Temporal trends in forage fish availability and predation in the northwest Atlantic with ties to climate change

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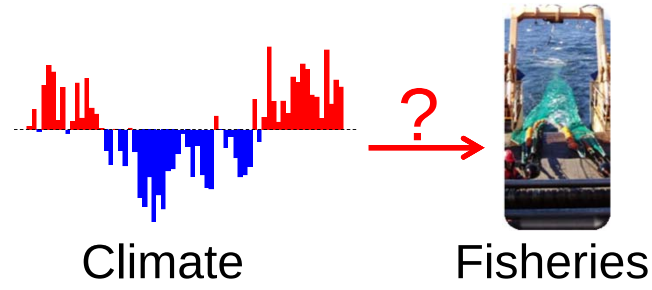
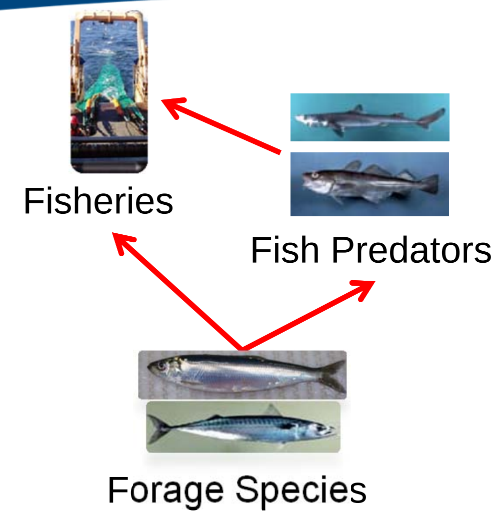


Major Objectives

- Identify trends of forage fish (Atlantic herring and Atlantic mackerel) abundance and their consumption by 13 fishes for the northeast U.S. continental shelf.

- Relate shelf-wide forage fish abundance and seasonal amounts of consumption to trends in the climatic indices Atlantic Multidecadal Oscillation (AMO) and North Atlantic Oscillation (NAO).

