Environmental drivers of forage dynamics in Chesapeake Bay

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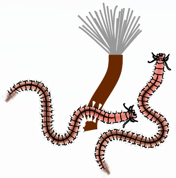
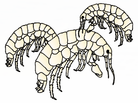
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

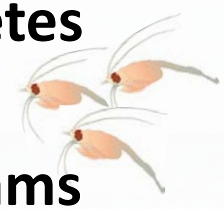
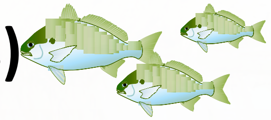
Role of forage in ecosystem-based fisheries management

- Critical consideration of EBFM (Bigford 2014)
  - Link lower to upper trophic levels
  - Predator consumption & production linked to forage availability
- Key forage identified for CBay predators (Ihde et al. 2015)

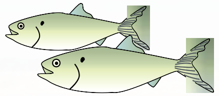
Role of forage in ecosystem-based fisheries management

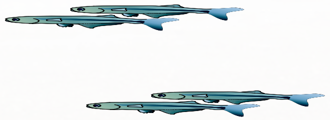
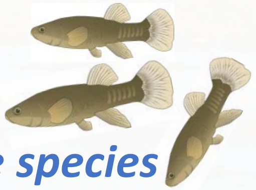
- **Bay Anchovy**
- **Polychaetes**
- **Mysids**
- **Razor clams**
- **Amphipods and isopods**
- **Weakfish (juveniles)**
- **Spot (juveniles)**
- **Mantis shrimp**
- **Sand shrimp**
- **Atlantic croaker (juveniles)**
- **Macoma clams**

Based on wet weight of prey in stomach analyses from ChesMMAP (VIMS)




- **Atlantic menhaden**
- **Blue crab**
- **Shad & river herrings**
- **Small bivalves**
- **Atl. silverside**
- **Mummichog**

Managed forage species

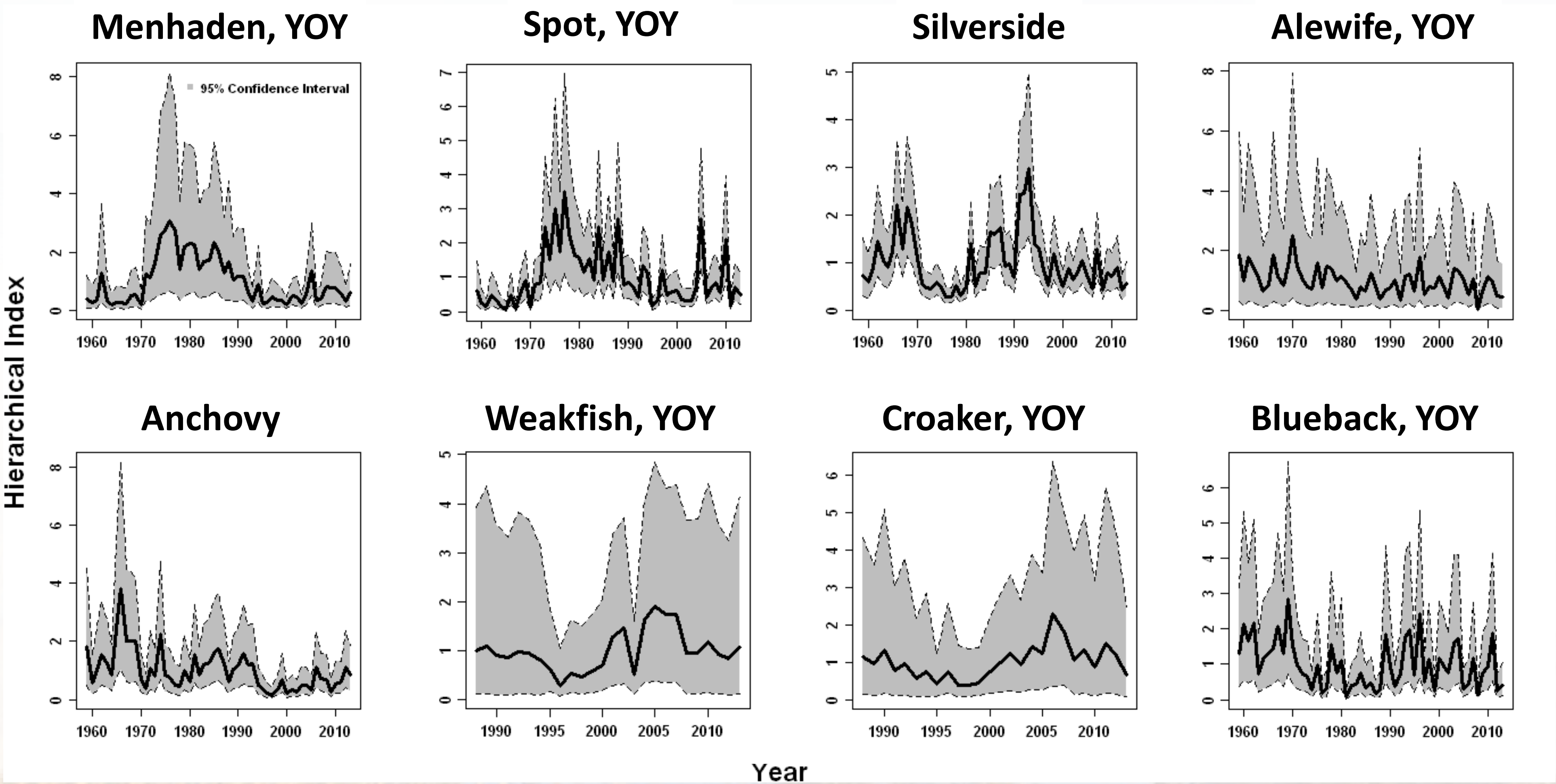
Historically important

Upriver

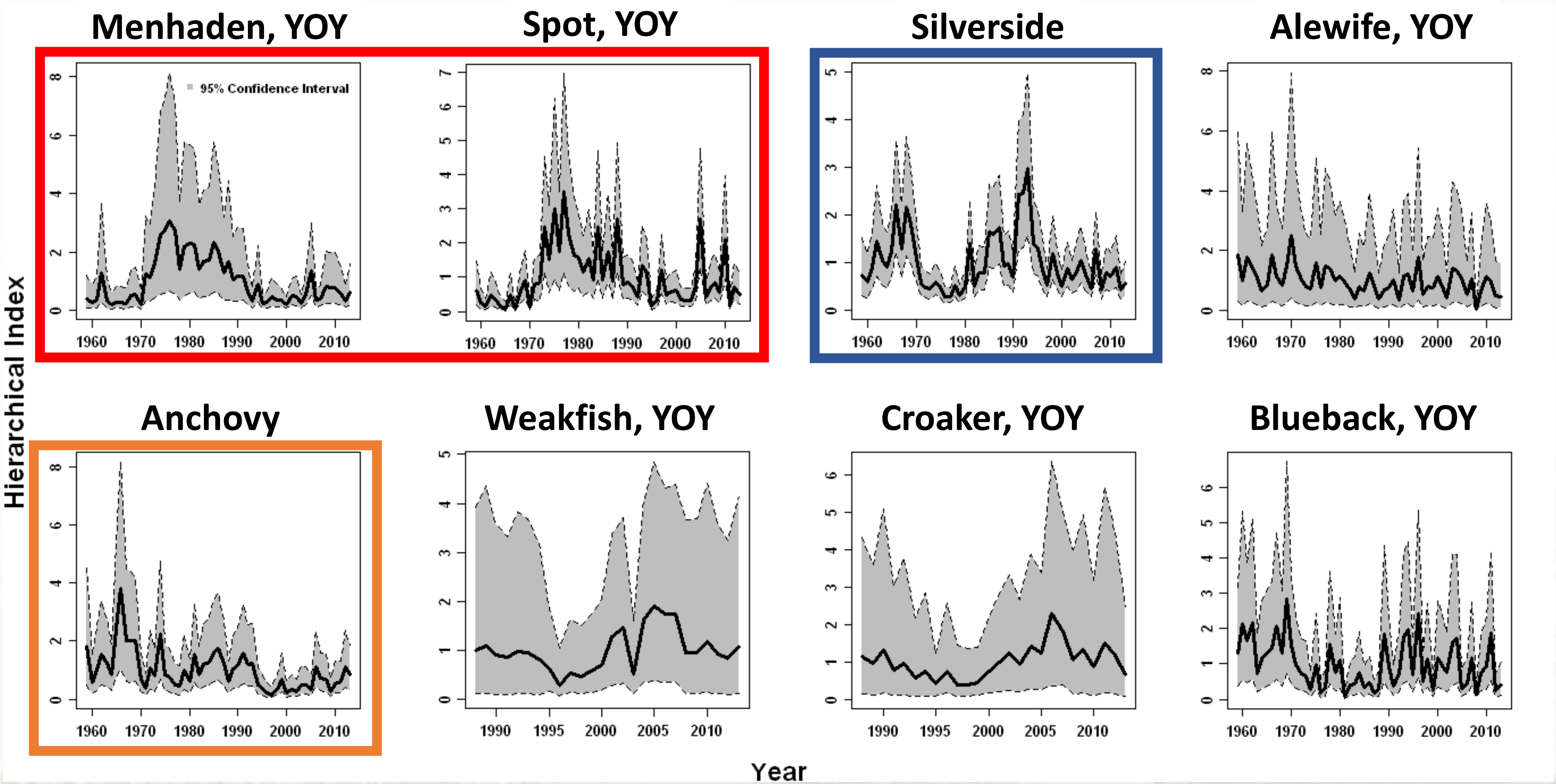
Role of forage in ecosystem-based fisheries management

- Critical consideration of EBFM (Bigford 2014)
  - Link lower to upper trophic levels
  - Predator consumption & production linked to forage availability
- Key forage identified for CBay predators (Ihde et al. 2015)
- Strong interannual patterns in forage abundance indices and predator consumption patterns (Buchheister et al. 2016)

