Empirical dynamic modeling for brown and white shrimp

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Shrimp Research/Assessment Timeline

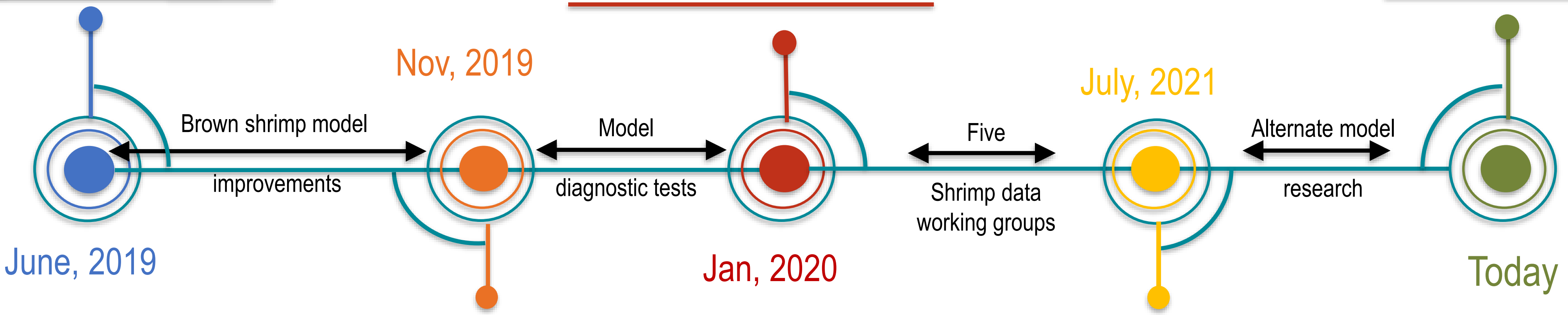
SEFSC internal model review workshop- review of shrimp age-structured models

Worked with Methot in Seattle; identified a number of technical issues

SEFSC leadership (+ Methot) reviewed shrimp model diagnostics & ID'd a # of technical issues among models that were not previously identified

SEAMAP considered representative index of Penaeid shrimp abundance; SEFSC moves Penaeids into SEDAR Research Track (2023/2024)

Consideration of an alternative model for Brown and White Shrimp stock assessments



Considerations for Assessing Penaeids

- Penaeids are considered **annual crops** (high natural mortality ∴ mostly dead by ~1 year)
- We lack age-structured data; limited biology data (current based on studies from the 70s); have no recruitment or environmental signal
- NMFS receives 'last year's' fishery landings data (from state Trip Tickets) ~ mid-year (e.g. in March 2020, I reported on the 2018 stock status). These data lags mean NMFS can't provide timely stock status information for these annual crops

Current Gulf Shrimp Reporting Requirements

Shrimp AM 15

- Requires annual SDC for Penaeids (benchmarks are MFMT = F_{msy} & MSST = B_{msy})
- These benchmarks were established using 2012 SS models
- If MFMT (F_{msy}) is exceeded for 2 consecutive yrs, action is considered by the Council
  - Given fishery data lags (~1.5 yrs), individuals are largely gone from the system when presented annually. Then if you add 2 years of monitoring overfishing, now you are ~4 yrs out from taking action (i.e., not very responsive)

Shrimp AM 17B

- Aggregate MSY (all managed shrimp species) only uses offshore landings, whereas species-specific MSY is inshore + offshore; therefore the aggregate MSY is not comparable to the species-specific estimates coming from SS
- Aggregate MSY is used to estimate aggregate OY (using a Schaeffer production model) – totally separate from species-specific estimates in Shrimp AM 15

Shrimp Assessment Modeling Takeaways

- Preliminary findings of the research track process (shrimp data working groups) show data limitations make age-structured models inappropriate (e.g. lack of recruitment information or environmental drivers)
- In 2021, the SEAMAP WG found SEAMAP to be a representative index of Penaeid stock abundance
- Considering the large # of technical concerns among Penaeid age-structured models, derived F_{msy} and B_{msy} were inaccurate
- The current shrimp FMP only requires annual estimates of relative SDC
- **So, do we really need a data rich age-structured model to provide relative SDC?**

Model Complexity

Data limitations & responsiveness

Empirical dynamic modeling

Based on Takens (1981) Theorem of time-delay embedding

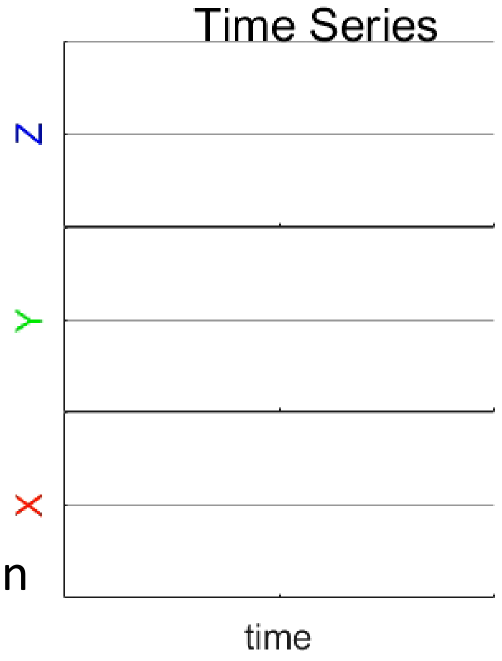
-> Implicitly account for unobserved variables using lags of the observed variables

Many other names:
'Time-delay embedding'
'Nonlinear forecasting'
'state-space reconstruction'

