The Baby Food Chronicles: Analysis of early-stage fish feeding ecology over three decades in the Hudson River

Eric T. Schultz

Michael G. Smircich

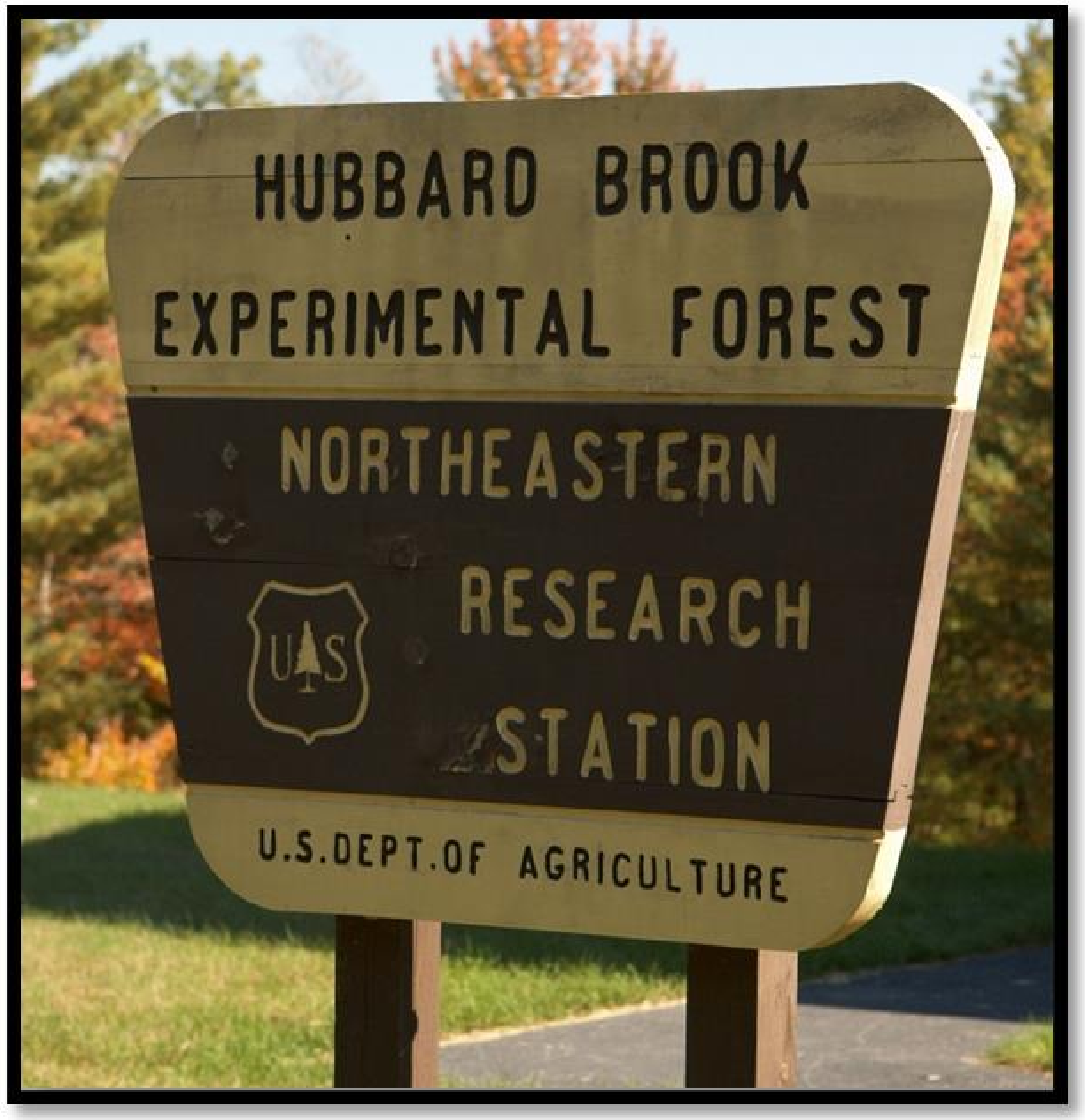
David L. Strayer

Department of Ecology and Evolutionary Biology, University of Connecticut

Cary Institute of Ecosystem Studies

Long-term ecological studies facilitate

monitoring responses to environmental change;
identifying unsuspected trends;
managing species or ecosystems;
collaborative studies.



Estuaries are dynamic ecosystems that

span extreme environmental gradients;

are among the most productive natural habitats;

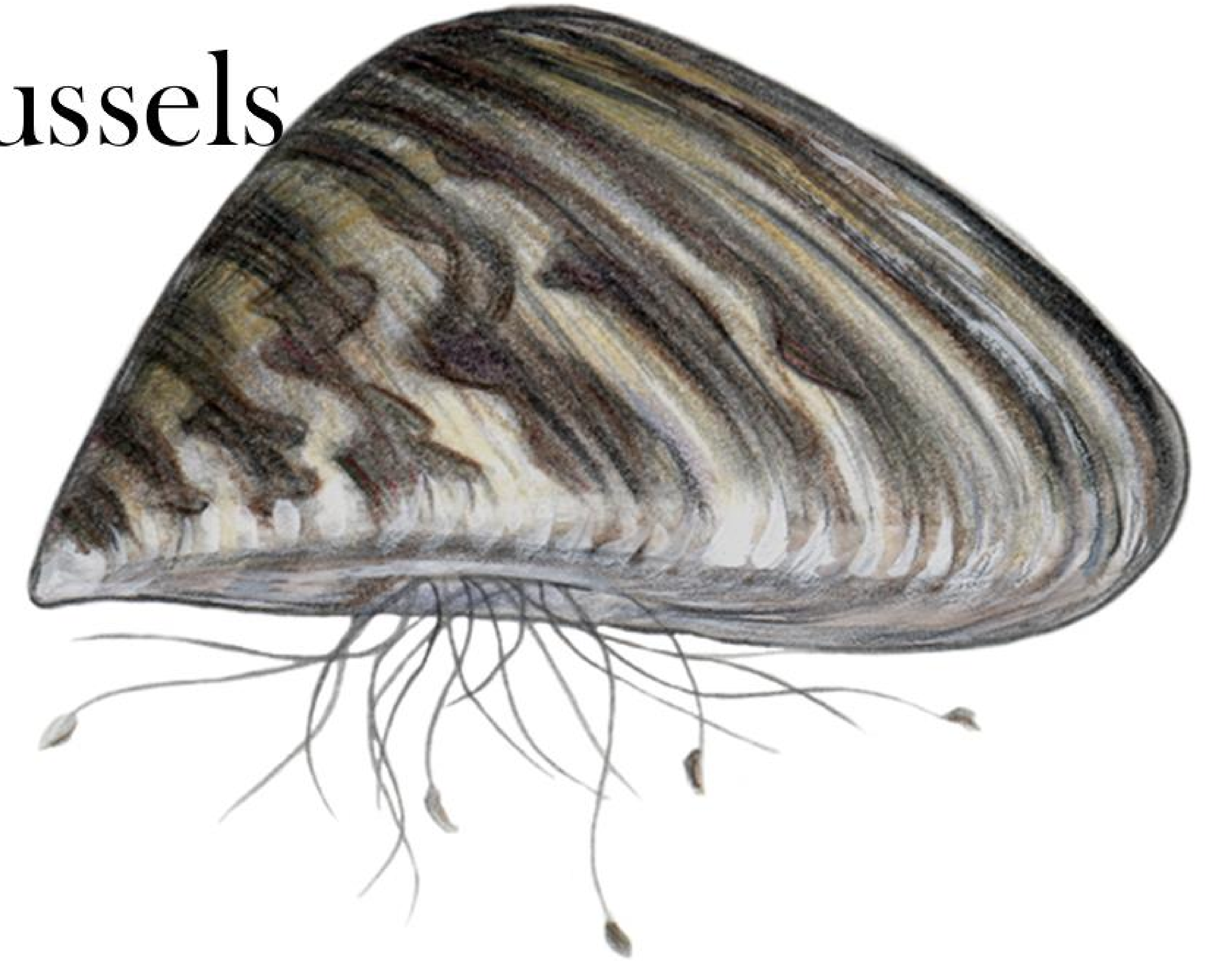
are highly vulnerable to anthropogenic impacts such as invasive species.

http://geowiki.ucdavis.edu/

Many come, few stay

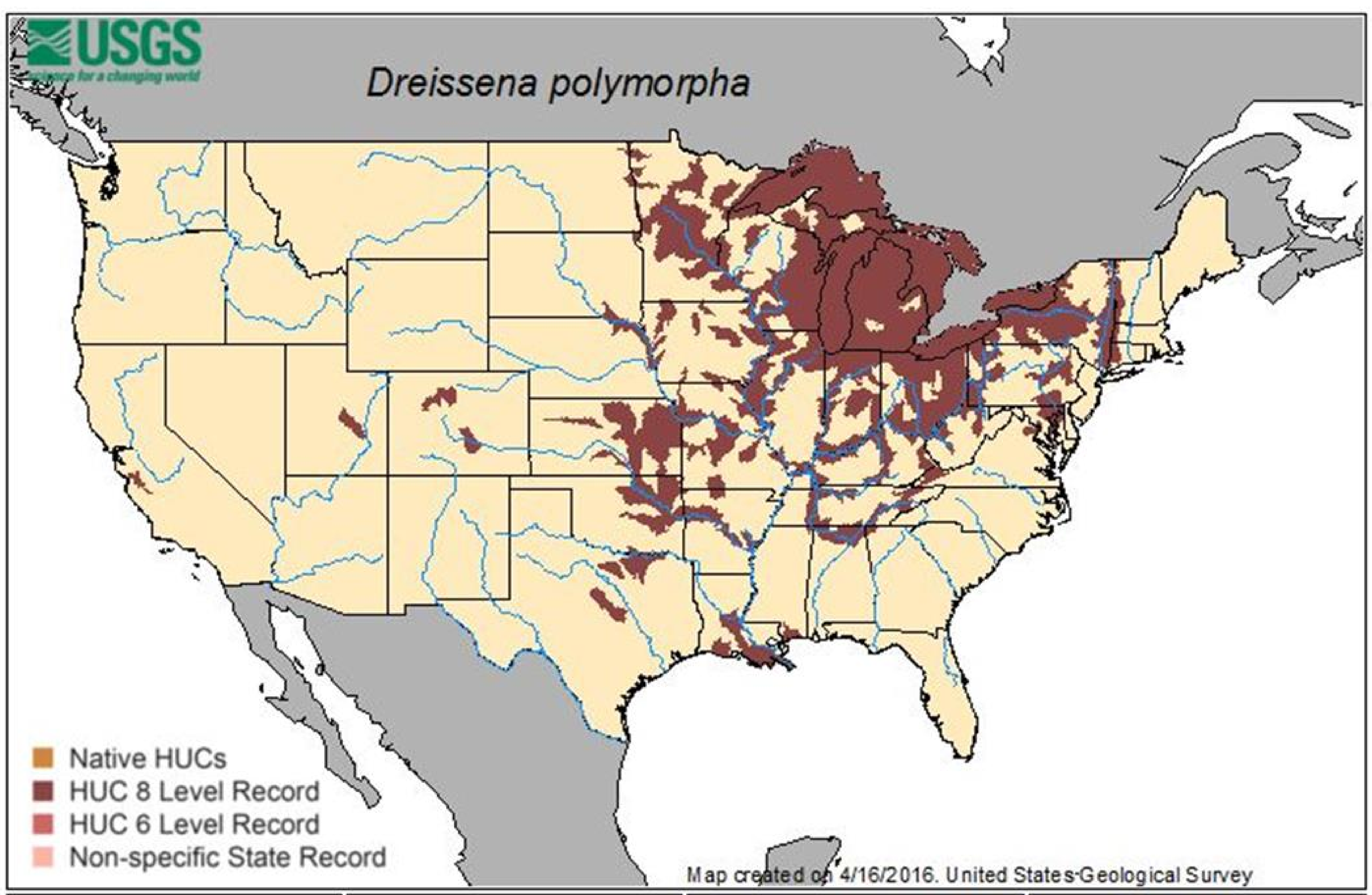
- The estuarine fish fauna is diverse
  - It includes diadromous, freshwater, and marine seasonal migrants
- Estuaries are nursery habitat where larval fish first feed and year-class strength is determined

Zebra Mussels

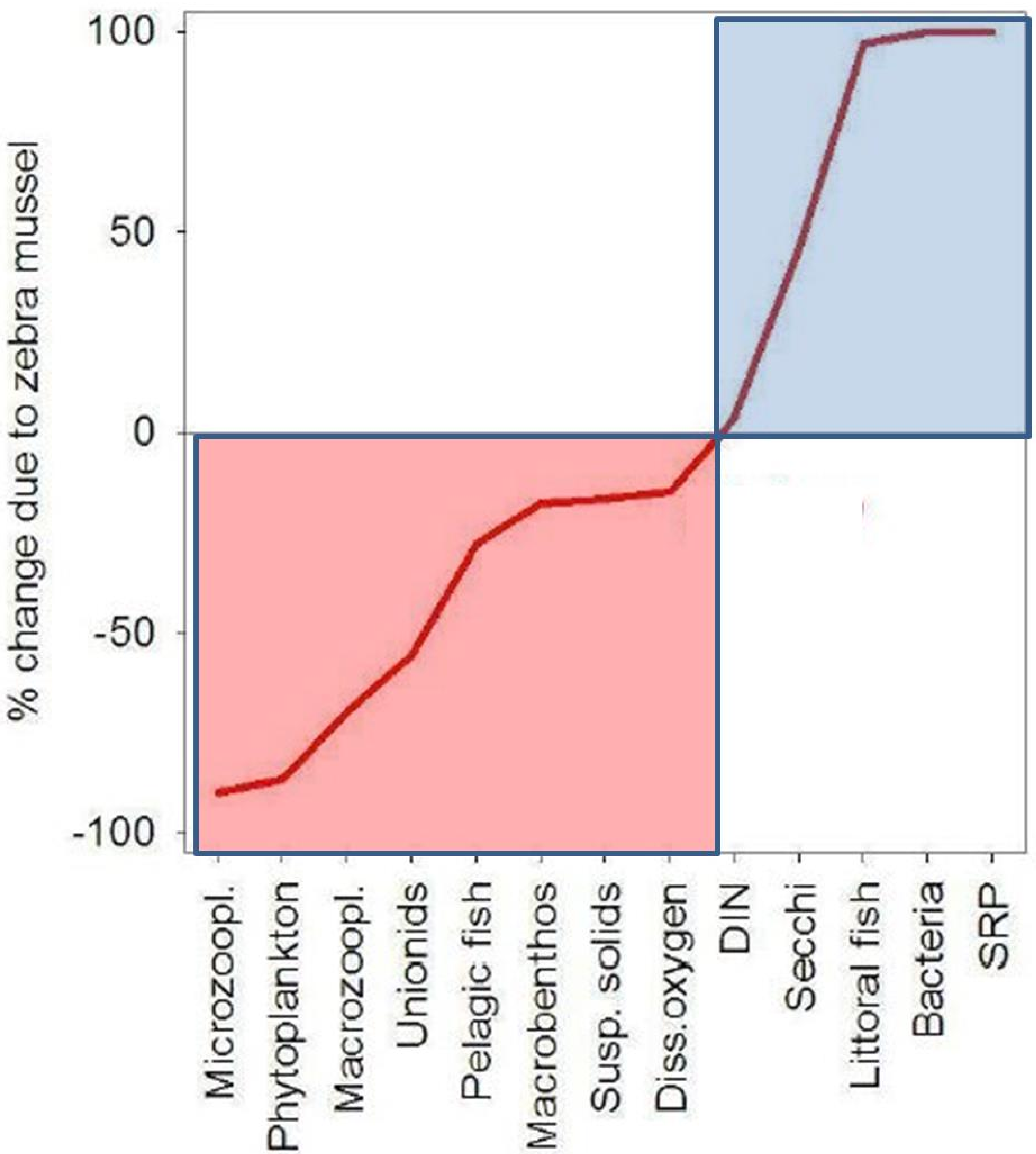


Gina Mikel, http://www.scientificillustrator.com

J. Lubner, Wisconsin Sea Grant



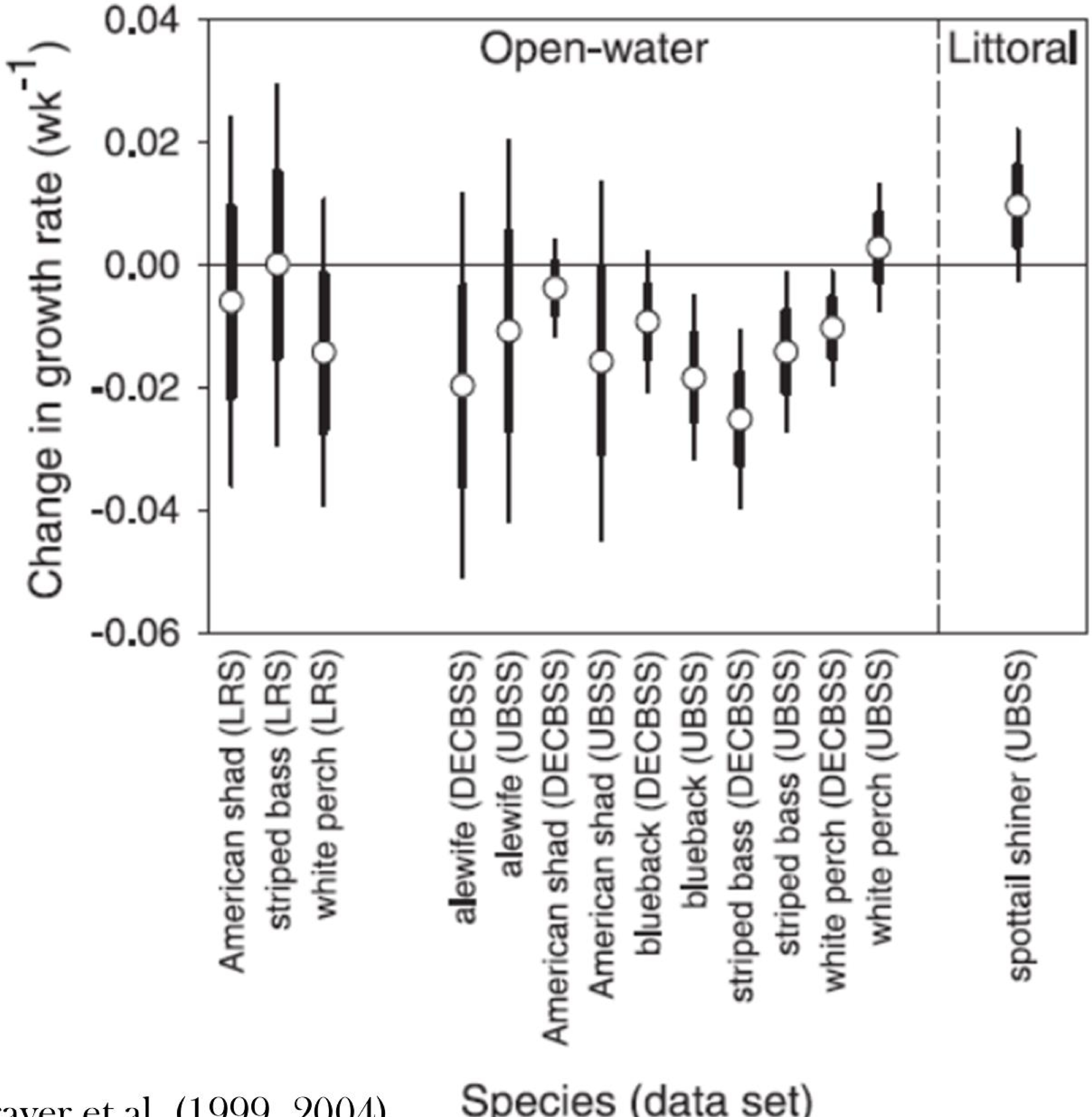
Zebra mussels in the Hudson



Littoral fish +97%
Water clarity +45%
Submersed plants +38%
Littoral zoobenthos +20%
Pelagic fish -28%
Zooplankton -71%
Native bivalves -72%
Phytoplankton - 80%

modified from Strayer et al. (1999, 2004) and Caraco et al. (2000)

