**Supplementary Material**

**Supplementary Tables**

**Table SM1.** List of symbols used in the joint, dynamic species distribution model following notation from Thorson (2019).

|  |  |  |  |
| --- | --- | --- | --- |
| **Symbol** | **Description** | **Dimensions** (n = number) | **Type** |
| *i* | Observation | ̶ | Index |
|  | Category (i.e., species) | ̶ | Index |
| *s* | Spatial location | ̶ | Index |
| *t* | Time interval (i.e., year) | ̶ | Index |
| *f* | Factor | ̶ | Index |
| *g* | Cluster | ̶ | Index |
|  | Number of observations |  | ̶ |
|  | Number of locations |  | ̶ |
|  | Number of species |  | ̶ |
|  | Number of years |  | ̶ |
|  | Number of temporal factors in linear predictor 1 |  | ̶ |
|  | Number of temporal factors in linear predictor 2 |  | ̶ |
|  | Number of spatial factors in linear predictor 1 |  | ̶ |
|  | Number of spatial factors in linear predictor 2 |  | ̶ |
|  | Biomass (i.e., survey catch) data |  | Data |
|  | Area-swept for each observation |  | Data |
|  | Area associated with each location |  | Data |
|  | Distance between locations and |  | Data |
|  | Variance for positive catch for each species |  | Fixed effect |
|  | Intercept for 1st linear predictor |  | Fixed effect |
|  | Intercept for 2nd linear predictor |  | Fixed effect |
|  | Loadings matrix for temporal covariation for 1st linear predictor |  | Fixed effect |
|  | Loadings matrix for temporal covariation for 2nd linear predictor |  | Fixed effect |
|  | Loadings matrix for spatial covariation for 1st linear predictor |  | Fixed effect |
|  | Loadings matrix for spatial covariation for 2nd linear predictor |  | Fixed effect |
|  | Decorrelation rate for 1st linear predictor |  | Fixed effect |
|  | Decorrelation rate for 2nd linear predictor |  | Fixed effect |
|  | Smoothness parameter in Matérn correlation function, where ν |  | Fixed effect (Constant) |
|  | Temporal factors for 1st linear predictor |  | Random effect |
|  | Temporal factors for 2nd linear predictor |  | Random effect |
|  | Spatial factors for 1st linear predictor |  | Random effect |
|  | Spatial factors for 2st linear predictor |  | Random effect |
|  | 1st linear predictor |  | Internally derived |
|  | 2st linear predictor |  | Internally derived |
|  | 1st link-transformed predictor that follows Poisson process |  | Internally derived |
|  | 2nd link-transformed predictor |  | Internally derived |
| **R1** | Spatial correlation matrix for 1st linear predictor |  | Internally derived |
| **R2** | Spatial correlation matrix for 2nd linear predictor |  | Internally derived |
| **H** | Anisotropy/ Isotropy matrix |  | Internally derived |
|  | Joint covariance matrix calculated for temporal and spatial component separately |  | Externally derived |
|  | Total variance between species and | 1 | Externally derived |
|  | Loadings matrix from either temporal or spatial covariation from 1st linear predictor |  | Externally derived |
|  | Loadings matrix from either temporal or spatial covariation from 2nd linear predictor |  | Externally derived |
|  | Index of abundance |  | Externally derived |
|  | Predicted density |  | Externally derived |
|  | Distance between a set of species and based on covariance matrix | 1 | Externally derived |
|  | Spatial component estimates from 1st linear predictor |  | Externally derived |
|  | Spatial component estimates from 2nd linear predictor |  | Externally derived |
|  | Total spatial component estimate |  | Externally derived |
|  | Total average spatial value for each cluster |  | Externally derived |
|  | Temporal component estimates from 1st linear predictor |  | Externally derived |
|  | Temporal component estimates from 2nd linear predictor |  | Externally derived |
|  | Total temporal component estimate |  | Externally derived |
|  | Difference between total temporal estimates from *t*-1 and *t* |  | Externally derived |
|  | Total average difference between temporal estimates from *t*-1 and *t* for each cluster |  | Externally derived |