Empirical Dynamic Modeling

Three-species model with type-2 functional response

Z – predator
Y – grazer
X – producer



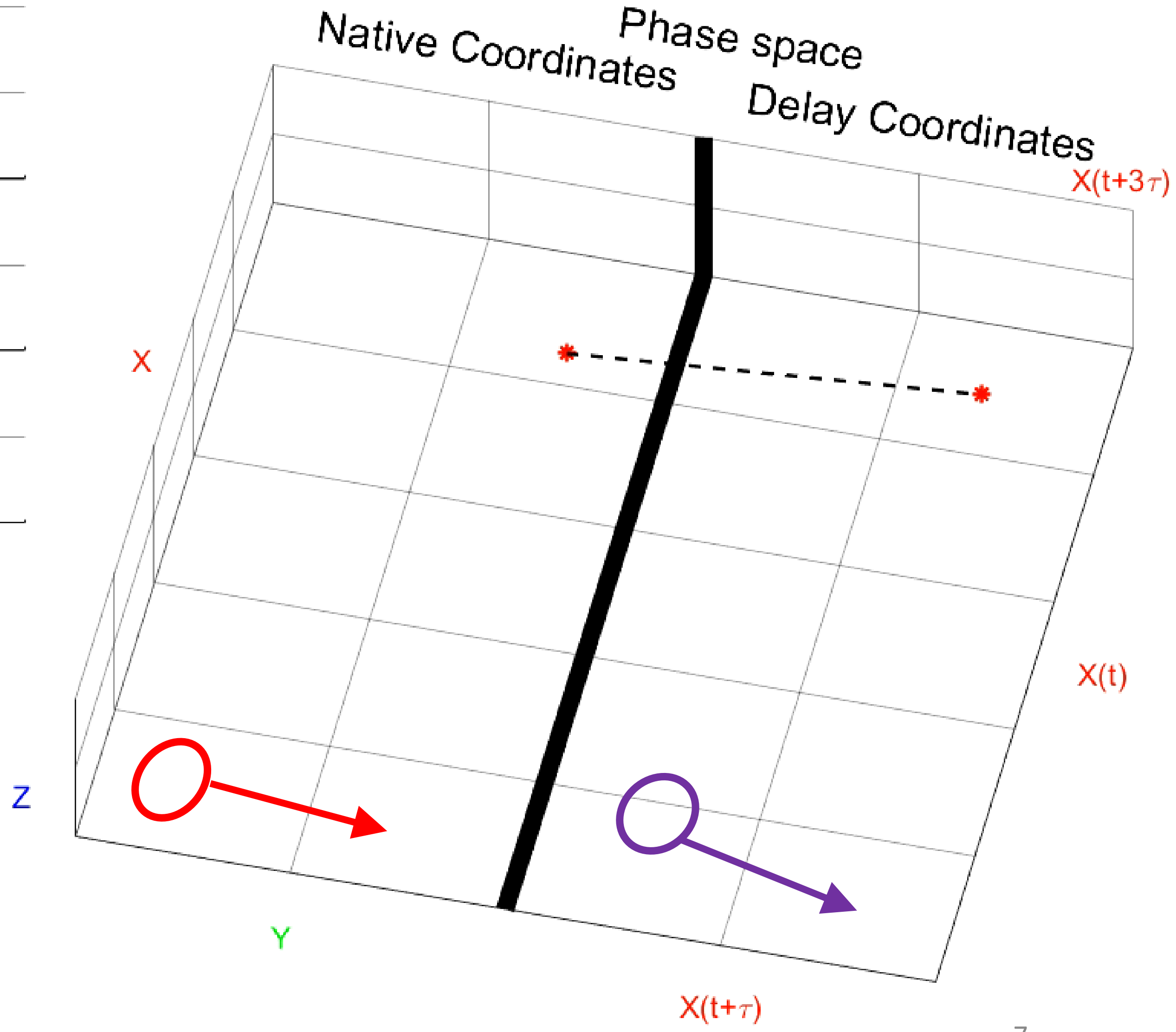
Trace nearby trajectories to obtain discrete time model

$$x_{t+1} = F[x_t, y_t, z_t]$$

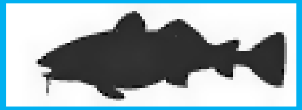
Analogous model in 'delay coordinates'

$$x_{t+1} = \tilde{F}\,[x_t, \ldots, x_{t-E}]$$

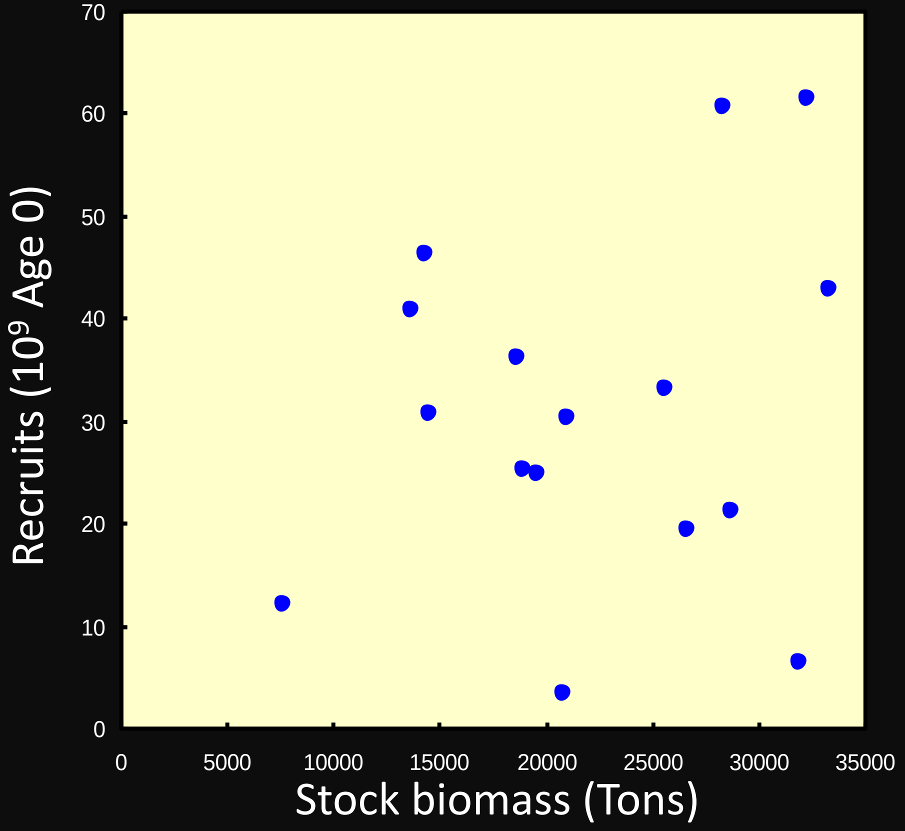
Dynamics equivalent to full state space, based only on observed time series