Zebra mussels in the Hudson



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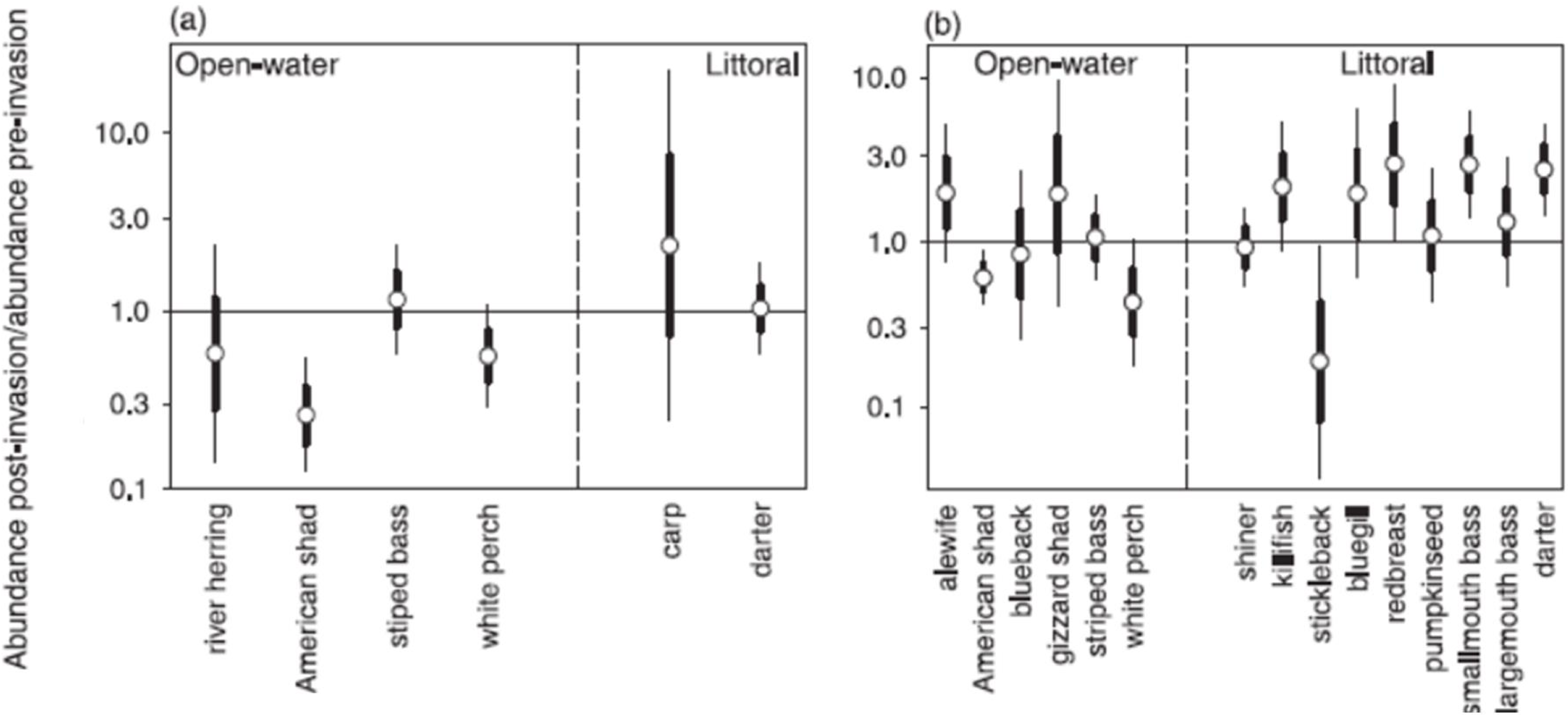

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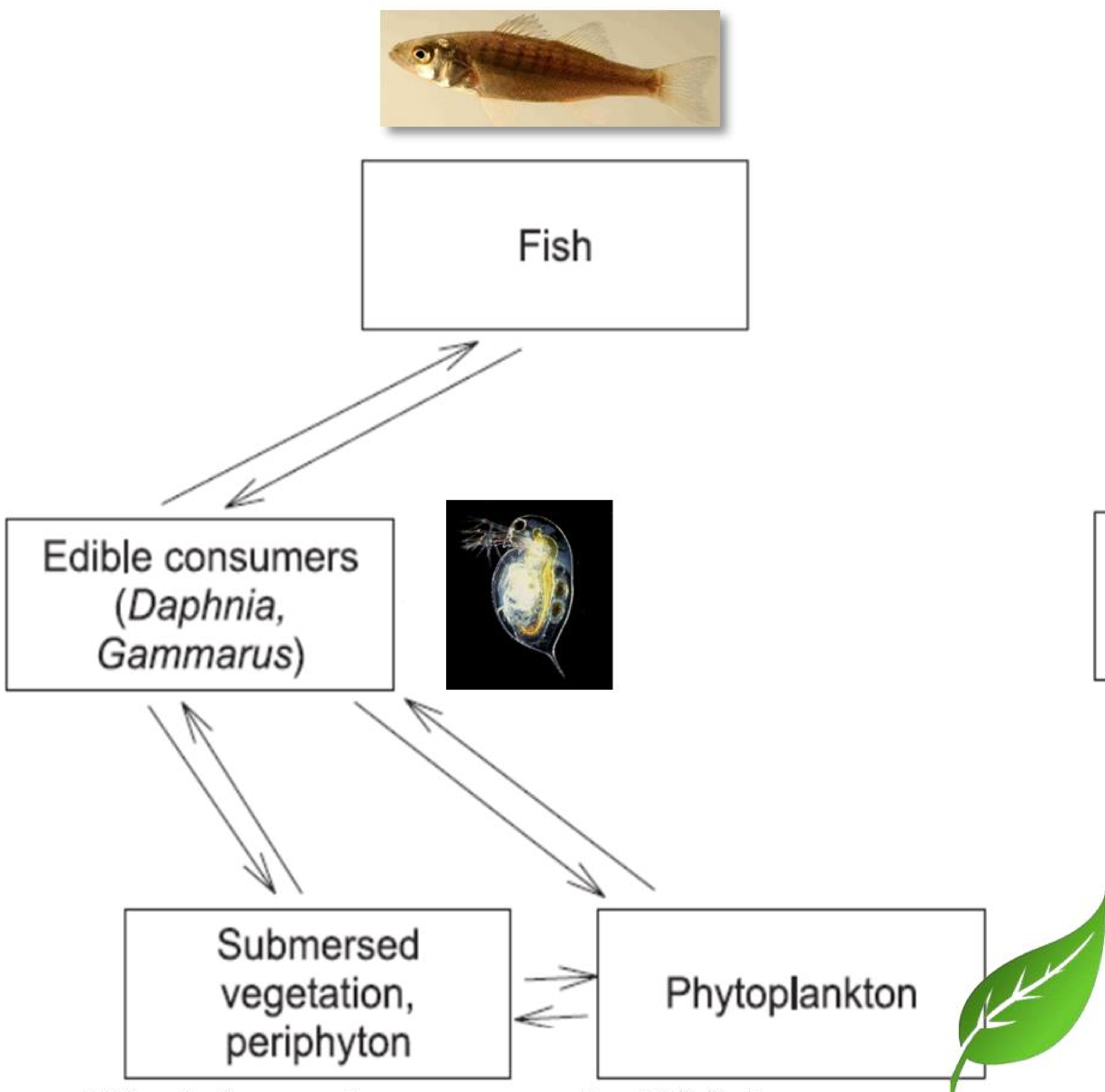
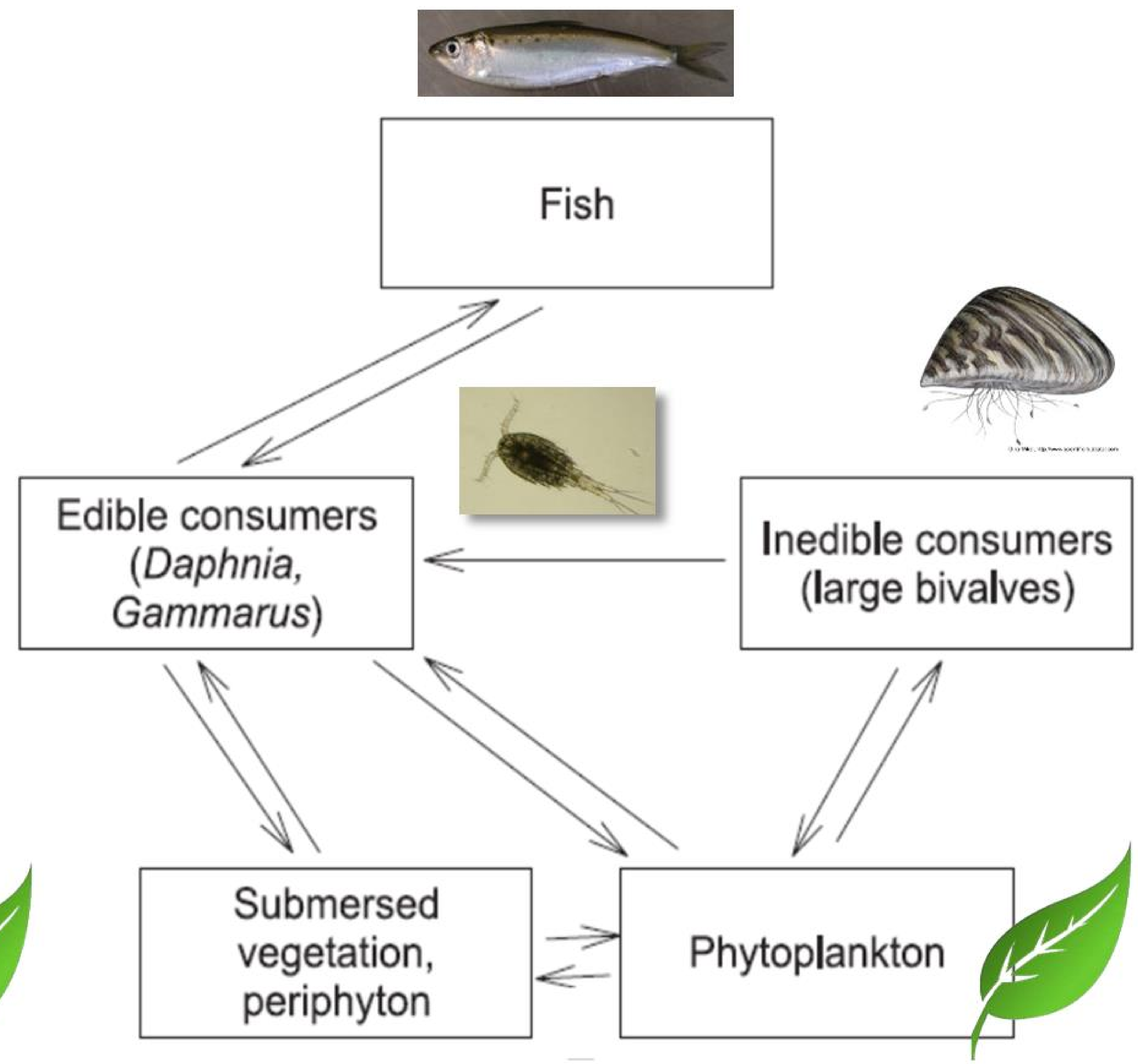
Zebra mussels in the Hudson





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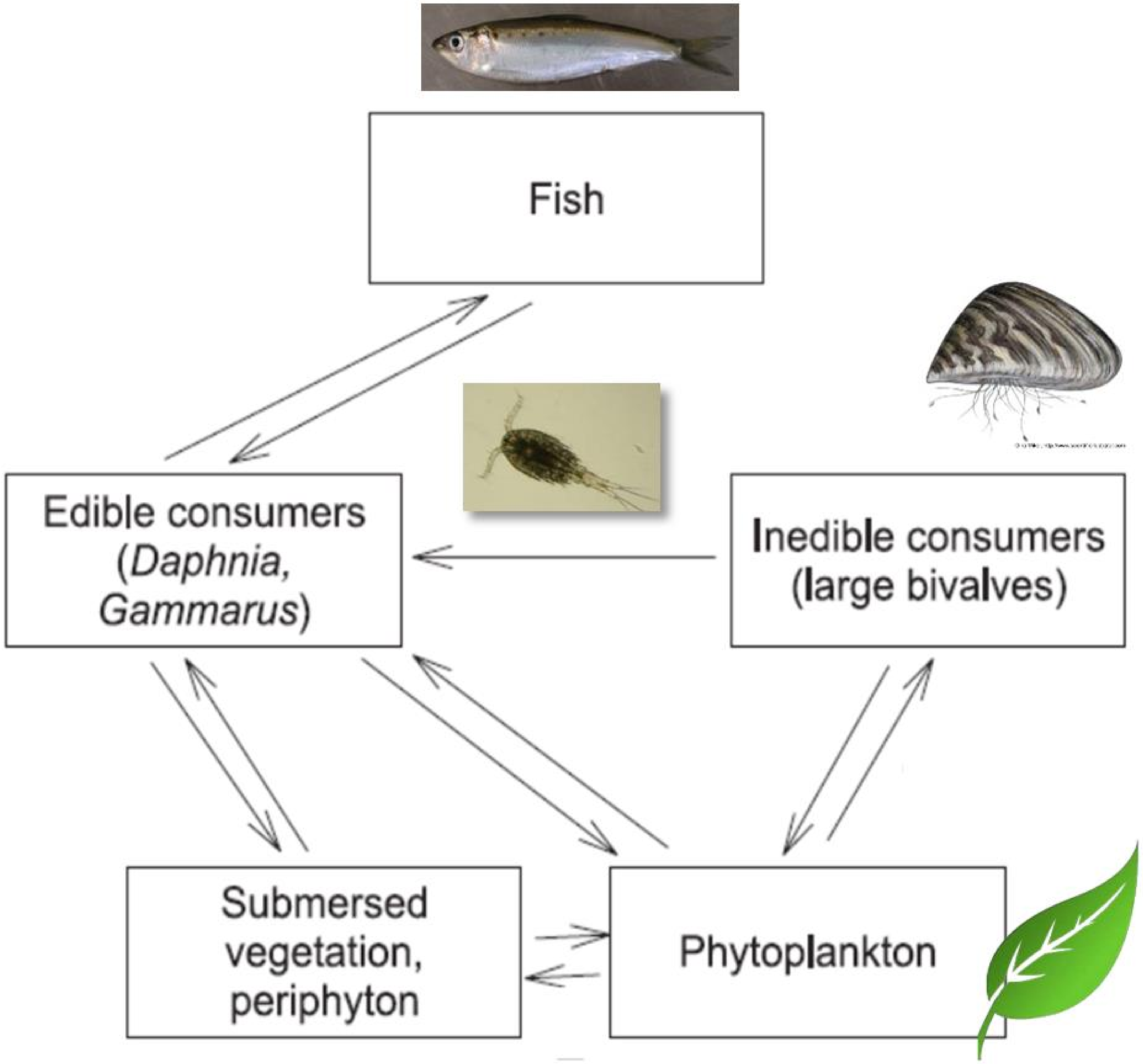
Zebra mussels in the Hudson



Temperature
Dissolved oxygen
Discharge/flow
Salinity
Chlorophyll
Prey abundance
Mussel abundance

Research objectives

1. Characterize early-stage fish diet composition and feeding success over a multi-decade time span

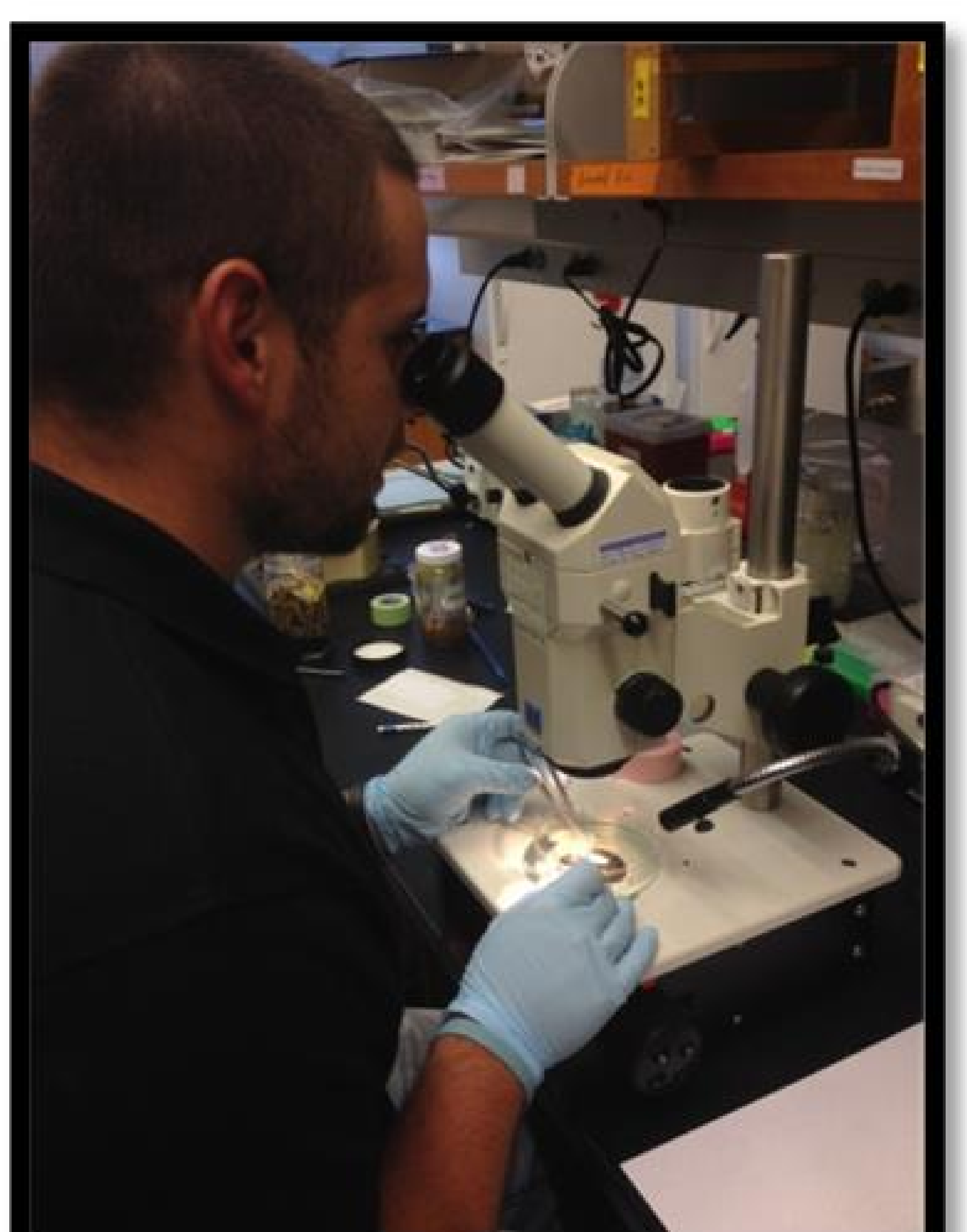
2. Test what effects zebra mussels have had on the feeding ecology of early-stage fish

3. Determine what ecological factors most influence feeding success

Larval Fish Samples

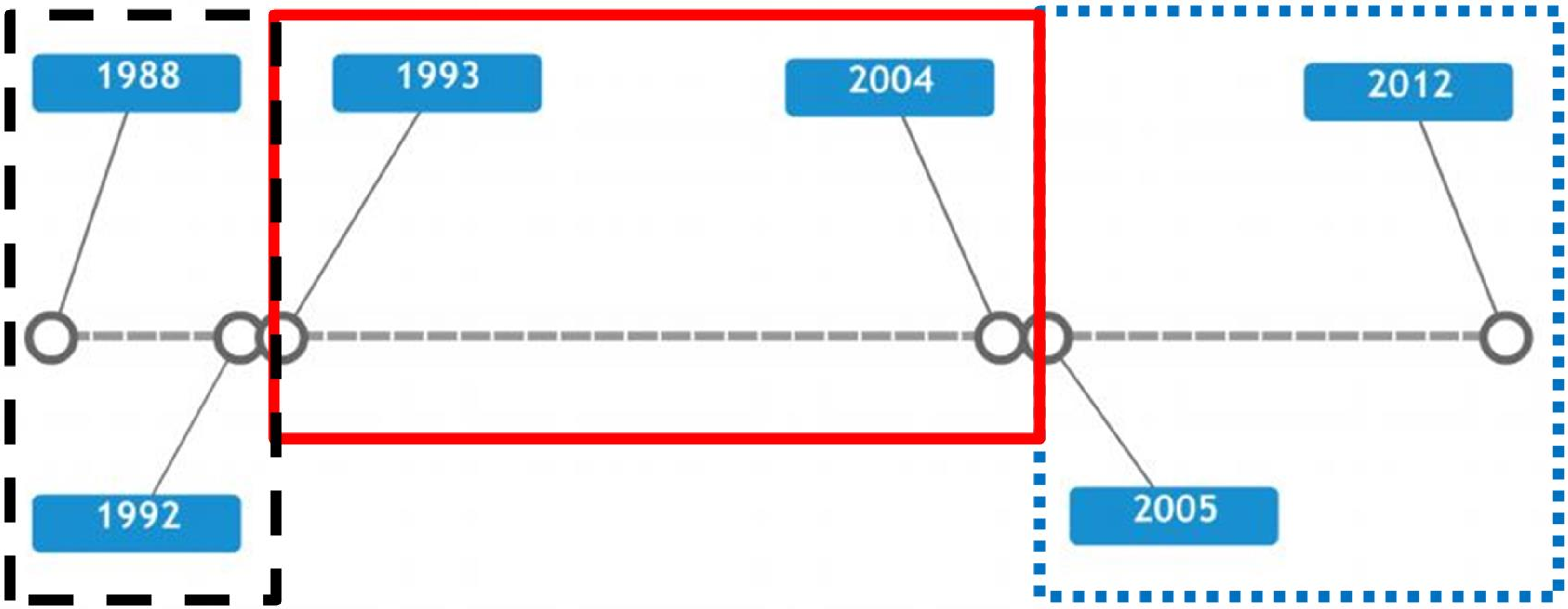
Hudson River Utilities Long River Survey