**Table SM2.** Life history characteristics for rockfish borrowed from a literature review in Omori *et al.* (2021).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Max age | Age at maturity | Length at maturity | Max length |
| canary | 71 | 9 | 480 | 580 |
| harlequin | 34 | 9 | 230 | 323 |
| redbanded | 106 | 4 | 420 | 698 |
| redstripe | 55 | 8 | 290 | 420 |
| sharpchin | 58 | 10 | 270 | 350 |
| silvergray | 75 | 10 | 460 | 623 |
| yelloweye | 117 | 22 | 475 | 644 |
| yellowmouth | 99 | 11 | 380 | 469 |
| yellowtail | 64 | 9 | 410 | 530 |

**Table SM3.** Scaled harvest fractions for each rockfish species used for Ward’s hierarchical cluster analysis.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 1993 | 1996 | 1999 | 2001 | 2003 | 2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017 | 2019 |
| canary | 0.165 | 1 | 0.936 | 0.488 | 0.584 | 0.109 | 0.084 | 0.16 | 0.104 | 0.614 | 0.142 | 0.162 | 0.232 |
| harlequin | 0 | 0.013 | 0.089 | 0.126 | 0.721 | 0.788 | 0.598 | 0.911 | 0.61 | 0.53 | 1 | 0.807 | 0.624 |
| redbanded | 0.089 | 0.574 | 0.371 | 0.477 | 0.484 | 0.372 | 0.444 | 0.434 | 0.726 | 0.996 | 0.722 | 1 | 0.857 |
| redstripe | 0 | 0.031 | 0.034 | 0.017 | 0.211 | 0.056 | 0.212 | 0.228 | 0.506 | 0.188 | 0.374 | 0.571 | 1 |
| sharpchin | 1 | 0.203 | 0.078 | 0.077 | 0.183 | 0.036 | 0.058 | 0.051 | 0.094 | 0.038 | 0.088 | 0.102 | 0.056 |
| silvergray | 0.032 | 0.127 | 0.156 | 0.078 | 0.23 | 0.047 | 0.215 | 0.296 | 0.932 | 0.267 | 0.642 | 0.732 | 1 |
| yelloweye | 0.407 | 0.95 | 0.729 | 0.816 | 1 | 0.573 | 0.684 | 0.764 | 0.741 | 0.929 | 0.612 | 0.688 | 0.589 |
| yellowmouth | 0.001 | 0.001 | 0.001 | 0.001 | 0.278 | 0 | 0.037 | 0.009 | 0 | 0 | 0 | 0 | 1 |
| yellowtail | 0.013 | 0.112 | 0.177 | 1 | 0.146 | 0.035 | 0.041 | 0.039 | 0.041 | 0.048 | 0.076 | 0.04 | 0.031 |

**Table SM4.** Total and first three eigenvalues associated with each linear predictor and total spatial ( and temporal () model components.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Total | 1 | 2 | 3 |
|  | 204.24 | 147.96 | 19.06 | 14.77 |
|  | 4.58 | 3.06 | 0.74 | 0.53 |
|  | 165.72 | - | - | - |
|  | 38.5172 | - | - | - |
|  | 0.87 | - | - | - |
|  | 3.72 | - | - | - |

**Table SM5.** Combined rotated factor loading values for the spatial components.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| canary | 2.034 | 2.873 | -0.829 | 0.191 | -1.295 | 0.068 | 0.567 | -0.002 | -0.252 |
| harlequin | 4.453 | -1.131 | -1.443 | 1.069 | -0.240 | 0.453 | 0.064 | 0.820 | 0.196 |
| redbanded | 2.755 | 0.620 | 2.147 | 1.465 | 1.013 | 0.580 | 0.306 | -0.094 | -0.164 |
| redstripe | 5.475 | -0.835 | 0.120 | -1.122 | 0.789 | -0.761 | 0.782 | 0.211 | -0.144 |
| sharpchin | 6.247 | -0.564 | -0.021 | 1.001 | -0.642 | -0.854 | -0.328 | -0.643 | 0.142 |
| silvergray | 3.958 | 0.826 | 0.375 | -0.495 | 0.152 | -0.096 | -1.008 | 0.420 | -0.417 |
| yelloweye | 4.280 | -0.855 | -1.143 | -0.854 | 0.143 | 1.187 | -0.030 | -0.624 | -0.108 |
| yellowmouth | 3.166 | 0.394 | 2.206 | -1.040 | -0.990 | 0.382 | -0.017 | 0.187 | 0.417 |
| yellowtail | 1.843 | 2.562 | -1.034 | -0.208 | 1.368 | -0.085 | -0.181 | -0.058 | 0.427 |