Applying GP-EDM to fish recruitment time series



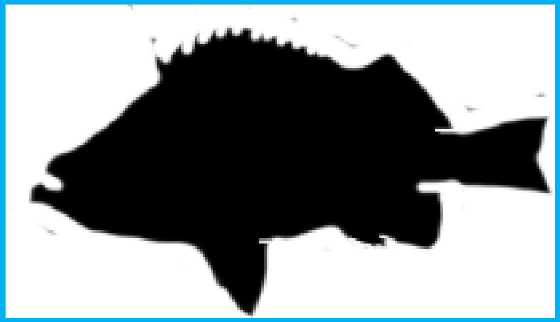
Sand Eel (Shetland)

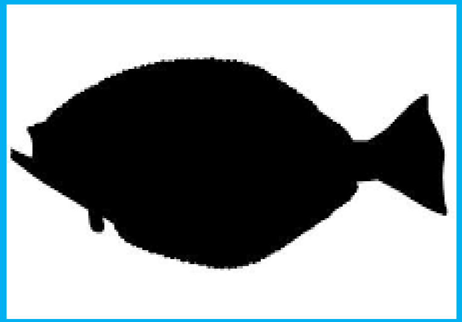


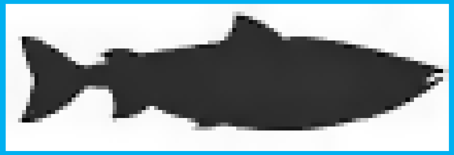
Global database of 185 fish populations

72 species from 26 Families
At least 20 observations per population

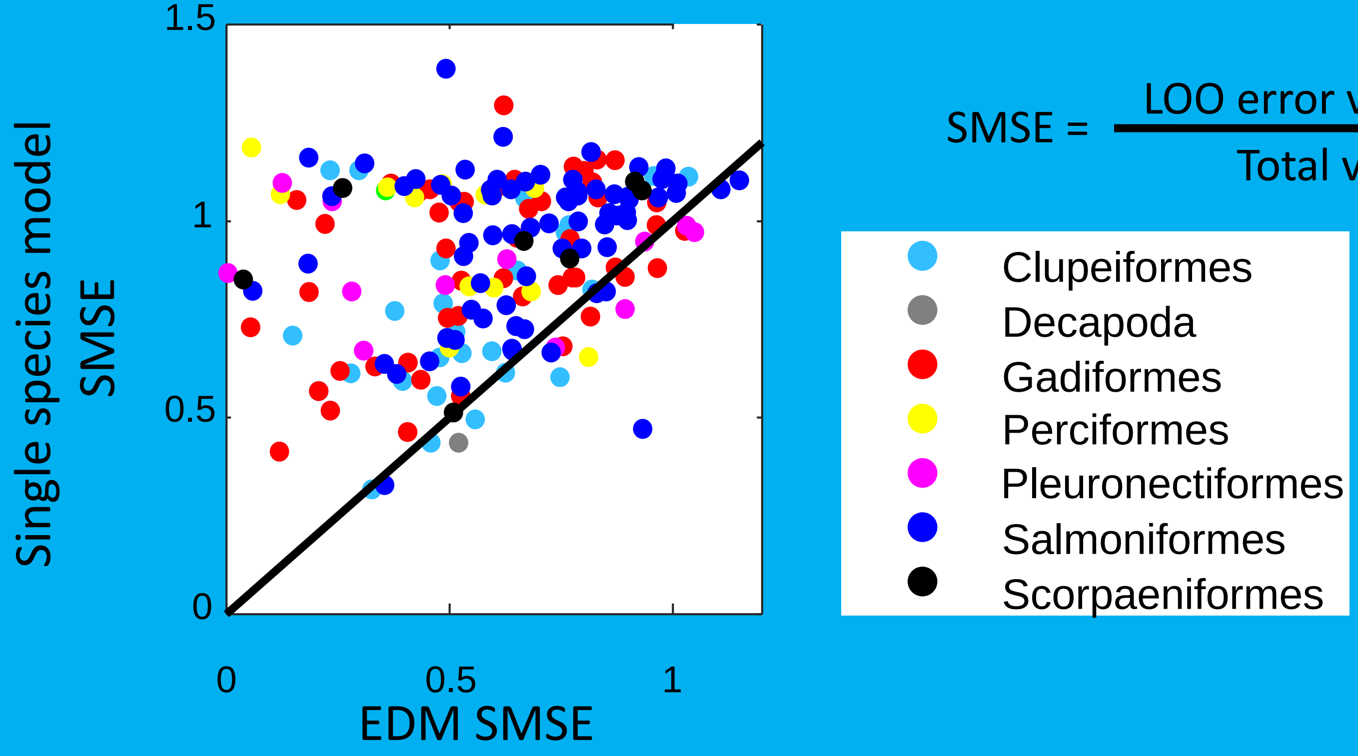
Compare prediction accuracy with 3 standard single-species models (Ricker, Beverton-Holt, Schnute)