Normandeau Associates/New York State Museum
(samples taken at night throughout the summer)



University of Connecticut

Sampling design



Analyzed Years:

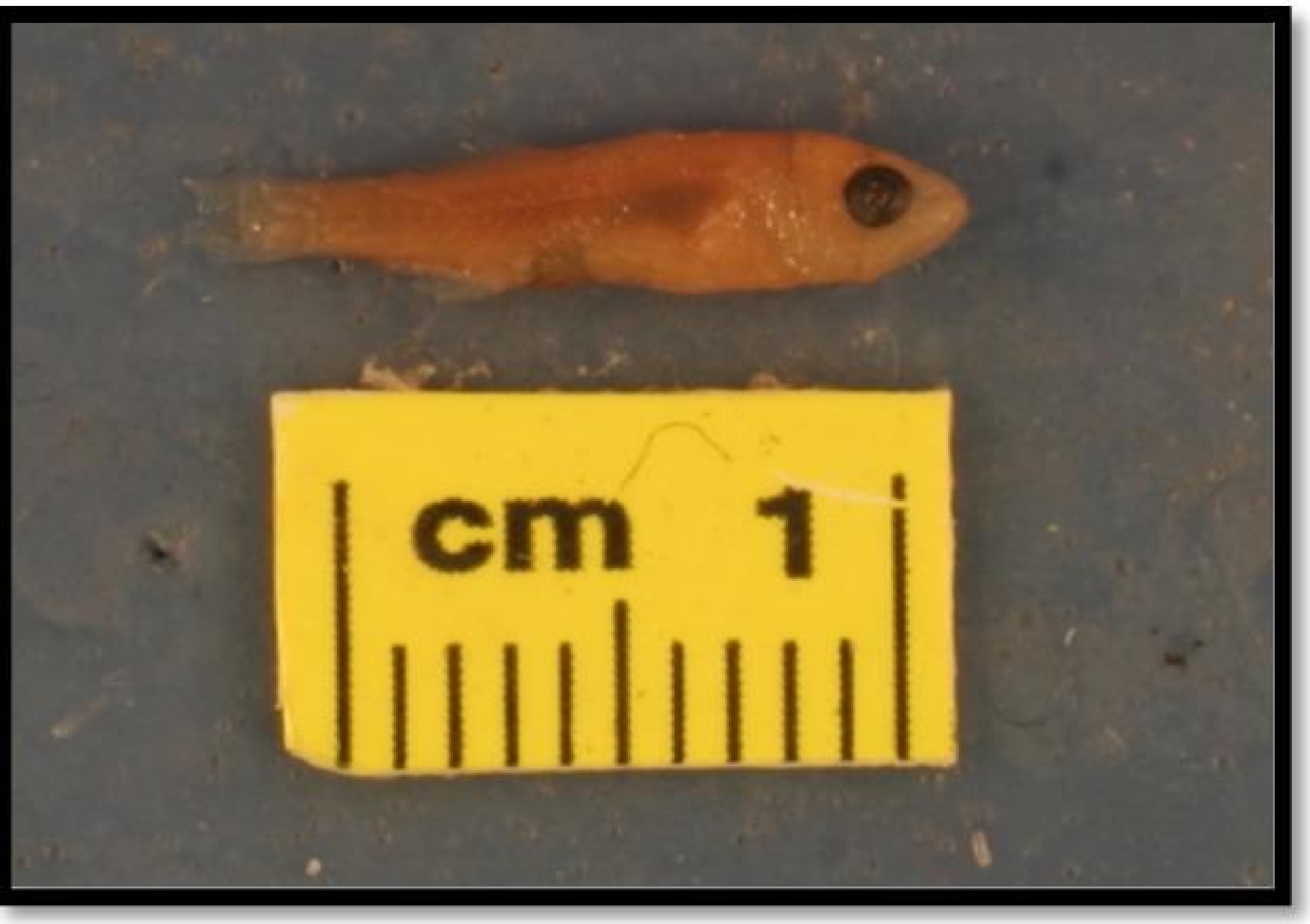
1988	1993	2005
1991	1994	2006
1992	1997	2007
	1999	2009
	2003	2010
		2011
		2012

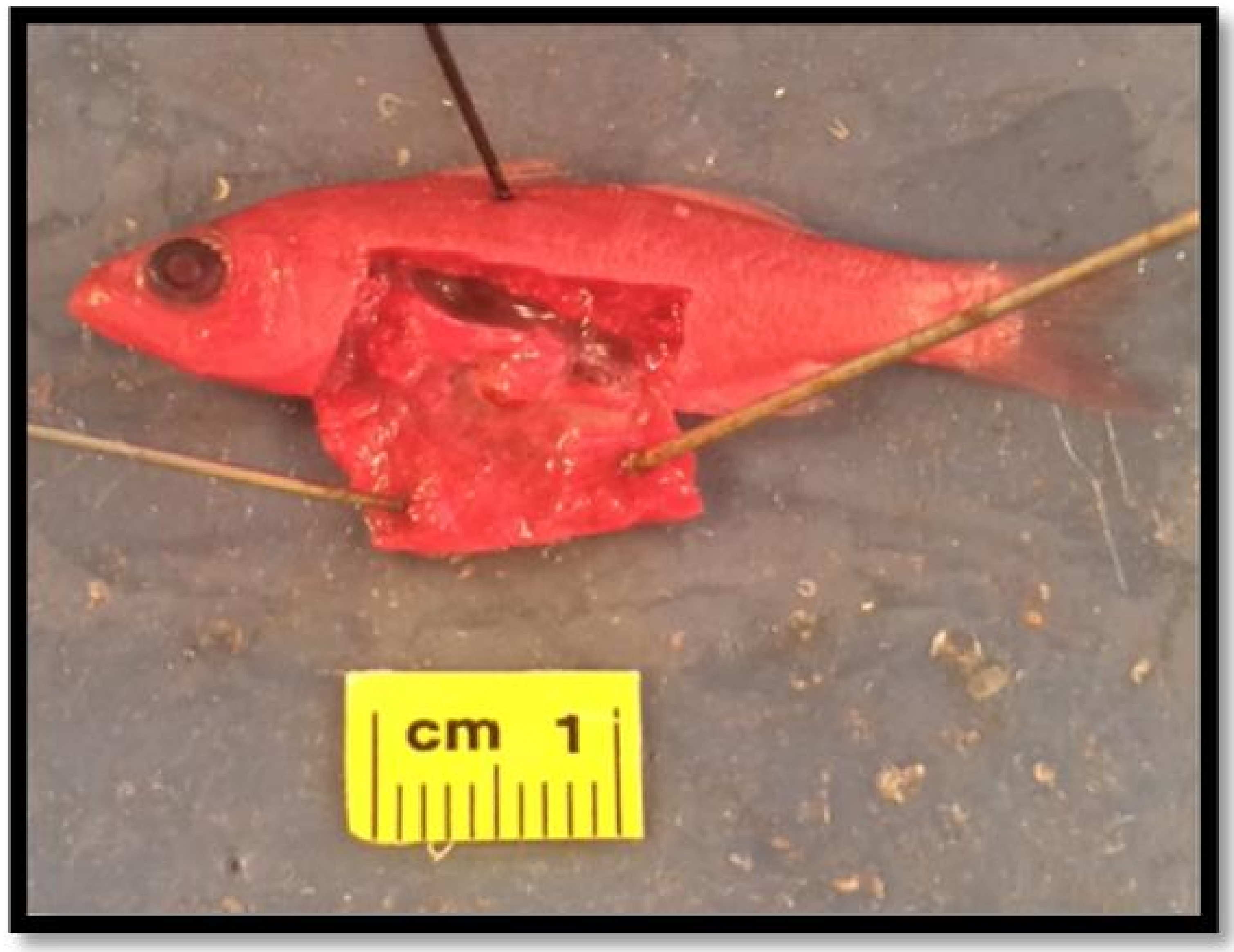
1) Pre-Invasion ('88 -'92)
2) Impact ('93 –'04)
3) Recovery ('05- Present)

Sampling design

usgs.gov

Characterizing diet composition





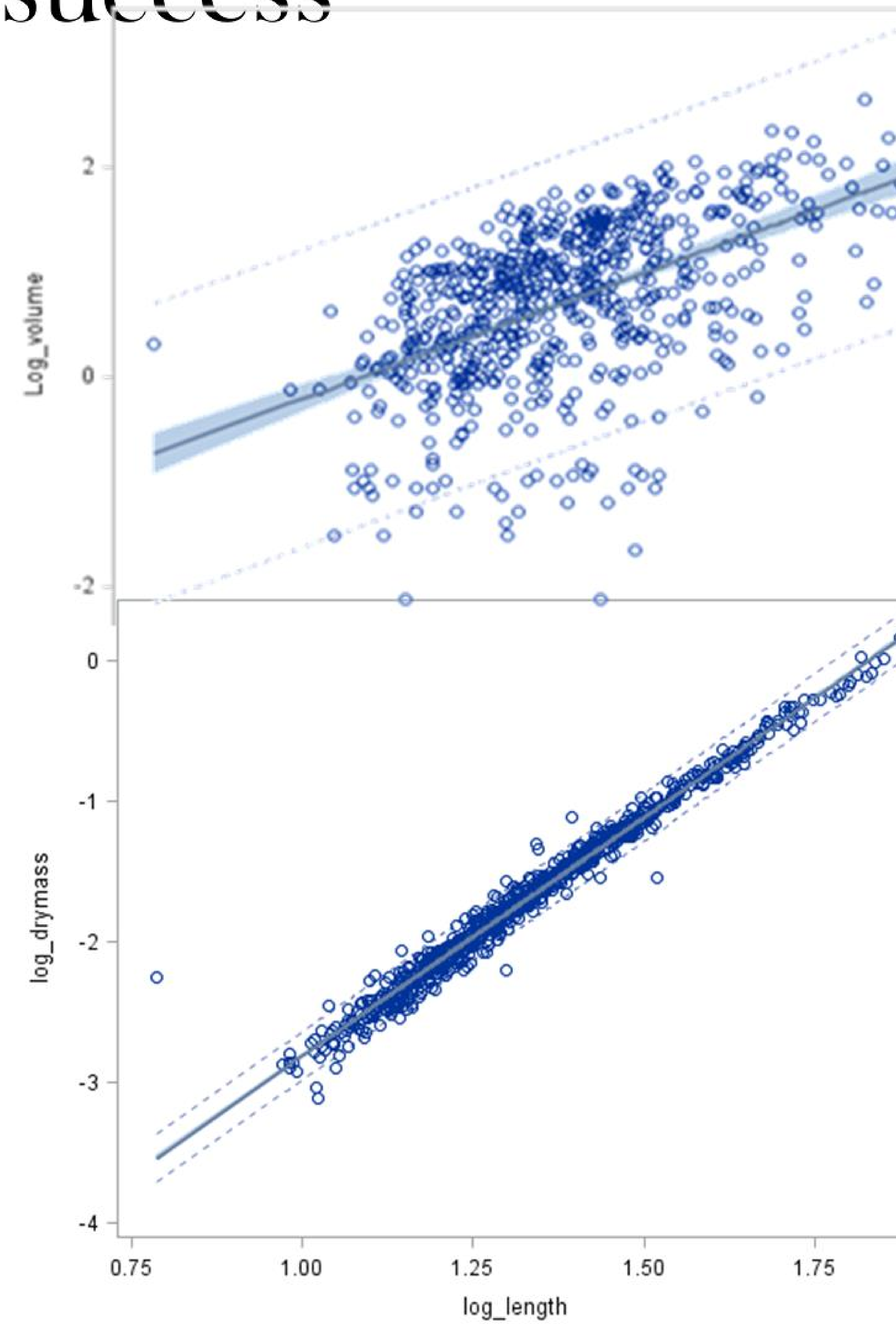
Prey-specific index of relative importance

$$\%PSIRI_i = \frac{pFO_i * (pPN_i + pPW_i) * 100}{2}$$

$$pFO_i = \frac{n_i}{n}$$

$$pPN_i = \sum_{j=1}^{n} pN_{ij}/n_i, pPW_i = \sum_{j=1}^{n} pW_{ij}/n_i$$

Estimating feeding success



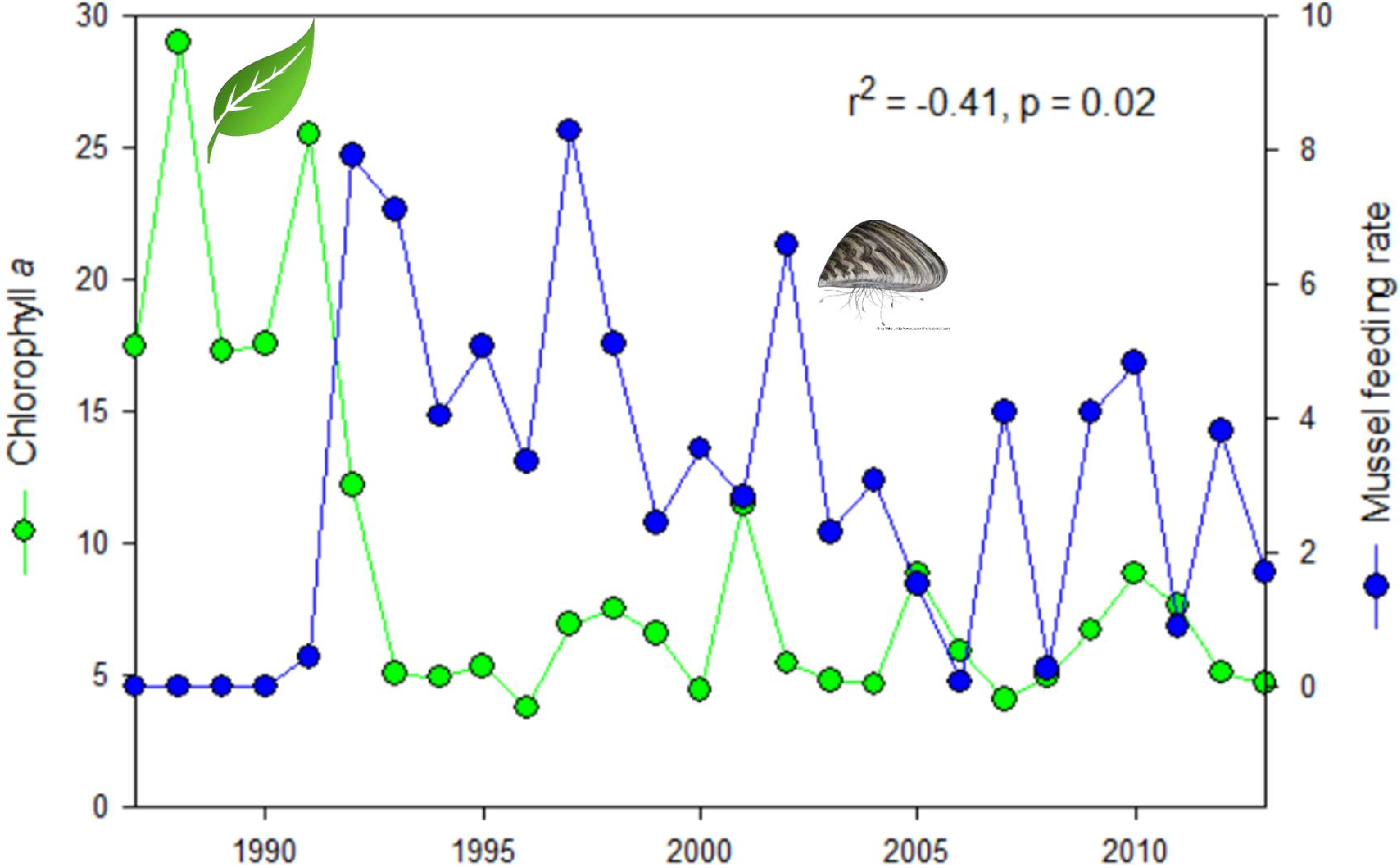
Short term: volume of gut contents at length

Long term: dry weight at length

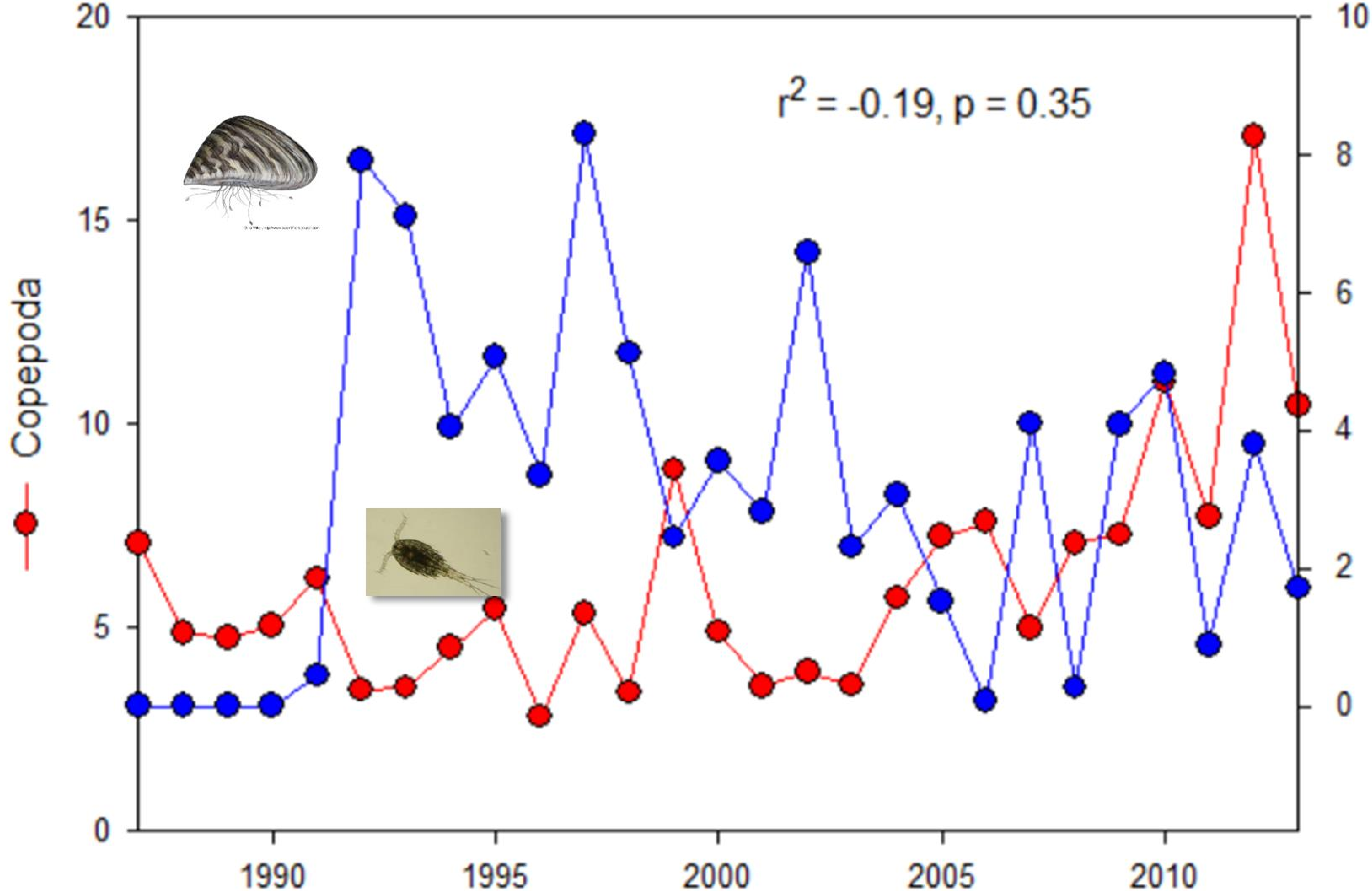
Influences on feeding success

Environmental variable	Source	Incorporated as
<u>Abiotic</u>		
Dissolved Oxygen (mg l^{-1})	LRS	Date & location-specific value
River Discharge ($m^2 sec^{-1} d^{-1}$)	USGS	Weekly mean at Green Island
Salinity (ppt)	LRS	Date & location-specific value
Temperature (°C)	LRS	Date & location-specific value
<u>Biotic</u>		
Amphipods (m^{-2})	Cary IES	Annual mean at Kingston
Chlorophyll *a* (µg l^{-1})	Cary IES	Annual mean at Kingston
Copepods (l^{-1})	Cary IES	Annual mean at Kingston
Mussel filtration ($m^3 m^{-2} d^{-1}$)	Cary IES	Annual mean at Kingston

