USGS
science for a changing world

Ecosystem-level changes in the Great Lakes and effects on fisheries

2016 Great Lakes Conference

March 8, 2016

Salmon, trout, burbot

"Piscivores"

Alewife

Rainbow smelt

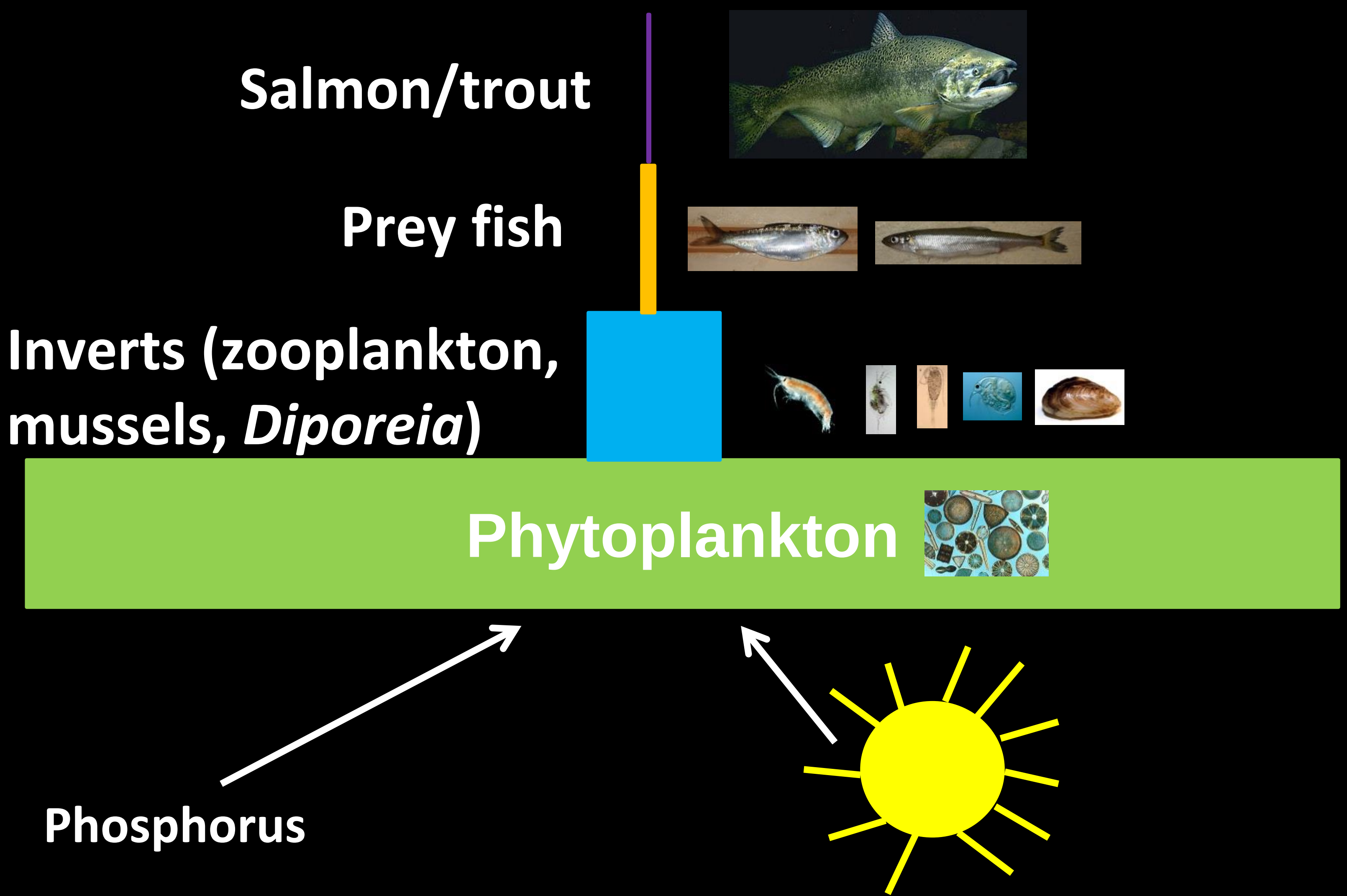
Deepwater sculpin, slimy sculpin, round goby

Bloater

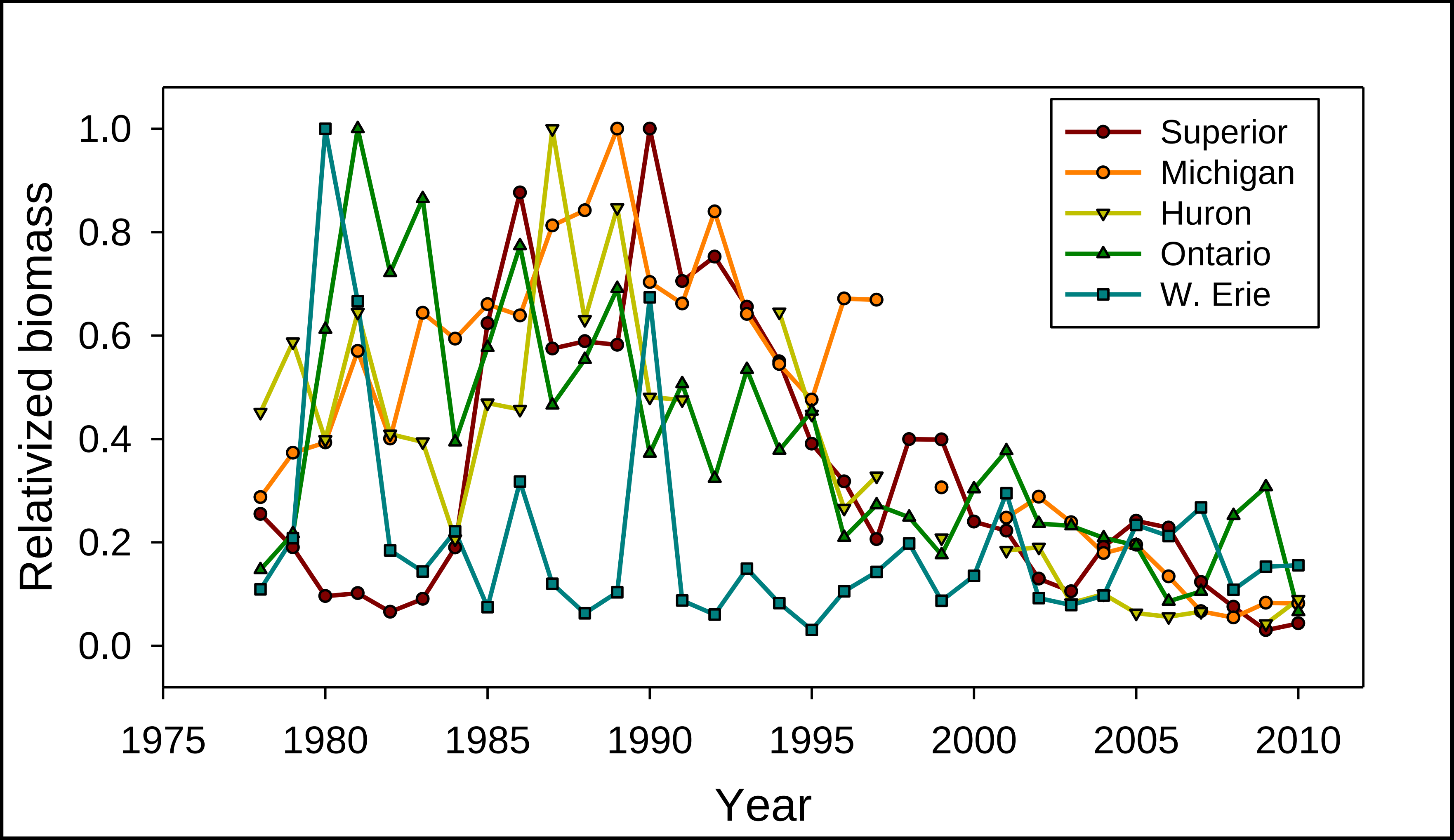
Ninespine stickleback

"Prey fishes"