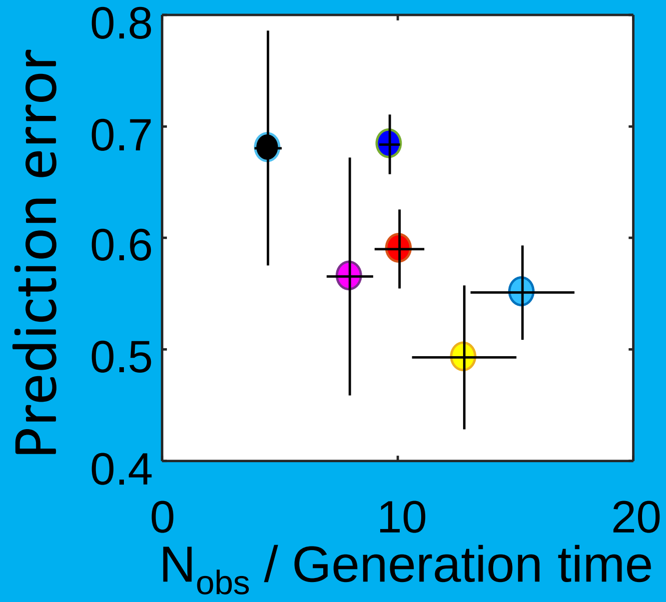




Prediction error across 185 fish populations



$$\text{SMSE} = \frac{\text{LOO error variance}}{\text{Total variance}}$$



GP-EDM forecasts better than traditional model for ~90% of populations

Works best for long time series and/or short-lived species

Prediction error is 25% less on average

Munch, et al. (2018) Fish and Fisheries

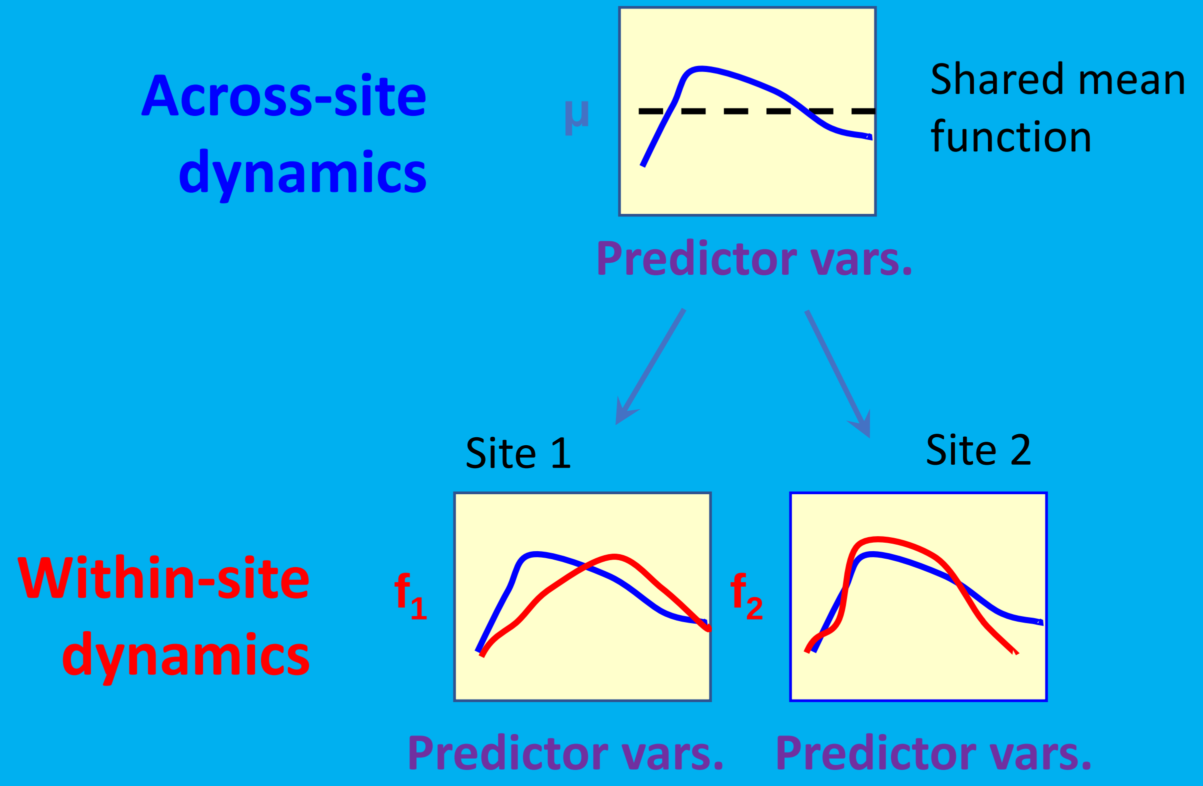
Making better use of short time series: Hierarchical EDM

Dynamics in site *i*

$$x_{i,t} = f_i(x_{i,t-1}\ldots, x_{i,t-E}) + \varepsilon_{i,t}$$

past population size

f_i = shared mean function + site-specific deviation



$$\rho_D = Corr[f_i(x), f_j(x)]$$

'Dynamic correlation' Estimates the similarity among maps

Poynor & Munch 2017. Env. Ecol. Stat. Munch et al. 2017 Ecological Complexity

Application to brown and white shrimp-

Hierarchical EDM used to predict abundance in each SEAMAP stat zone.

