Investigating Climate Impacts in the Gulf of Mexico with Dynamic Bayesian Networks

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Motivation

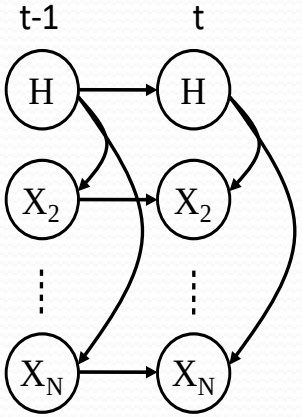
- Gulf of Mexico is an ecologically and economically important dynamic ecosystem
- Interactions with natural and anthropogenic factors

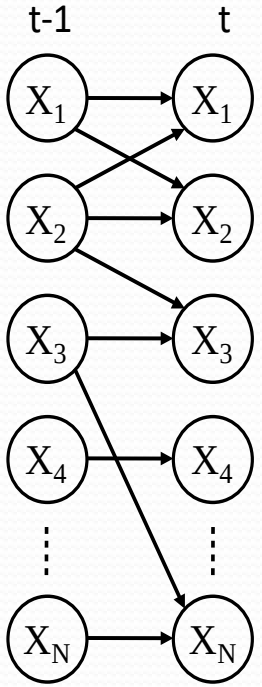
- Application of explorative, data-driven techniques
- Evaluation and implementation

- Potential response of the system to pressure
- Sustainability and management

Bayesian Networks for Classification & Feature Selection & Forecasting

- Nodes that can represents class labels or variables at "points in time"
- Also hidden variables via EM
- Inter and Intra slice connections
- Predict future observations given all the observations up to the present time: $y_{1:t} = (y_1,\ldots,y_t)$

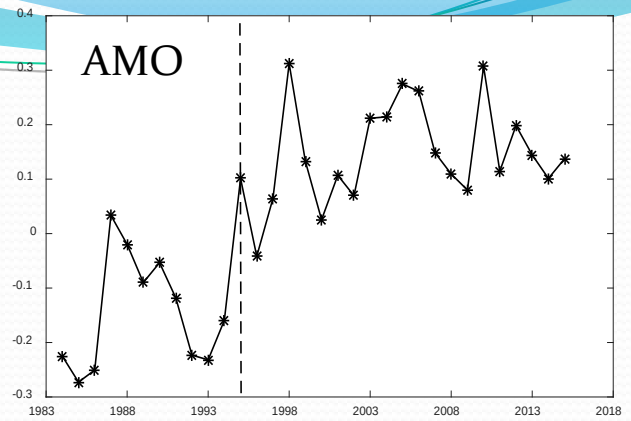


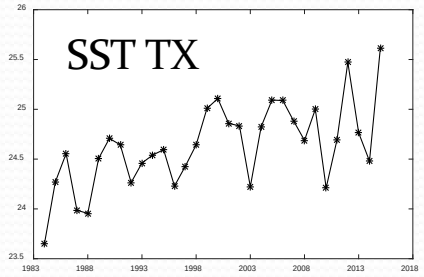


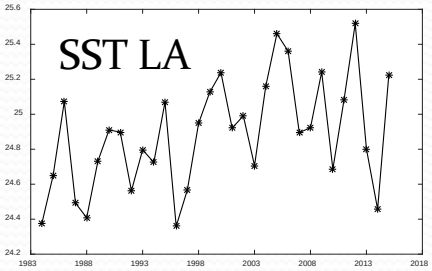
Data

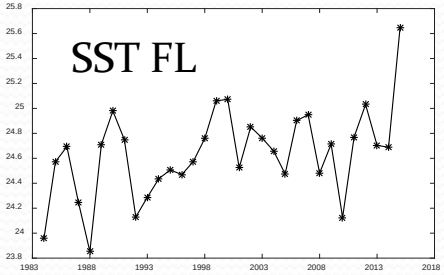
- Temporal data: 1984-2015

- Climate drivers: AMO and SST
- Physical pressures: Hypoxia
- Primary productivity
- Spring and fall zooplankton
- Shrimp recruitment estimates
- Fish recruitment deviations