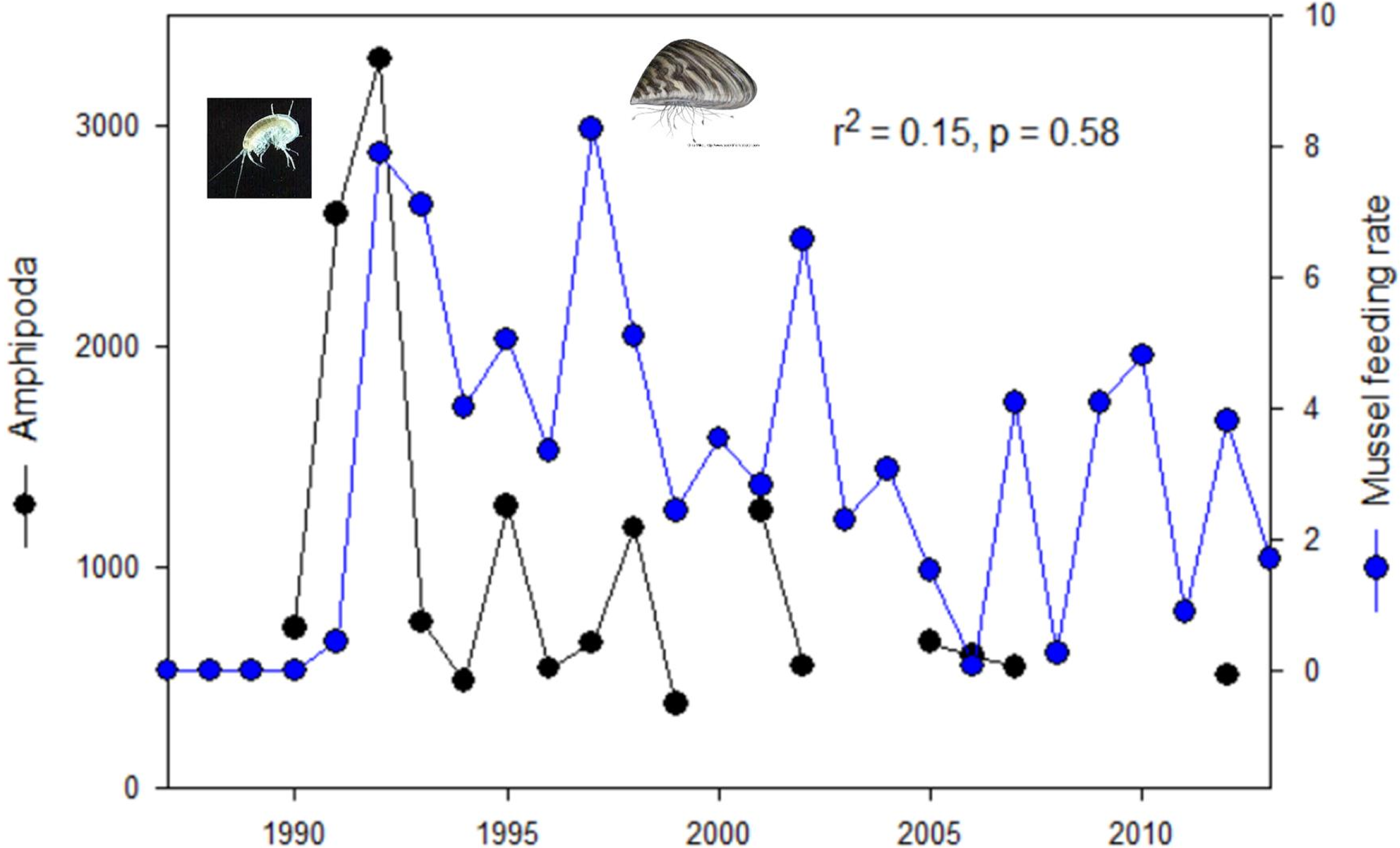
Zebra mussels reduce phytoplankton…



....but not copepods...



....or amphipods



Objectives 1 & 2: diet composition

Prediction:

Diet composition will shift to benthic prey during years of mussel impact, especially upriver

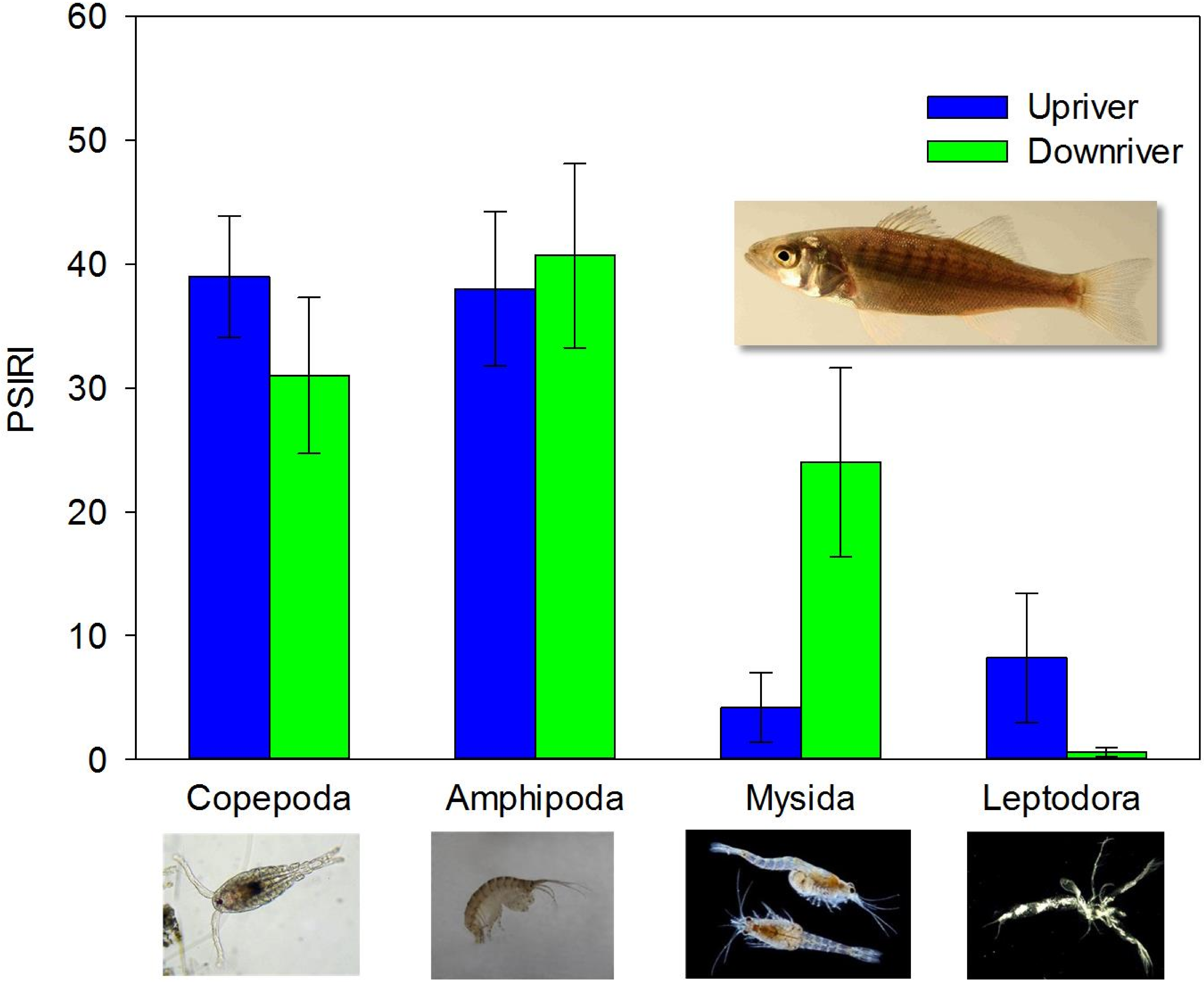
Methods:

30 per location (Upriver / Downriver) per year

Gut contents identified to the lowest possible taxon

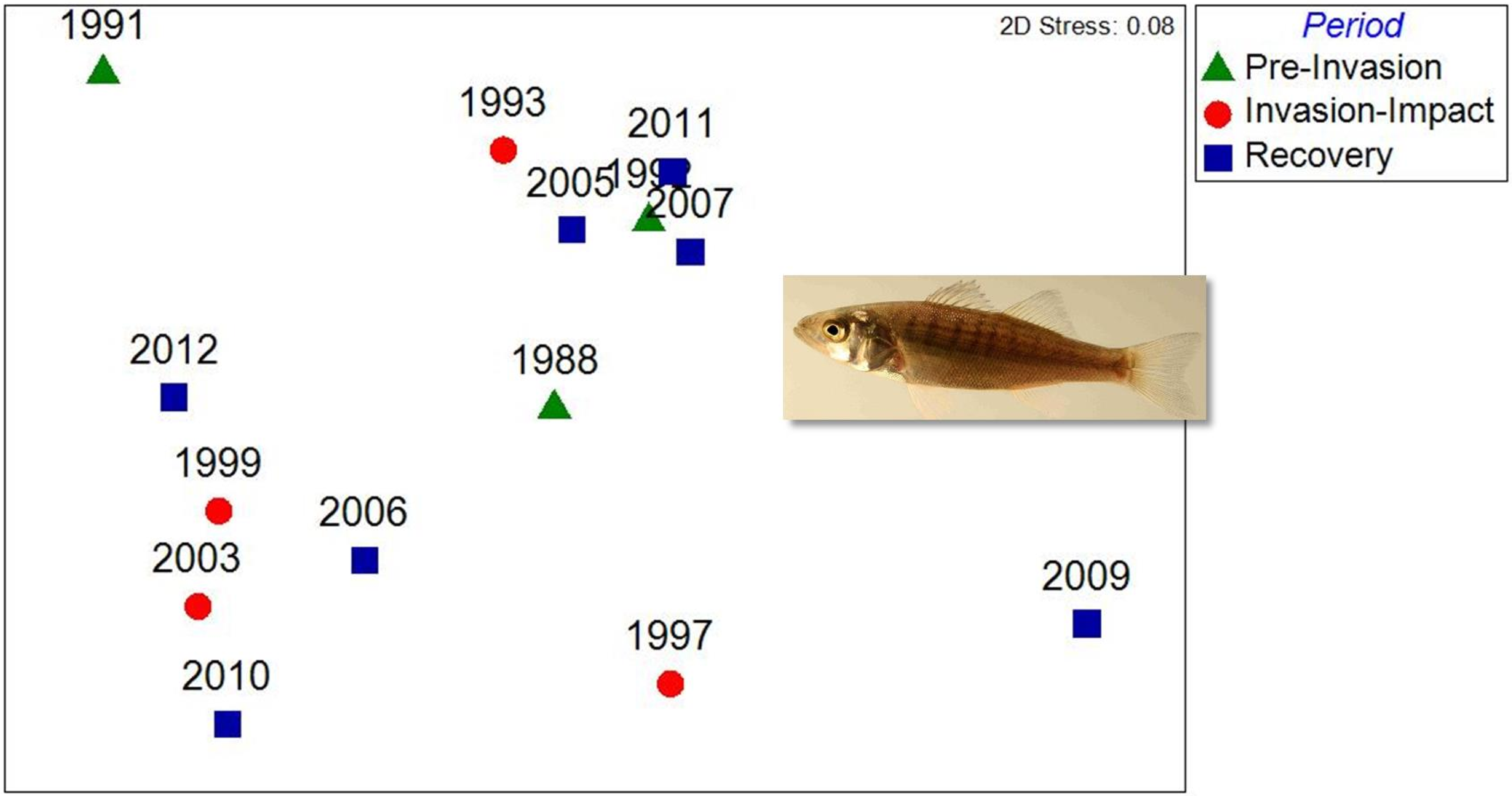
Prey-Specific Index of Relative Importance (PSIRI)

Diet composition is similar upriver & downriver



Diet composition differs among years, but not invasion periods

ANOSIM, global R=0.27, effect of year p=0.001



modified from Smircich et al. (Accepted)

Objectives 1 & 2: feeding success

Prediction:

feeding success will be low when zebra mussel feeding is high, especially upriver

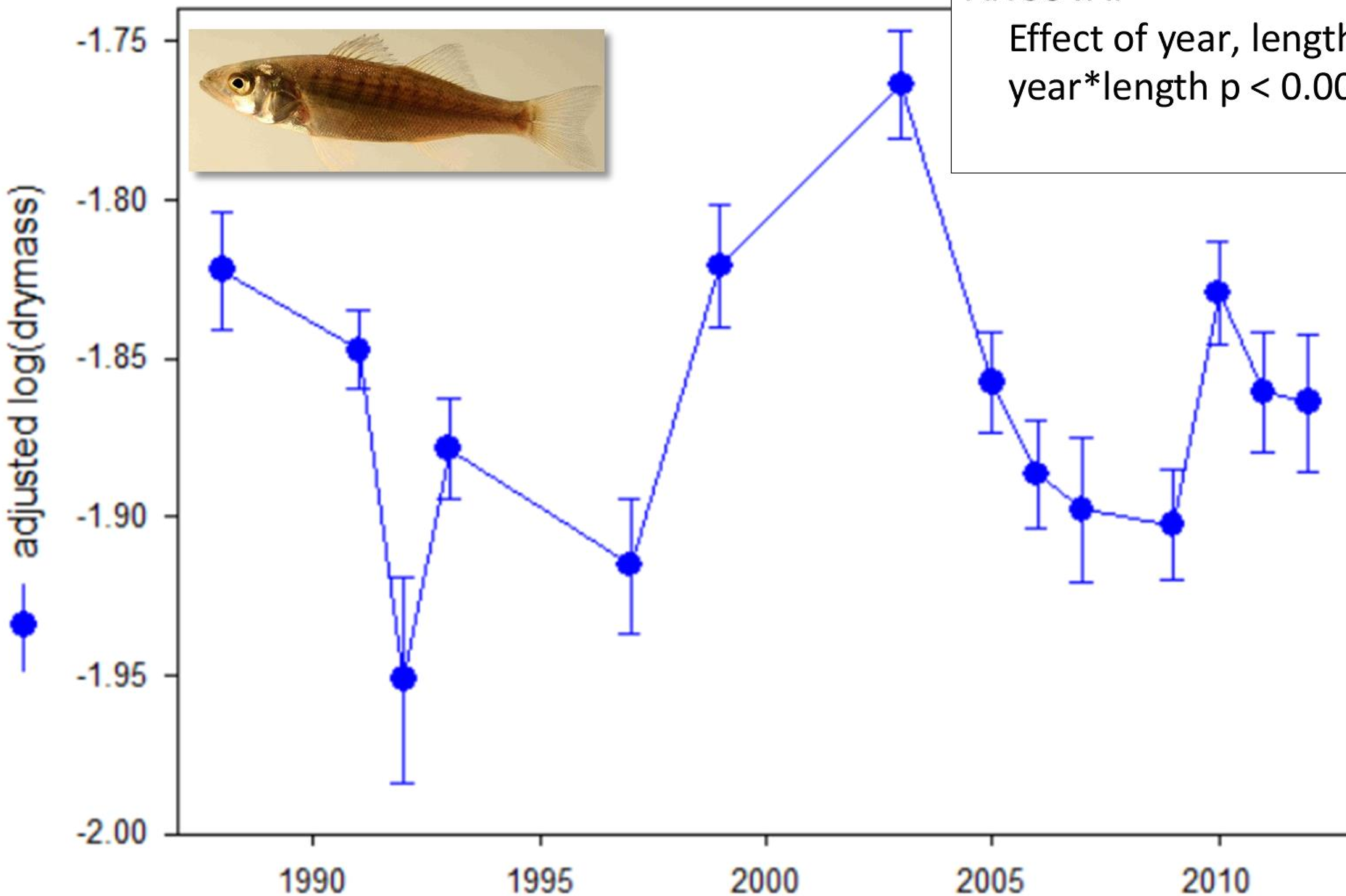
Methods:

Volume of gut contents is measure of short-term feeding success

Condition is measure of long-term feeding success

Long-term feeding success

Condition varies among years both upriver and downriver



ANCOVA:

Effect of year, length, year*length $p < 0.0001$

Objective 3: influences on feeding success

Methods:

AIC selection of mixed-effects models with

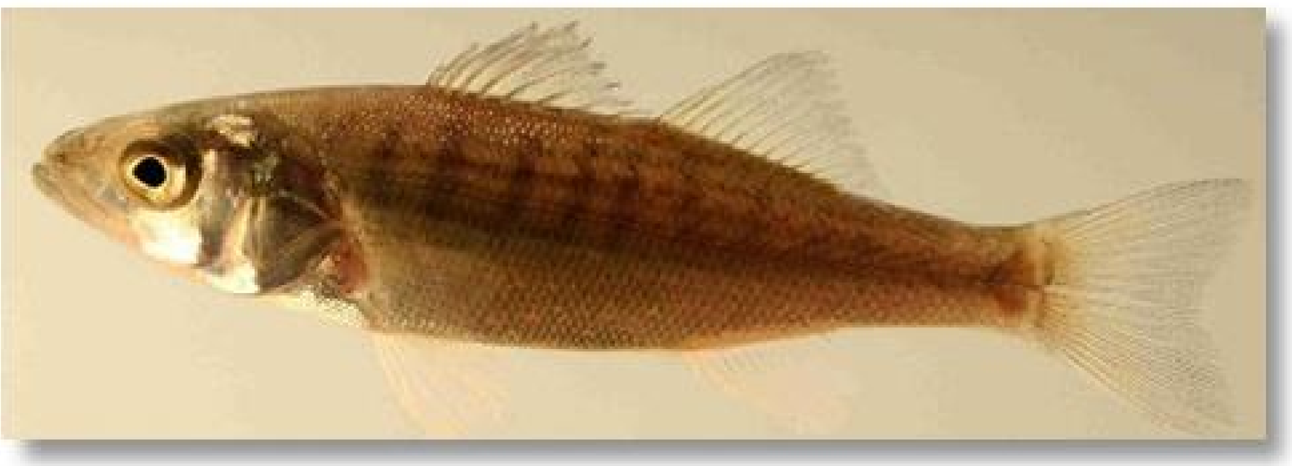
Dissolved Oxygen	Amphipod density
Salinity	Chlorophyll *a*
Temperature	Copepod density
	Zebra mussel filtration rate

Effect size of selected variables

predict condition at relatively low (5^{th} %ile) and high (95^{th} %ile) levels of predictors

Influences on feeding success

Upriver					Downriver				
Model	Predictors	AIC	ΔAIC	Wt	Model	Predictors	AIC	ΔAIC	Wt
1	Sal, ZMFR	-720.4	0	0.0440	1	Cop, DO, DO^2, ZMFR	-1059	0	0.288
2	DO, Sal, ZMFR	-720.3	0.100	0.0419	2	Chl, Cop, DO, DO^2, ZMFR	-1057	1.80	0.117
3	Cop, DO, Sal, ZMFR	-719.3	1.100	0.0254	3	Cop, DO, DO^2	-1057	1.80	0.117
4	Sal, $Temp^2$, ZMFR	-718.9	1.500	0.0208	4	Cop, DO, ZMFR	-1056	2.80	0.0710
5	Cop, Sal, ZMFR	-718.9	1.500	0.0208	5	Chl, Cop, DO, DO^2	-1054.8	3.80	0.0431



Upriver

+salinity, −mussel filtration rate

Mass at length was 33% higher (0.017 vs 0.013 g) at high salinity and low mussel filtration rate