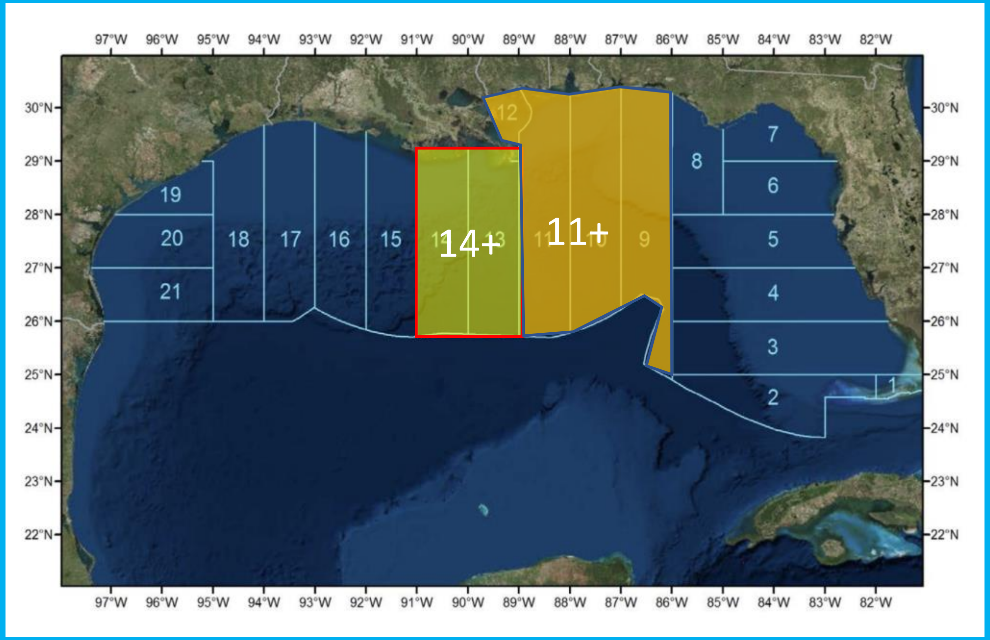
Short series in zones 9, 10, 11 and 12 were pooled
13 and 14 were pooled.

Models include lags of abundance in each zone, as well as current temperature, salinity, and dissolved oxygen.

Found only temperature and abundance were relevant.

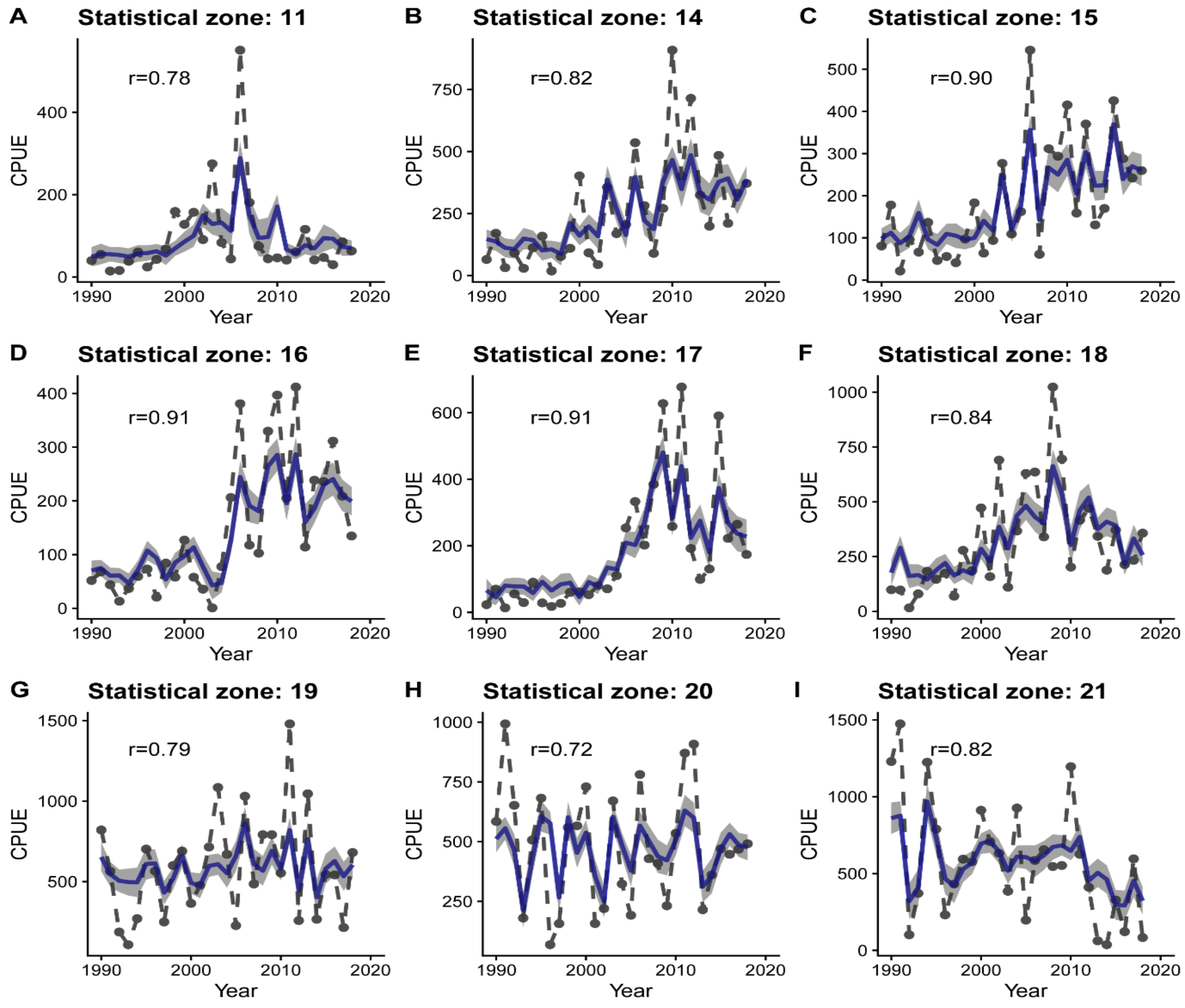
Predictions are sequential – use only data from previous years.