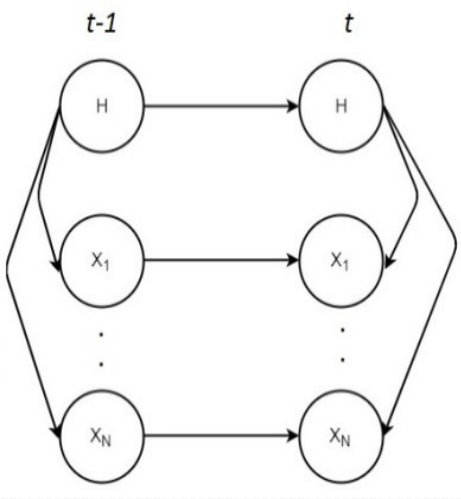


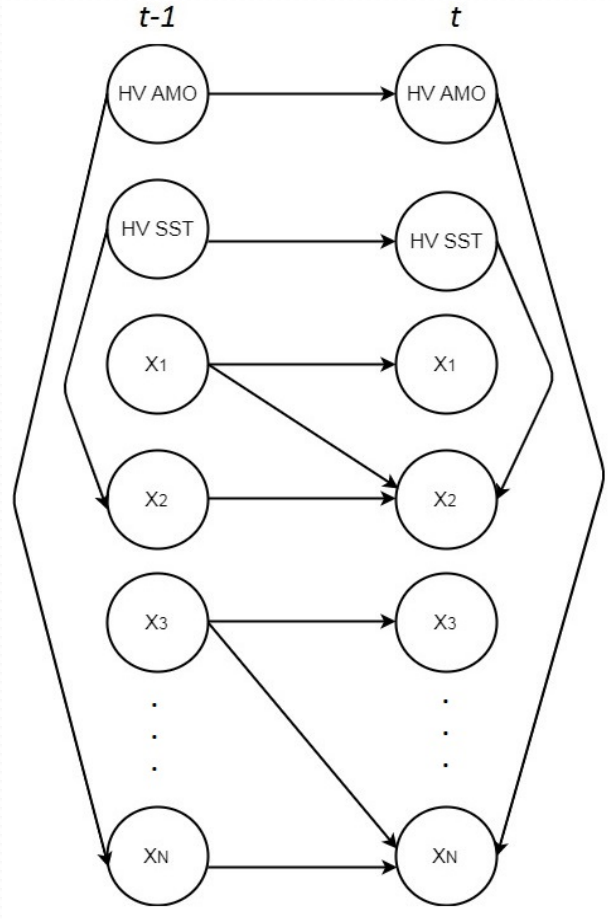


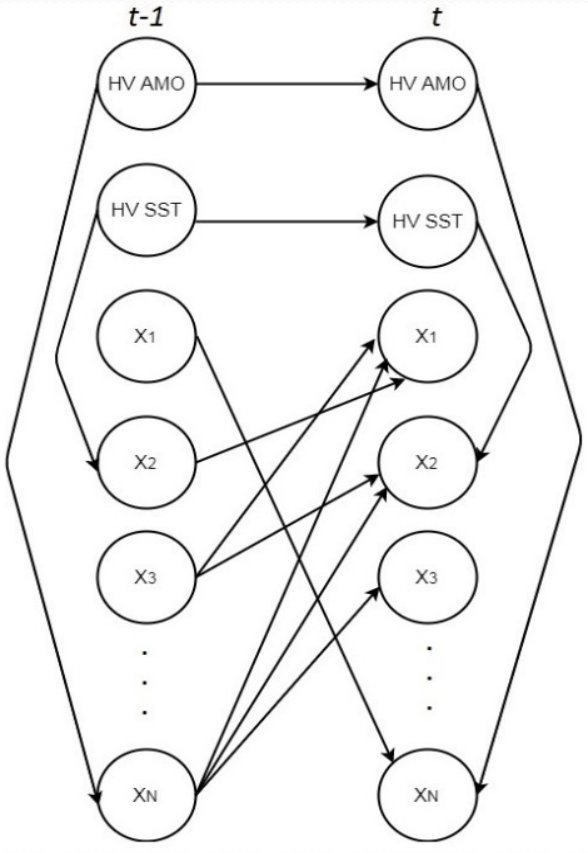
Learning Bayesian Networks

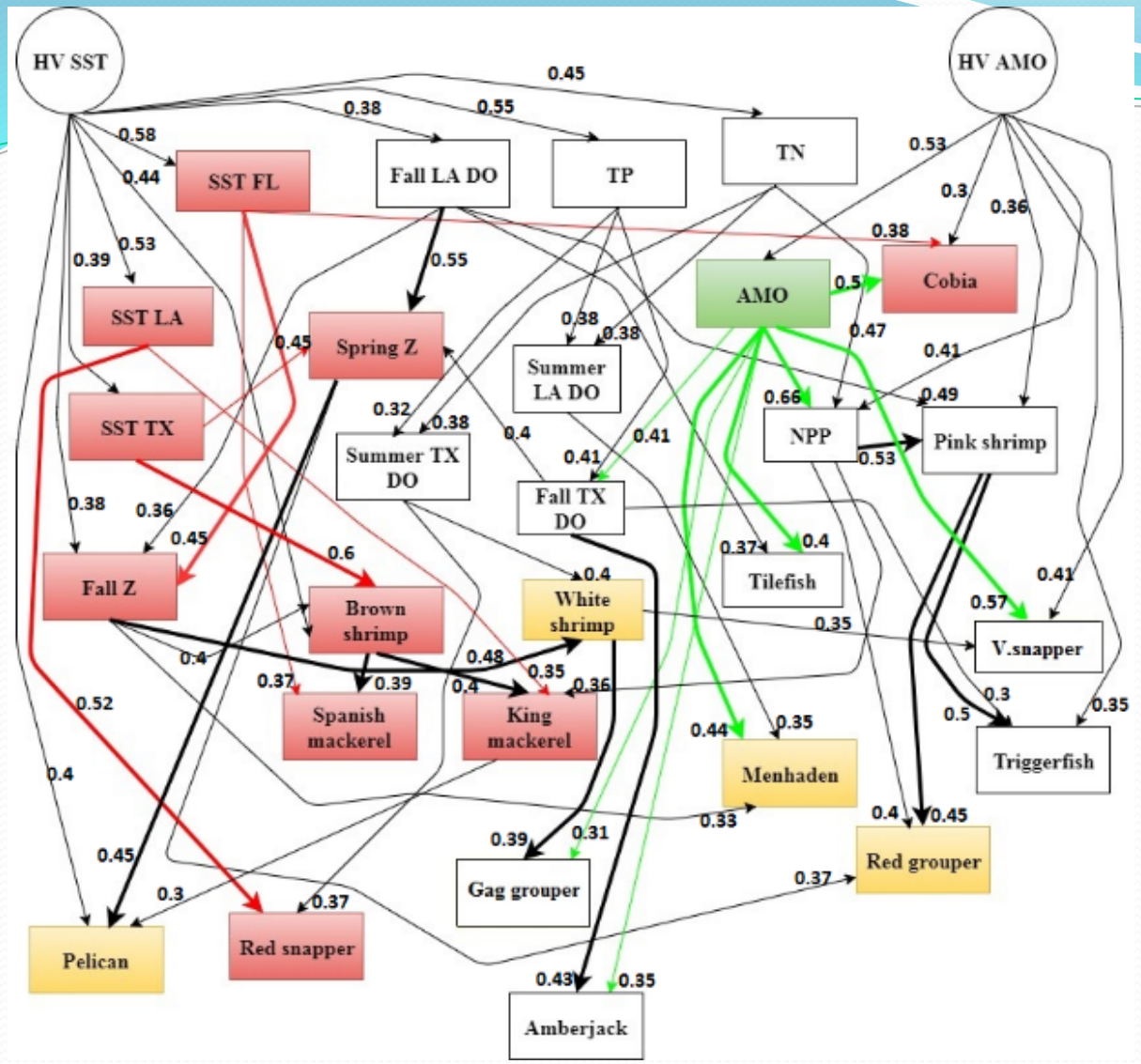
- Hill-climb optimization technique
- The learned BN links represent dependence, these are relationships that are predictive in an informative, not causal aspect
- The Bayesian Information Criterion was used for scoring candidate networks: $BIC = \log P(\Theta) + \log P(\Theta|D) - 0.5k \log(n)$