Downriver

+copepods, −DO

Mass at length was 35% higher (0.035 vs 0.032 g) when copepods were high and DO was low

modified from Smircich et al. (Accepted)

Striped Bass conclusions

Copepods and amphipods were the most important prey

Diet composition varied among years, there was no evident effect of the zebra mussel invasion

Feeding success varied among years

Zebra mussel filtration rate influenced feeding success in the mussel zone (upriver), copepods influenced feeding success downriver

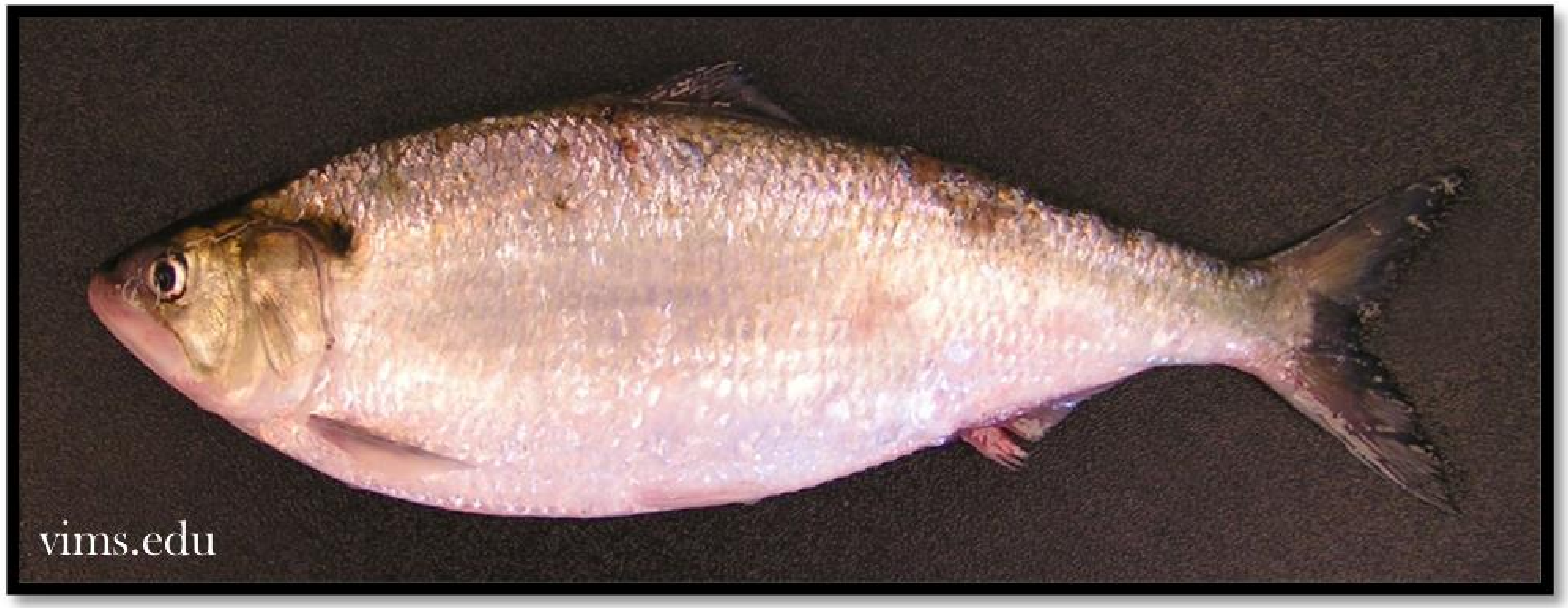
American Shad (*Alosa sapidissima*)

North America's largest herring

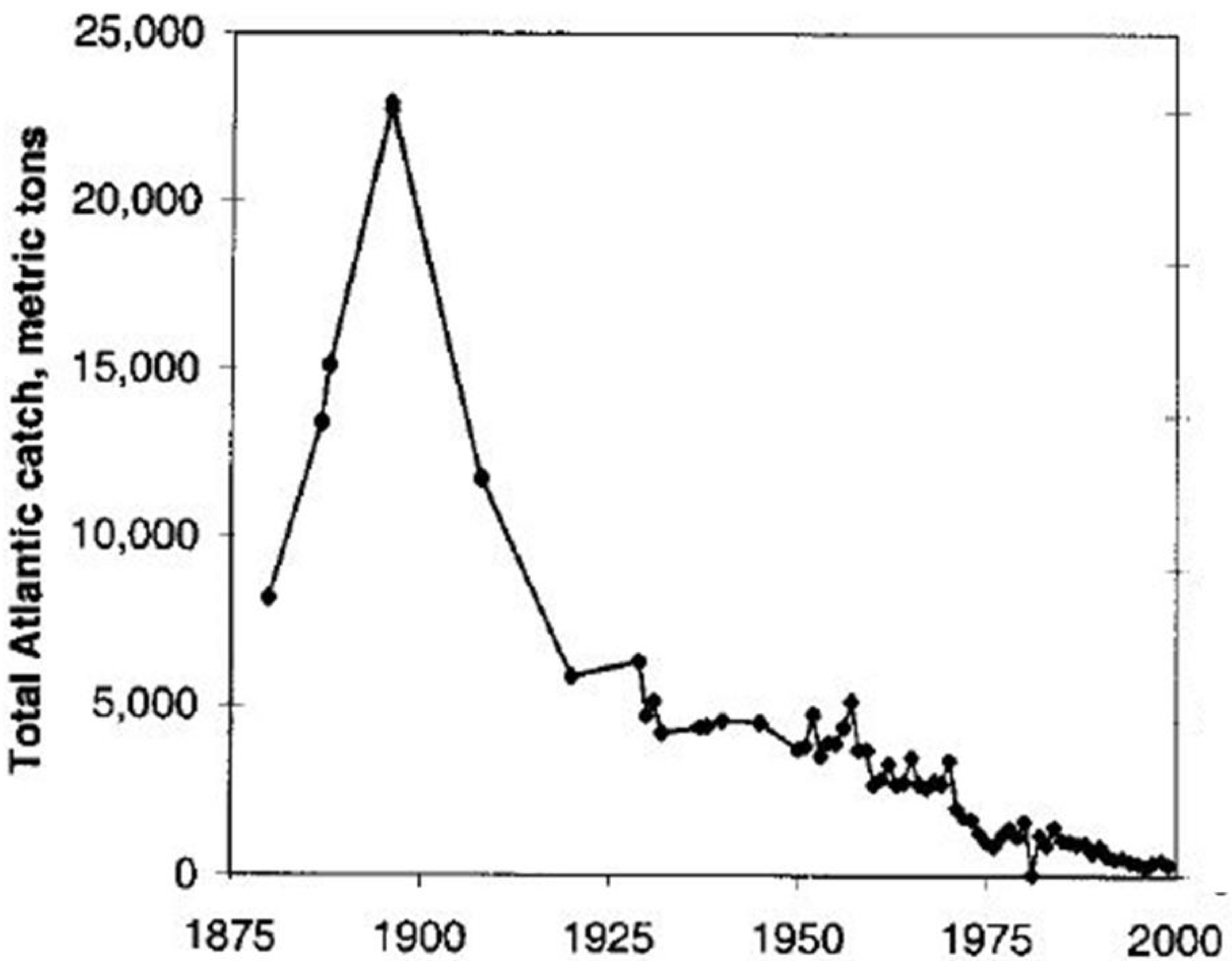
Grow to about 76 cm

Obligate anadromous fish

Native range from Florida to Canada

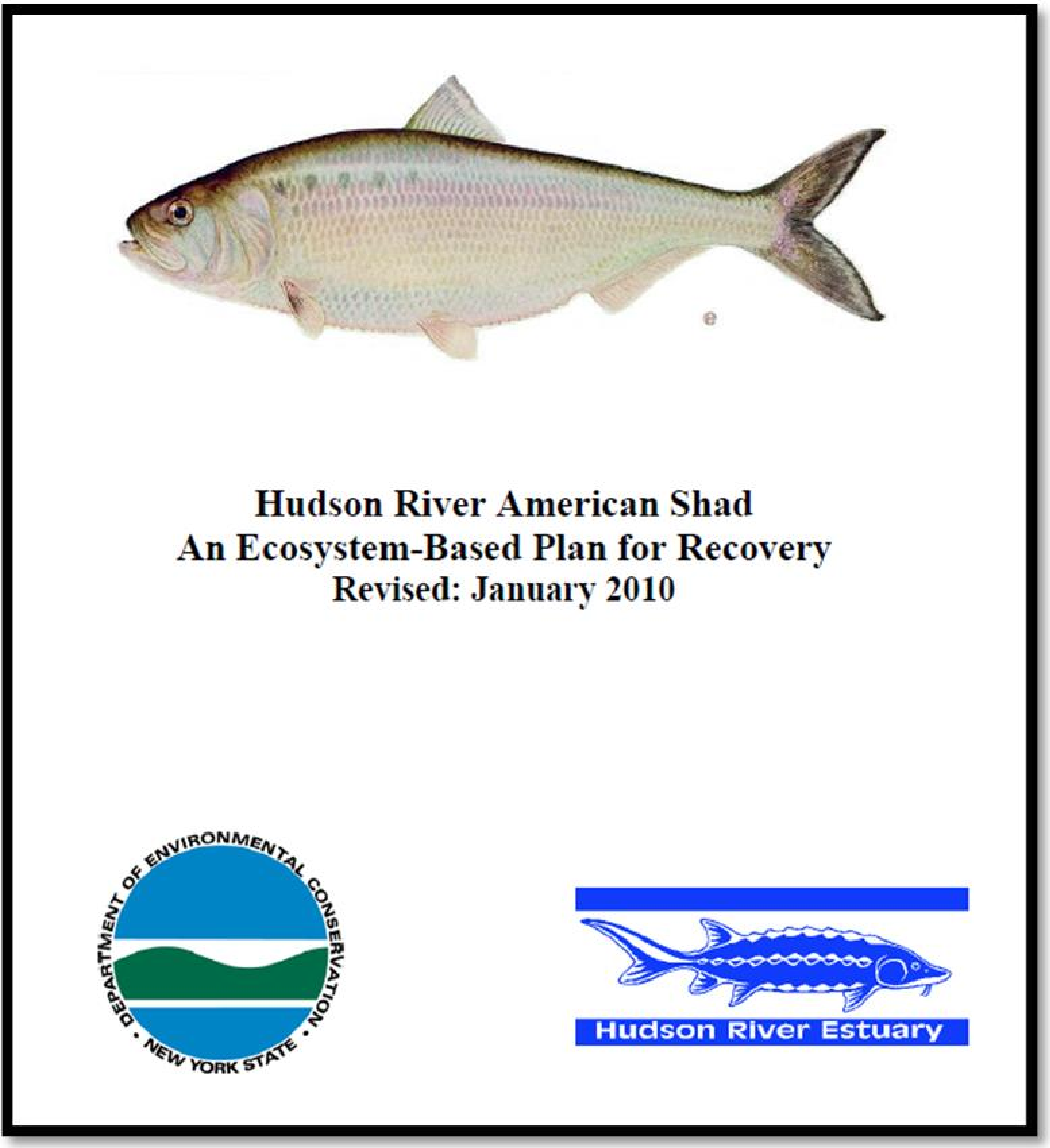


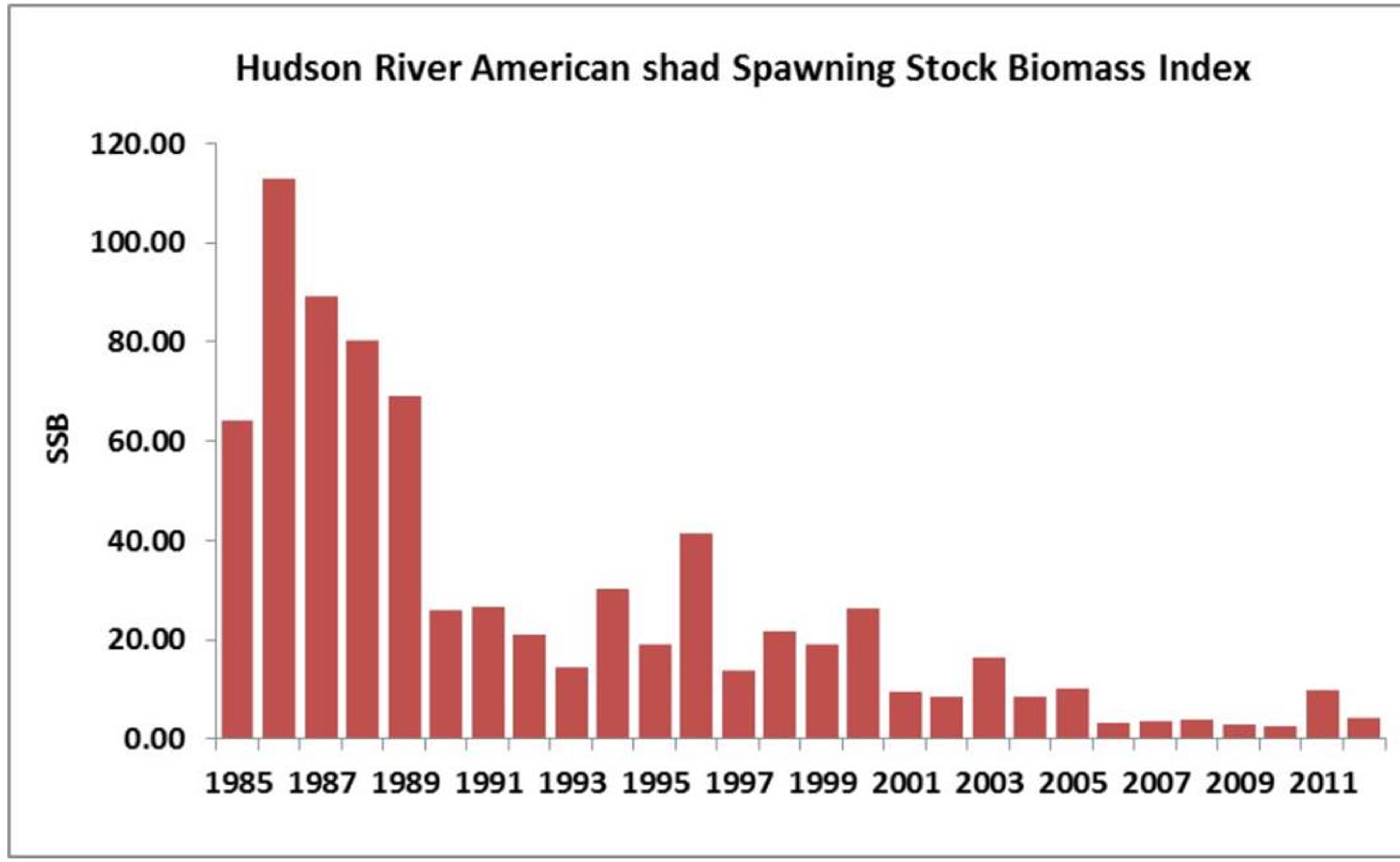
Shad have declined



State or country	Number of rivers	
	Historic	Today
Canada	>10	5?
Maine	27	2?
New Hampshire	10	3
Massachusetts	7	4
Rhode Island	4	2?
Connecticut	6	2?
New York	5?	1?
New Jersey	19	6?
Delaware	4	3
Maryland	10	4?
Virginia	3	3
North Carolina	14	14?
South Carolina	12	12
Georgia	5	5
Florida	2	2
Approximate total	138	68

Hudson River Shad have declined


Hudson River American Shad
An Ecosystem-Based Plan for Recovery
Revised: January 2010



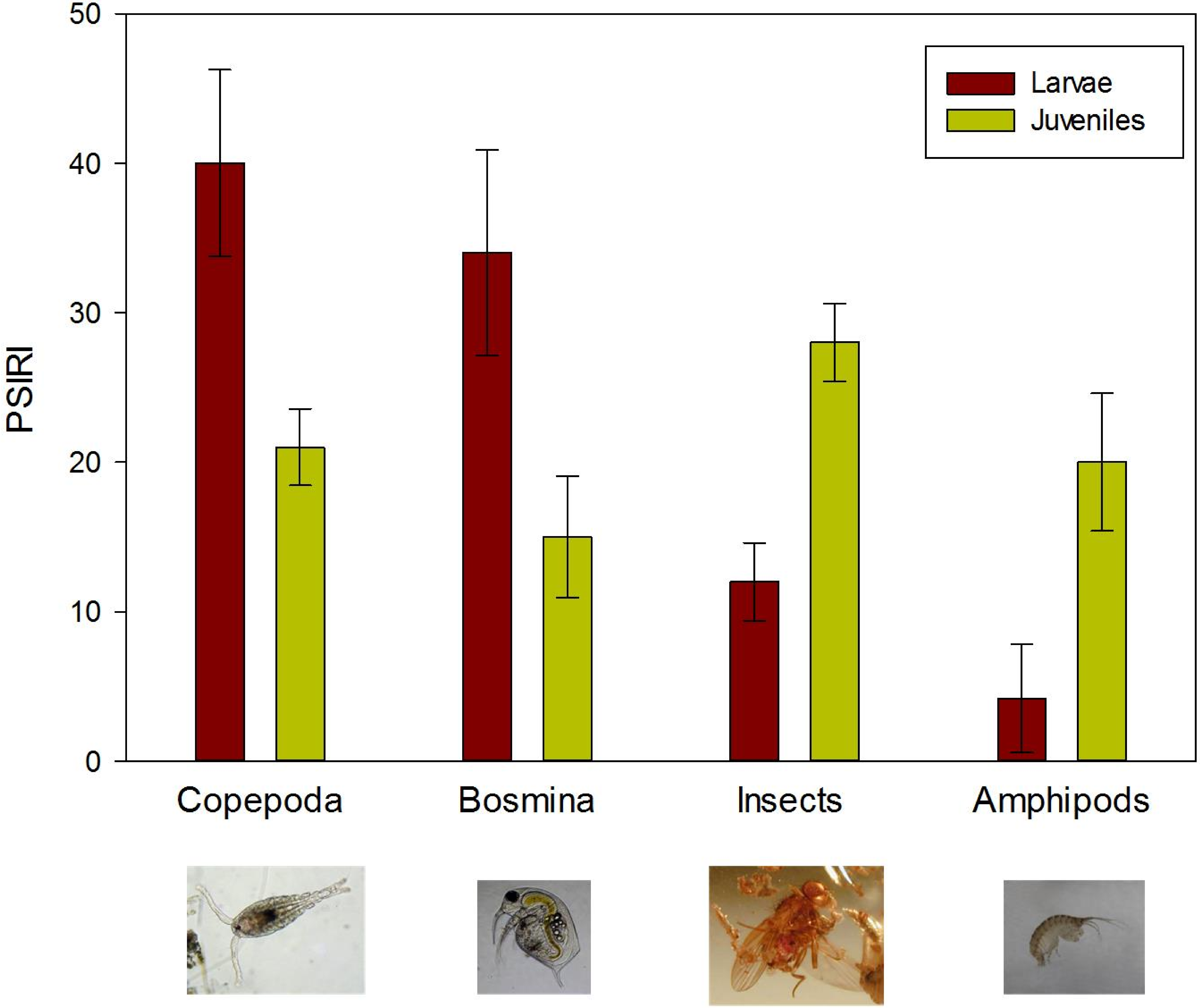
NY DEC

"It is not known if a diet shift has occurred in American Shad"

"Evaluate impacts of invasive species, such as zebra mussels, on larval and juvenile shad"