Rationale

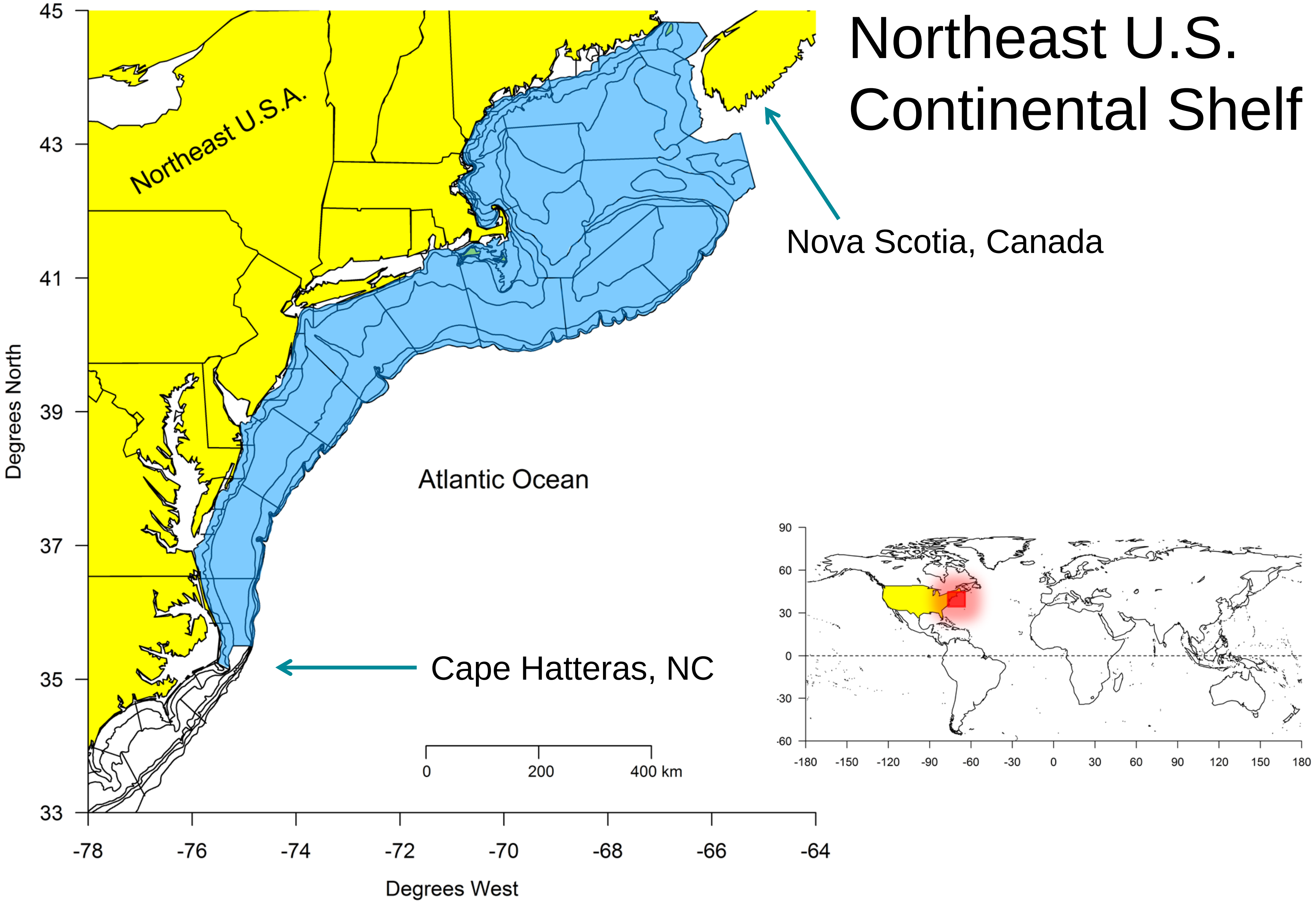


- Global concern for climate change and fish community dynamics.
- Climatic oscillations drive large-scale ocean processes; thus, ecosystems and their trophic interactions may be altered.
- Atlantic herring and mackerel link lower and upper trophic levels, are directly targeted by fisheries, and are food for targeted fishes.

Available Data

- Annual forage fish abundance: 1 time series of stratified mean abundance per tow from seasonal bottom trawl surveys, 1977-2012.
- Seasonal forage consumption: 24 time series (13 predators) from seasonal bottom trawl surveys, 1977-2012.
- Climate indices: 2 time series for AMO and NAO from NOAA, 1977-2012.