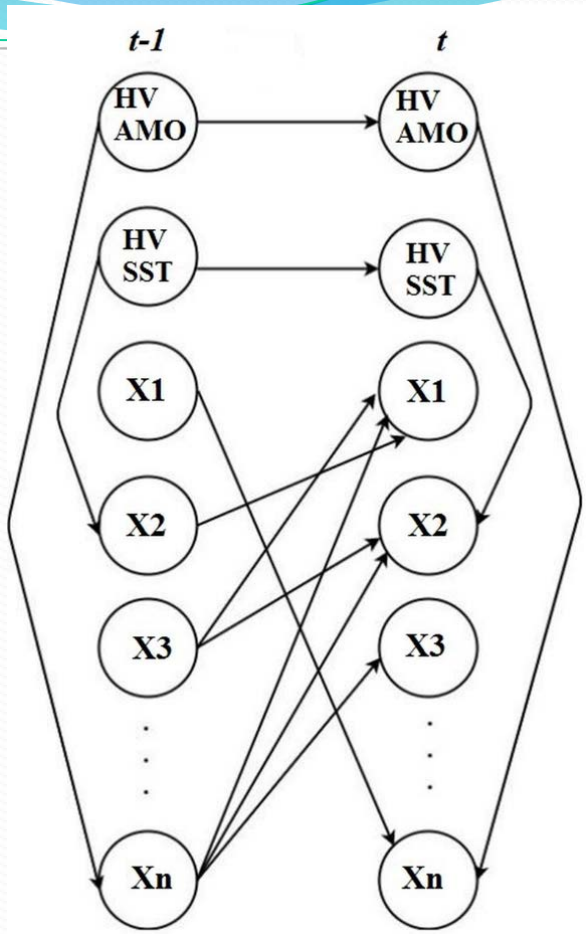
Model Comparison







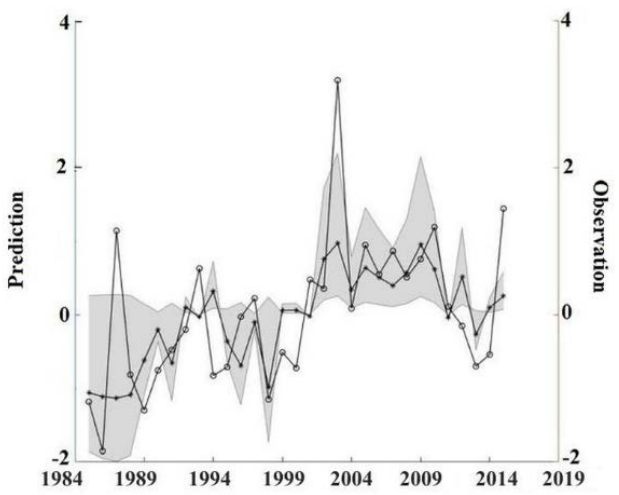




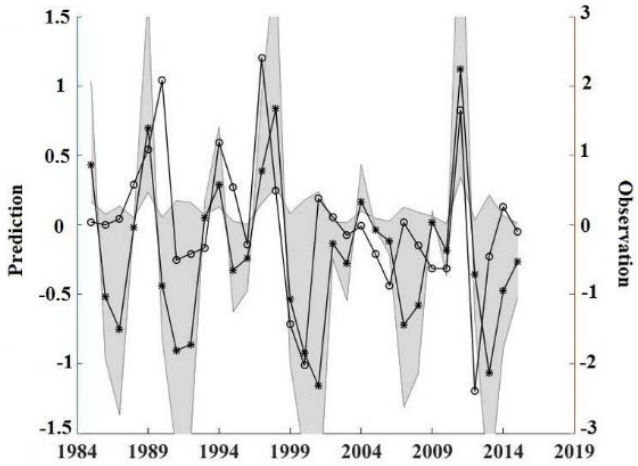
- *Data-driven dynamic BN*
- Nodes- ecosystem states
- Links- potential interactions
- Multiple associations and their changes over time