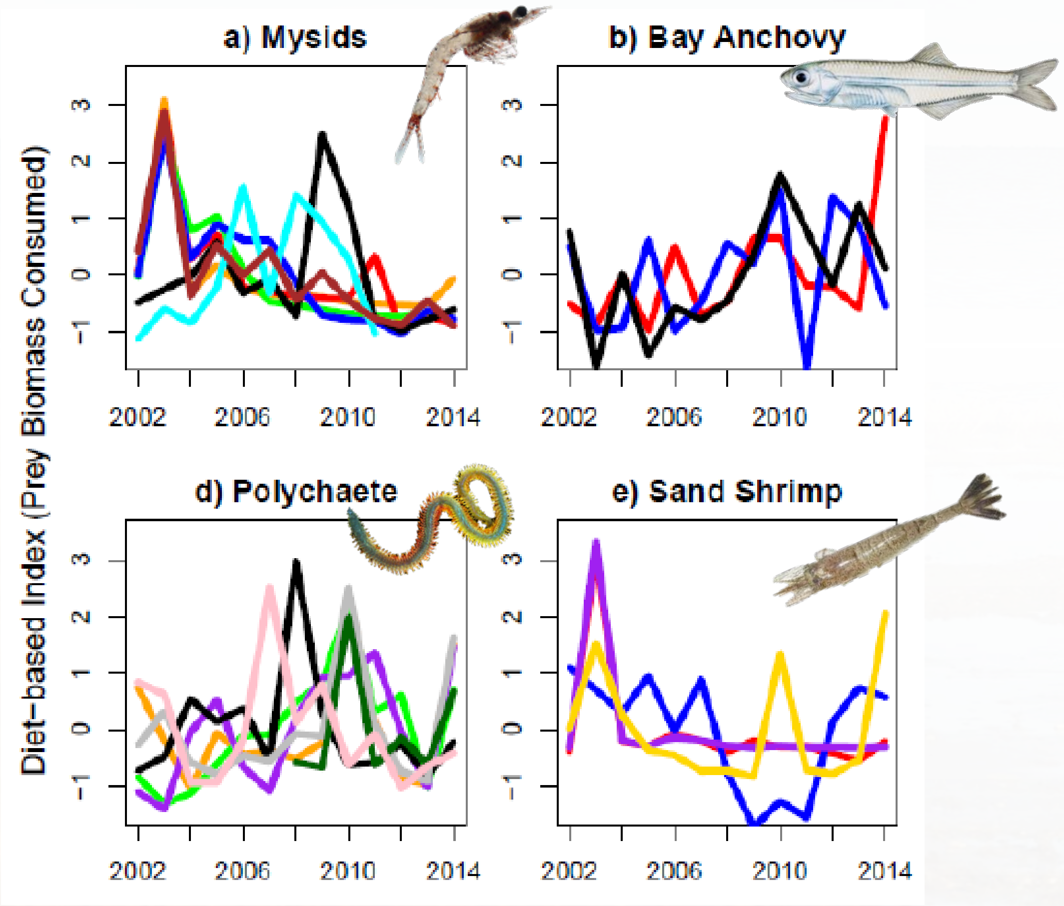
Role of forage in ecosystem-based fisheries management



Role of forage in ecosystem-based fisheries management



Role of forage in ecosystem-based fisheries management



What determines local and regional abundance of key forage?

How does local forage availability influence predator diet?

Role of forage in ecosystem-based fisheries management

Current Project

- **Objective 1** – *Identify environmental gradients associated with spatial and temporal patterns in relative abundance of forage taxa in Chesapeake Bay*

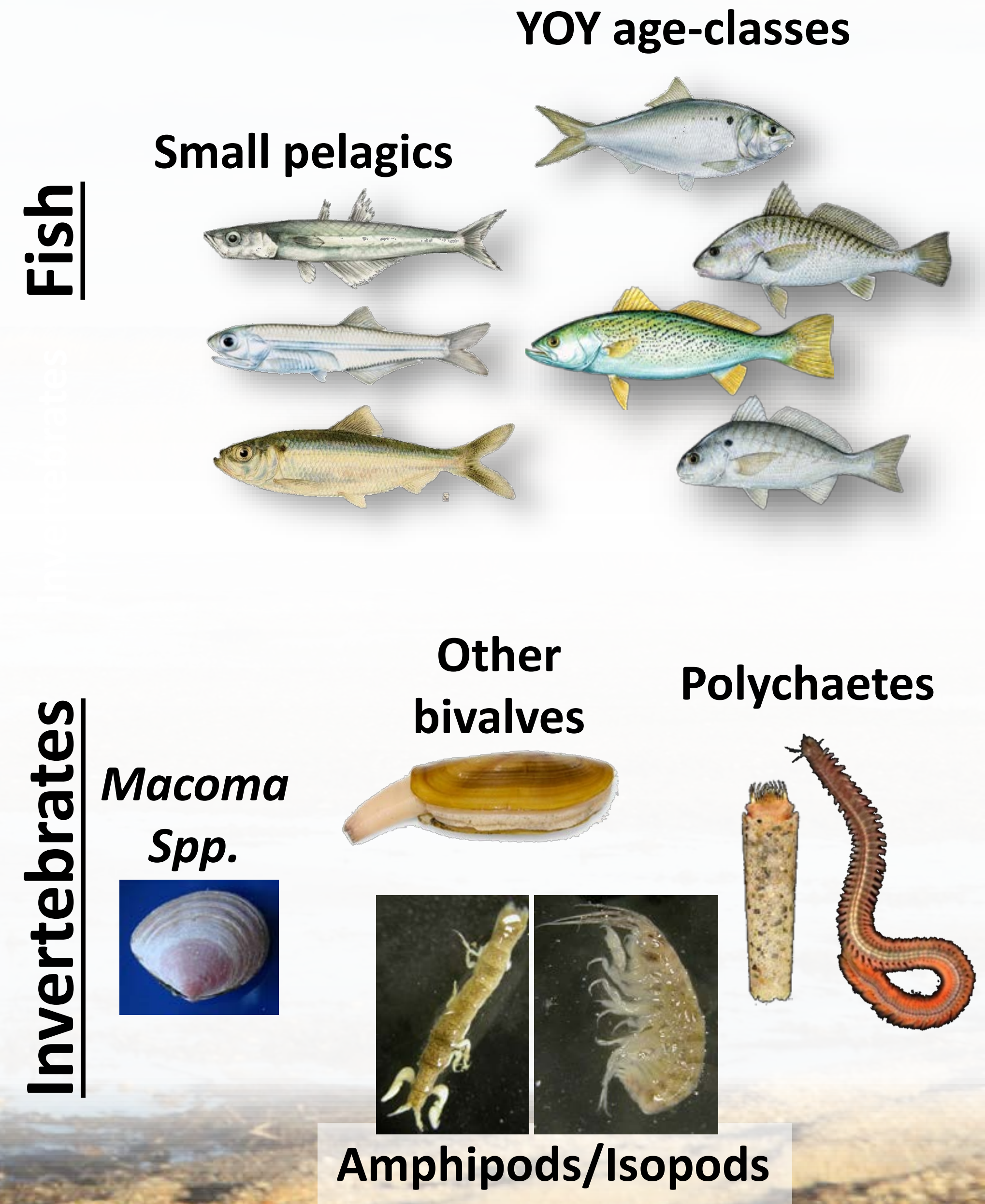
- **Objective 2** – *Explain how spatial and temporal gradients in environmental variables influence consumption of forage taxa, and quantify the effect of forage abundance on consumer populations*

Methods

- Forage indices
- Environmental data

Data type	Source	Area
Forage indices	ChesFIMS/TIES historical survey	Mainstem
	MDDNR/VIMS seine surveys	Tributaries
	CBP/Versar Benthic survey	Main/Trib
Env. conditions	CBP Water Quality survey	Main/Trib
	USGS flow gauges	Tributaries
	Modeled hypoxic basin volumes	Main/Trib
	Buoy & Pier temperature datasets	Baywide
	NOAA climate indices (AMO)	Baywide

