Supplementary Materials

Specification of priors

Let $P(\boldsymbol{\theta})$ be the prior specification for the hyperparameters $\boldsymbol{\theta} = \{\phi_1, \dots, \phi_m, V_e, \tau^2\}$. Here we set V_e and τ^2 to follow flat priors. Specifically, we set the probability density of priors as P(V_e/Var(y))=P(τ^2/Var(y))=Beta(1.1, 1.1), where Var(y) is the sample variance of CPUE data at next time step (a year ahead) and y is pre-scaled to mean zero and unit variance in prior to GP estimation. Var(y) is used to facilitate numerical stability and convergence, as well as for interpretations. Beta(.) is the beta-distribution with the parameter values to approximate a flat prior. For inverse-length-scale parameters, we set $\phi_1, \dots, \phi_m$ to draw from a half-normal prior distribution P(ϕ_m). We set P(ϕ_m) (m ranges from 1 to the embedding dimension), such that the expected number of local extrema in function f is 1 to constrain the "wigglyness vs. smoothness" of estimated GP functions.

Specification of spatial covariance kernel

We used the delay coordinate vectors within statistical zones to reconstruct the local shadow manifolds and directly estimated the spatial correlation (similarity), ρ in Eq. 3, between the local manifolds. We did not use the shared information of manifold distances between statistical zones. This assumption of the spatial covariance kernel in the second layer of hierarchical Gaussian process (GP) is somewhat simpler and slightly differed from Munch et al. (2017). Preliminary analyses show comparable prediction skills using either assumption of the spatial covariance kernel for both Brown and White Shrimp.

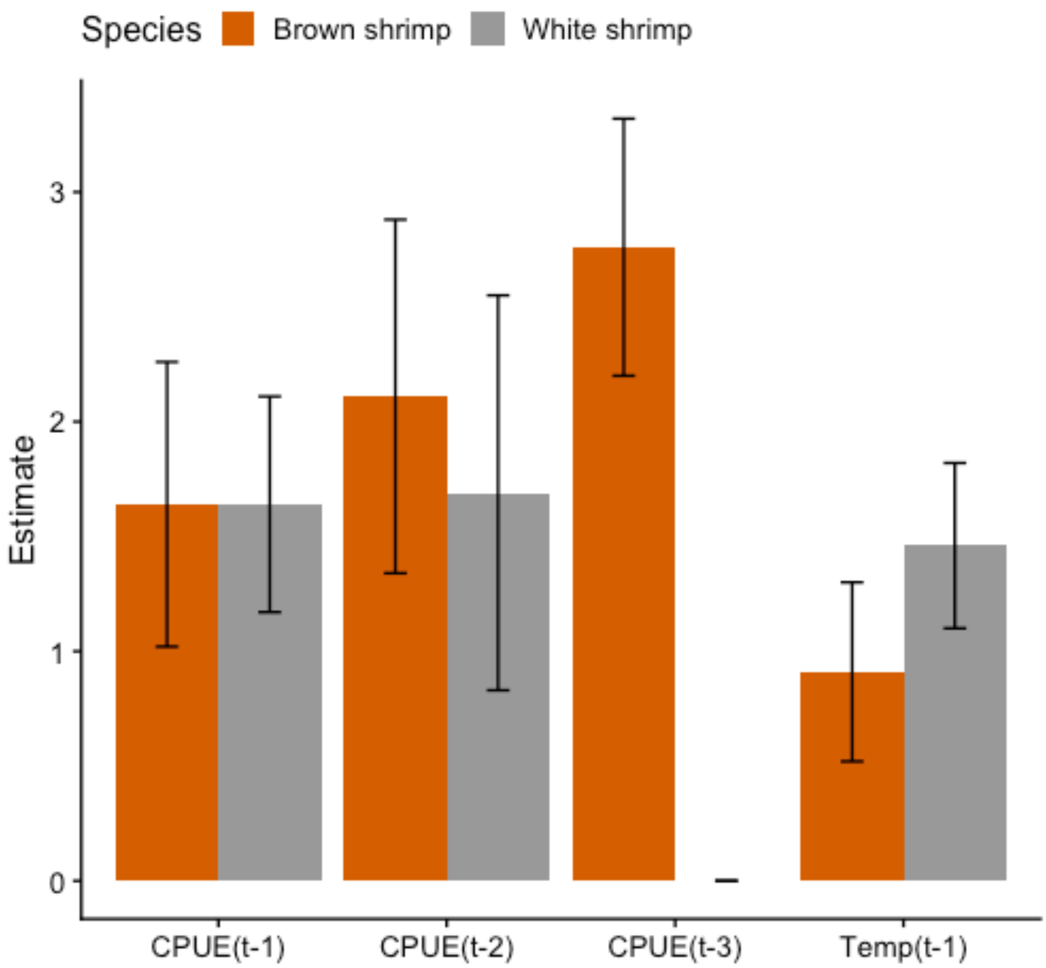

Fig. S1 Estimate of the inverse length-scale parameters ϕ_i as described in Materials and Methods. The magnitude in estimated parameter represents the relative importance of input variables, selected by automatic relevance determination (ARD) of GP-EDM. Brown and grey represent Brown Shrimp and White Shrimp. "CPUE" and "Temp" represent catch per unit effort and sea bottom temperature. Subscript t-1, t-2, and so on represents lag-1, lag-2 years, and so on. Error bar represents 1± SE of the estimate. Only the best predictive GP-EDM models (i.e., models with the highest predictive *r*), for Brown Shrimp and White Shrimp, are shown.