Spring zooplankton

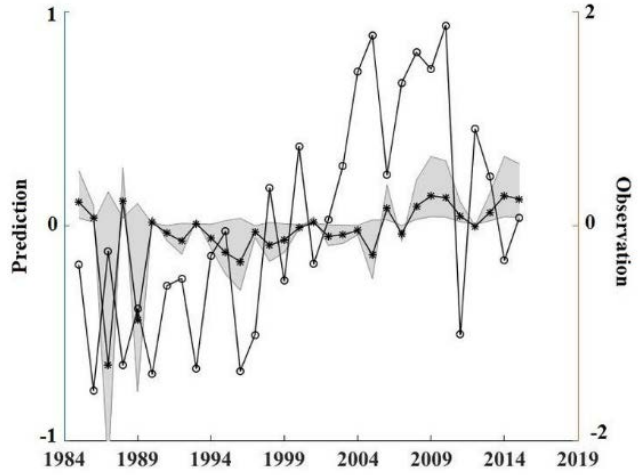
Baseline model (*) vs Original data (○)



Fall zooplankton



White shrimp



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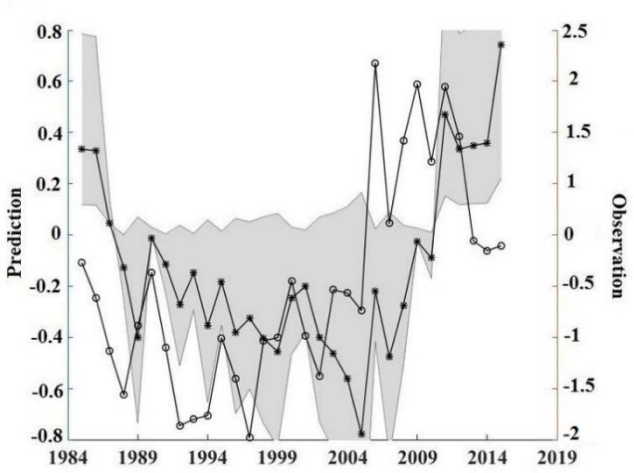
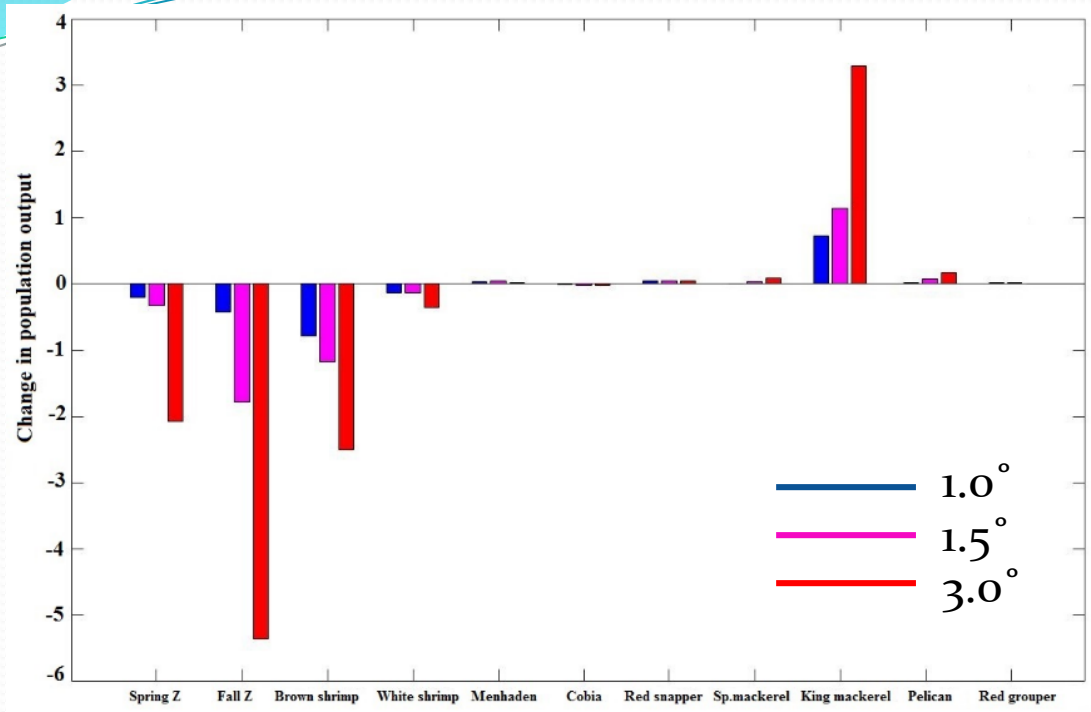