Forage groups



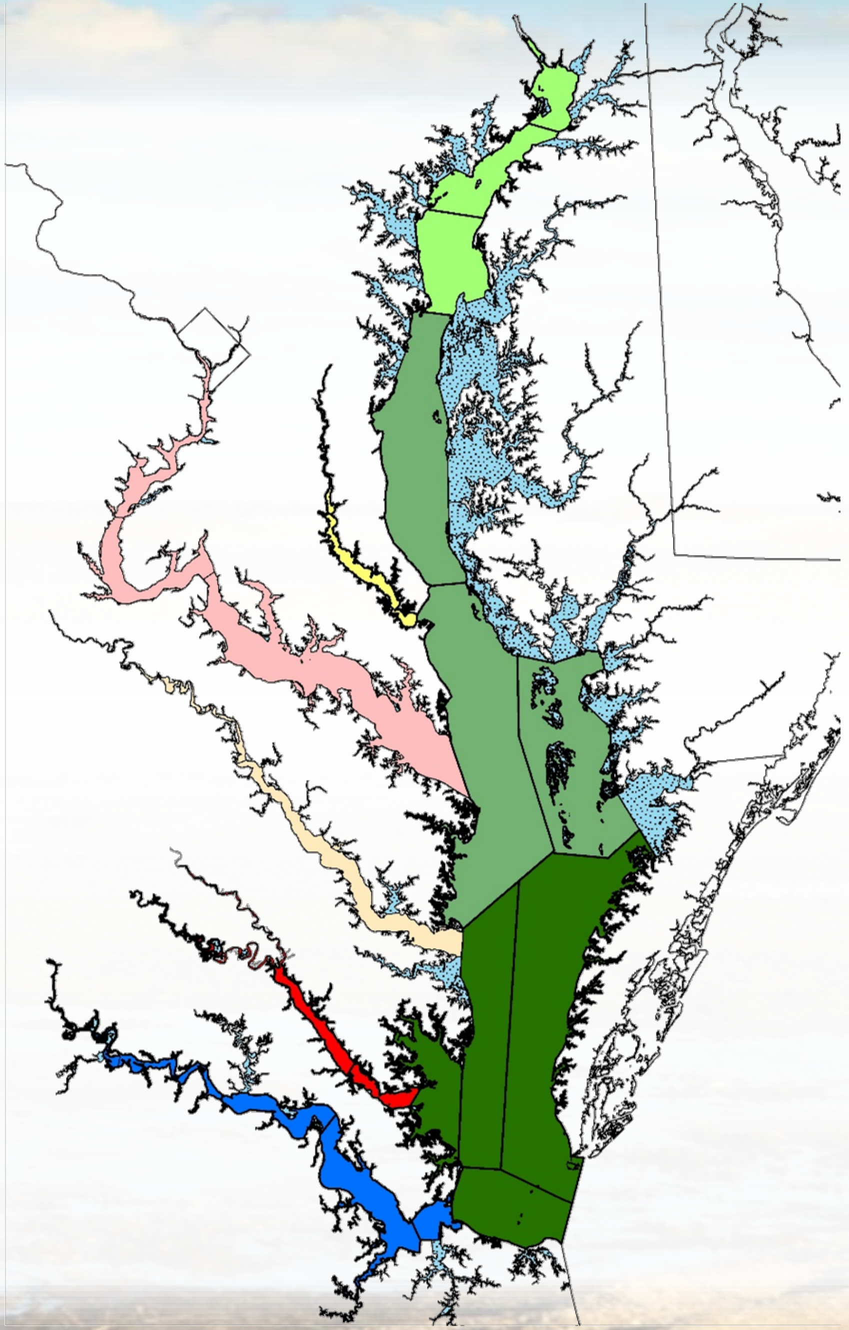
Methods

- Forage indices
- Environmental data
- Predator indices and stomach contents data
  - Area-swept estimates of abundance
  - Size-class, (non-)Index period, Year

Data type	Source	Area
Abundance	ChesMMAP survey	Mainstem/Regions
Diet/Consumption	ChesMMAP survey	Mainstem/Regions
Env. conditions	CBP Water Quality survey	Baywide
	ChesMMAP survey	Mainstem/Regions

Methods

<u>Spatial & Temporal domain</u>	<u>Gear</u>
• Forage	
• Benthic invertebrates: 1995/1996–2015 (*Mainstem/Tribs*)	Grab
• Forage fish: 1995-2007 (*Mainstem*)	MW
• Forage fish: 1968-1973, 1980-2013 (*VA Tribs*)	Seine
1959-2015 (*MD Tribs)*	Seine
• Predators	
• All species/size-classes: 2002-2015	BT

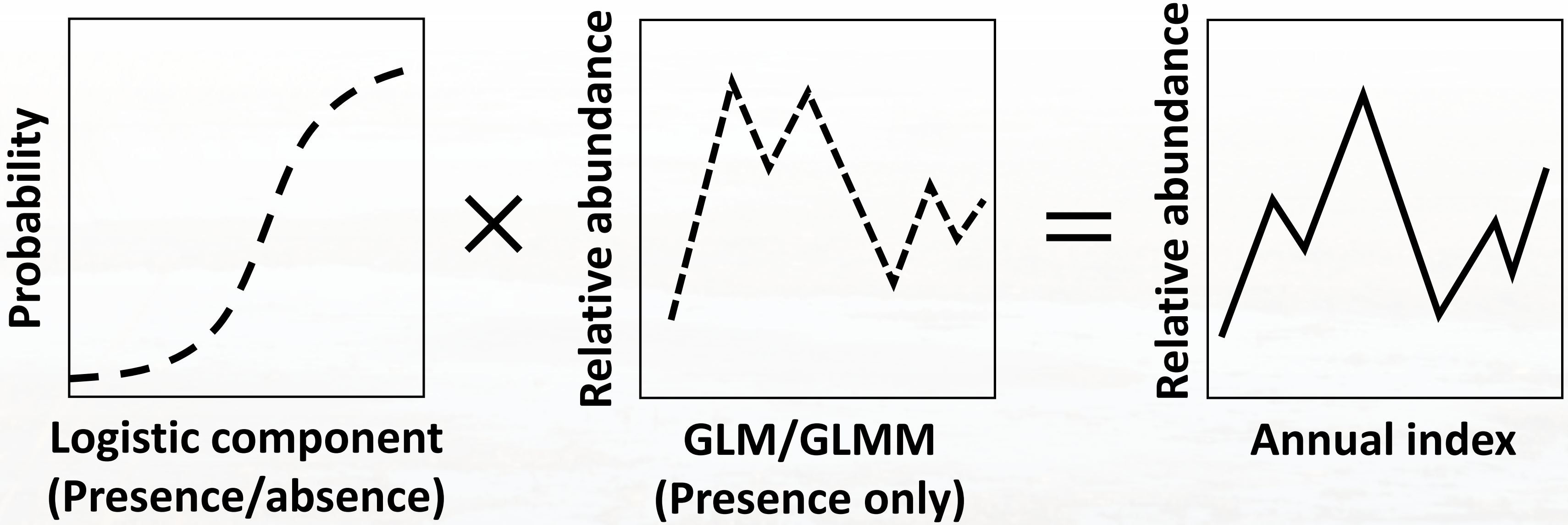


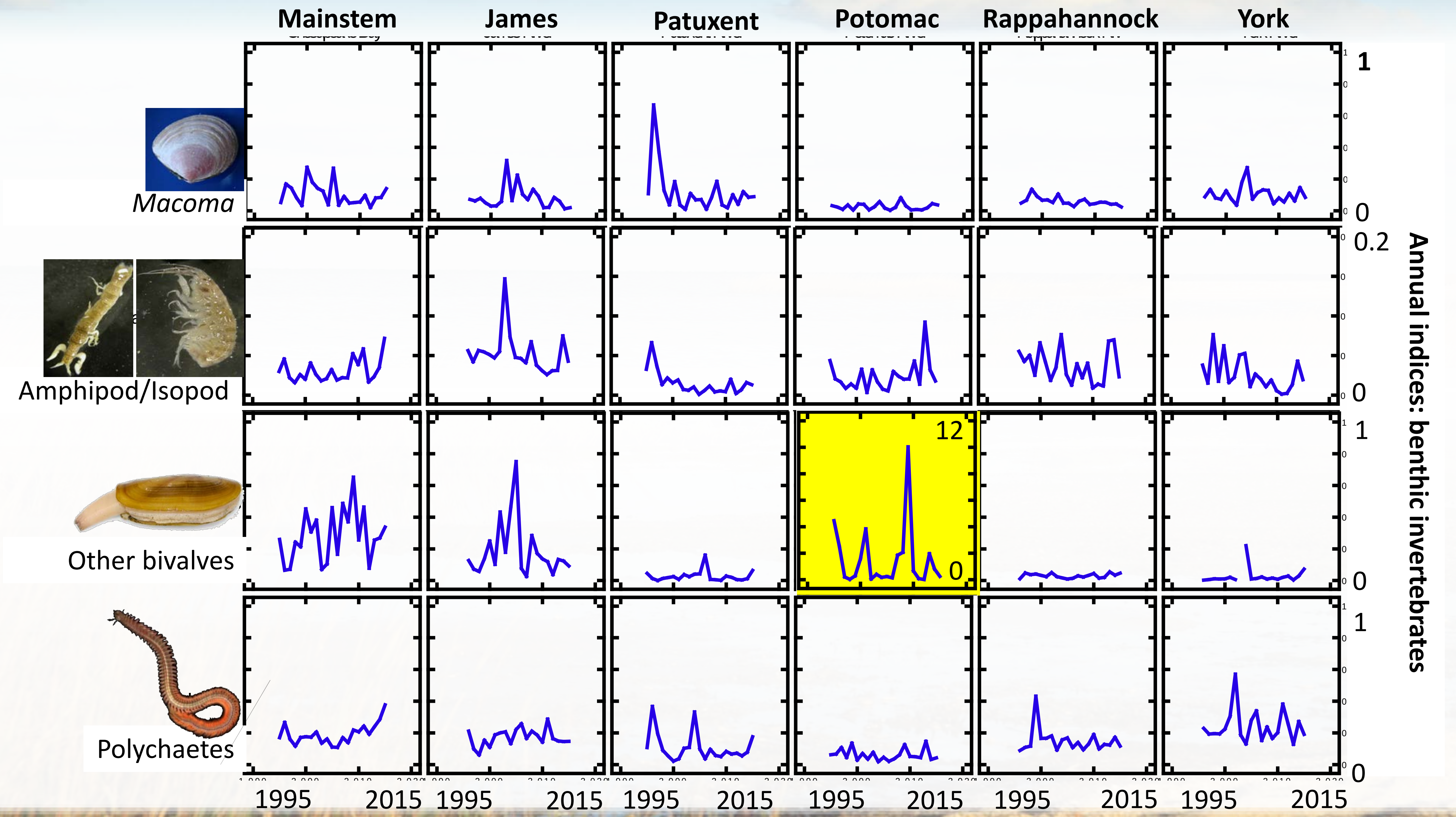
Forage indices (Fish/Invertebrates)