ATLANTIC STATES MARINE FISHERIES COMMISSION

Diet composition changes with development



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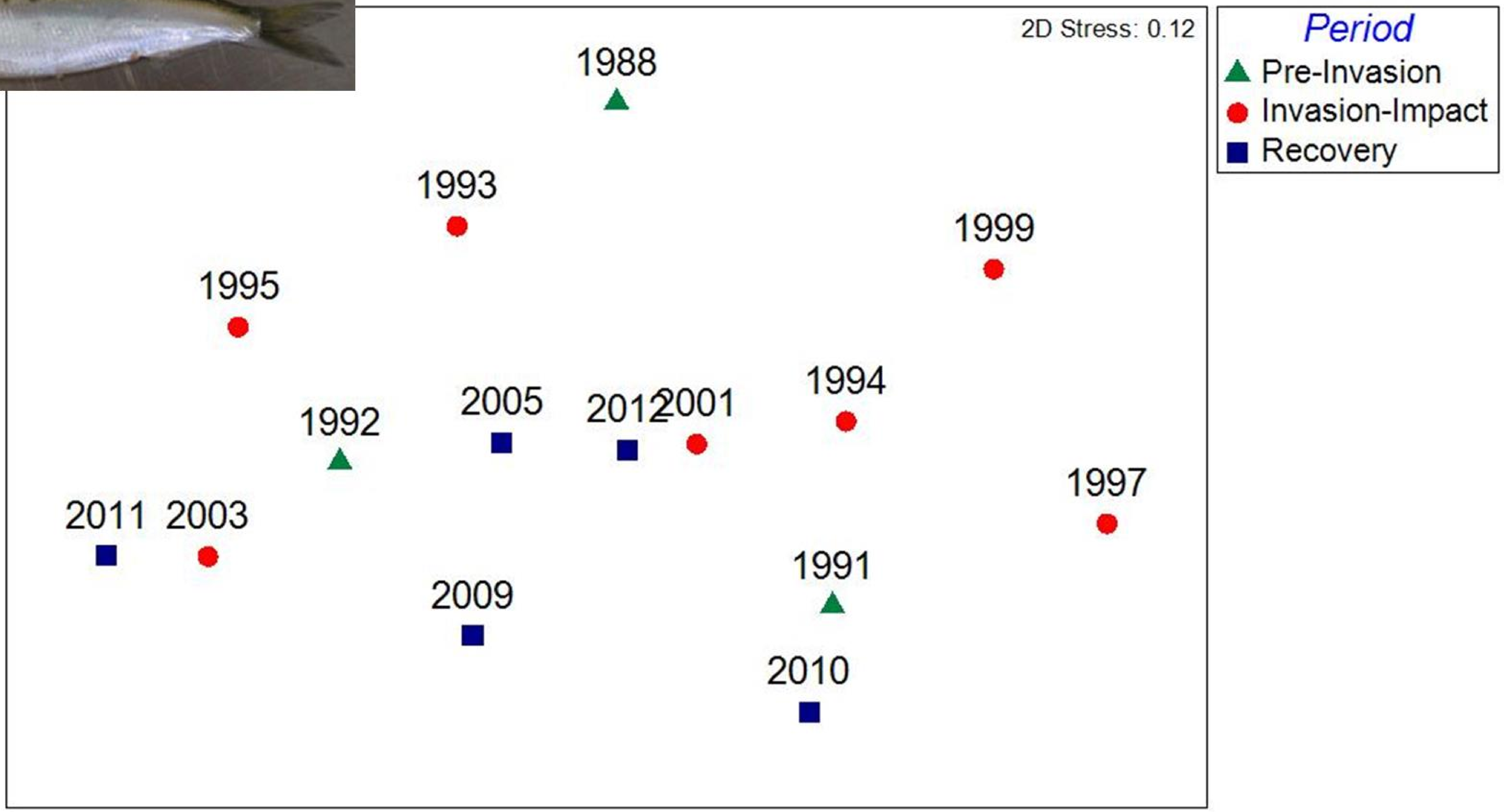
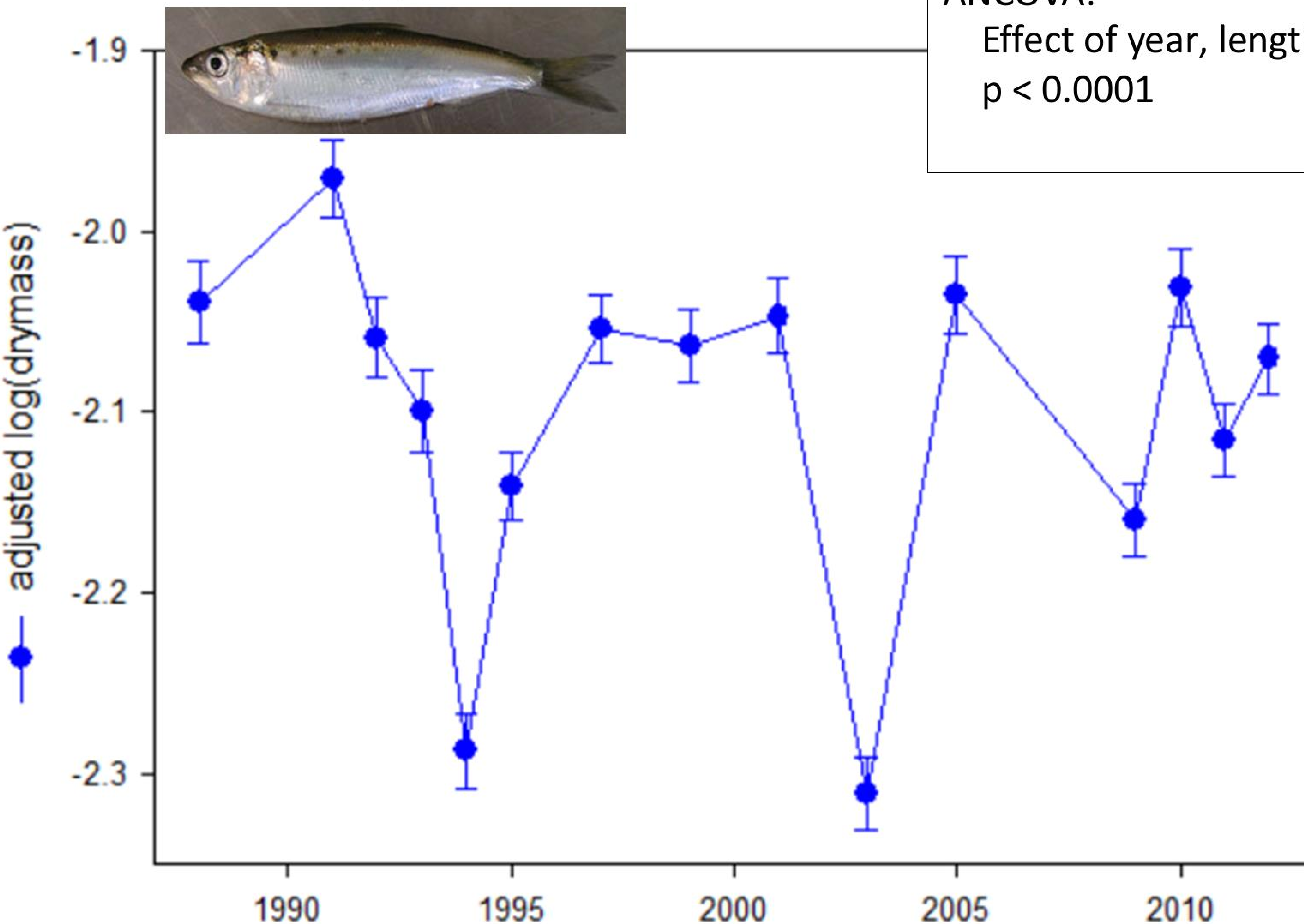


ANOSIM, global R=0.27, effect of year p=0.001

Long-term feeding success of larvae

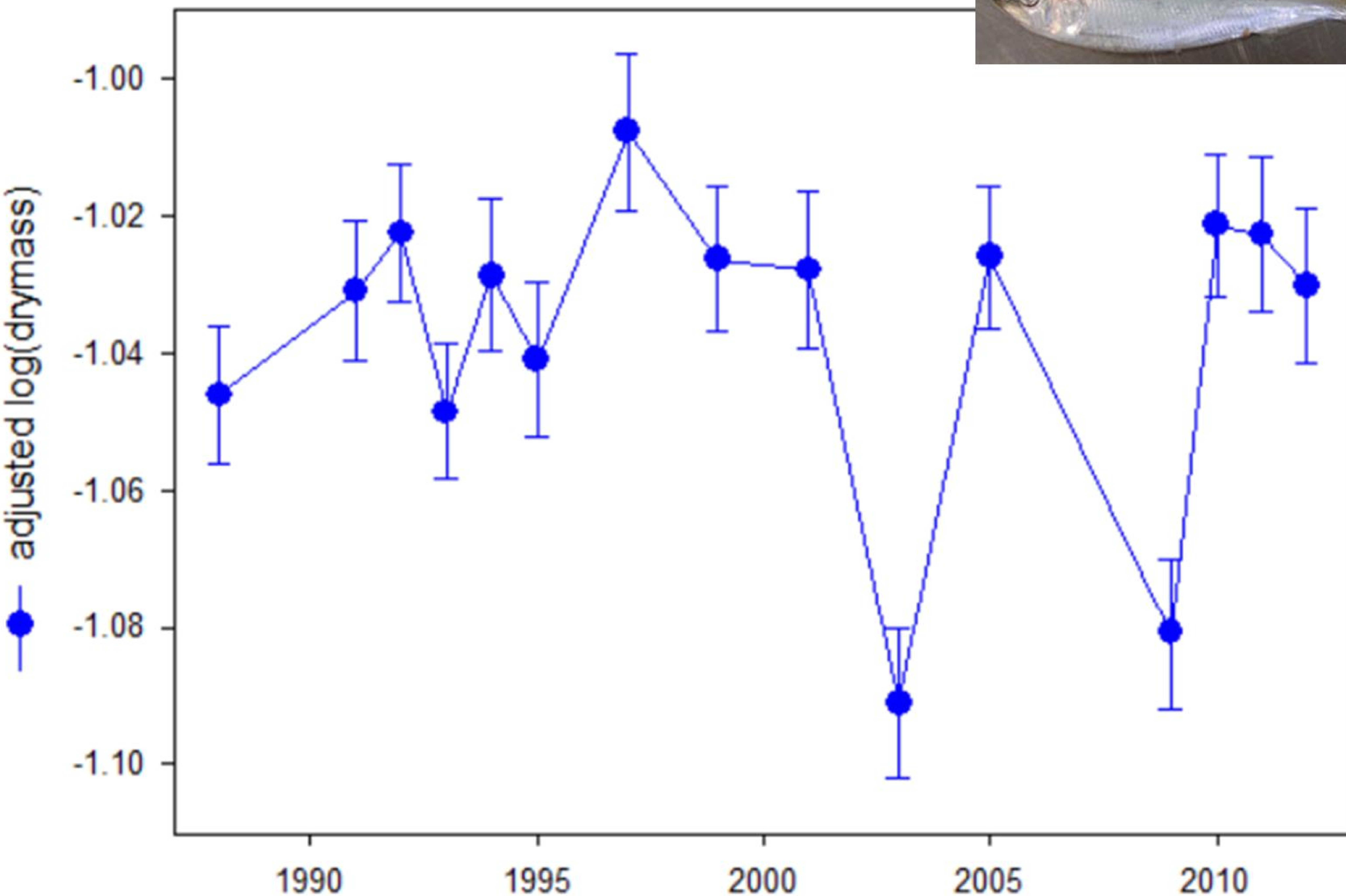
Condition varies among years



ANCOVA:
Effect of year, length
$p < 0.0001$

Long-term feeding success of juveniles

Condition varies among years



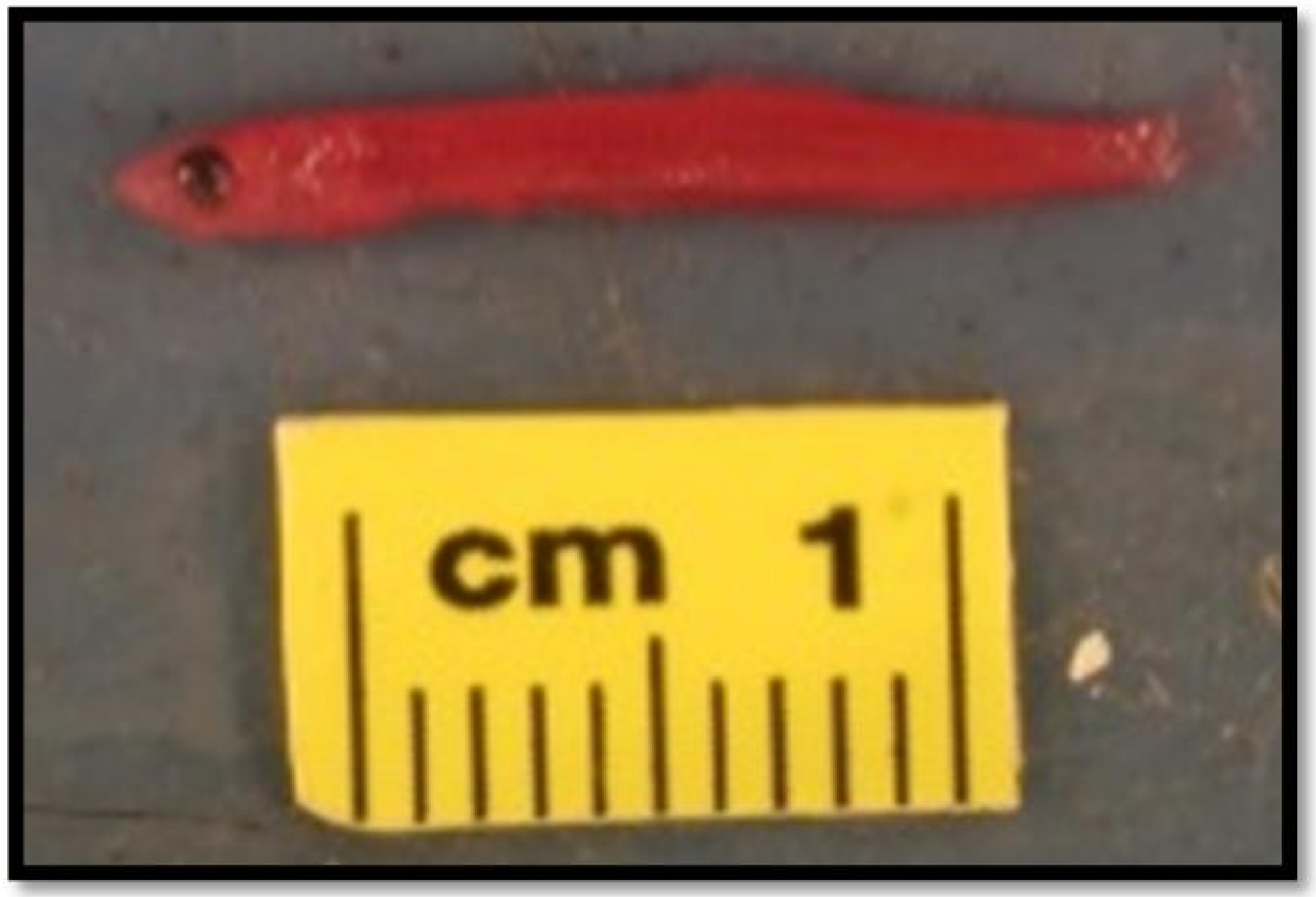
Objective 3: influences on feeding success

Methods:

AIC selection of mixed-effects models with

Dissolved Oxygen	Amphipod density
River discharge	Chlorophyll *a*
Salinity	Copepod density
Temperature	Zebra mussel filtration rate

Influences on feeding success



Larvae

+Chlorophyll, +Copepods, +Temperature, +Mussel filtration rate

Mass at length was 330% higher (0.0030 vs 0.012 g) at high values of predictors

Juveniles

+Chlorophyll, +Copepods, +River discharge, +Mussel filtration rate

Mass at length was 47% higher (0.066 vs 0.098 g) at high values of predictors

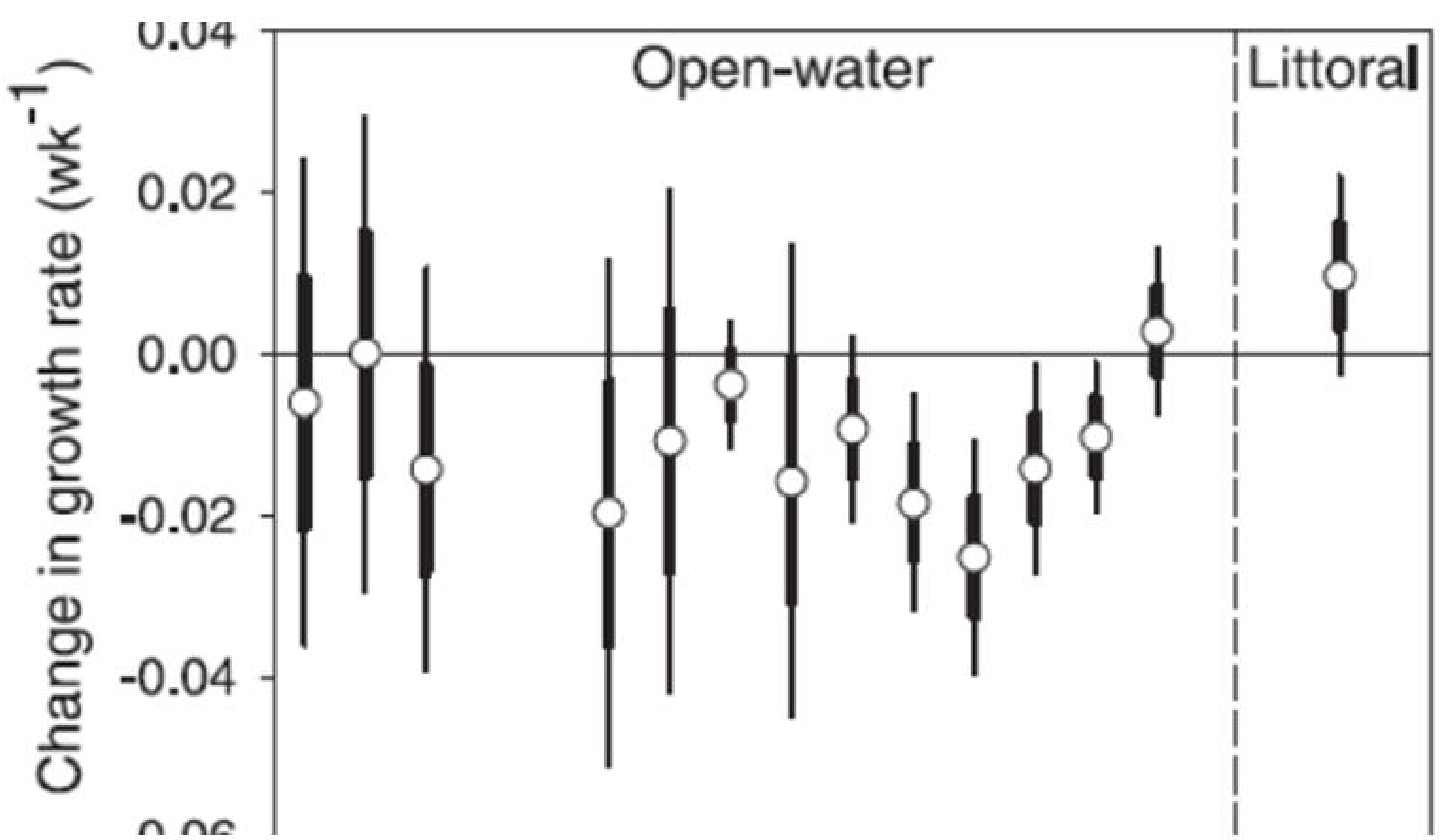
American Shad conclusions

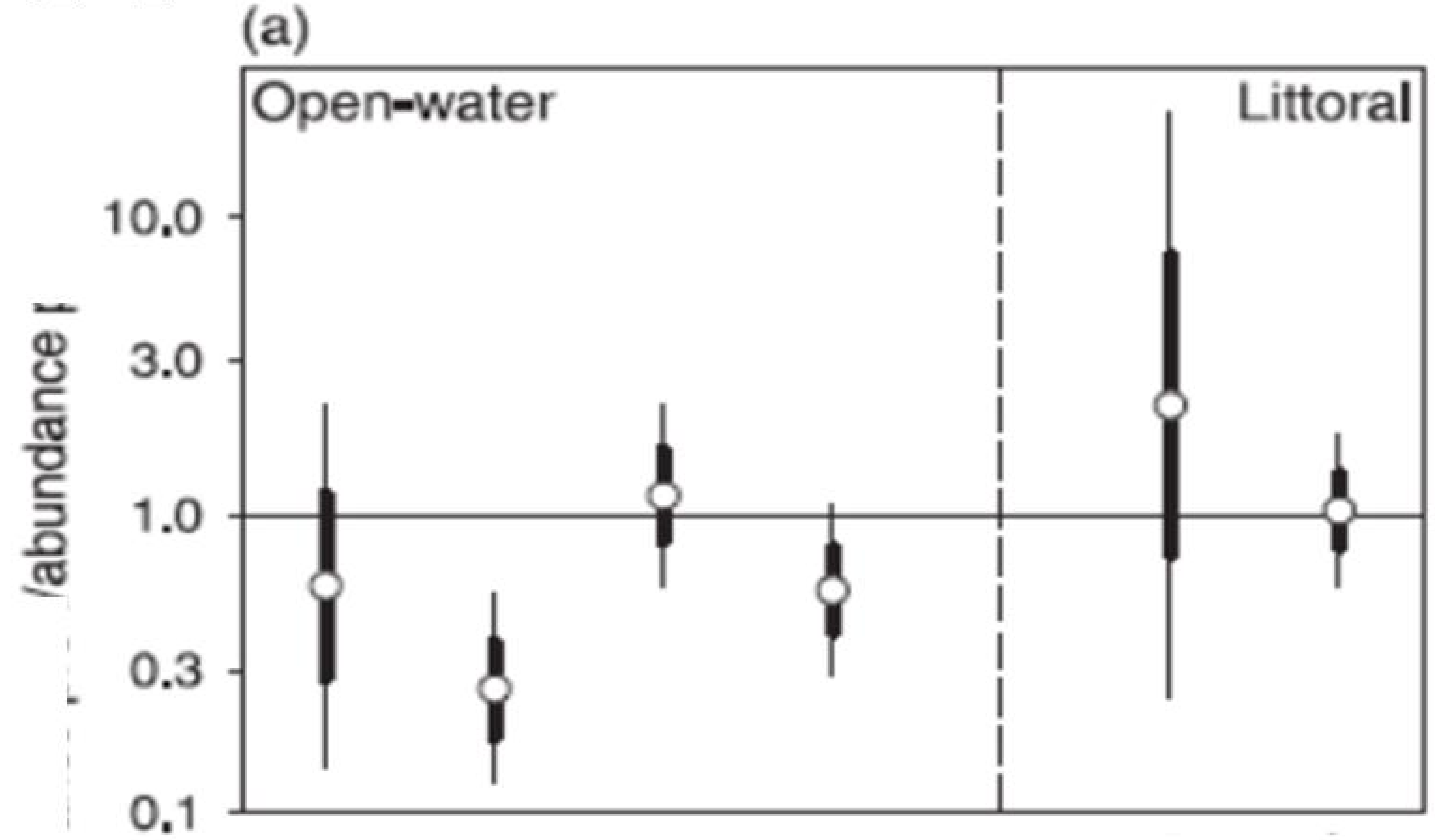
Copepods, *Bosmina*, amphipods, and insects were the most important prey