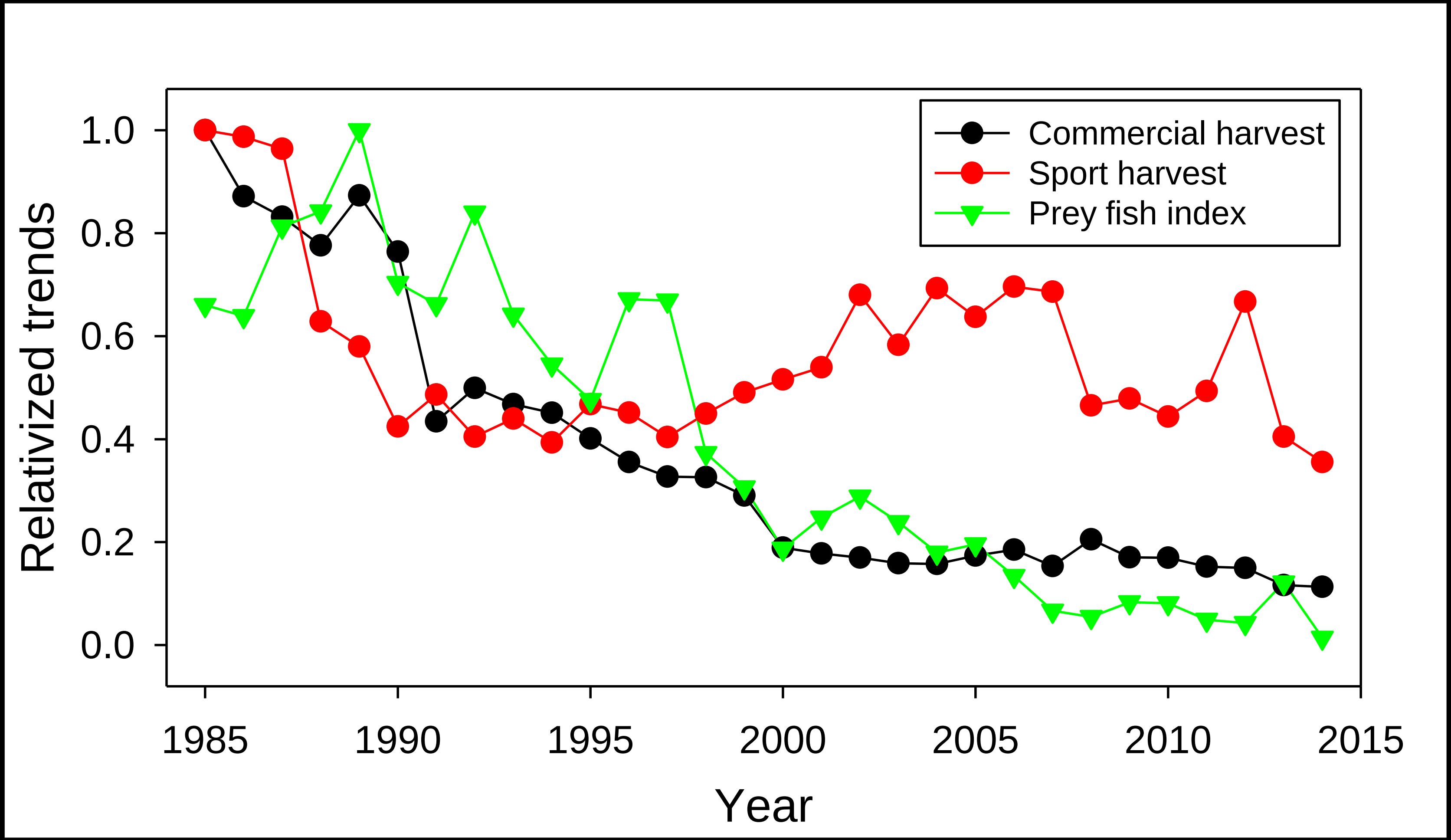
Bottom-up regulation?



Since the 1980s, “prey” fishes have trended downward (except W. Erie)

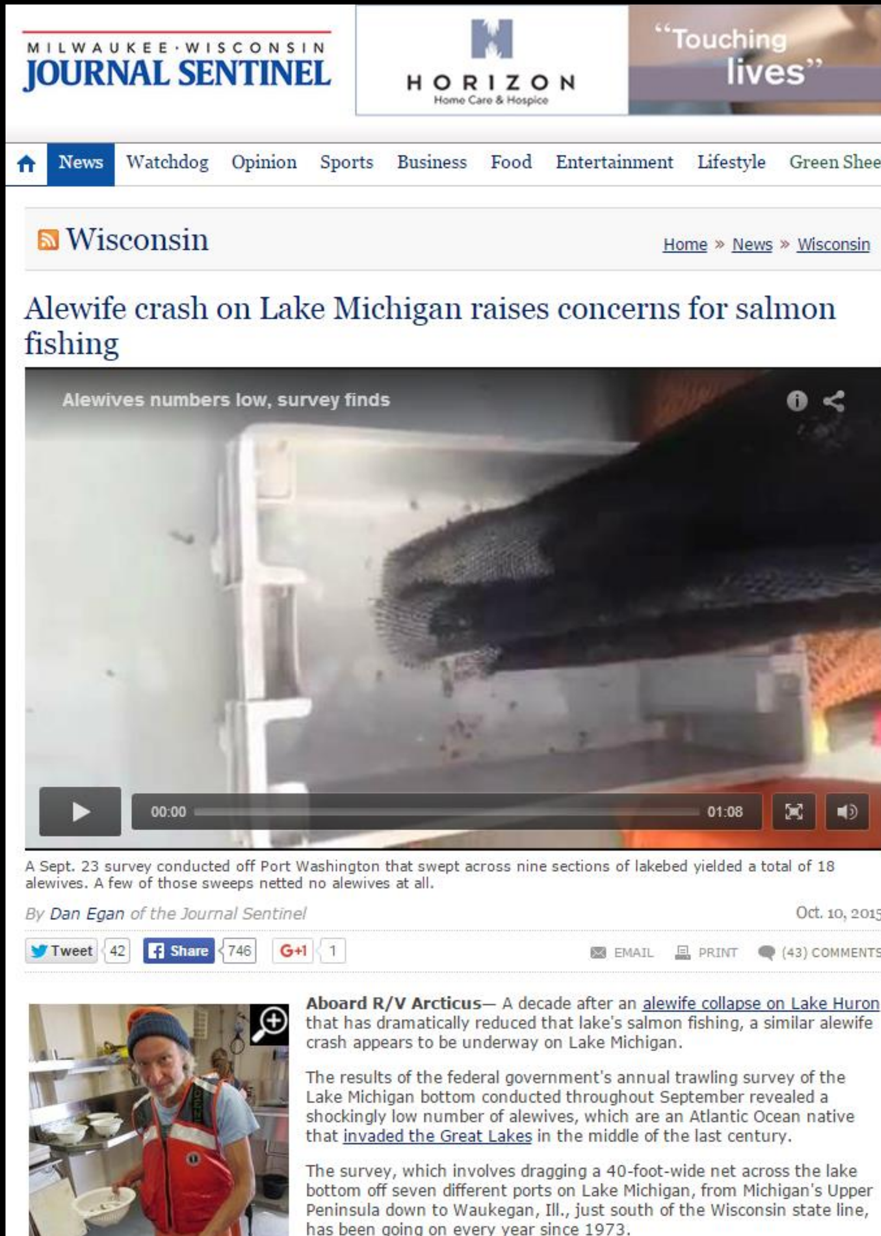


Since 1985-1990 in Lake Michigan- all groups of fish have declined



- Sport fish supplemented by stocking or migrants
- Commercial fishery faced closures/restrictions

Fisheries in the news: Are alewife collapsing in Lake Michigan?