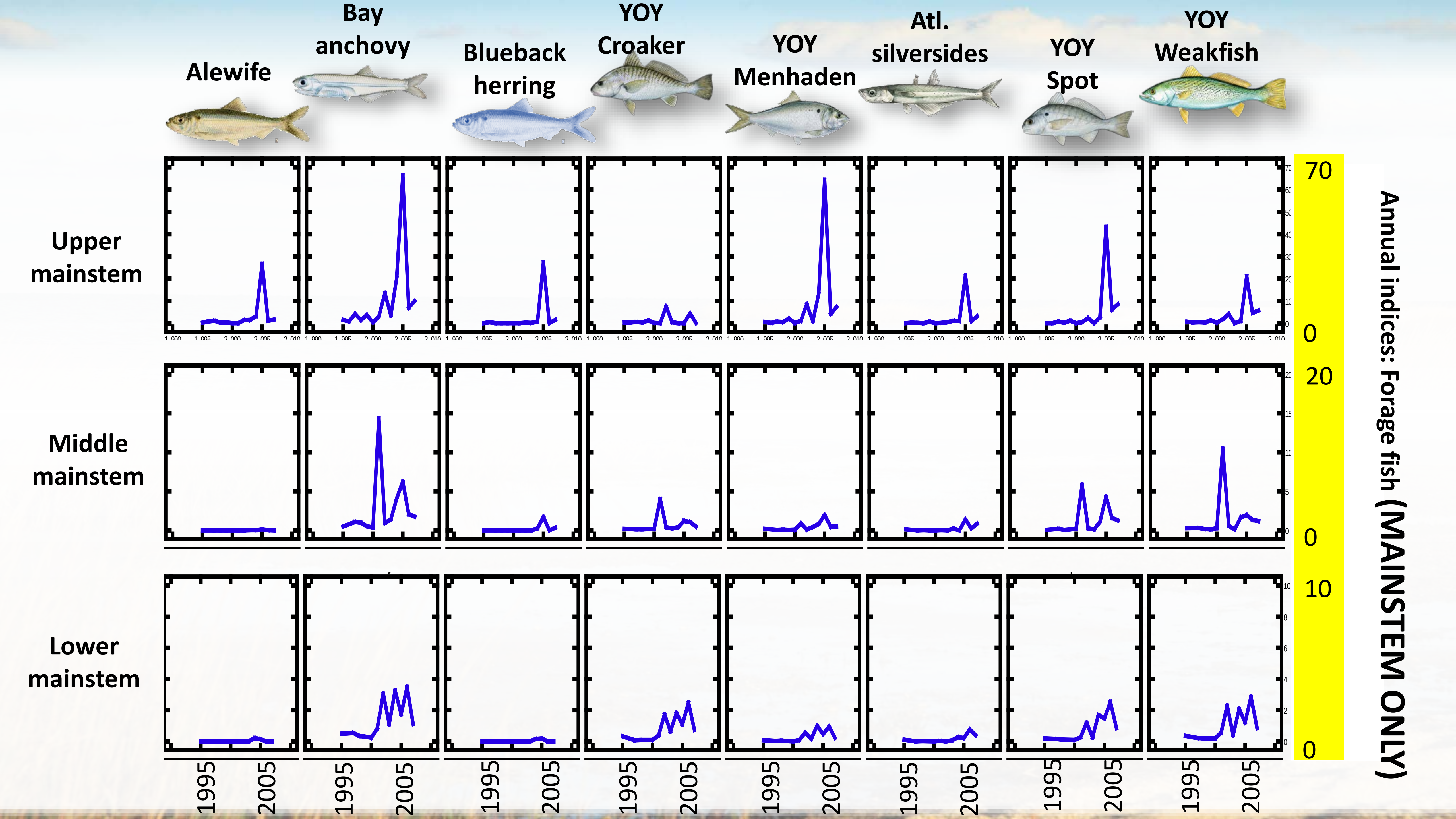
Project Objective	***Modeling approach***
Indices	**Delta-GLM**
Large-scale	GLM
Time-series	DFA

Delta-generalized linear models

- Response variables
  - Biomass per square meter; catch per unit effort

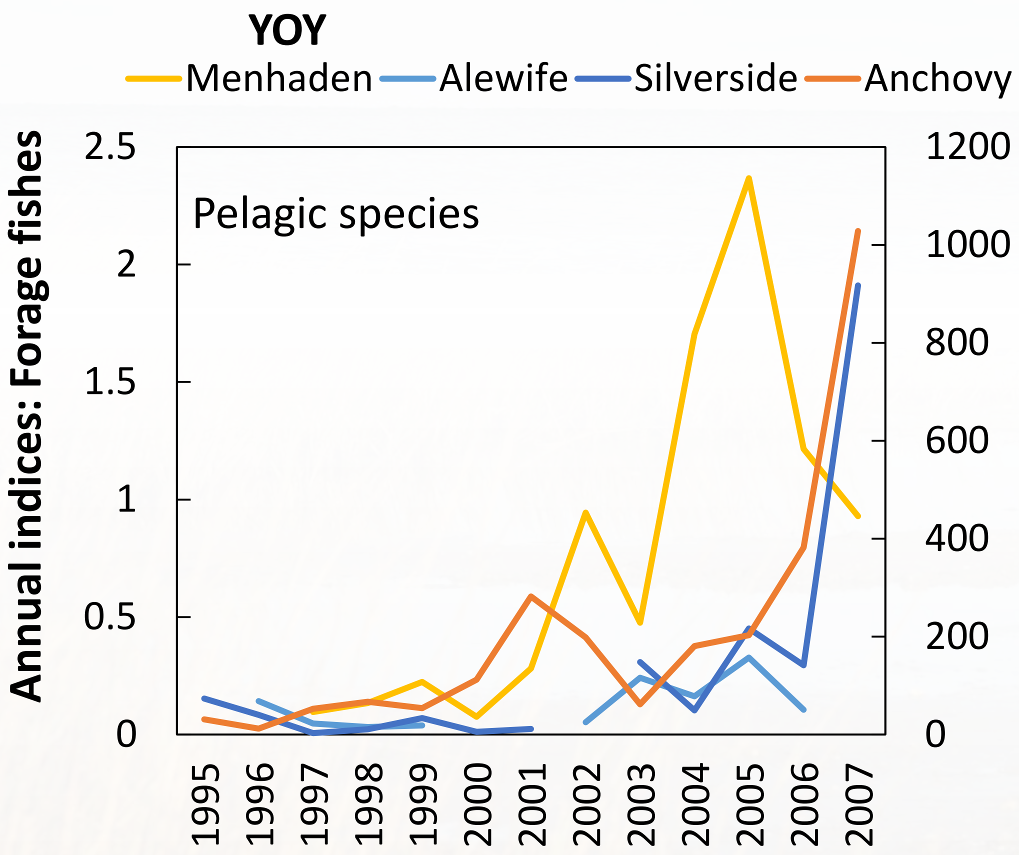


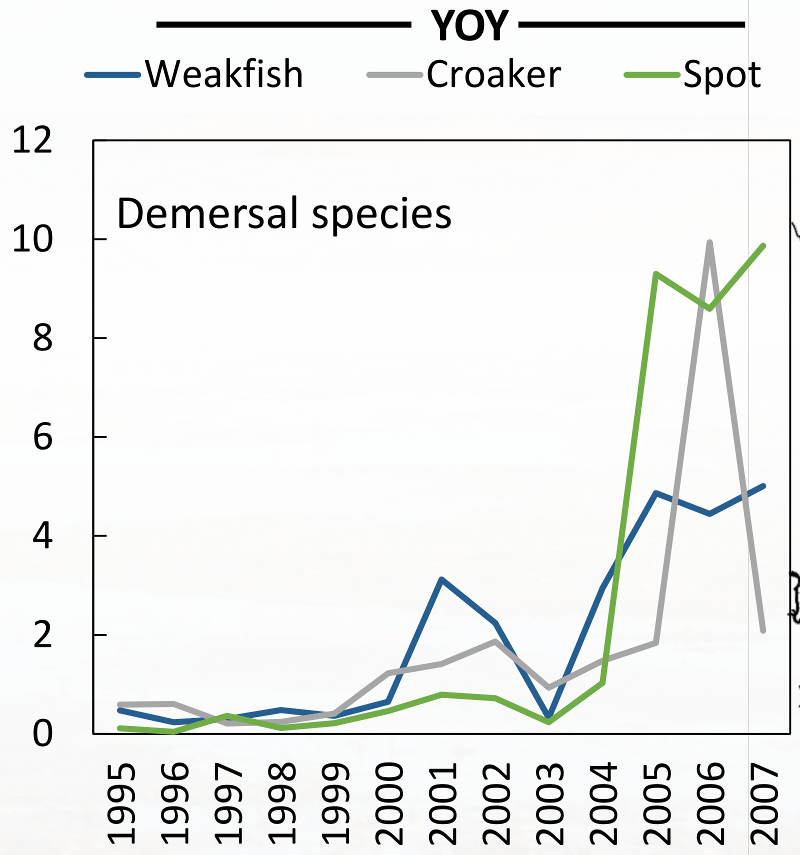

Mainstem
James
Patuxent
Potomac
Rappahannock
York
Macoma
Amphipod/Isopod
Other bivalves
Polychaetes
1
0
0.2
0
1
0
12
0
1
0
1995
2015
Annual indices: benthic invertebrates