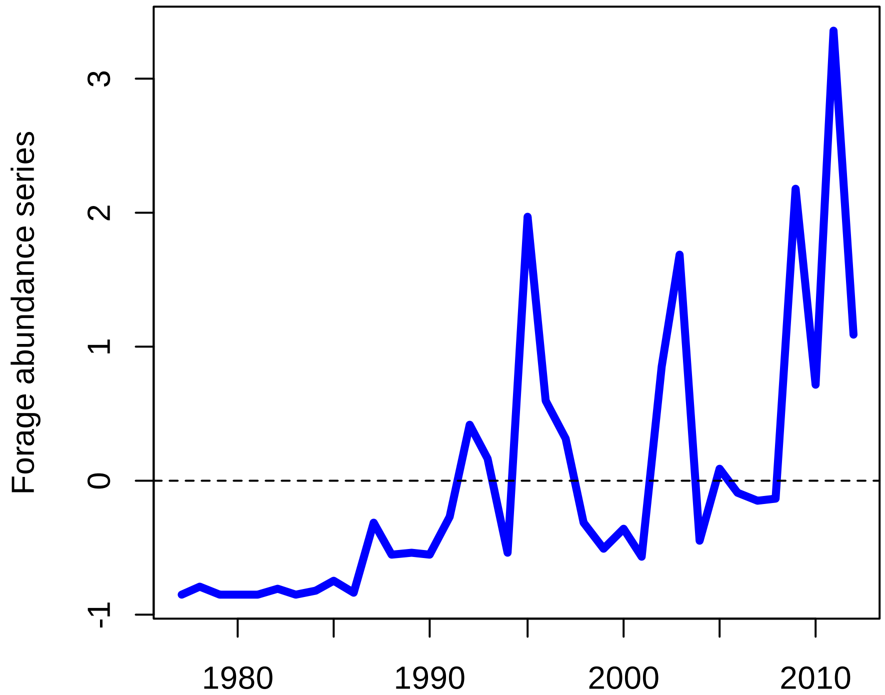
Northeast U.S. Continental Shelf



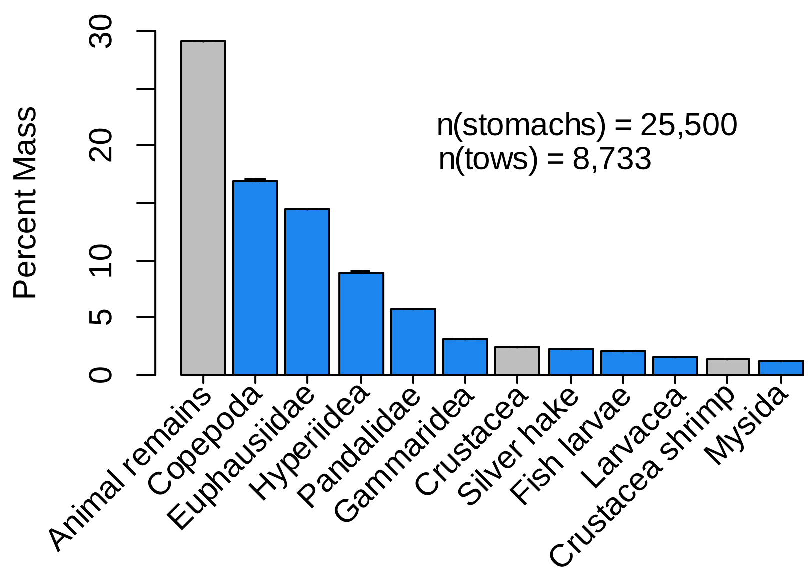
Forage Fish Abundance and Diet

- Annual stratified mean number of fish per tow.
- Fish collected during seasonal bottom trawl surveys.
- Time series means ~ 24 herring and 3 mackerel per tow.