SEAMAP Survey

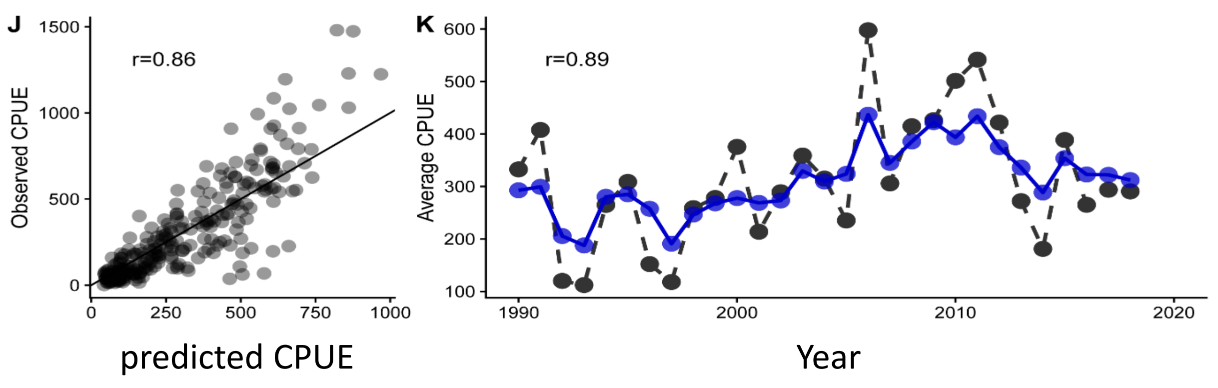


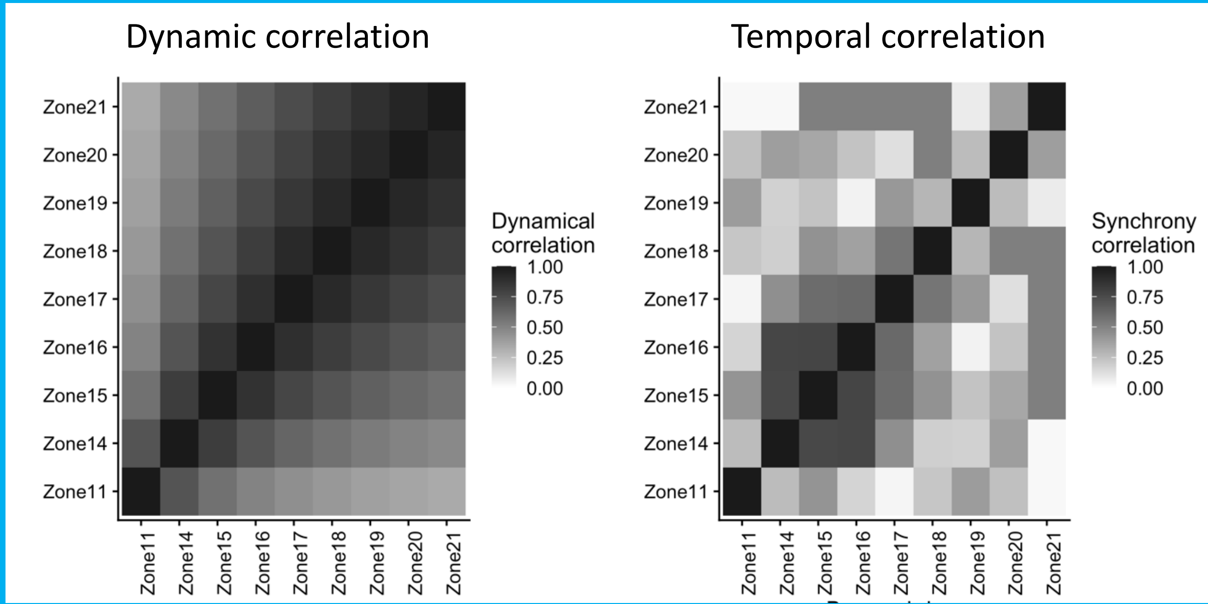
Brown shrimp

Within-zone predictions



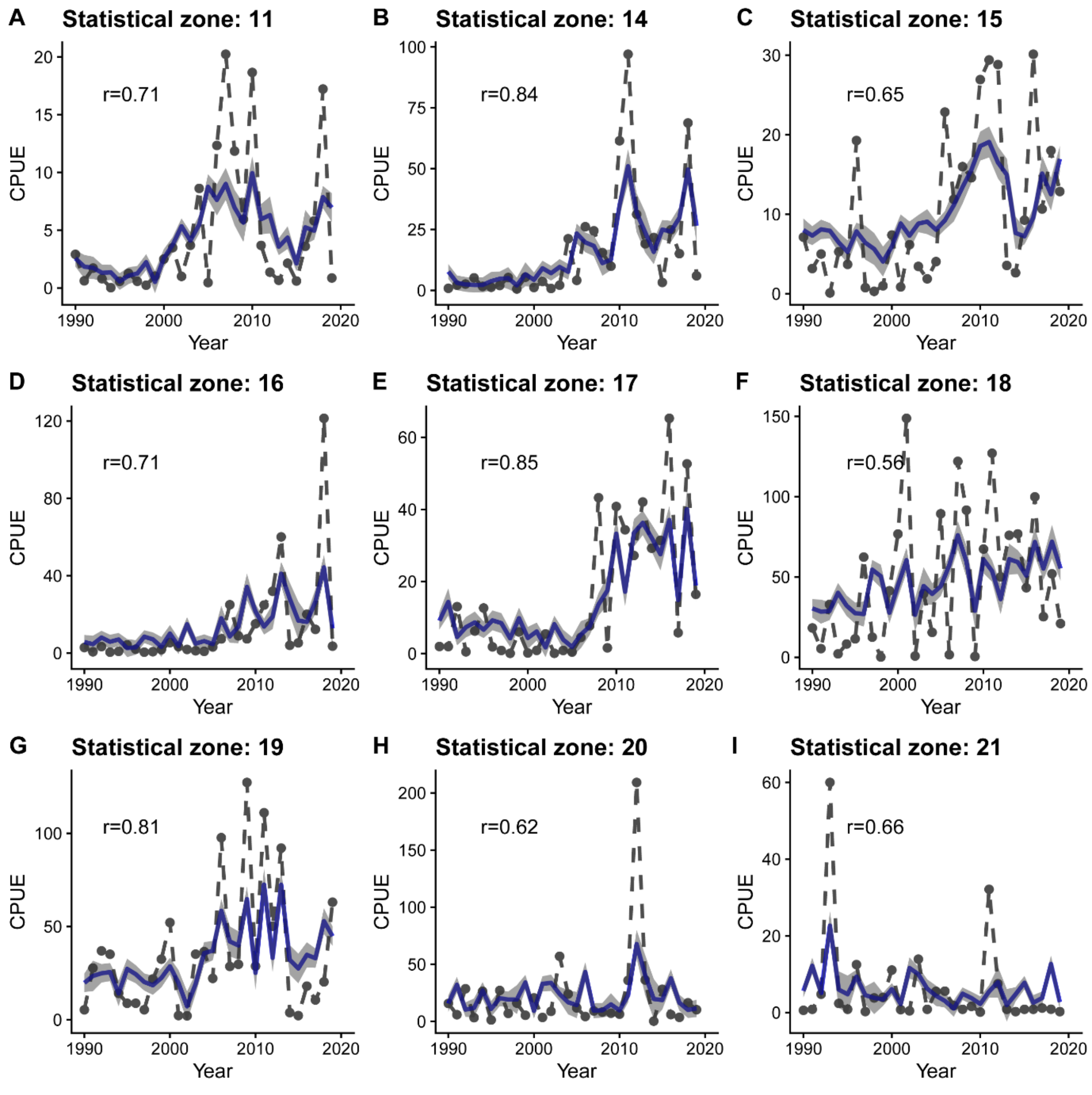
Overall performance



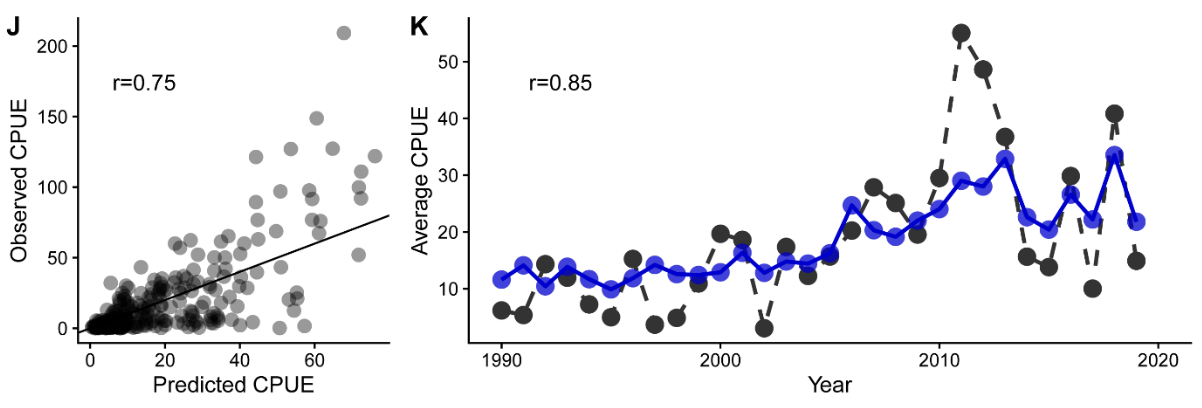


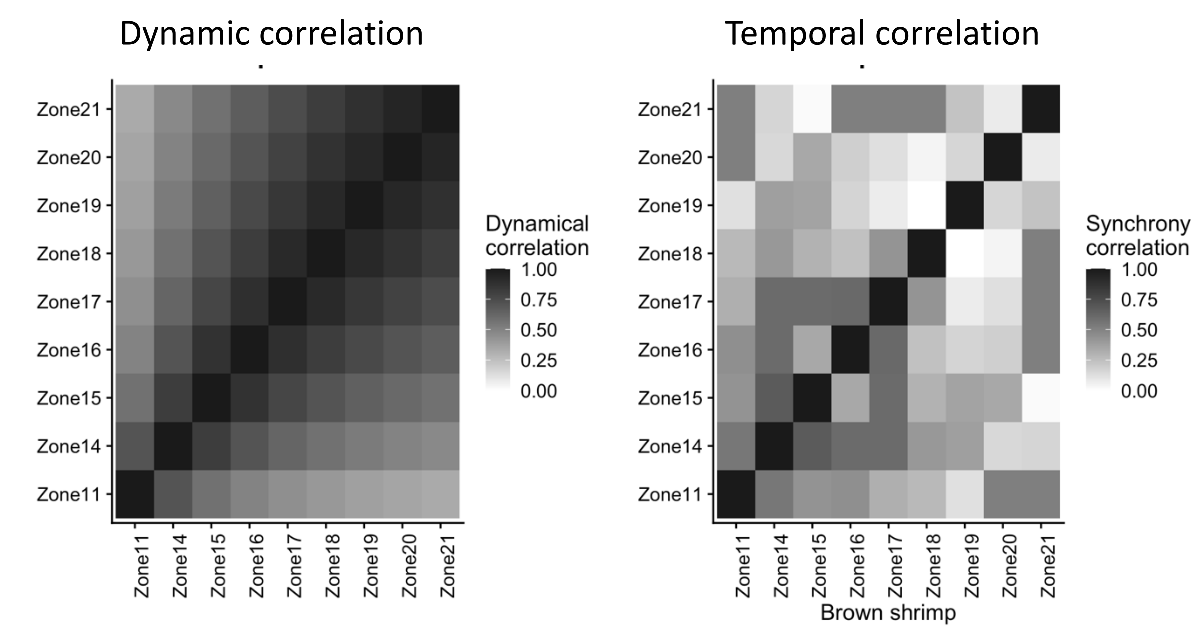
White shrimp

Within-zone predictions



Overall performance





Using EDM to determine stock status

Use GP-EDM to estimate

$$B_t = F(B_{t-1}, \ldots, B_{t-d}, C_{t-1}, \ldots, C_{t-d}) + \varepsilon_t$$

Current Biomass

Past Biomass