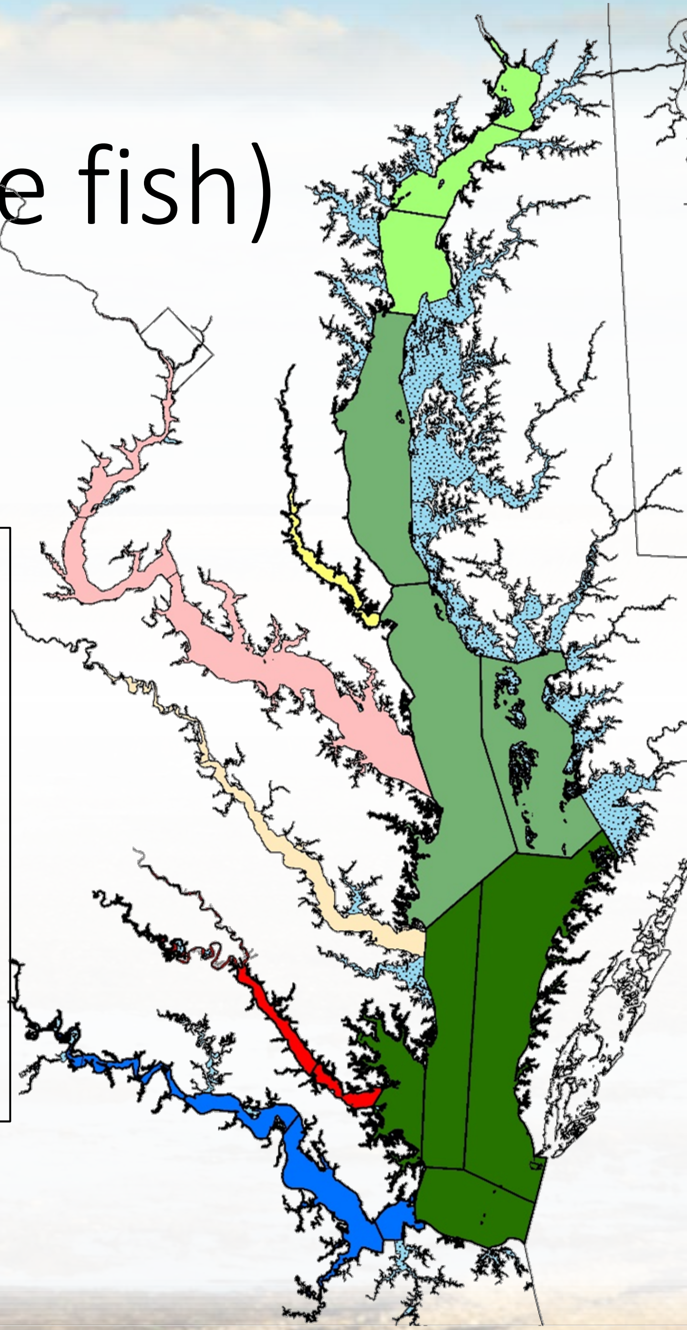


Alewife
Bay anchovy
Blueback herring
YOY Croaker
YOY Menhaden
Atl. silversides
YOY Spot
YOY Weakfish
Upper mainstem
Middle mainstem
Lower mainstem
70
0
20
0
10
0
1995
2005
Annual indices: Forage fish (MAINSTEM ONLY)

Forage indices of abundance (Forage fish)



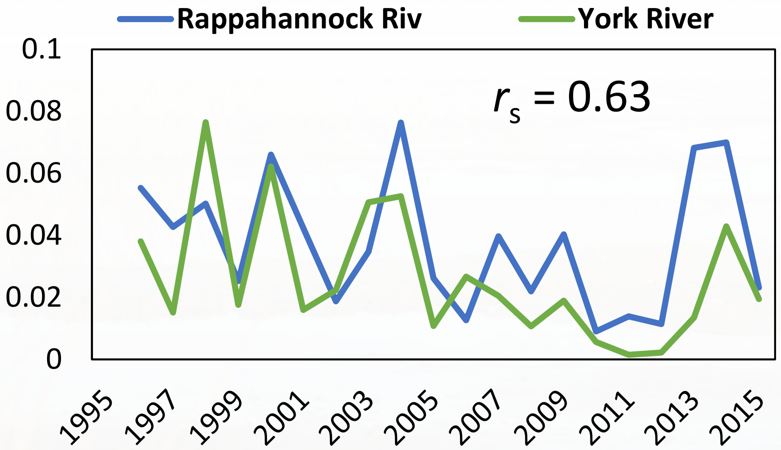


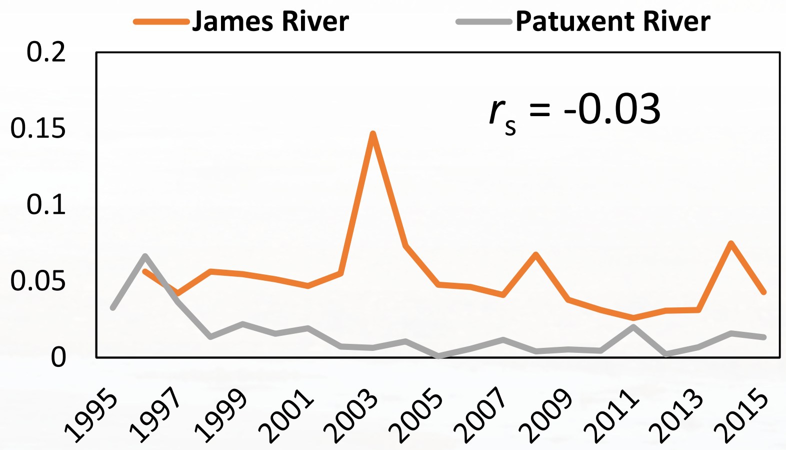


Ongoing analysis: Spatial portfolio effect

- Use of multiple areas likely has benefits for forage and predators – reduces risk to forage (different conditions), reduces spatially variability of food for predators (less patchy)
- Assess importance of maintaining a *portfolio* of suitable habitats in Chesapeake Bay for forage

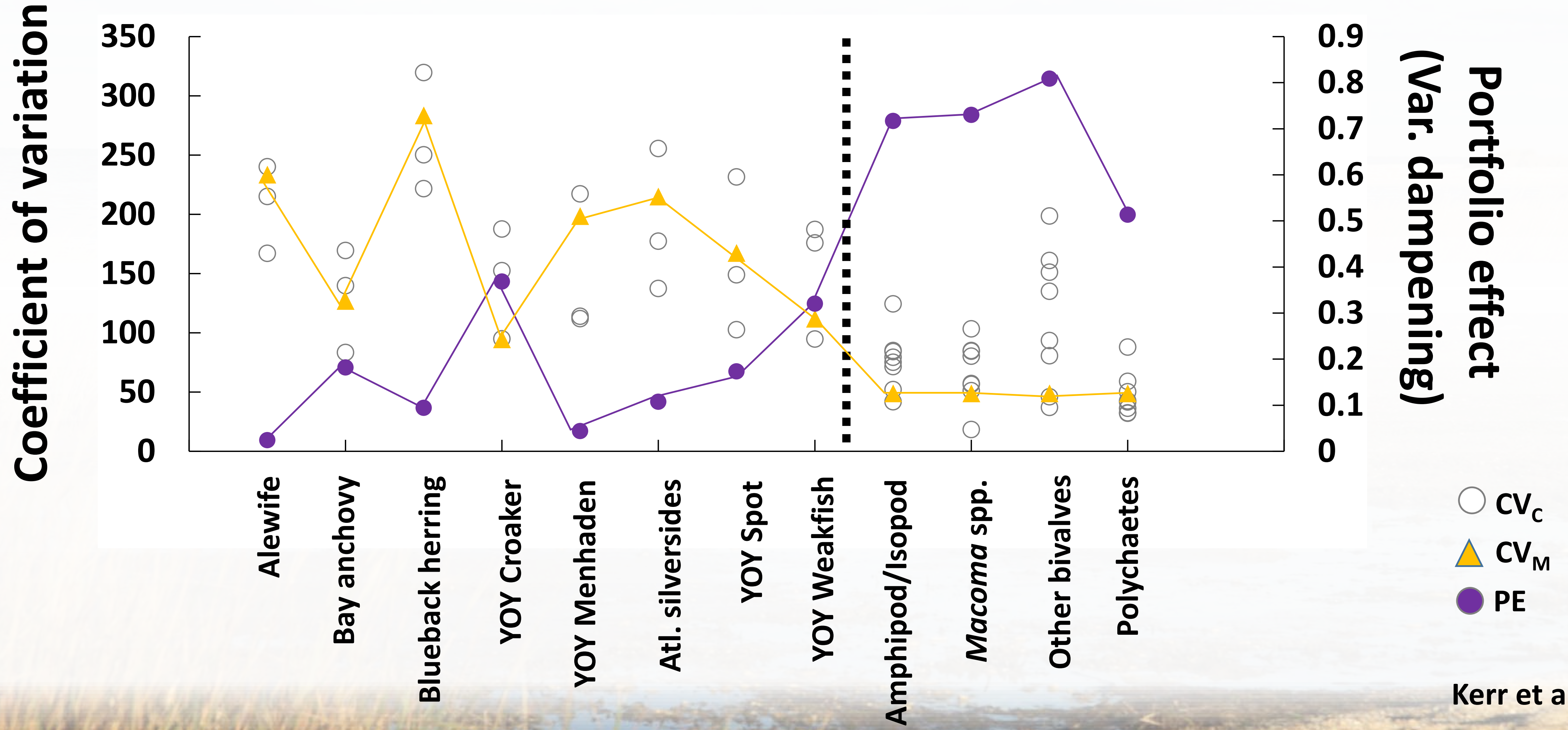
Amphipods /Isopods





- Identify the reduction in total forage variability arising from spatial covariance

Ongoing analysis: Spatial portfolio effect



Kerr et al. 2009

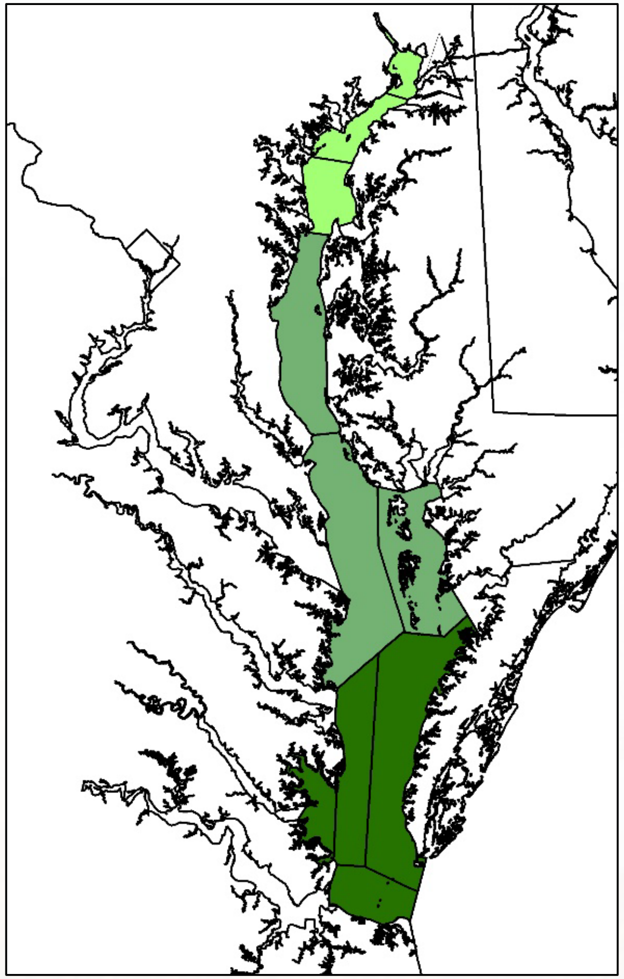
Forage-environment analysis

Project Objective	*Modeling approach*
Indices	Delta-GLM
Large-scale	**GLM**
Time-series	DFA