**Table SM6.** Combined rotated factor loading values for the temporal components.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| canary | 1.221 | 0.001 | -0.119 | -0.021 | 0.020 | -0.022 | -0.032 | 0.000 | 0.000 |
| harlequin | 0.404 | 0.290 | -0.367 | 0.027 | -0.162 | 0.038 | 0.010 | 0.000 | 0.000 |
| redbanded | 0.069 | 0.027 | 0.004 | 0.091 | 0.130 | -0.021 | 0.037 | 0.000 | 0.000 |
| redstripe | 0.398 | 0.223 | 0.205 | 0.088 | -0.097 | -0.079 | 0.006 | 0.000 | 0.000 |
| sharpchin | 0.315 | 0.416 | -0.219 | -0.060 | 0.192 | 0.001 | 0.002 | 0.000 | 0.000 |
| silvergray | 0.199 | 0.088 | 0.287 | 0.223 | 0.054 | 0.045 | -0.032 | 0.000 | 0.000 |
| yelloweye | 0.107 | 0.089 | -0.094 | 0.222 | -0.014 | 0.012 | 0.028 | 0.000 | 0.000 |
| yellowmouth | 0.614 | 0.230 | 0.450 | -0.147 | -0.025 | 0.038 | 0.027 | 0.000 | 0.000 |
| yellowtail | 0.843 | -0.603 | -0.051 | 0.017 | 0.020 | 0.012 | 0.020 | 0.000 | 0.000 |