Past Catch

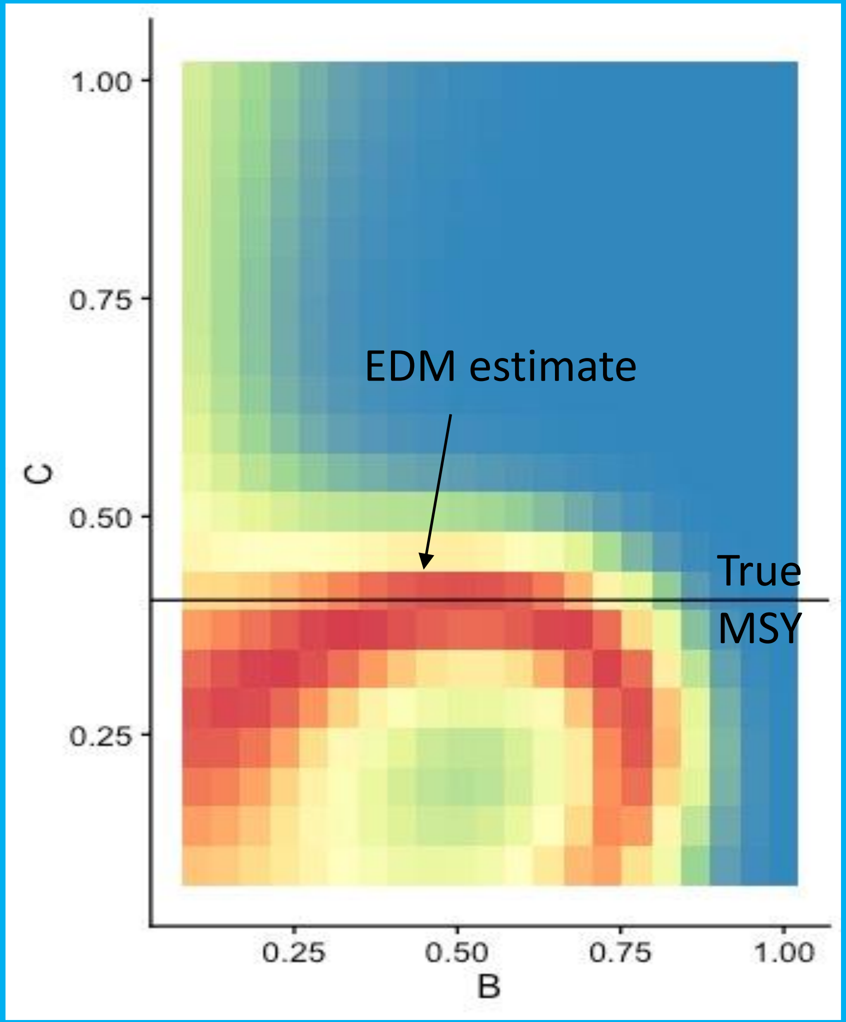
At steady state, we'd have

$$\tilde{B} = F(\tilde{B}, \ldots, \tilde{B}, C, \ldots, C)$$

Vary C to find MSY, BMSY

Status determination: Compare $B_t, BMSY$
C_t, MSY

Simulation example



Correct status in 85% of single-species simulations, 78% of 2-species simulations….

Conclusions and Next Steps

- Following the data working groups, the preliminary findings show that data limitations for Penaeids suggest that age-structured models are not appropriate and are not responsive enough for an annual crop
- Our research suggests EDM is a viable alternative for assessing Brown and White Shrimp stock dynamics, with the intention of using these models to derive annual SDC
- Next steps:
  - Derive SDC for Brown and White Shrimp, provide an update to the SSC in late 2022
  - Peer-review of Brown and White Shrimp models – shrimp SEDAR research track (2023)
- Today, we request SSC input on their interpretation of EDM as being an appropriate consideration for Brown and White Shrimp assessment models