Forage-environment: generalized linear model

- **Response variable** – Annual indices of relative abundance
- **Distribution –** Gamma w/log link
- **Explanatory variables (all continuous)**
  - Atlantic Multidecadal Oscillation
  - Spring river discharge (ft^3/sec; USGS)
  - DOY 500 5°C degree days (Buoy/VIMS/CBL pier dataset)
  - Spring chlorophyll concentration (Feb-May; CBP WQ survey)
  - January-June hypoxic volume (UMCES/UMichigan)

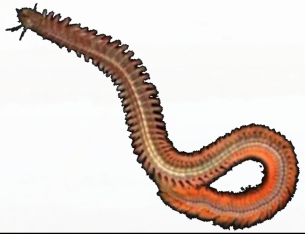
Forage-environment analysis



	Forage group	AMO	Chla	DD	Flow	Hypoxia	Pseudo-r^2
Inverts	Amphipods/Isopods	+			–	+	0.56
	Macoma spp.	–					0.31
	Other bivalves		–		–	+	0.51
	Polychaetes						0.44
Forage fish	Alewife	–	+		–	+	0.87
	Bay anchovy			–	–	+	0.57
	Croaker			–	–	+	0.72
	Menhaden						0.39
	Atl. silverside			–			0.32
	Spot			–		+	0.55
	Weakfish			–		+	0.52

- Moderate-low flow and warmer springs (fish) positively related
- Hypoxic volume positively related to forage abundance*

Forage-environment analysis

Forage	Tributary	AMO	Chla	DD	Flow	Hypoxia	Pseudo-r^2
	Patuxent	−					0.43
	Potomac		+				0.38
	Rappahannock			+			0.45
	Patuxent	−			+		0.59
	Potomac					+	0.28
	James			+	−		0.41
	Patuxent	+					0.24
	Potomac	−					0.37
	York		+	+			0.55
	James				−		0.20
	Patuxent		−		+		0.61
	Potomac			+			0.30
	Rappahannock	+		+	−		0.50

- Highly variable, even within taxa (strong tributary-level effects)
- Cooler springs positively related to forage fish

Forage analysis: discussion

Portfolio Effect

- Multiple suitable benthic habitats a strategy for stable benthic forage

Forage-Environment models

- Evidence of climate-forcing but not (AMO, spring flow)
  - growing literature on AMO effects (Wood and Austin 2009, Nye et al. 2014, Buchheister et al. 2016)
  - High spring flows correlated with low forage abundance in mainstem
- Differential influence of rapid vernal warming – vertebrates(+) vs inverts(-)
  - increased prevalence of earlier warming possible under future climate change
- Hypoxic volume
  - positive effect – linked to change in catchability or spatial recruitment pattern?

Nearing completion (this summer)

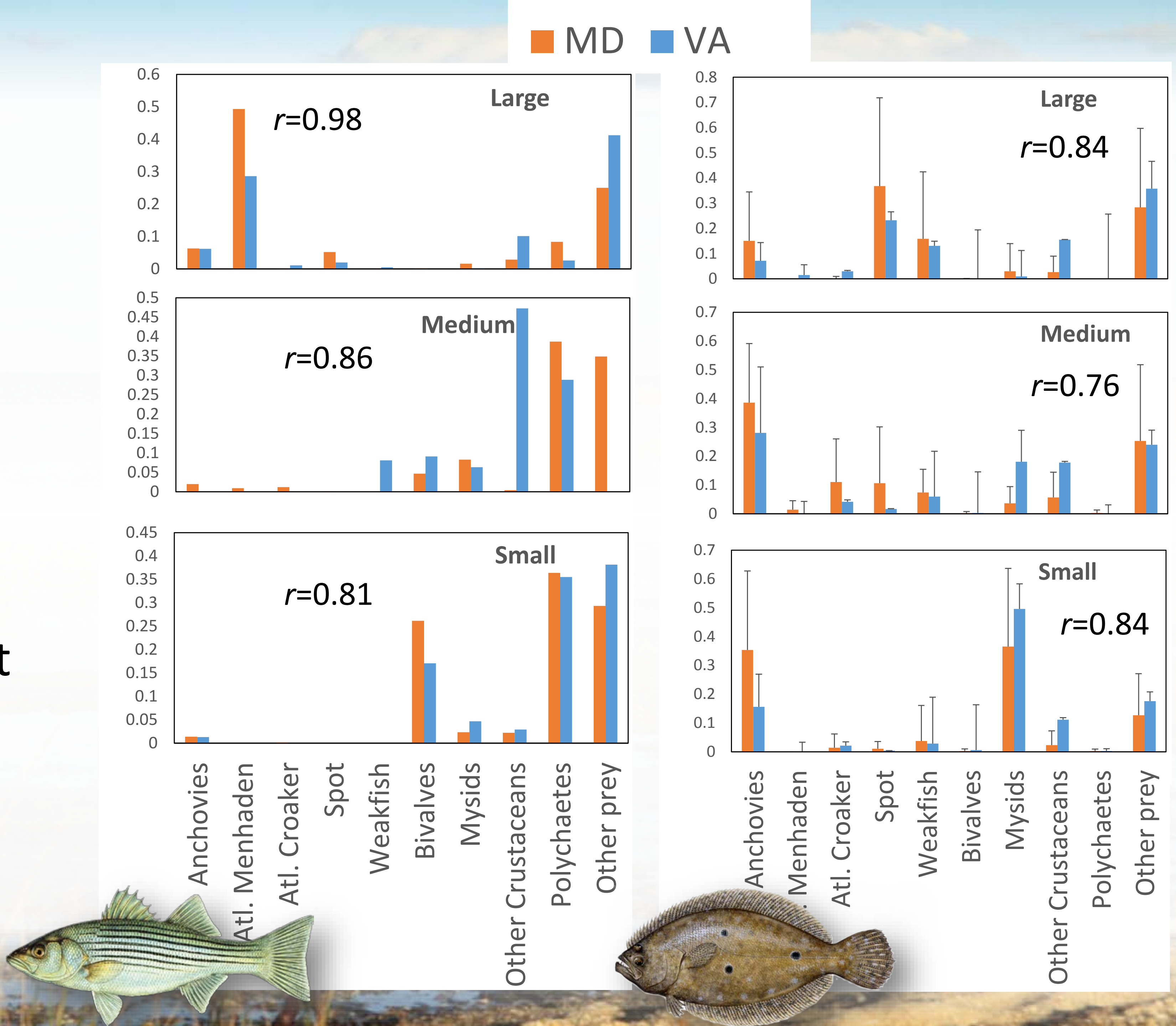
- Forage fish in tributaries
  - Forage-Environment modeling and Portfolio Effect

- Dynamic factor analysis (DFA)
  - Shared trends across regions relative to key environmental gradients

- Integration of forage and predator consumption results
  - Correlation between forage abundance and consumption
  - Consumption relative to environmental gradients
  - ***Spatial aspect of consumption - difficult***

EXAMPLES: Spatial differences in diet (within mainstem)

- Mean proportional stomach contents
- Some similarities/ differences apparent but statistical power?
- Highly variable



Thank you!

Methods: Predator consumption estimates

Annual consumption by predator (C)

$$= \sum_{Size} \sum_{time} \text{Per capita, daily consumption } (c) \times \text{Predator abundance } (N) \times \text{Time period } (t) \times \text{Diet proportion } (D)$$

Evacuation rate model → (c)

Data inputs:

- Avg. stom. contents
- Water temp.

Area-swept estimates → (N)

– No efficiency, selectivity

– Conservative estimates

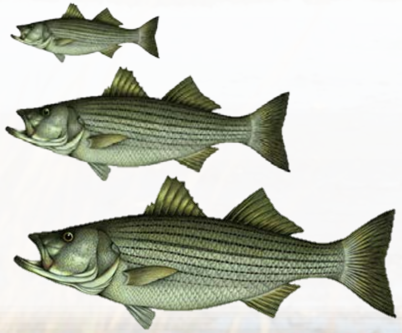
6-month seasons → (t)

Index (higher abund.)

Non-Index

Gut contents → (D)

Predator-specific size classes



S: <30 cm

M: 30-50 cm

L: >50 cm

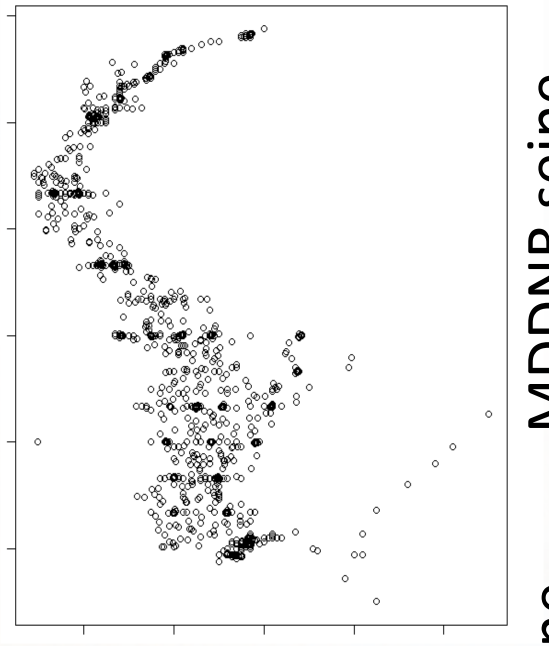
Approach accounts for:

- Predator size
- Diet shifts
- "Seasons" (e.g., migration)
- Temperature

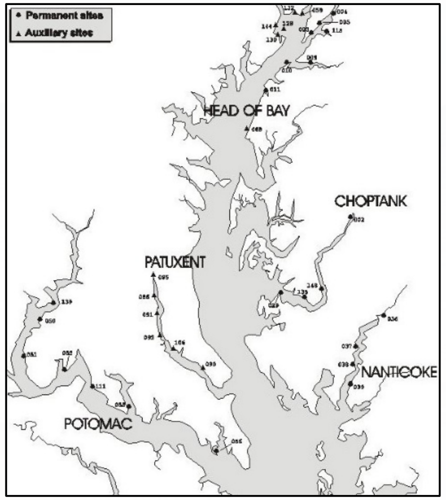
E.g., Link and Sosebee 2008, Overholtz and Link 2007

Forage fish

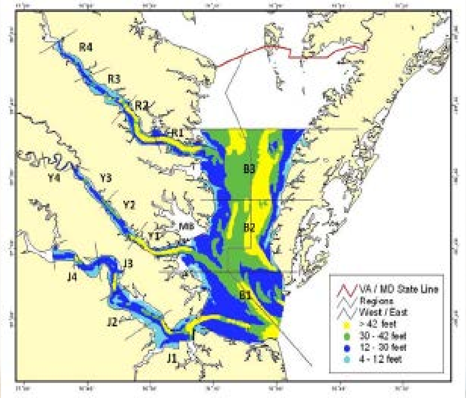
TIES/ChesFIMS



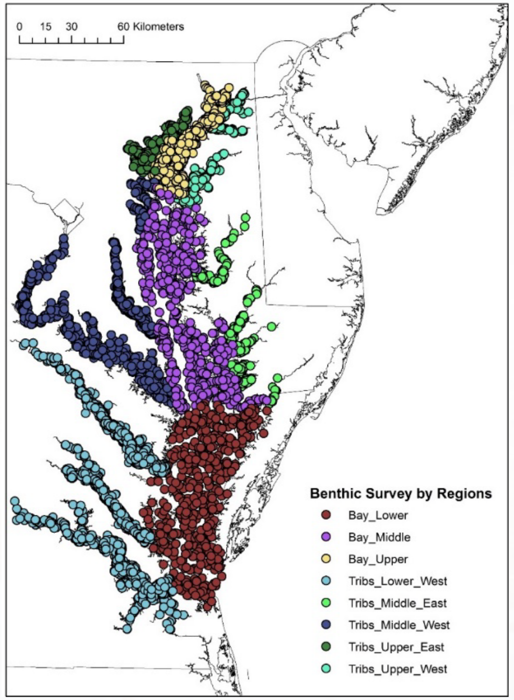
MDDNR seine



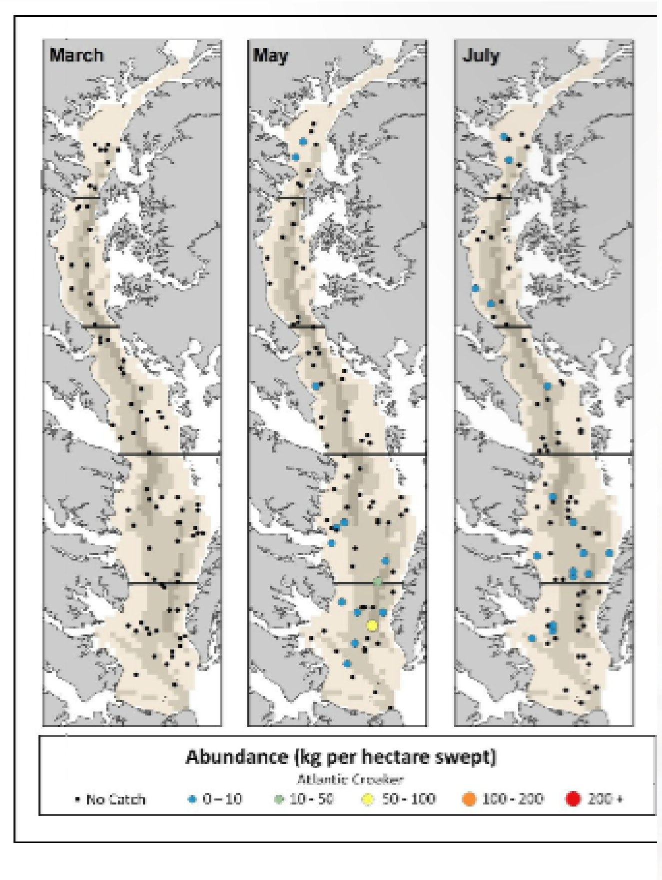
VIMS seine



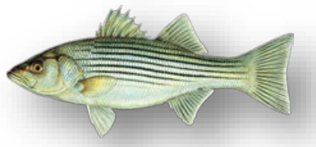
Benthic forage

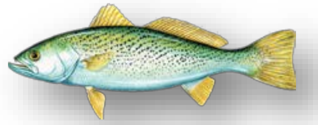


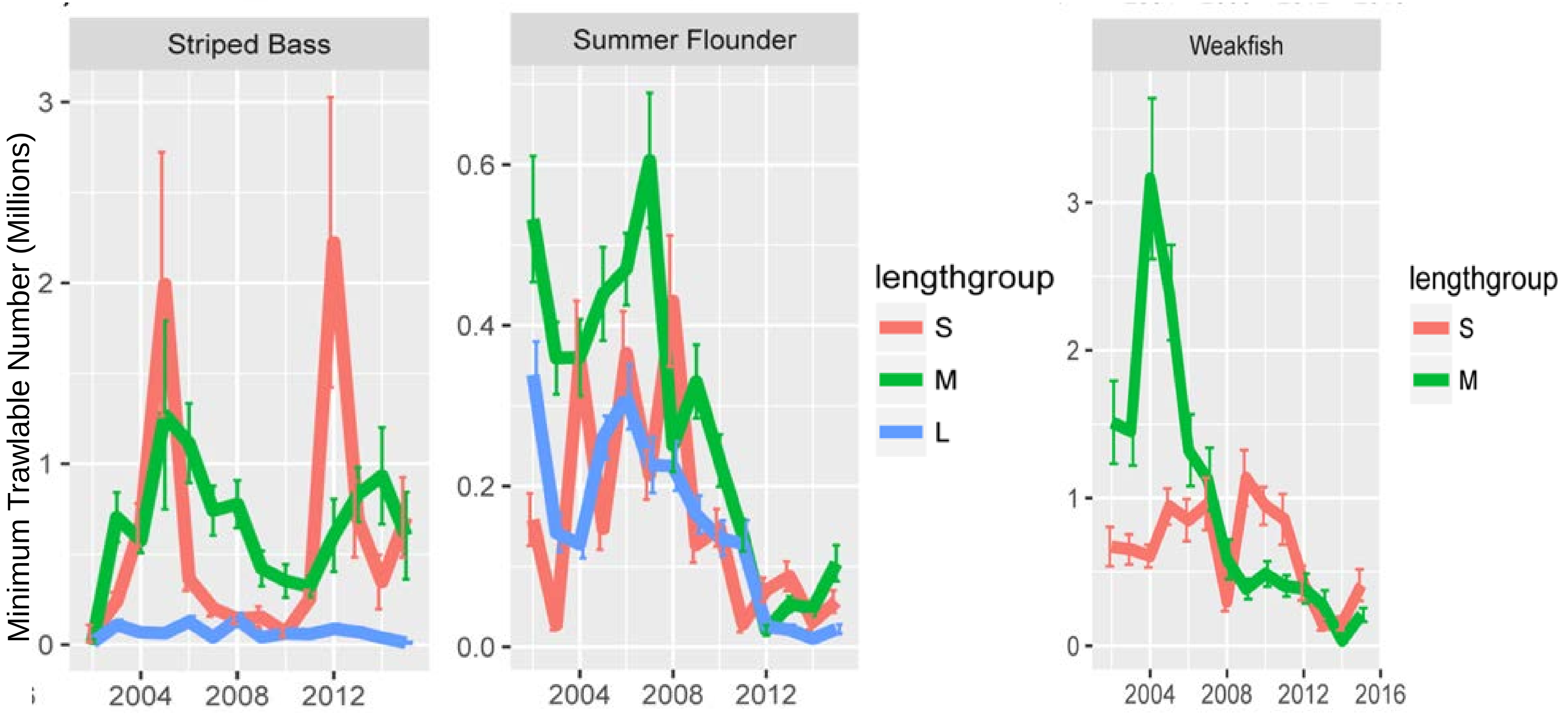
Predators



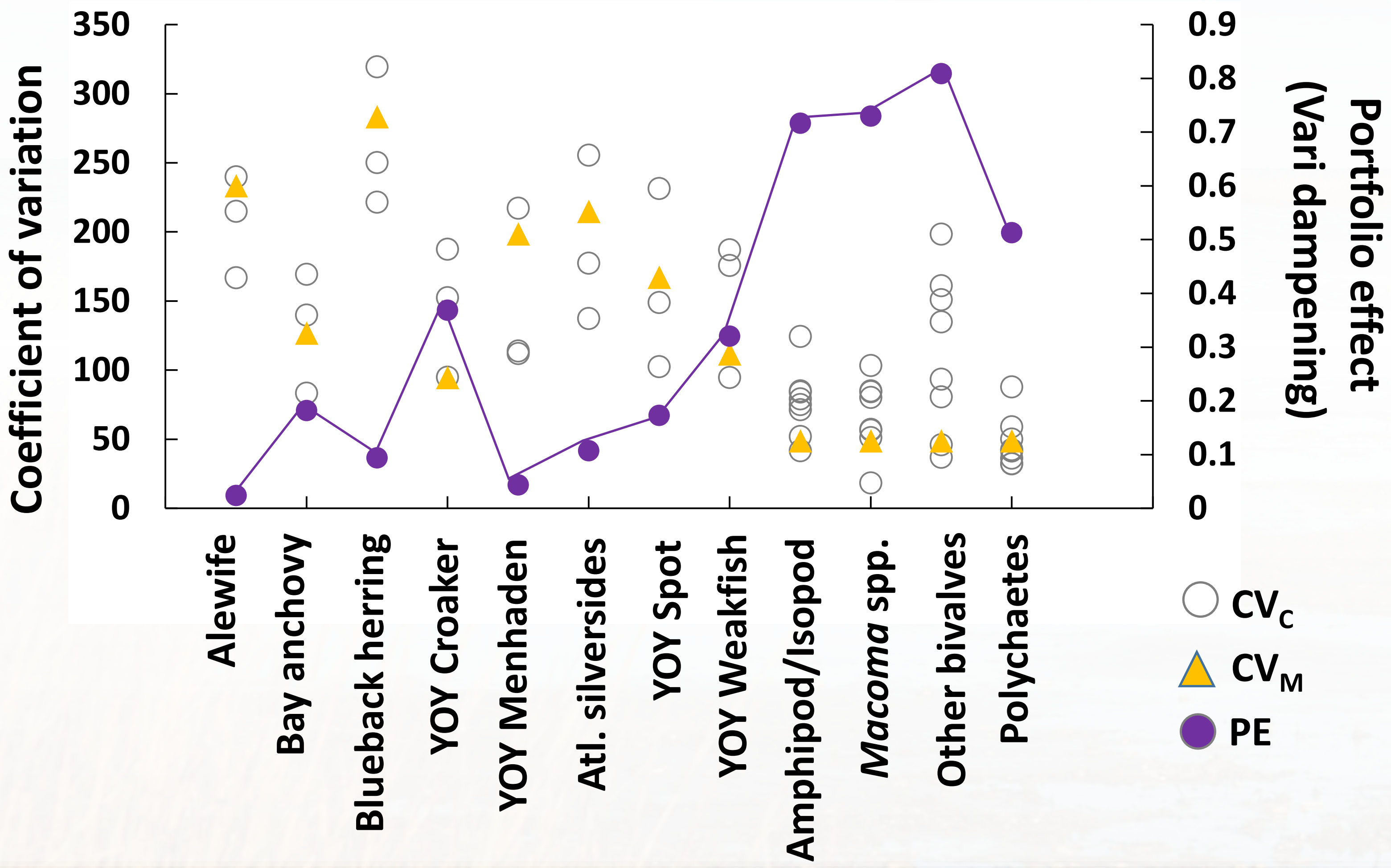
Abundance Indices