Abundance

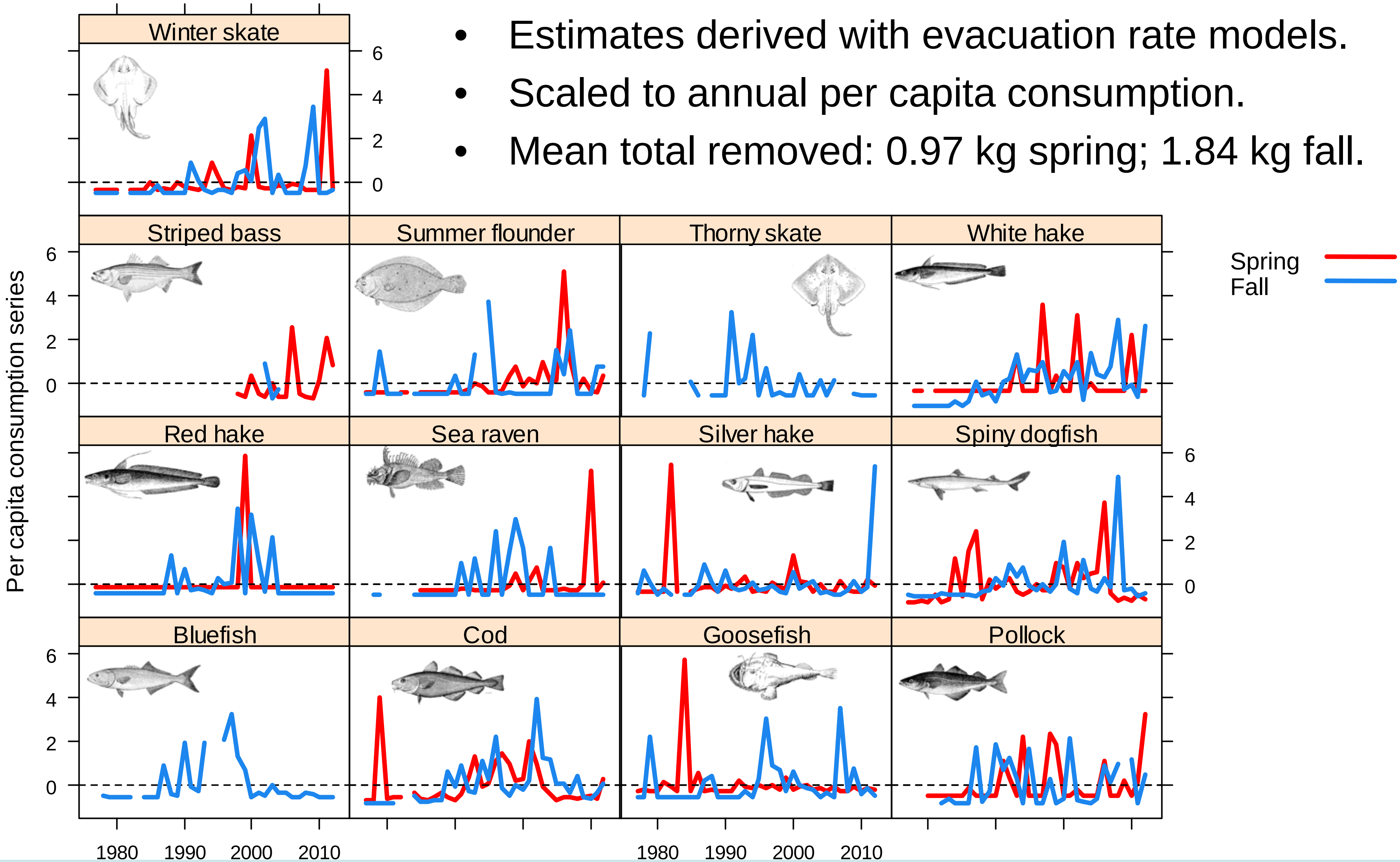


Diet



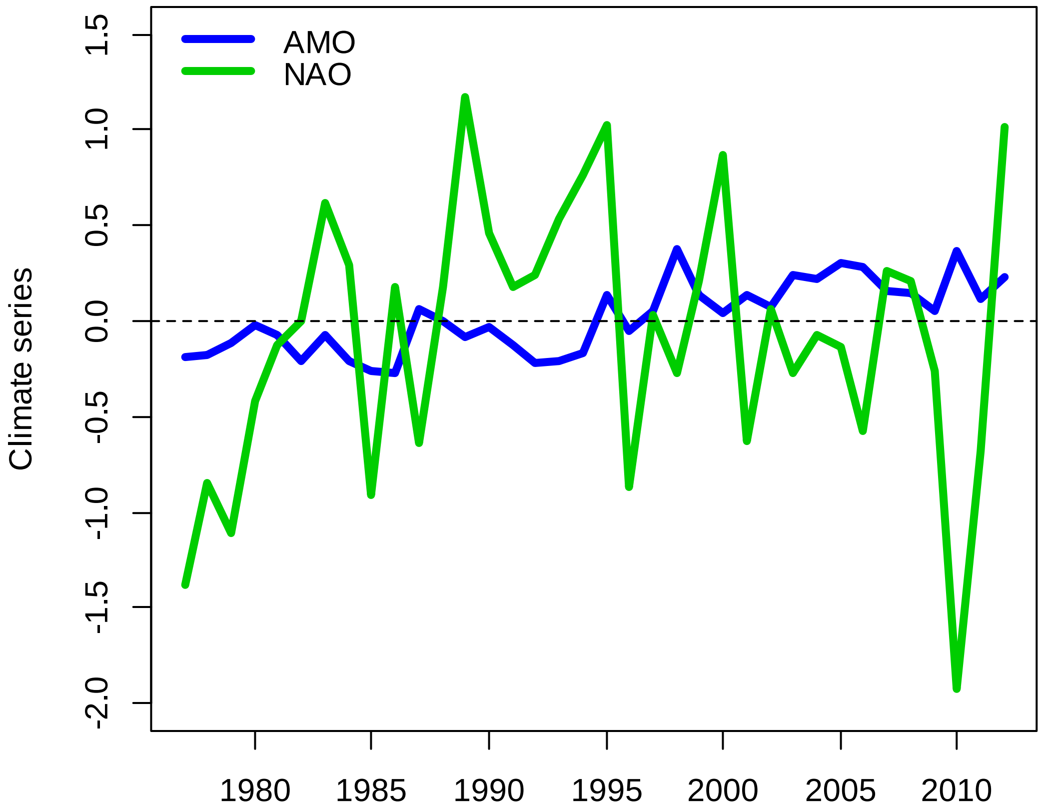
Forage Fish Consumption

- Estimates derived with evacuation rate models.
- Scaled to annual per capita consumption.
- Mean total removed: 0.97 kg spring; 1.84 kg fall.