MILWAUKEE · WISCONSIN JOURNAL SENTINEL

HORIZON Home Care & Hospice "Touching lives"

Alewife crash on Lake Michigan raises concerns for salmon fishing

Alewives numbers low, survey finds

00:00 01:08

A Sept. 23 survey conducted off Port Washington that swept across nine sections of lakebed yielded a total of 18 alewives. A few of those sweeps netted no alewives at all.

By Dan Egan of the Journal Sentinel Oct. 10, 2015

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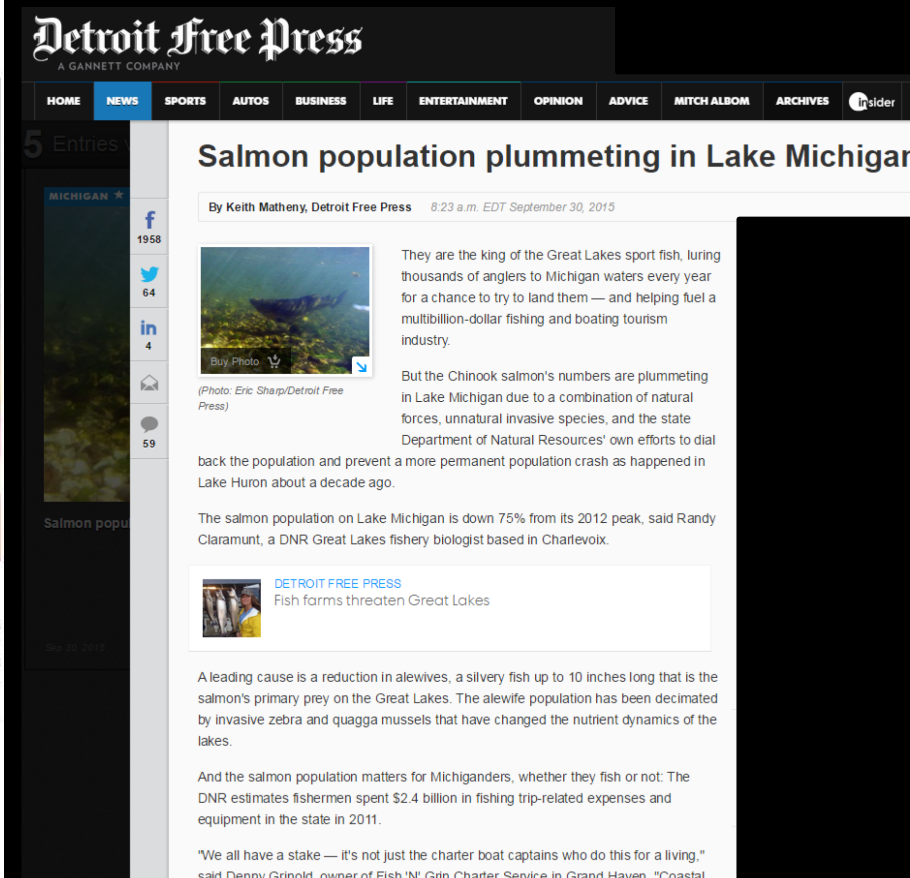
Aboard R/V Arcticus— A decade after an alewife collapse on Lake Huron that has dramatically reduced that lake's salmon fishing, a similar alewife crash appears to be underway on Lake Michigan.

The results of the federal government's annual trawling survey of the Lake Michigan bottom conducted throughout September revealed a shockingly low number of alewives, which are an Atlantic Ocean native that invaded the Great Lakes in the middle of the last century.

The survey, which involves dragging a 40-foot-wide net across the lake bottom off seven different ports on Lake Michigan, from Michigan's Upper Peninsula down to Waukegan, Ill., just south of the Wisconsin state line, has been going on every year since 1973.



Detroit Free Press
A GANNETT COMPANY

Salmon population plummeting in Lake Michigan

By Keith Matheny, Detroit Free Press 8:23 a.m. EDT September 30, 2015

Buy Photo

(Photo: Eric Sharp/Detroit Free Press)

They are the king of the Great Lakes sport fish, luring thousands of anglers to Michigan waters every year for a chance to try to land them — and helping fuel a multibillion-dollar fishing and boating tourism industry.

But the Chinook salmon's numbers are plummeting in Lake Michigan due to a combination of natural forces, unnatural invasive species, and the state Department of Natural Resources' own efforts to dial back the population and prevent a more permanent population crash as happened in Lake Huron about a decade ago.

The salmon population on Lake Michigan is down 75% from its 2012 peak, said Randy Claramunt, a DNR Great Lakes fishery biologist based in Charlevoix.

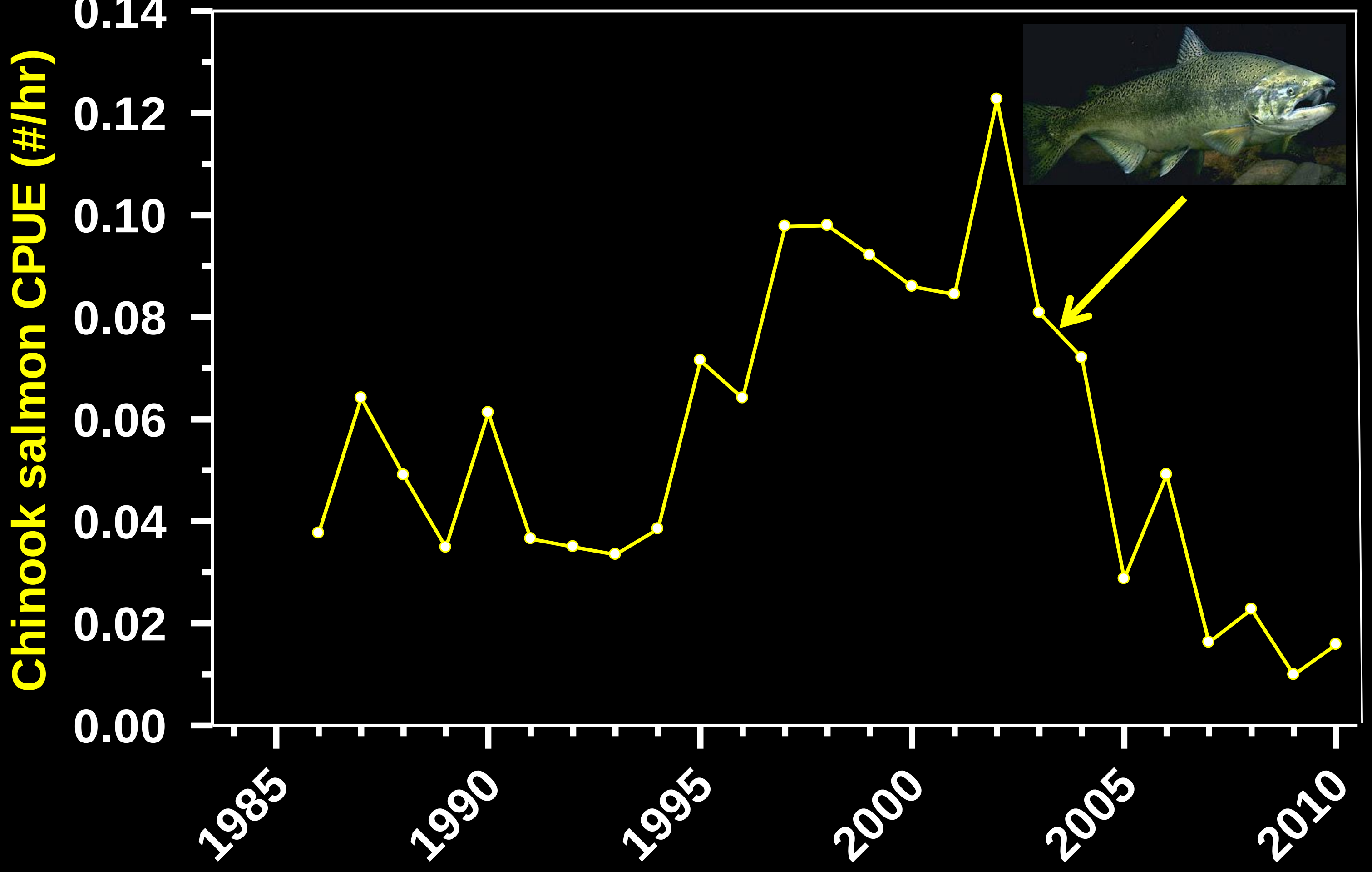
DETROIT FREE PRESS
Fish farms threaten Great Lakes

A leading cause is a reduction in alewives, a silvery fish up to 10 inches long that is the salmon's primary prey on the Great Lakes. The alewife population has been decimated by invasive zebra and quagga mussels that have changed the nutrient dynamics of the lakes.