**Table SM7.** Fixed effect estimates from species distribution model (i.e., VAST model).

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Estimates |  | canary | harlequin | redbanded | redstripe | sharpchin | silvergray | yelloweye | yellowmouth | yellowtail |
|  |  | 1.19 | 1.47 | 1.07 | 1.41 | 1.51 | 1.19 | 0.78 | 1.37 | 1.21 |
|  |  | -6.05 | -2.43 | -2.11 | -4.38 | -4.48 | -2.83 | -4.30 | -5.40 | -4.83 |
|  |  | 0.38 | 1.08 | 0.41 | 0.72 | 1.07 | 0.47 | 1.24 | 0.19 | 0.27 |
|  | *f =* 1 | -0.341 | 0.197 | -0.084 | -0.040 | 0.124 | -0.080 | 0.028 | -0.164 | -0.606 |
|  | *f =* 2 | 0.000 | -0.190 | -0.119 | -0.098 | -0.201 | -0.146 | -0.241 | 0.130 | 0.206 |
|  | *f =* 3 | 0.000 | 0.000 | 0.028 | -0.174 | 0.098 | -0.029 | -0.012 | -0.052 | 0.066 |
|  | *f =* 4 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 5 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 6 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 7 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 8 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 9 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 1 | -1.179 | -0.508 | -0.047 | -0.378 | -0.389 | -0.151 | -0.124 | -0.544 | -0.702 |
|  | *f =* 2 | 0.000 | -0.278 | 0.054 | 0.135 | -0.127 | 0.321 | 0.006 | 0.244 | 0.057 |
|  | *f =* 3 | 0.000 | 0.000 | 0.072 | -0.048 | 0.327 | -0.073 | -0.050 | -0.021 | -0.238 |
|  | *f =* 4 | 0.000 | 0.000 | 0.000 | -0.262 | -0.144 | -0.159 | 0.042 | -0.505 | 0.335 |
|  | *f =* 5 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 6 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 7 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 8 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 9 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  |  | -3.80 | -3.80 | -3.80 | -3.80 | -3.80 | -3.80 | -3.80 | -3.80 | -3.80 |
|  | *f =* 1 | -3.282 | -1.797 | -1.468 | -2.637 | -2.627 | -2.082 | -2.020 | -1.621 | -2.714 |
|  | *f =* 2 | 0.000 | 3.758 | 1.956 | 4.259 | 4.943 | 2.865 | 4.109 | 2.237 | 0.403 |
|  | *f =* 3 | 0.000 | 0.000 | 2.973 | 0.239 | 1.076 | 0.646 | -0.963 | 1.357 | -0.015 |
|  | *f =* 4 | 0.000 | 0.000 | 0.000 | -1.093 | -0.283 | -0.712 | -0.240 | -1.028 | -0.249 |
|  | *f =* 5 | 0.000 | 0.000 | 0.000 | 0.000 | 0.619 | 0.279 | 0.117 | 0.308 | 1.109 |
|  | *f =* 6 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | -1.082 | 0.203 | 0.201 | -0.971 |
|  | *f =* 7 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.579 | 0.415 | -0.686 |
|  | *f =* 8 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.922 | -1.288 |
|  | *f =* 9 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  |  | -2.81 | -2.81 | -2.81 | -2.81 | -2.81 | -2.81 | -2.81 | -2.81 | -2.81 |
|  | *f =* 1 | 2.099 | 0.781 | 0.004 | -0.394 | 1.536 | 1.198 | 0.148 | 0.674 | 0.491 |
|  | *f =* 2 | 0.000 | 2.711 | -0.010 | 1.173 | 1.589 | 0.110 | 0.570 | -0.680 | -0.198 |
|  | *f =* 3 | 0.000 | 0.000 | 1.184 | 0.743 | 0.301 | 0.615 | 0.271 | 0.428 | 0.531 |
|  | *f =* 4 | 0.000 | 0.000 | 0.000 | 2.323 | 1.399 | 1.030 | 0.159 | 1.215 | -0.052 |
|  | *f =* 5 | 0.000 | 0.000 | 0.000 | 0.000 | -1.462 | 0.411 | 0.327 | 0.220 | 0.790 |
|  | *f =* 6 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | -0.600 | 0.160 | -0.551 | 0.292 |
|  | *f =* 7 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 8 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | *f =* 9 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**Supplementary Figures**

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**Fig. SM1.** Map of the Gulf of Alaska with points indicating each haul of the fisheries-independent trawl survey from 1984 to 2019 and NMFS management areas outlined in black. The GOA Other Rockfish complex of species covers species in each of these bounded areas; however, the seven species associated with the Demersal Shelf Rockfish complex are managed separately only in Area 650.

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**Fig. SM2.** A) Map of the Gulf of Alaska with red points indicating the spatial extent of the 500 knots estimated in the mesh, which covers the entire spatial range of the trawl survey data used in the VAST model. B) The mesh used from the SPDE process in INLA.

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**Fig. SM3.** Q-Q plots comparing the empirical versus simulated distributions for the positive catches for each species.

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**Fig. SM4.** Predictive density distributions for each species.



**Fig. SM5.** Factor loadings with 1st and 3rd (left panel) and 2nd and 3rd (right panel) factors after PCA rotation on the combined spatial covariance matrix.

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**Fig. SM6.** Correlation estimates among the nine GOA rockfish from the spatial component of the VAST model.



**Fig. SM7.** Factor loadings with 1st and 3rd (left panel) and 2nd and 3rd (right panel) factors after PCA rotation on the combined temporal covariance matrix.

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**Fig. SM8.** Correlation estimates among the nine GOA rockfish from the temporal component of the VAST model.



**Fig. SM9.** Total yearly biomass from the trawl survey (Index\_raw) compared to the JDSDM model biomass estimates (Index\_VAST) in kg.