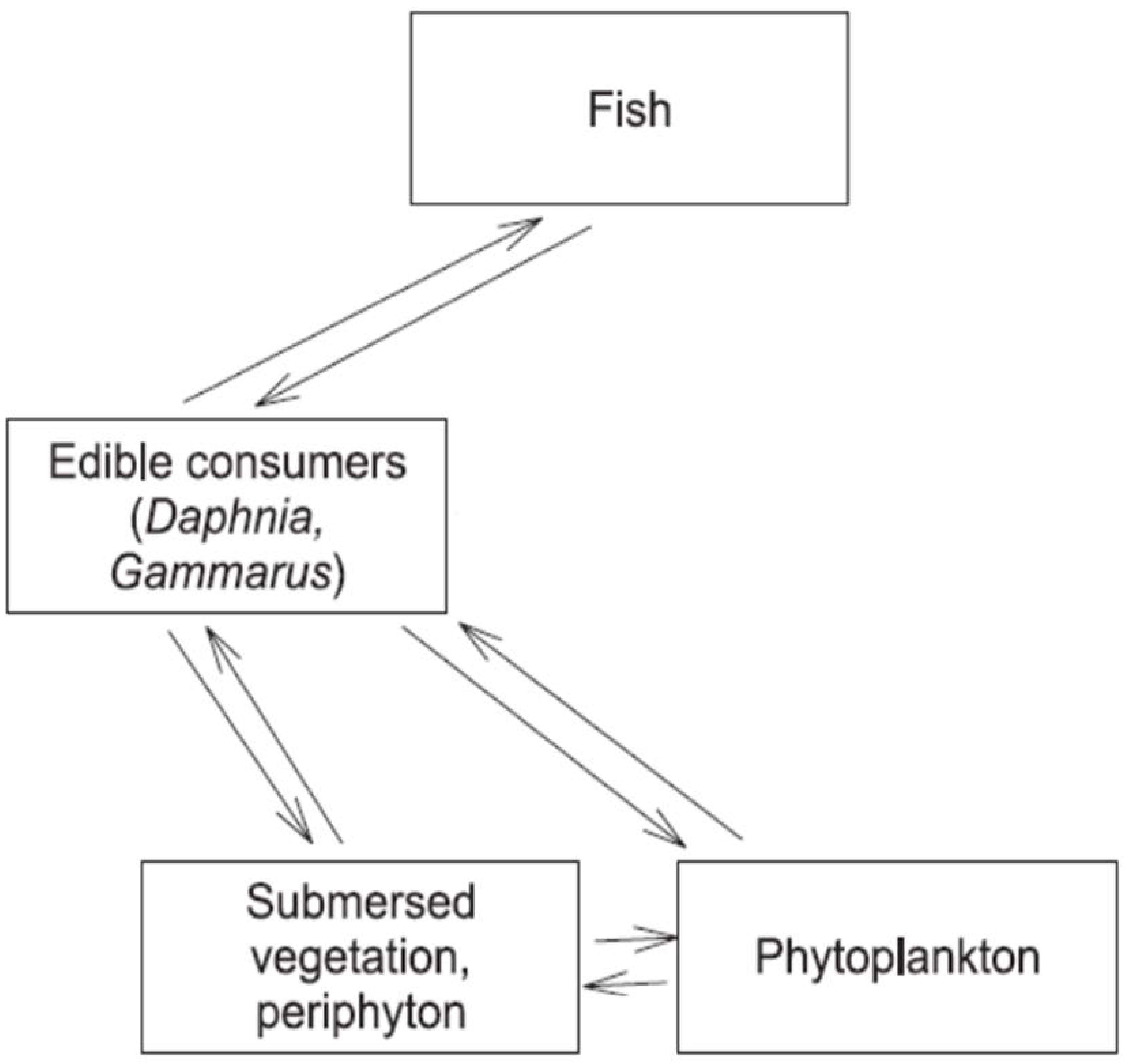
Diet composition and feeding success varied among years

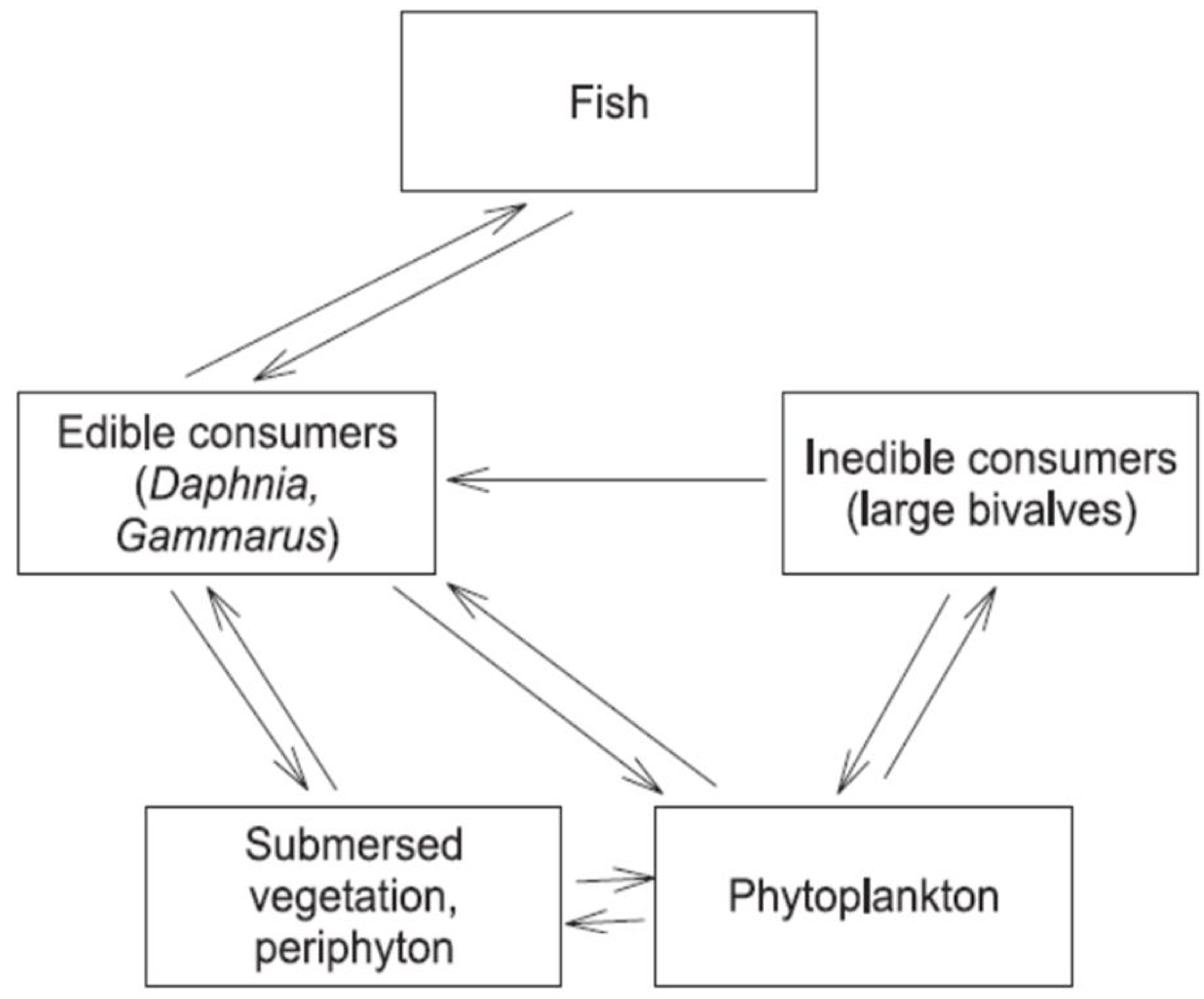
Chlorophyll, copepods, and zebra mussels had an effect on feeding success of both life stages

What happened?









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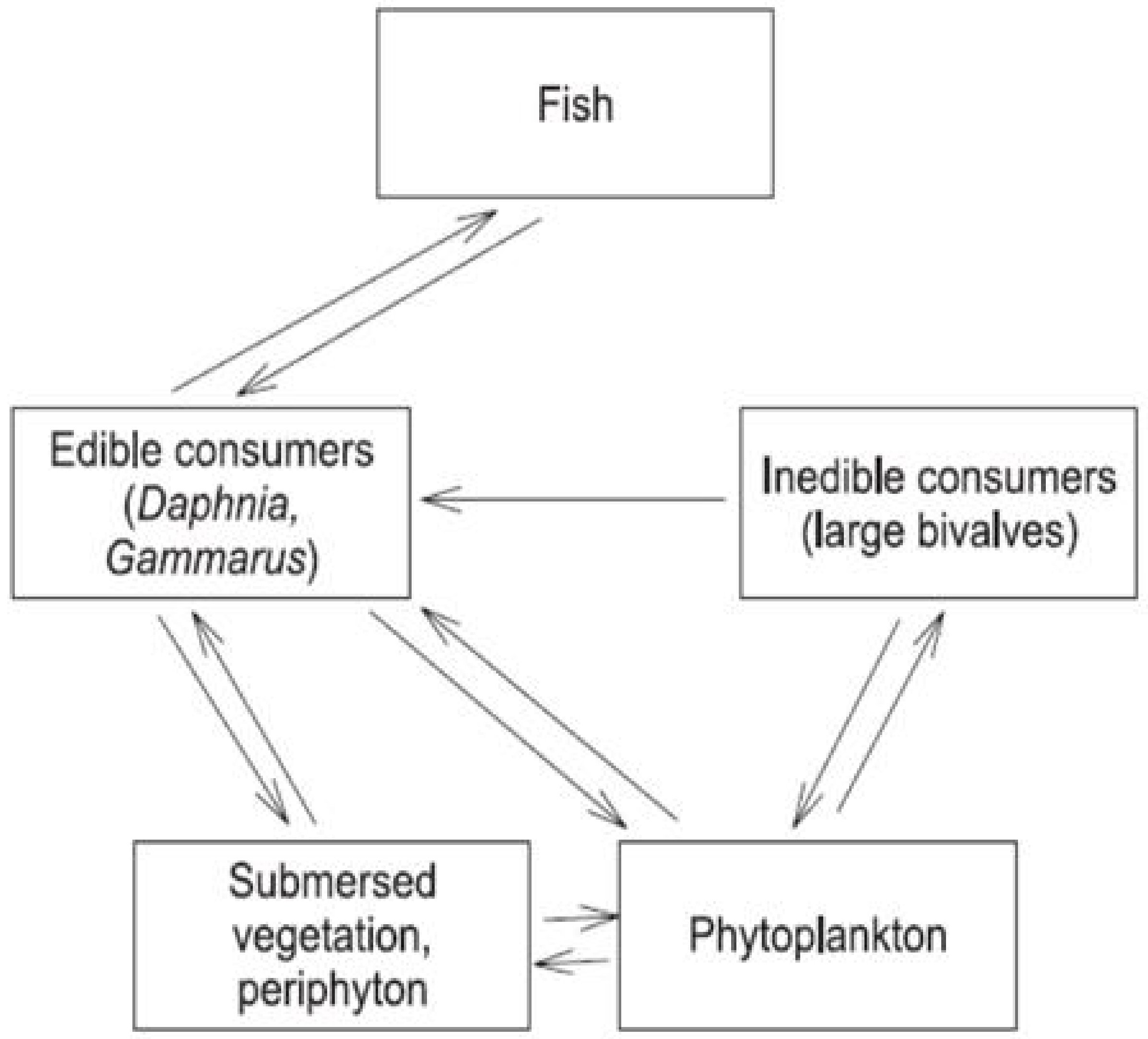