And the salmon population matters for Michiganders, whether they fish or not: The DNR estimates fishermen spent $2.4 billion in fishing trip-related expenses and equipment in the state in 2011.

"We all have a stake — it's not just the charter boat captains who do this for a living," said Denny Grinold, owner of Fish 'N' Grin Charter Service in Grand Haven. "Coastal

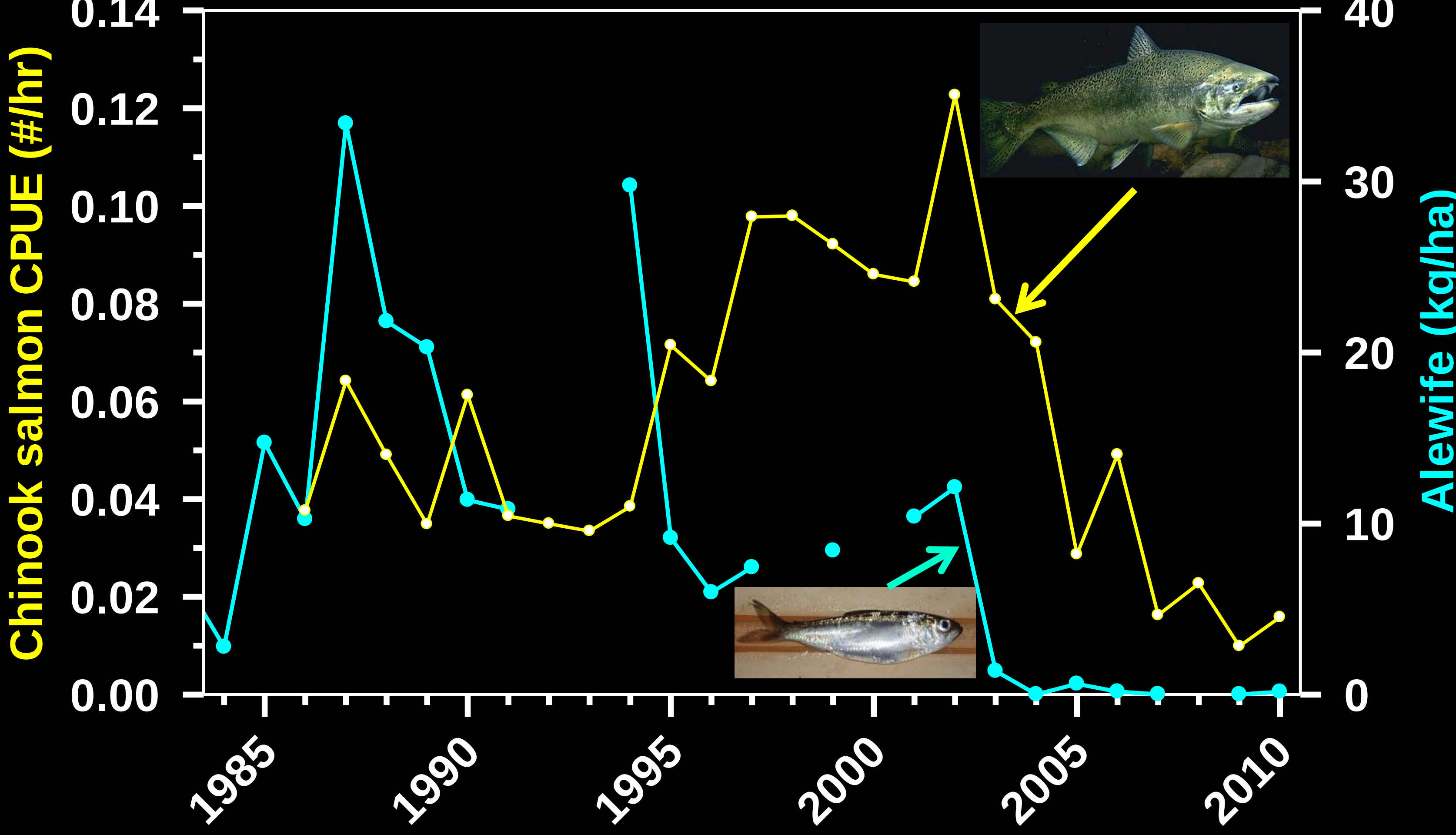
Trying to avoid 2003-2004 in Lake Huron



Jim Johnson, Michigan DNR

USGS bottom trawl data

Trying to avoid 2003-2004 in Lake Huron



Jim Johnson, Michigan DNR

USGS bottom trawl data

2013-current: 50% stocking reduction in Chinoook salmon

Lake Michigan Committee
REPRESENTING THE FISHERY MANAGEMENT AGENCIES OF LAKE MICHIGAN

For Immediate Release
August 27, 2012

PROPOSED SALMON STOCKING REDUCTIONS ANNOUNCED FOR LAKE MICHIGAN

ANN ARBOR, MI—Following more than a year of consultation with angler groups and other stakeholders, the Lake Michigan Committee (LMC) has proposed a new management strategy for Lake Michigan salmon. Beginning in spring of 2013, the LMC recommends that Chinook salmon stocking in Lake Michigan be reduced to one-half of current stocking levels. With salmon egg collections to begin in September, 2012, fisheries management agencies are now developing plans to decrease fingerling production targets to levels supporting reduced stocking, for a minimum of three years. The LMC comprises representatives from each of the state fisheries management agencies in Indiana, Illinois, Michigan, Wisconsin, and the Chippewa Ottawa Resource Authority (CORA). The Great Lakes Fishery Commission (GLFC) facilitates the committee's activities.