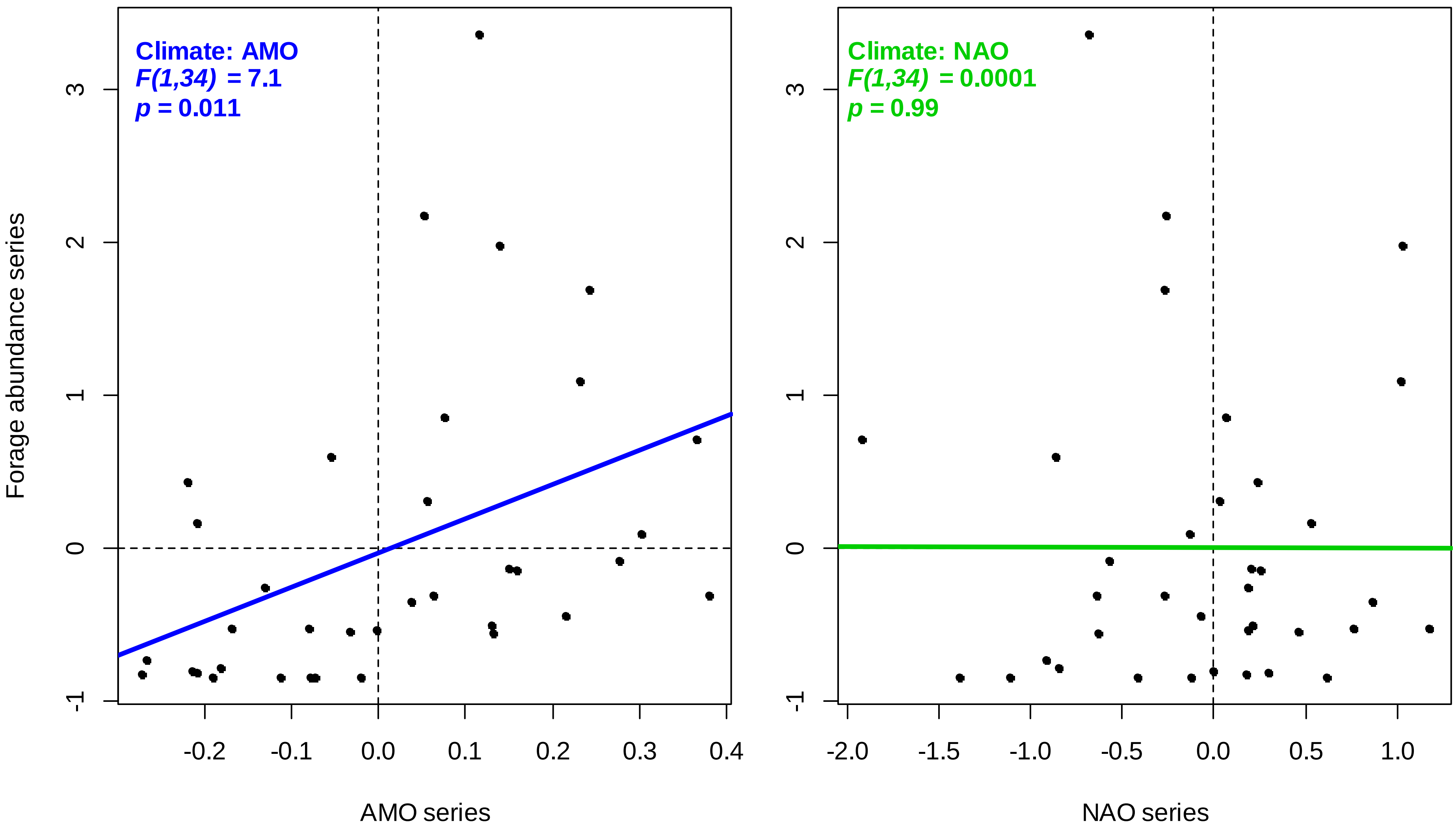
Climate Indices

- Annual AMO and NAO standardized indices.
- AMO characterized by lows <1995 and highs 1995+.
- NAO more variable, highs 1990s, lows early and late.