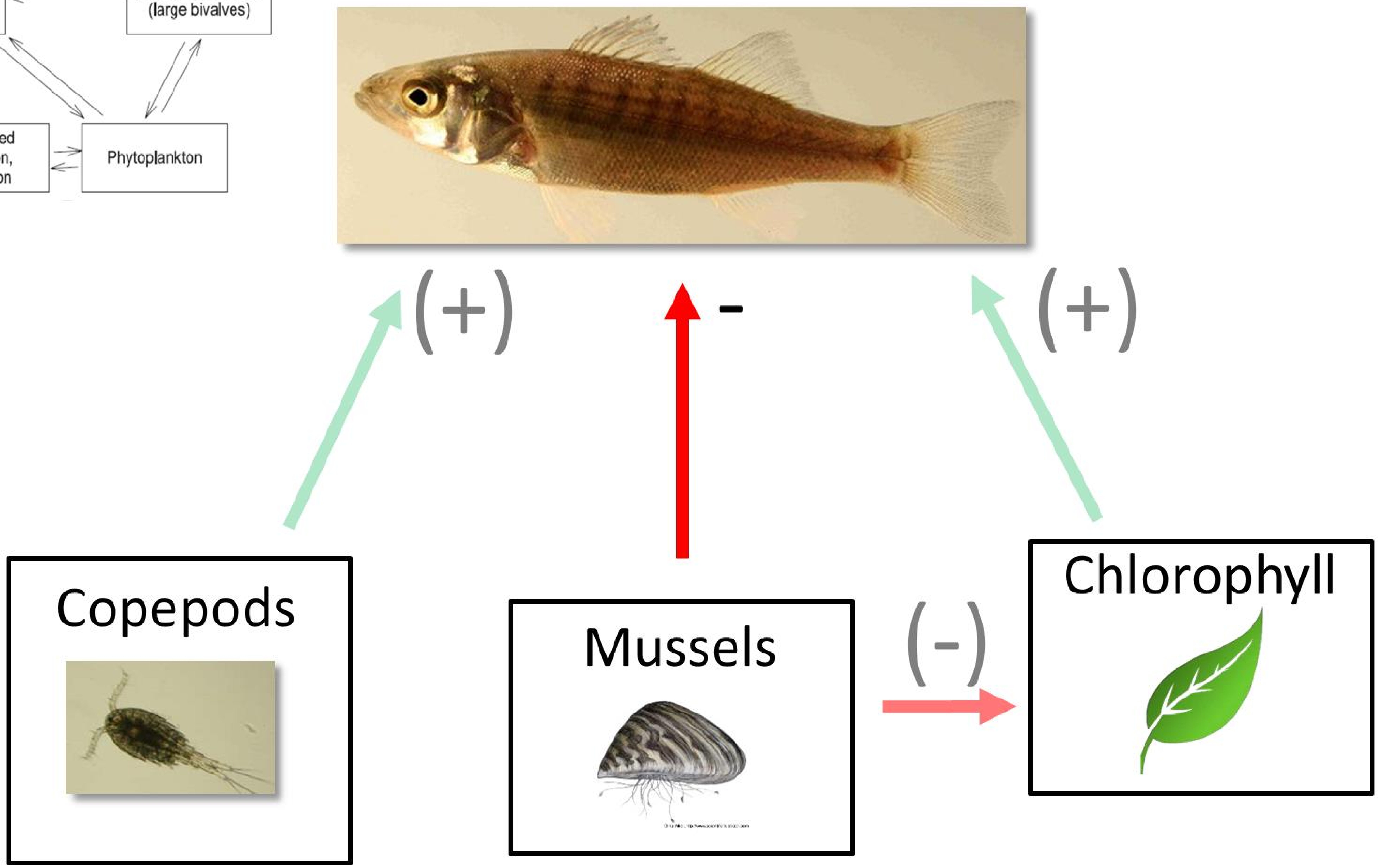

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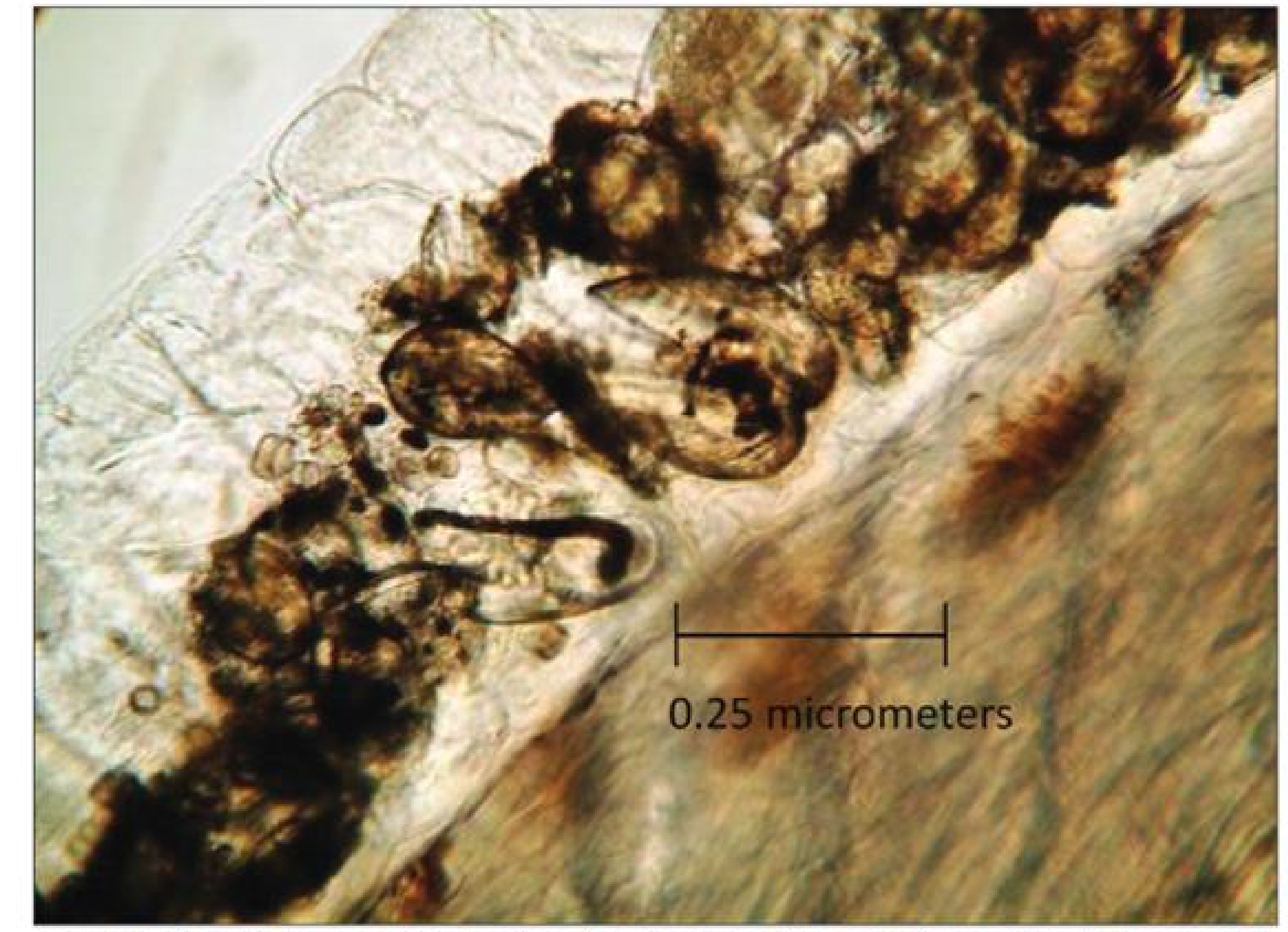
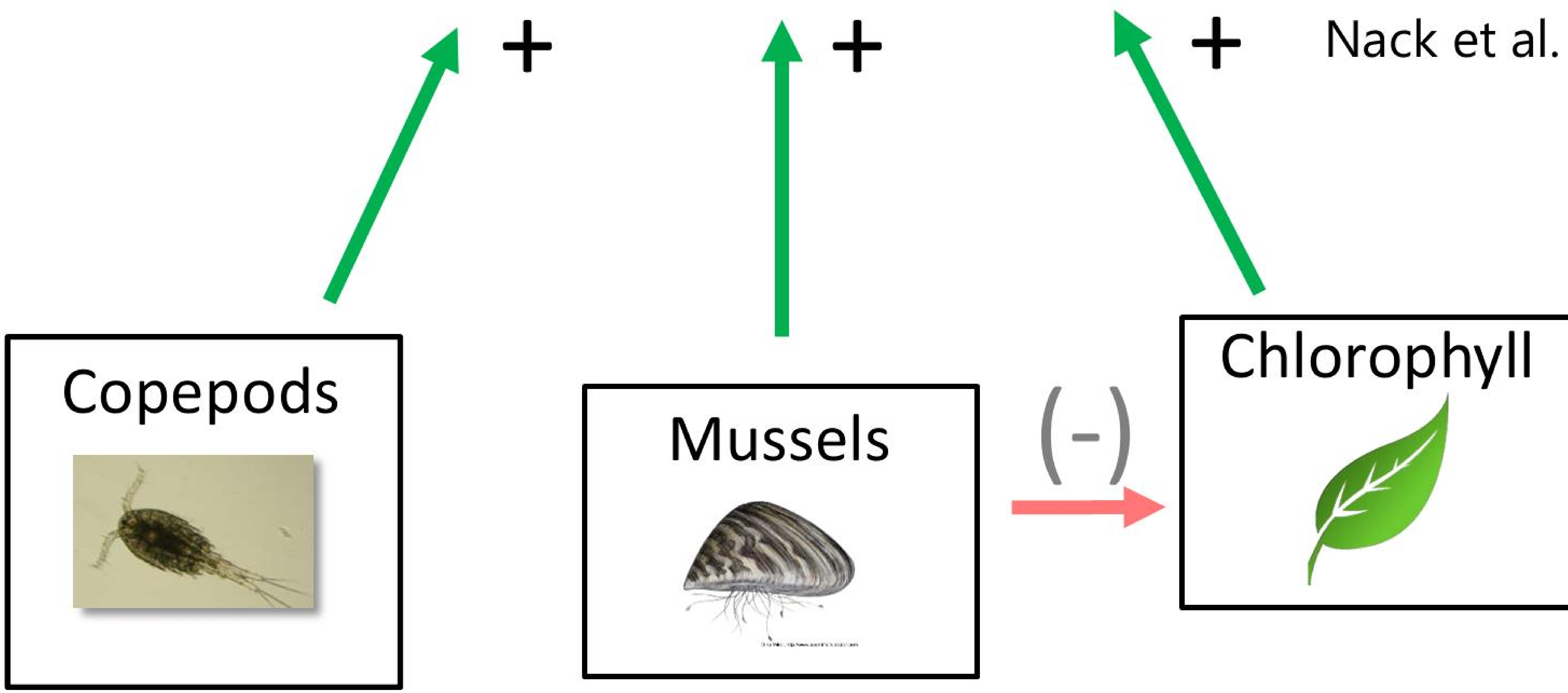


Figure 1. Larval American Shad gut containing Zebra Mussel veligers. Note that some veligers appear to be open while others are still closed. Bottom right quadrant shows pigmented myomeres of the larva.

Nack et al. (2015)



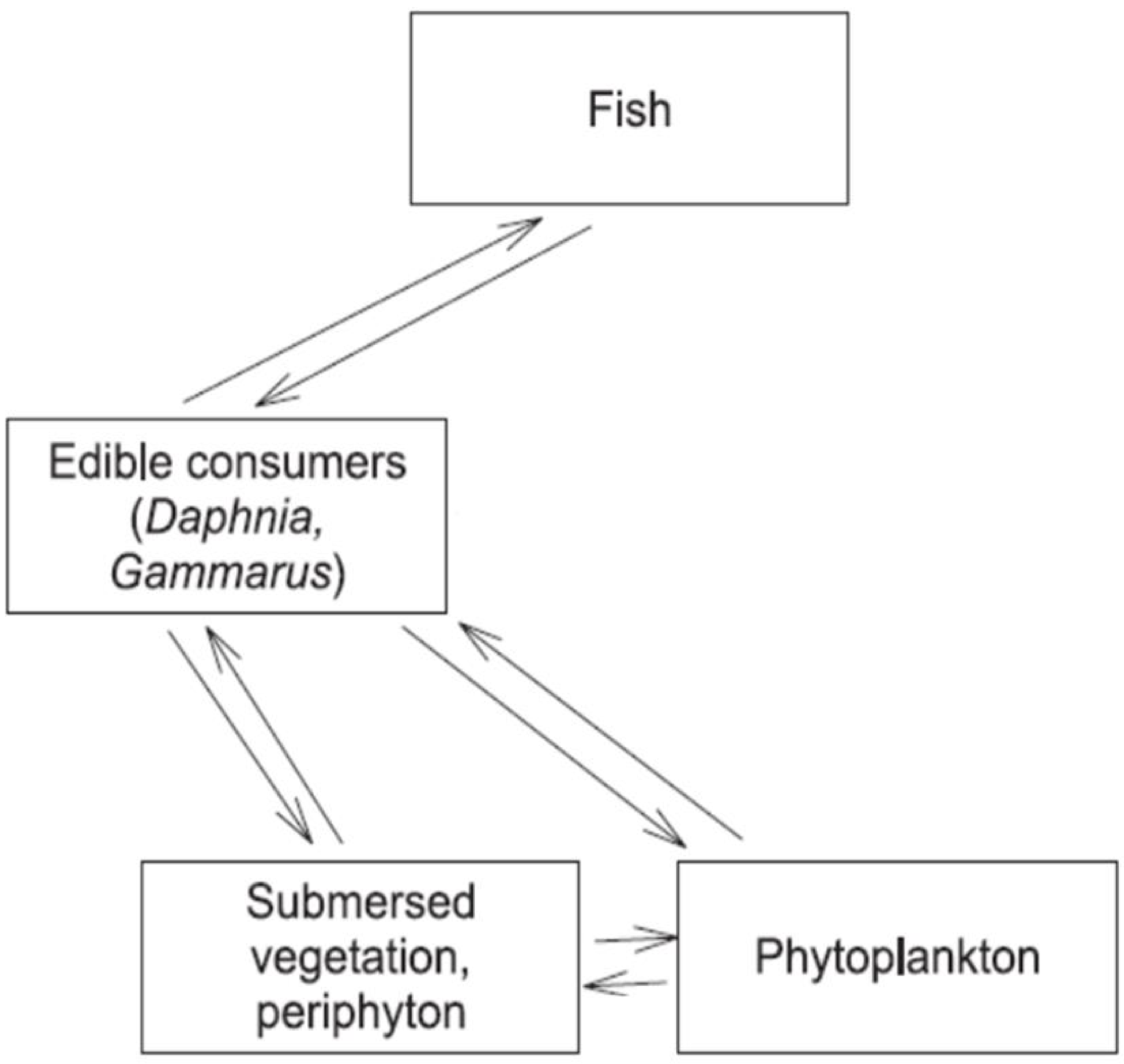
What’s so interesting?

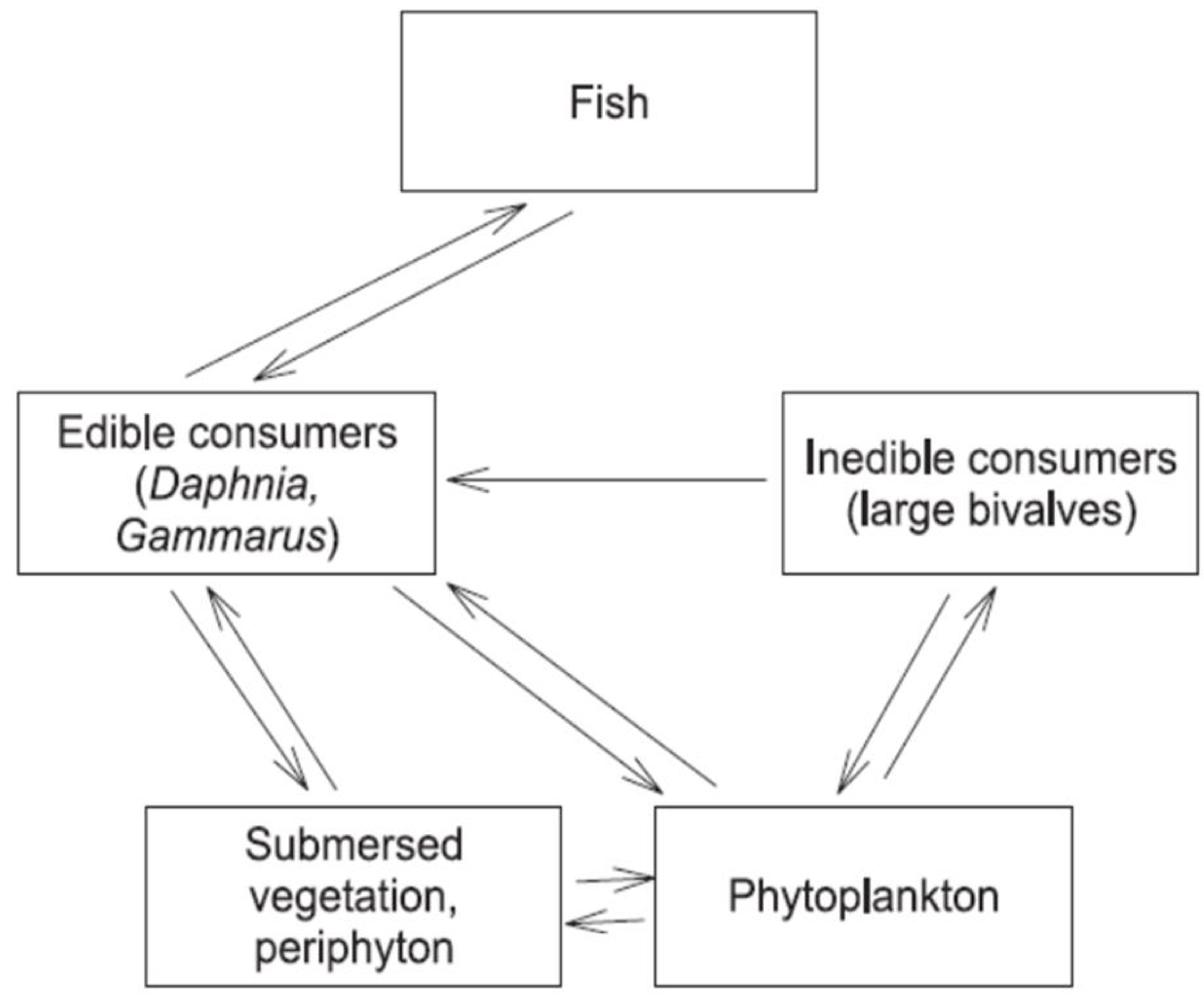
Long-term study of feeding ecology of early-stage fishes in estuaries demonstrated resilience to a major ecological perturbation in spite of strong environmental forcings on feeding success

An invasive species is both a competitor and prey for early-stage fishes

What don't we understand?

What pathway of production is supporting zooplankton and fish in lieu of primary production that is depleted by zebra mussels?





Objectives 1 & 2: niche breadth

Predictions:

1) Juveniles will have greater niche breadth

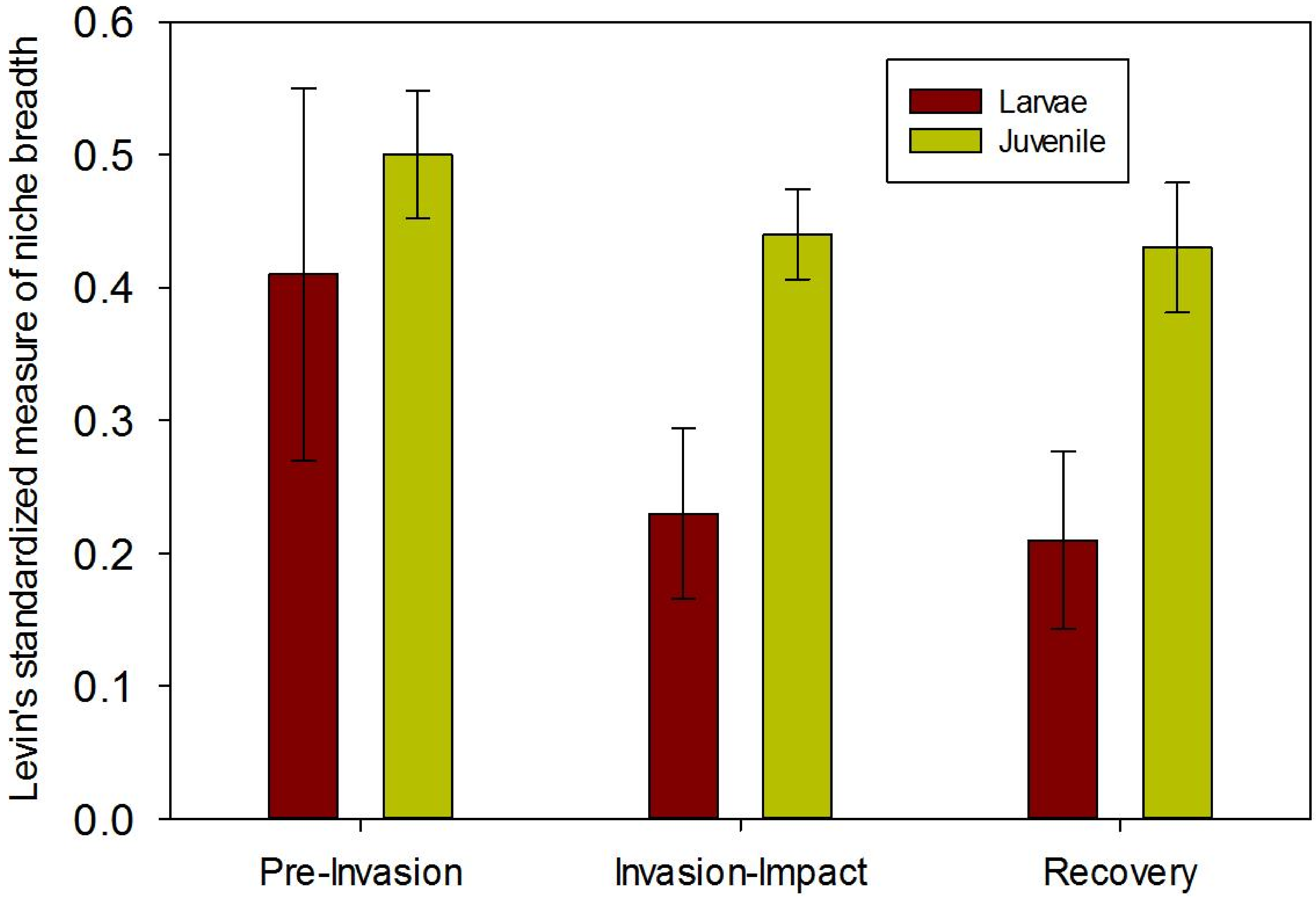
2) Niche breadth will be greater in years of mussel impact

Methods:

- Calculated Levin's measure (B) and standardized measure (B_A) of niche breadth

$$B = \frac{1}{\sum p_j^2} \qquad B_A = \frac{(B-1)}{(n-1)}$$

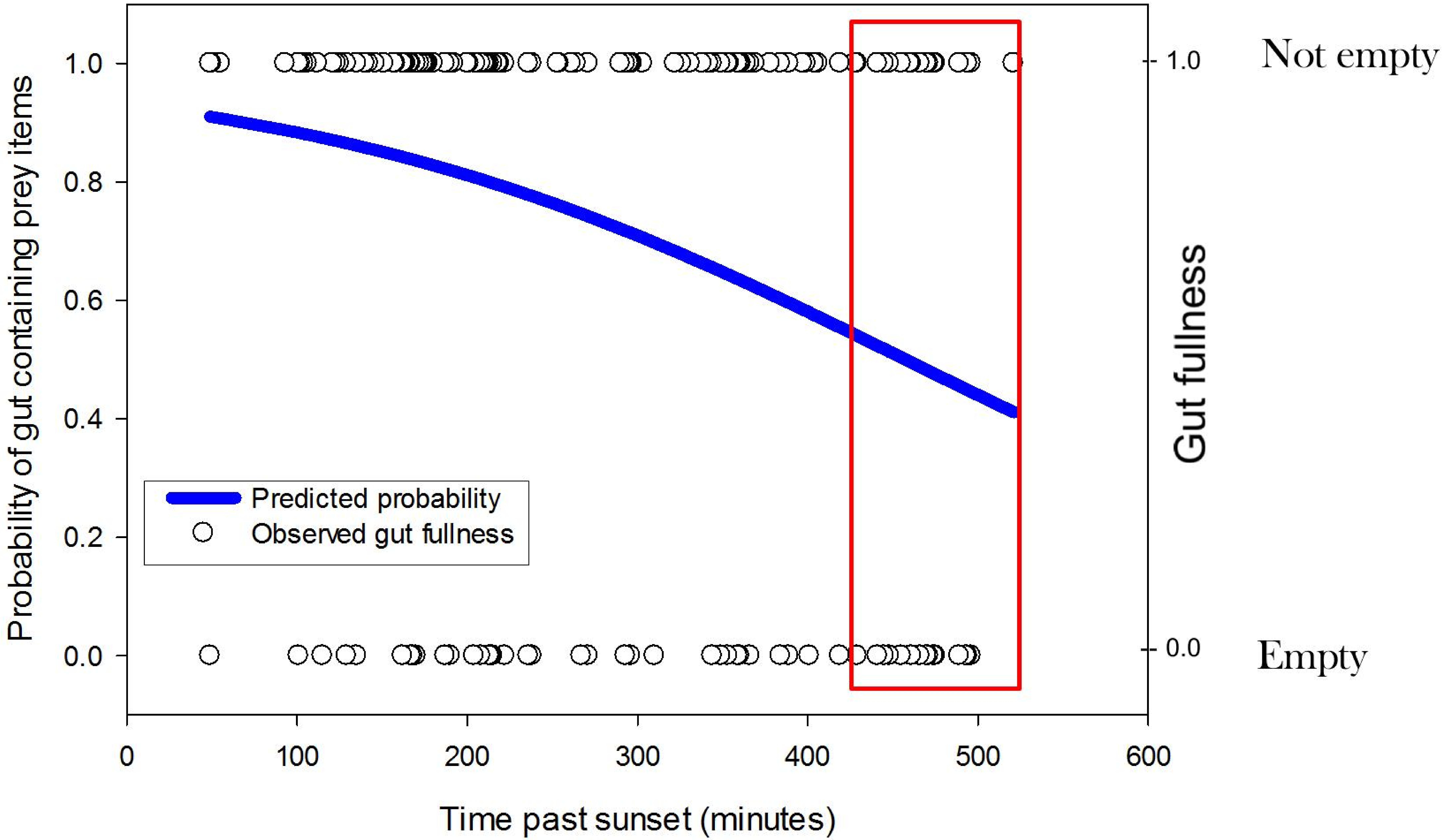
Juvenile shad have a greater niche breadth than larvae ($z=-4.7$, $p < 0.001$)



Niche breadth does not differ among zebra mussel periods in larval ($\chi^2=0.79$, $p=0.7$) or juvenile shad ($\chi^2=3.3$, $p=0.2$)

High proportion of empty larvae guts

- Larvae 64% empty
- Juveniles 10% empty



(Logistic regression, 2=41, p<0.001)