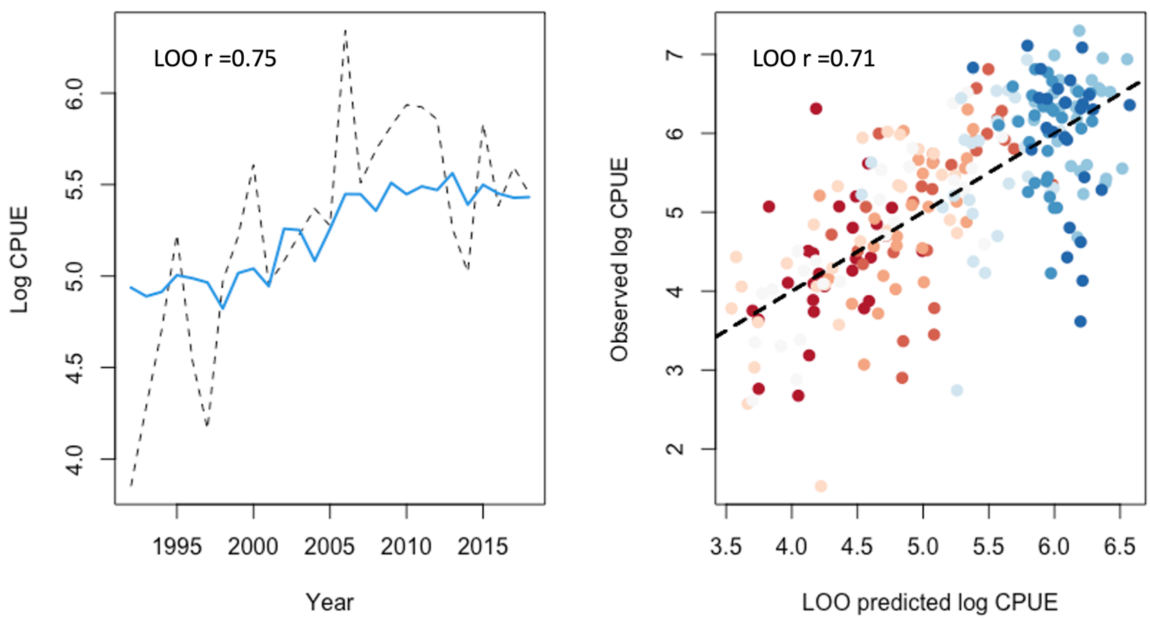

Fig. S2 Out-of-sample (Leave-one-out, LOO) predictions for CPUE of Brown Shrimp across statistical zones. In the left panel, the dashed line represents the raw CPUE data, and the blue line represents GP-EDM predictions. In the right panel, X-axis represents the CPUE (catch-per-unit-effort) predicted by hierarchical GP-EDM and Y-axis represents the observed SEAMAP CPUE on log scale. The colors indicate statistical zones, from the east side (red) to the west side (blue) of the gulf.

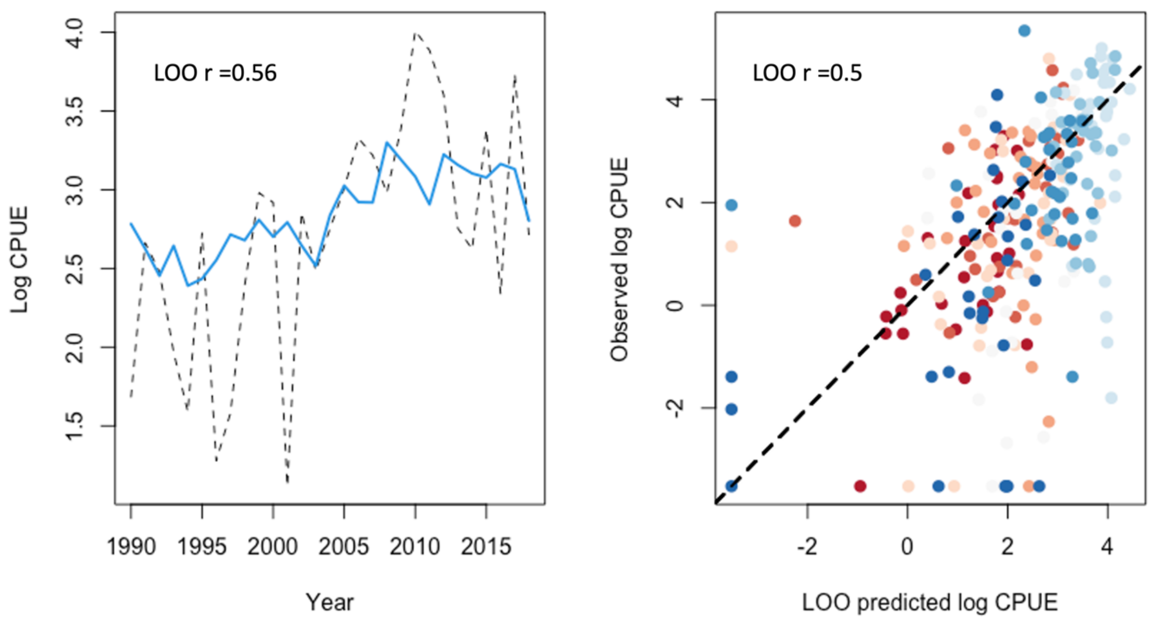

Fig. S3 Out-of-sample (Leave-one-out, LOO) predictions for CPUE of White Shrimp across statistical zones. In the left panel, the dashed line represents the raw CPUE data, and the blue line represents GP-EDM predictions. In the right panel, X-axis represents the CPUE (catch-per-unit-effort) predicted by hierarchical GP-EDM and Y-axis represents the observed SEAMAP CPUE on log scale. The colors indicate statistical zones, from the east side (red) to the west side (blue) of the gulf.