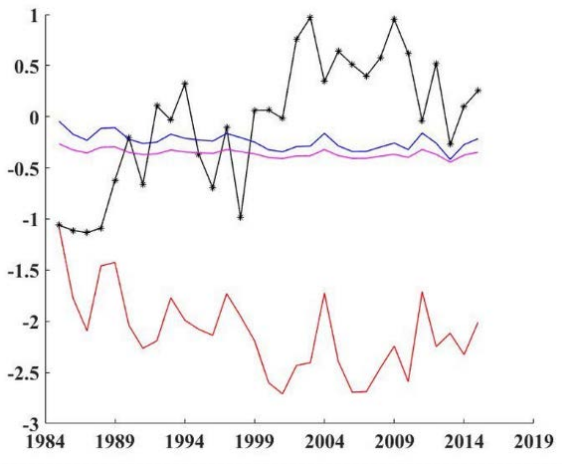
SST Scenarios and Generating Predictions

- *Baseline* model *vs* SST scenarios: 1.0°C, 1.5°C and 3.0°C
- Given a graphical structure, BNs naturally perform prediction using inference
- X[t] where X = X_1 … X_n are the *n* variables observed along time *t*
- Non-parametric bootstrap (re-sampling with replacement from the training set) was applied 250 times
- The hidden variables were parameterised using the EM algorithm

Temperature scenarios



Spring zooplankton



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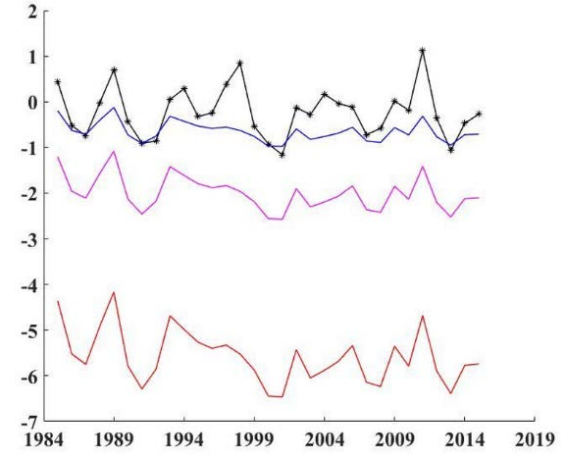

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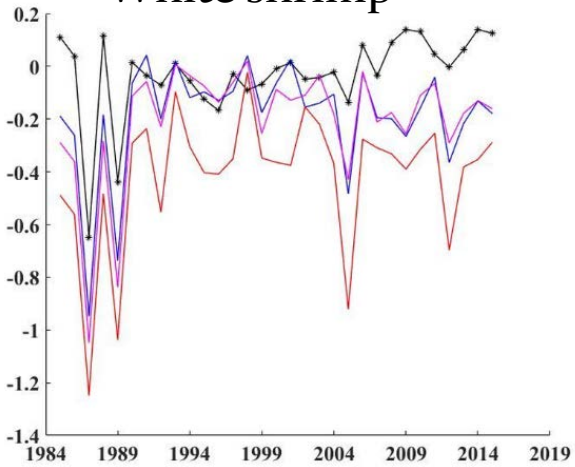

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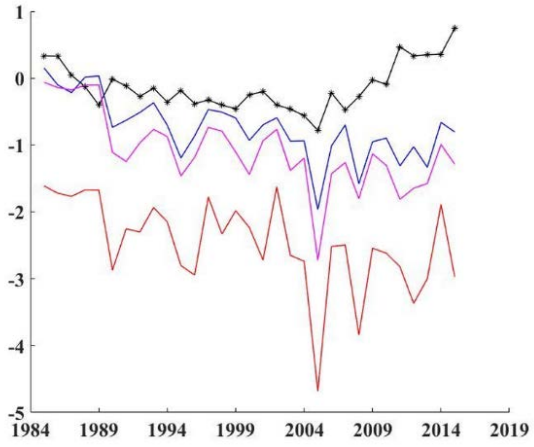

Summary

- Relationships are not causal, but model outputs are groundwork for new hypotheses that can be tested
- The data-driven approach provides contrast to other climate prediction methods that are predicated on assumed climate-fish relationships (e.g. NMFS climate vulnerability analysis)
- Variance in inputs can be directly extrapolated through network and into future climate predictions
- Network could easily be expanded to include other components of ecosystem (e.g., protected species)

Acknowledgments

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