Ongoing analysis: Spatial portfolio effect



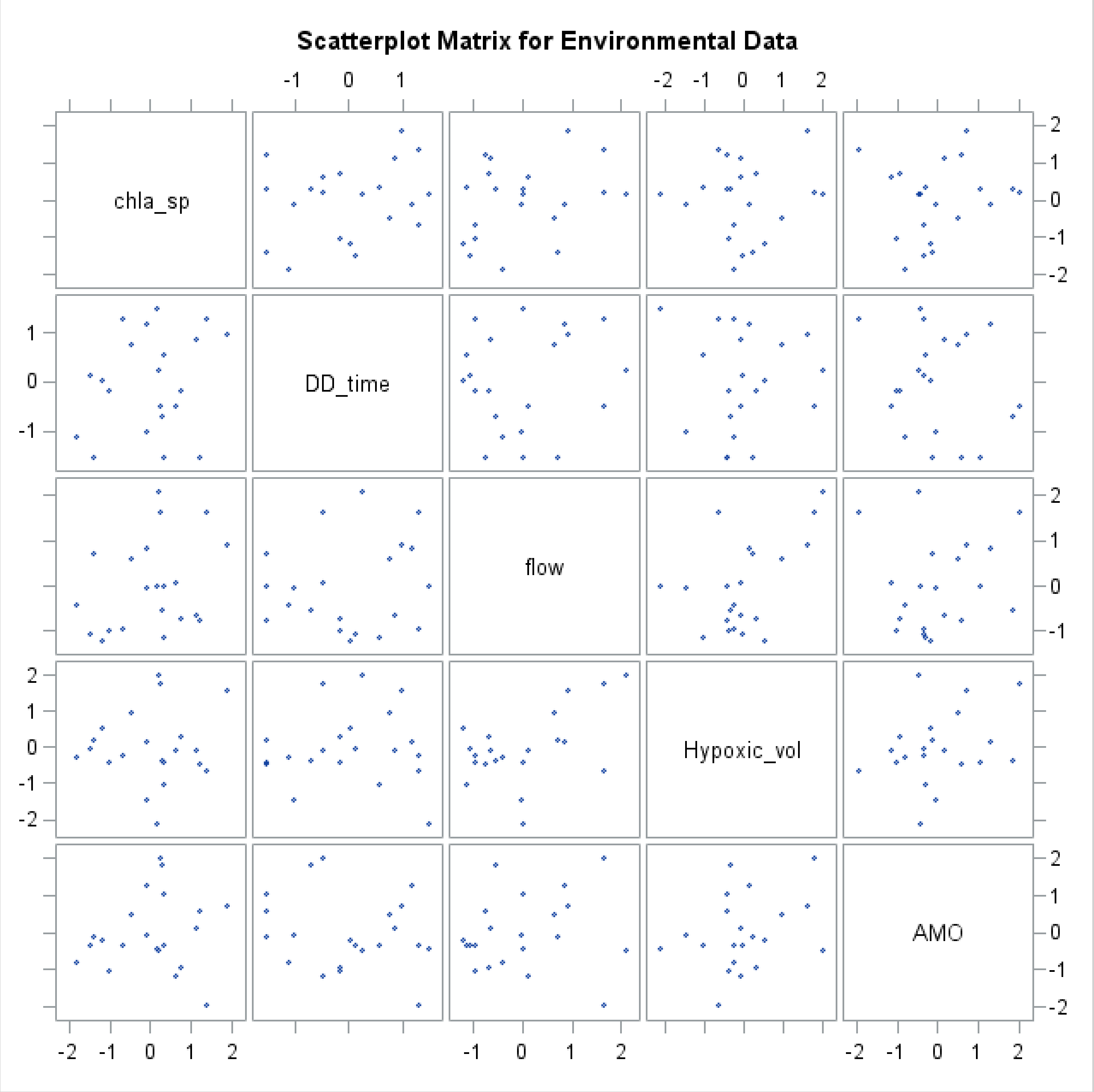
- Biomass-weighted coefficient of variation (CV_M*) assuming regional abundance is perfectly correlated

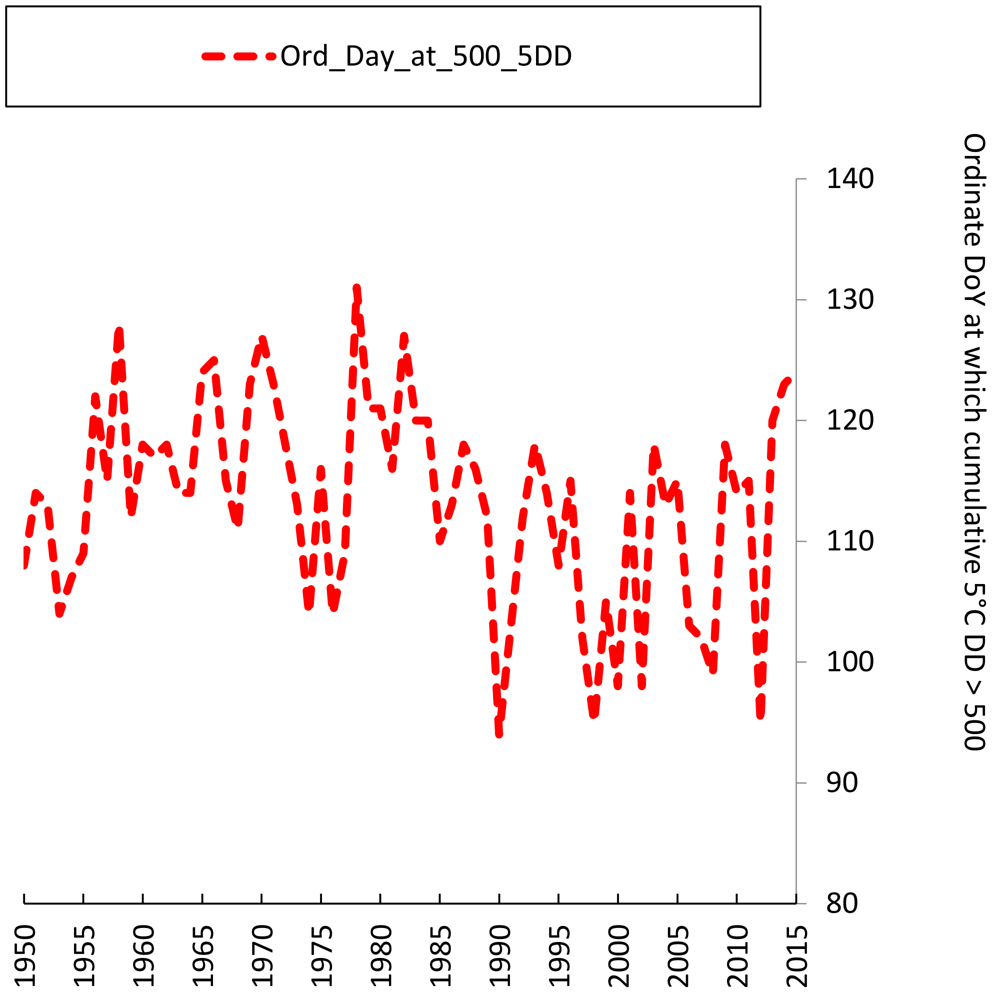
$$CV_{M*} = \sum_{C=1}^{C=k} \left(\frac{S_C}{S_M} CV_C \right)$$

- Observed CV across regions (CV_M)
- PE – extent of variance dampening

$$PE = 1 - \left(\frac{CV_M}{CV_{M*}} \right)$$

Kerr et al. 2009


Scatterplot Matrix for Environmental Data
chla_sp
DD_time
flow
Hypoxic_vol
AMO


Ord_Day_at_500_5DD
Ordinate DoY at which cumulative 5°C DD > 500