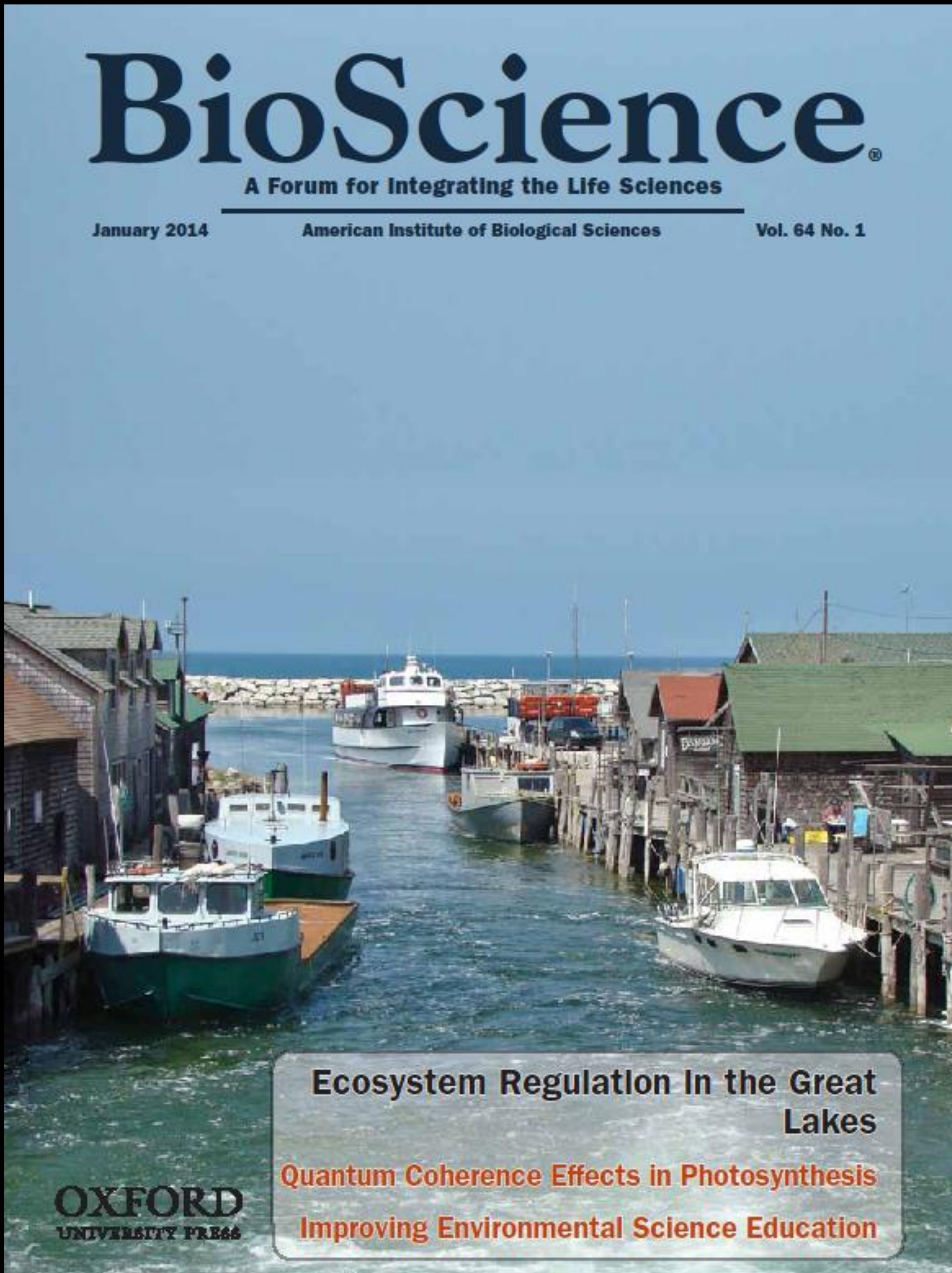
- ✓ Wild fish > stocked fish.
- ✓ Alewife were nearing record-low levels.

Today's talk:

1. Ecosystem-level trends across the Great Lakes

2. Effects of lower trophic level changes on fishes.

3. Impacts of climate change



- Assemble trends across trophic levels- "report card".
- Commonalities across lakes?
- "Bottom-up" vs. "top-down" regulation?

Collaborative team:

USGS — science for a changing world

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Summary of Lake Michigan trends (since 1998)

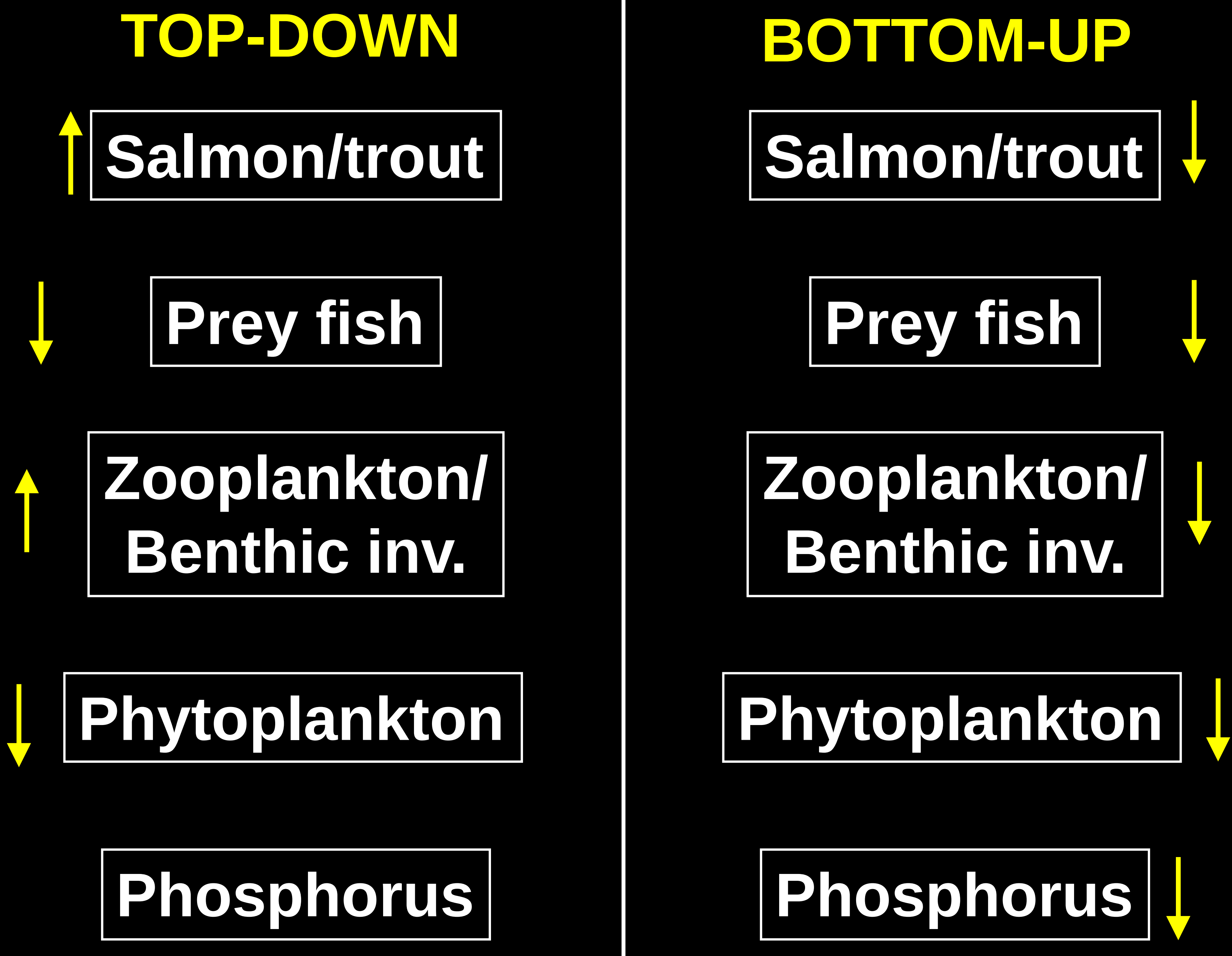
	Positive	No trend	Negative
Phosphorus inputs			
Phosphorus in lake			
Water clarity			
Phytoplankton			
Zooplankton			
Native benthic invert.			
Dreissenid mussels			
Prey fish biomass			
Piscivore biomass			
Piscivore stocked			

Summary of Lake Michigan trends (since 1998)