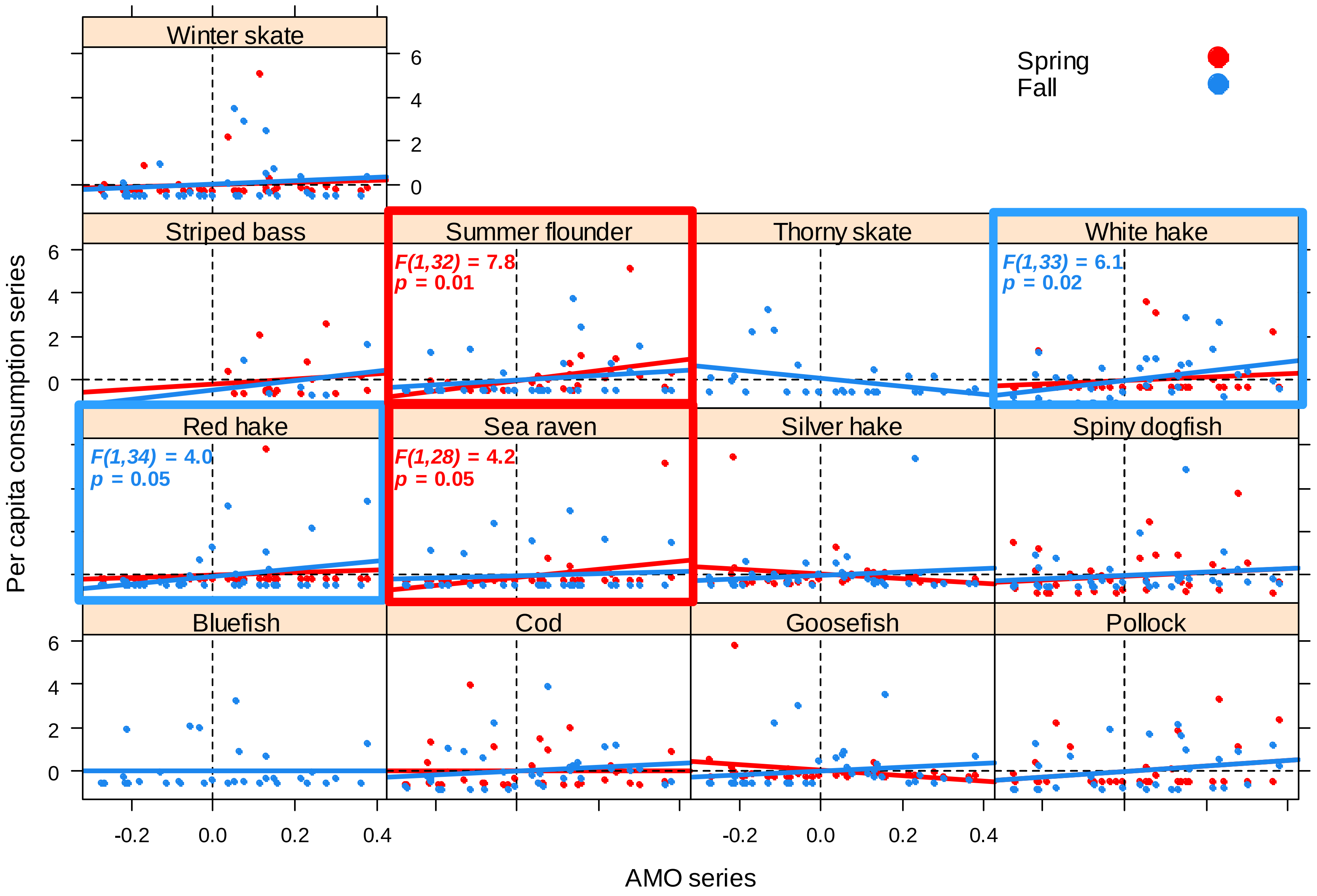


- Benefits: long term climatic conditions.
- AMO driven by sea surface temperature.
- NAO driven by atmospheric pressure.

