution models in the Aleutian Islands, Alaska. *ICES J. Mar. Sci*, *75*(1), 199–209.](https://www.zotero.org/google-docs/?VeCzQm)

[Walbridge, S., Slocum, N., Pobuda, M., & Wright, D. J. (2018). Unified geomorphological analysis workflows with Benthic Terrain Modeler. *Geosci*, *8*(94). http://github.com/EsriOceans/btm.](https://www.zotero.org/google-docs/?VeCzQm)

[Wood, S. N. (2003). Thin plate regression splines. *J. R. Statist. Soc. B*, *65*(1), 95–114.](https://www.zotero.org/google-docs/?VeCzQm)

Wood, S. N. (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *J. R. Statist. Soc. B*, *73*(1), 3-36.

[Wright, D. J., Pendleton, M., Boulware, J., Walbridge, S., Gerlt, B., Eslinger, D., & Sampson, D. (2012). *ArcGIS Benthic Terrain Modeler (BTM), v. 3.0, Environmental Systems Research Institute, NOAA Coastal Services Center, Massachusetts Office of Coastal Zone Management*.](https://www.zotero.org/google-docs/?VeCzQm)

[Zimmermann, M., Prescott, M. M., & Rooper, C. N. (2013a). *Smooth Sheet Bathymetry of the Aleutian Islands* (p. 250, 43).](https://www.zotero.org/google-docs/?VeCzQm)

Zurell, D., Franklin, J., König, C., Bouchet, P. J., Dormann, C. F., Elith, J., Fandos, G., Feng, X., Guillera‐Arroita, G., & Guisan, A. (2020). A standard protocol for reporting species distribution models. *Ecography*, 43, 1261–1277.

Zuur, A. F., N., E., Ieno, N. J. W., Saveliev, A. A., & Smith, G. M. (2009). Mixed Effects Models and Extensions in Ecology with R. Springer Science+Business.