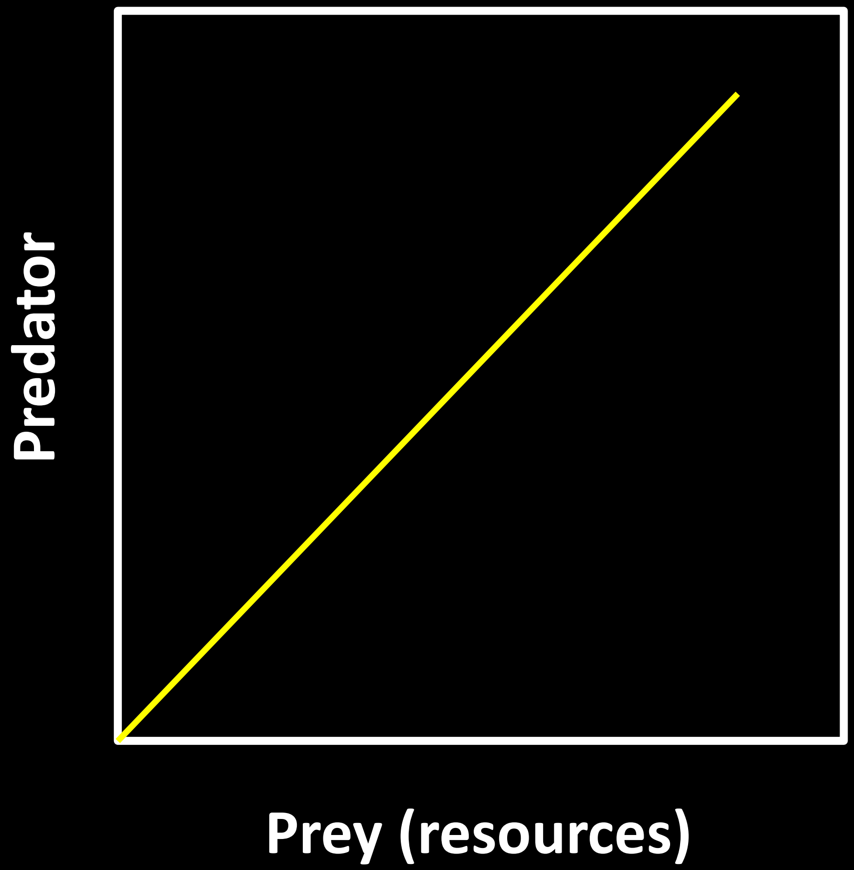
	Positive	No trend	Negative
Phosphorus inputs		X	
Phosphorus in lake			X
Water clarity	X		
Phytoplankton			X
Zooplankton		X	
Native benthic invert.			X
Dreissenid mussels	X		
Prey fish biomass			X
Piscivore biomass	X		
Piscivore stocked		X	

Common trends across three or more lakes

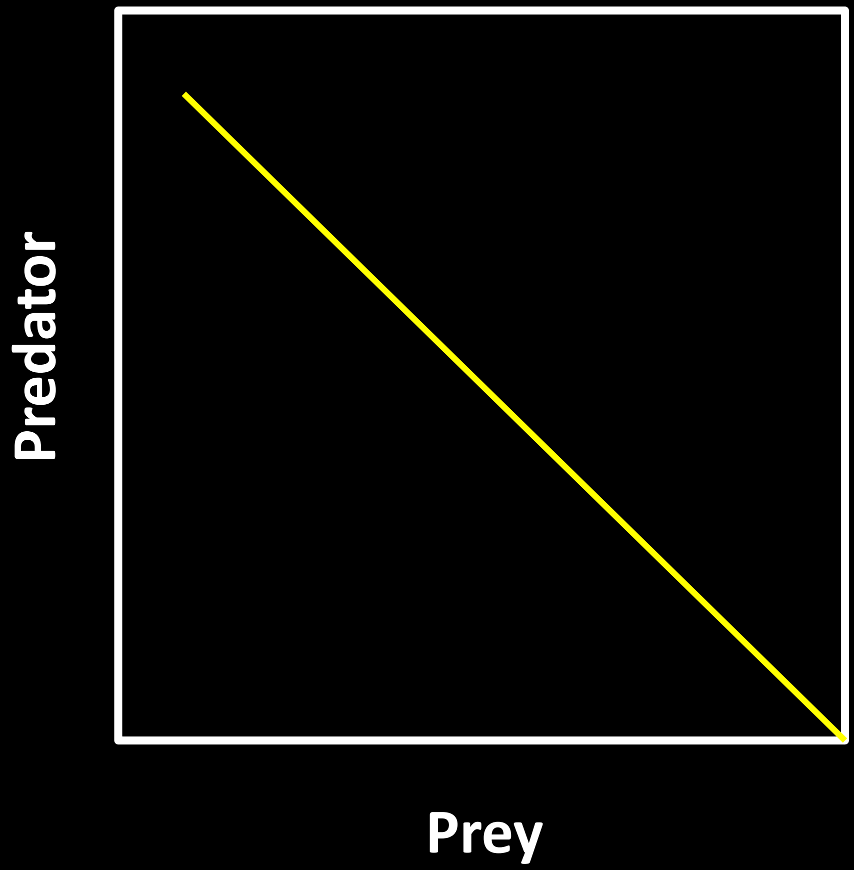
	Positive	No trend	Negative
Phosphorus inputs			
Phosphorus in lake			
Water clarity (3)	X		
Phytoplankton *(3)*			X
Zooplankton			
Native benthic invert. (3)			X
Dreissenid mussels			
Prey fish biomass (3)			X
Piscivore biomass			
Piscivore stocked			


TOP-DOWN
Salmon/trout
Prey fish
Zooplankton/
Benthic inv.
Phytoplankton
Phosphorus
BOTTOM-UP
Salmon/trout
Prey fish
Zooplankton/
Benthic inv.
Phytoplankton
Phosphorus