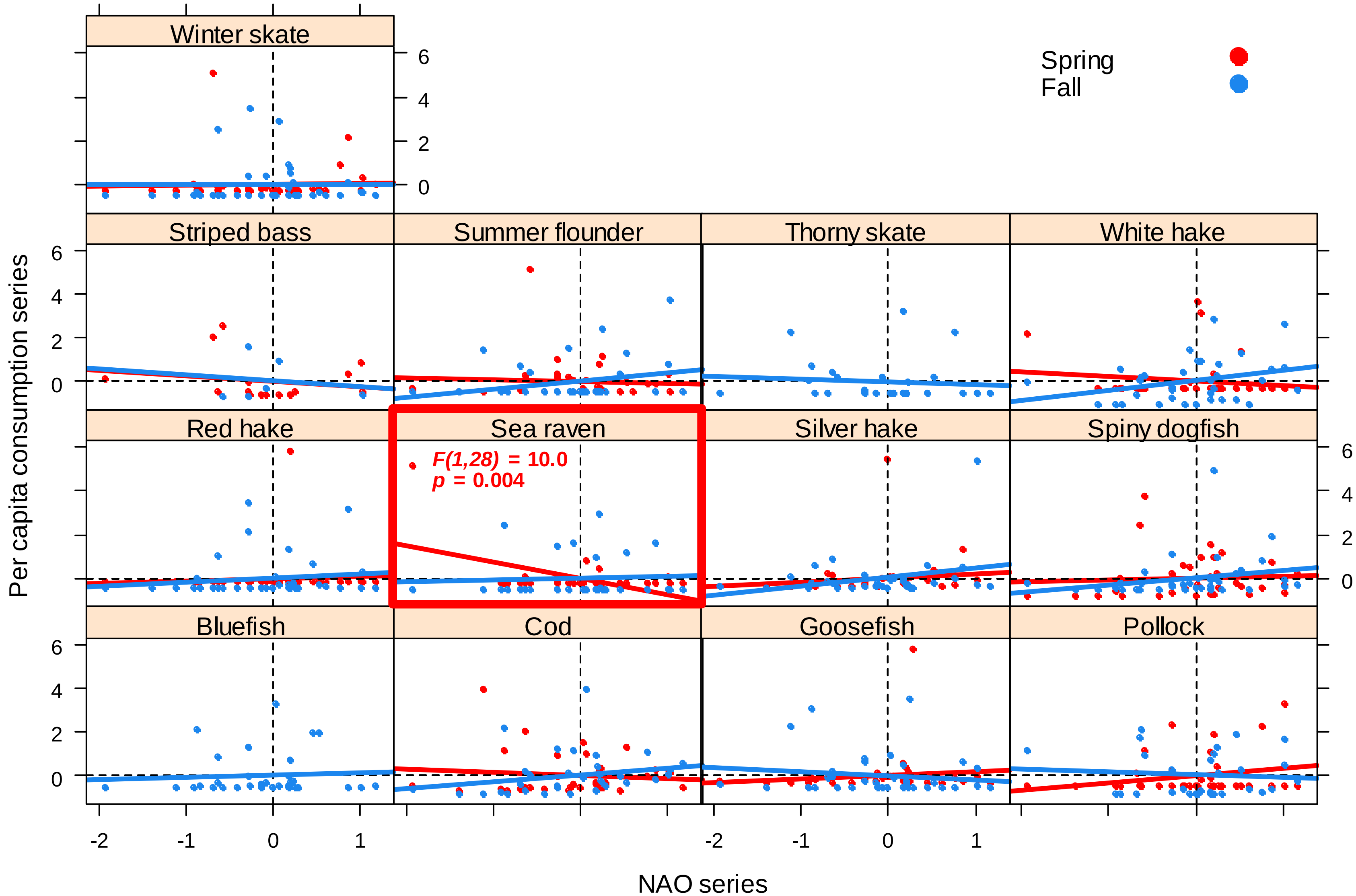
Time Series Correlations: Abundance



Time Series Correlations: Consumption vs AMO



Time Series Correlations: Consumption vs NAO



Time Series Modeling

- Multivariate autoregressive state-space models

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ \vdots \\ y_{24} \end{bmatrix} = \begin{bmatrix} Z_{1,1} & Z_{1,2} & Z_{1,3} & Z_{1,4} & Z_{1,5} \\ Z_{2,1} & Z_{2,2} & Z_{2,3} & Z_{2,4} & Z_{2,5} \\ Z_{3,1} & Z_{3,2} & Z_{3,3} & Z_{3,4} & Z_{3,5} \\ Z_{4,1} & Z_{4,2} & Z_{4,3} & Z_{4,4} & Z_{4,5} \\ Z_{5,1} & Z_{5,2} & Z_{5,3} & Z_{5,4} & Z_{5,5} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ Z_{24,1} & Z_{24,2} & Z_{24,3} & Z_{24,4} & Z_{24,5} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} + \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ \vdots \\ a_{24} \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ \vdots \\ v_{24} \end{bmatrix}$$

$$\begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_{24} \end{bmatrix} \sim \mathbf{MVN}\left(\begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}, \begin{bmatrix} \mathbf{R}_{1,1} & \mathbf{R}_{1,2} & \dots & \mathbf{R}_{1,24} \\ \mathbf{R}_{2,1} & \mathbf{R}_{2,2} & \cdots & \mathbf{R}_{2,24} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{R}_{24,1} & \mathbf{R}_{24,2} & \dots & \mathbf{R}_{24,24} \end{bmatrix} \right)$$

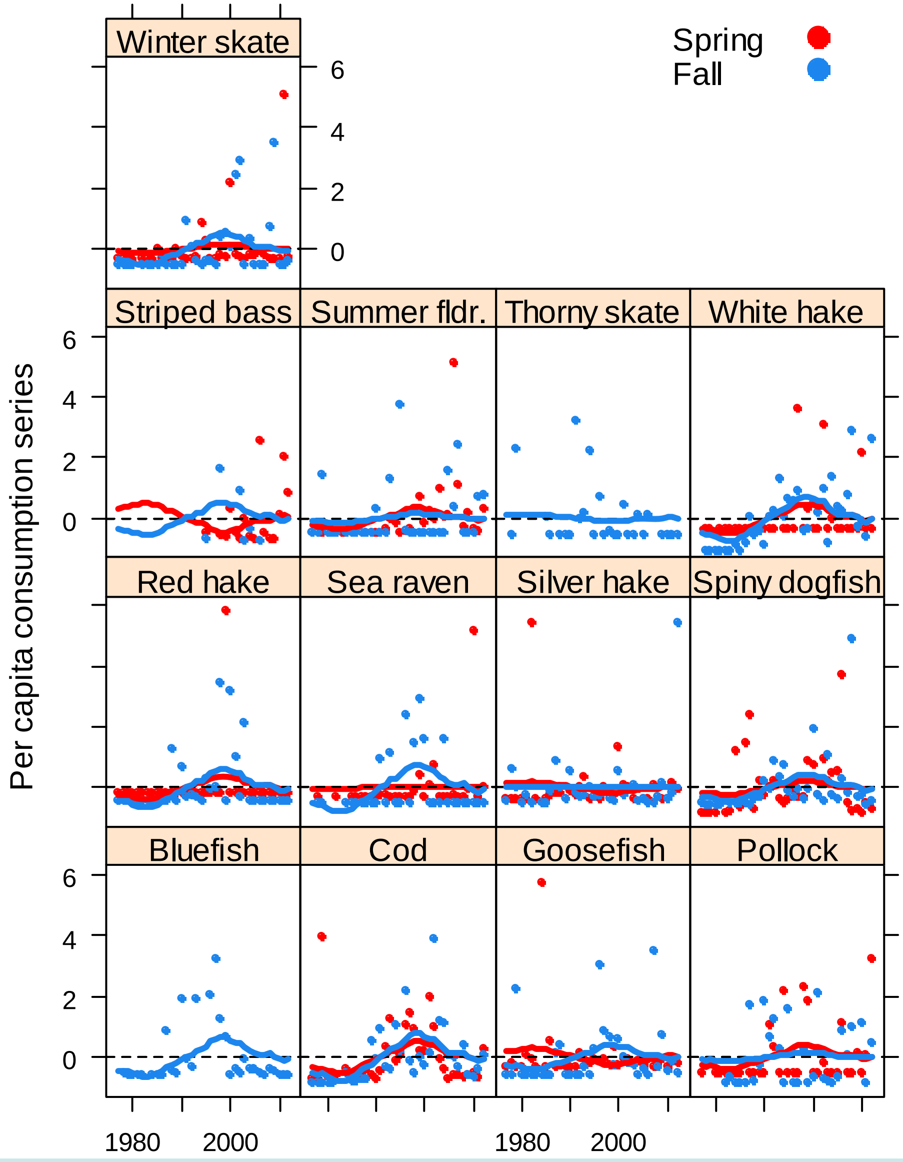
- Non-stationary data
- Missing data
- Dynamic factor analysis
- Model process and observation error separately
- EM algorithm
- Trend based on random walk

Identifying Trends and Modeling Forage Consumption

Model Selection

R = covariance matrix structure; m = number of trends; AICc = selection measure.

Model	R	m	AICc
1	**diagonal and equal**	**1**	**2154.8**
2	diagonal and equal	2	2174.7
amo covariate	diagonal and equal	1	2176.2
nao covariate	diagonal and equal	1	2180.0
amo nao covariates	diagonal and equal	1	2198.4
6	diagonal and unequal	1	2201.9
3	diagonal and equal	3	2211.0
7	diagonal and unequal	2	2221.1
4	diagonal and equal	4	2249.7
8	diagonal and unequal	3	2257.6
5	diagonal and equal	5	2288.1
9	diagonal and unequal	4	2293.6
10	diagonal and unequal	5	2331.1

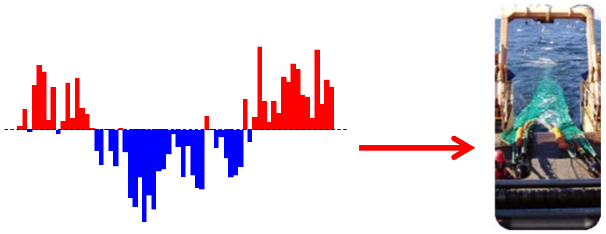


Conclusions

- Cycling of forage abundance and consumption appear to follow a climatic pattern (AMO), but not apparent for all predators.
- Other trophic relationships such as cannibalism or prey preference may have limited the collective importance of AMO as a covariate.
- For generalist feeders, diets can reflect changes in the environment; yet, the effects of these diet shifts remain unknown.

Discussion

- The addition of climate was not optimal for modeling multivariate forage consumption, however, for some predators, stronger relationships may exist.
- For the NE continental shelf food web, herring and mackerel are important prey for many species (e.g. birds, highly migratory species, and sharks).
- Examining environmental patterns and community interactions for use in stock assessments remains important.



Discussion

- Managing fisheries resources remains an intriguing challenge with pivotal roles of stocks as major prey for commercial fish and fisheries.
- Advancing the use of oceanographic and ecological processes into assessments is essential with their potential disruption due to climatic oscillations and other global perturbations.

Thank you!