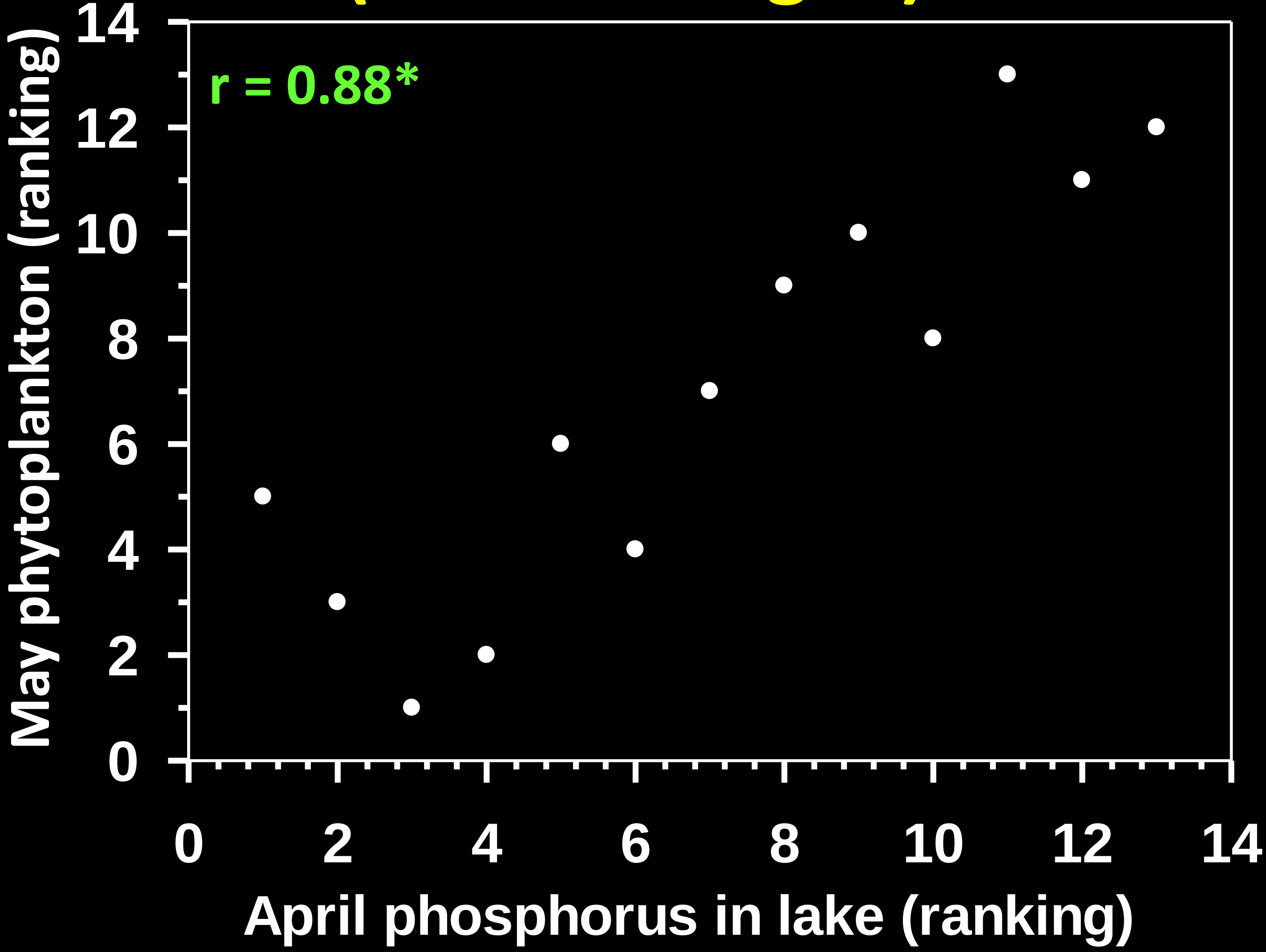
Bottom-up



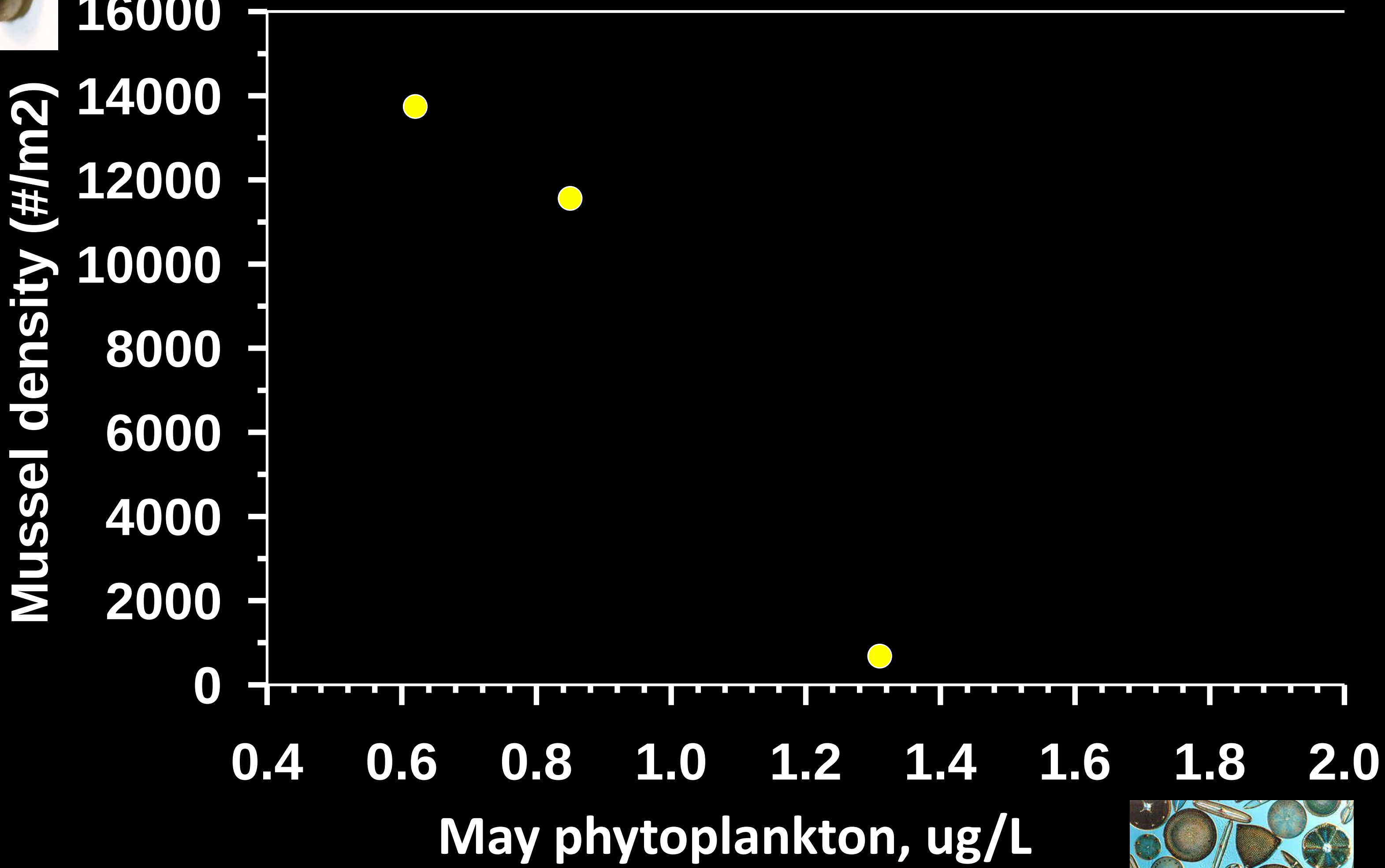
Top-down



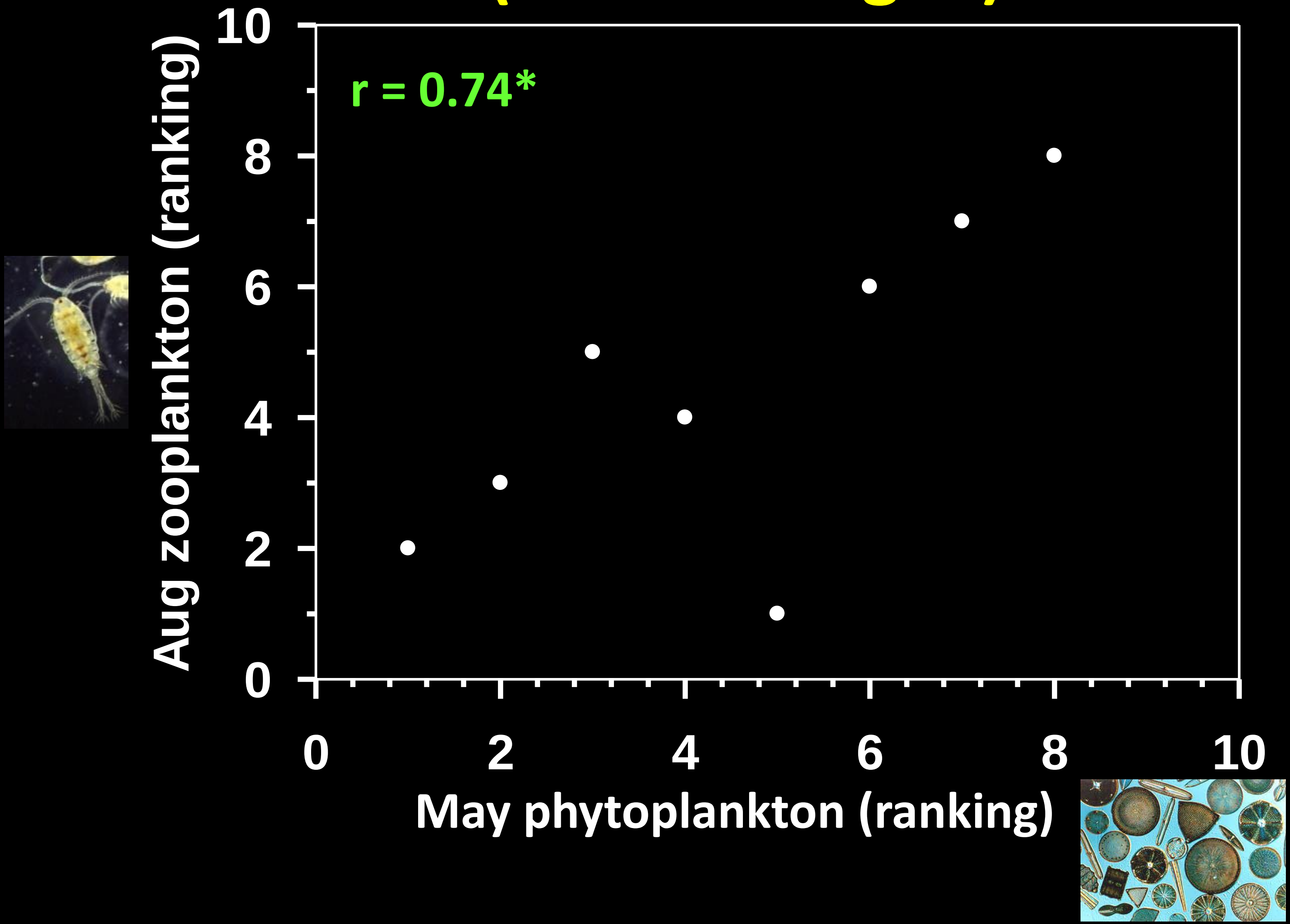
Bottom-up control of phytoplankton (Lake Michigan)



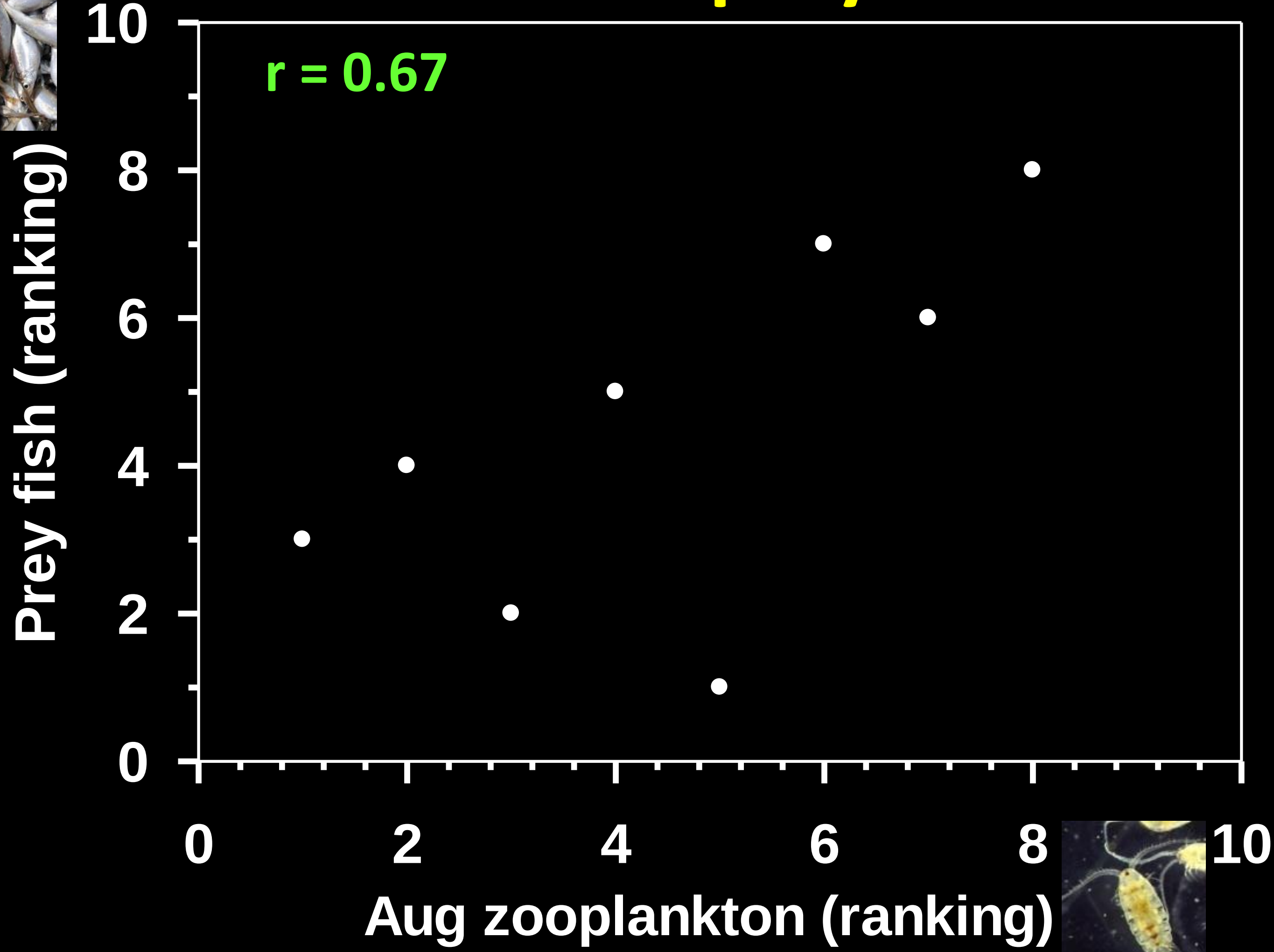
Top-down control of phytoplankton (Lake Michigan)



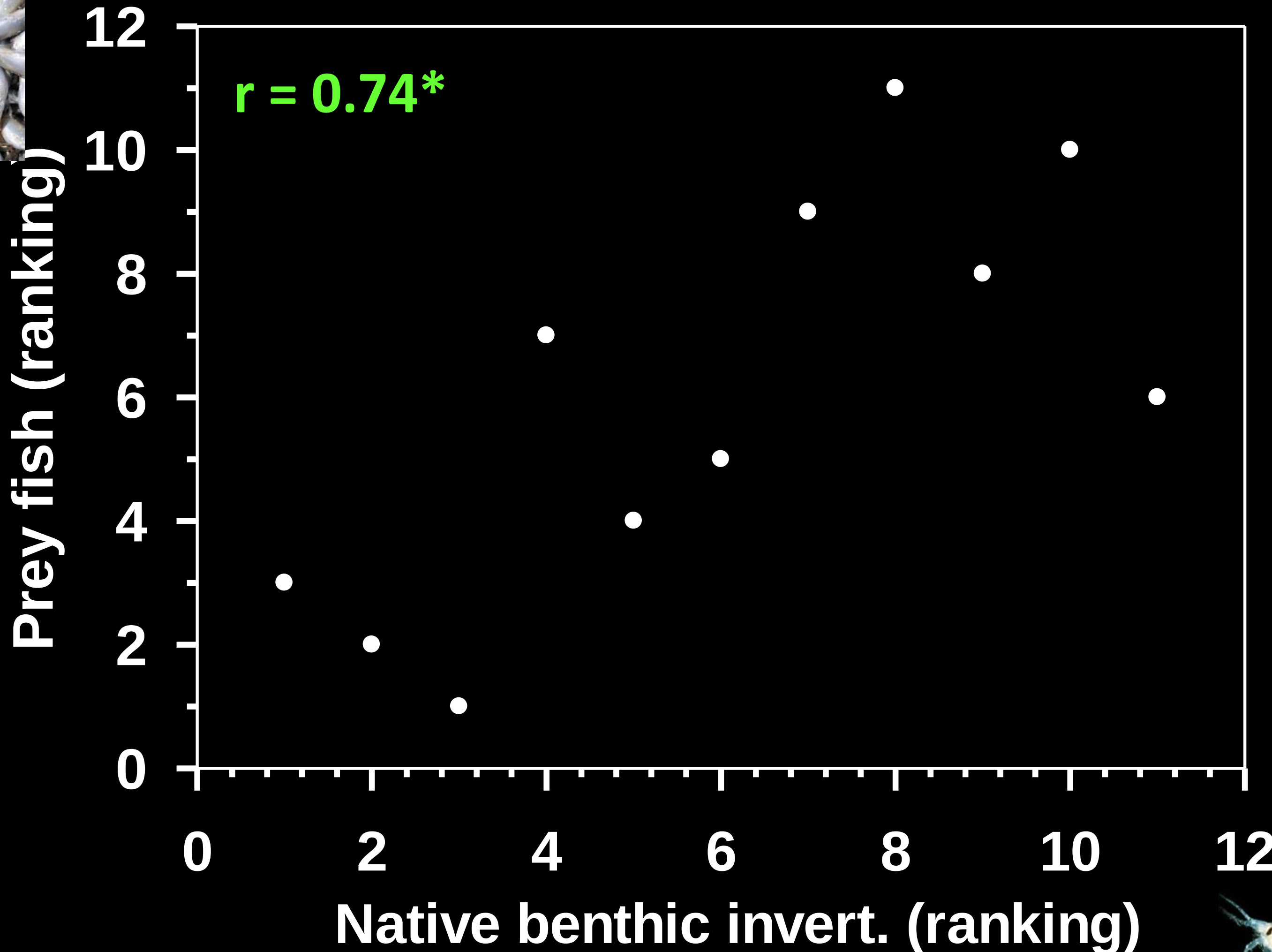
Bottom-up control of zooplankton (Lake Michigan)



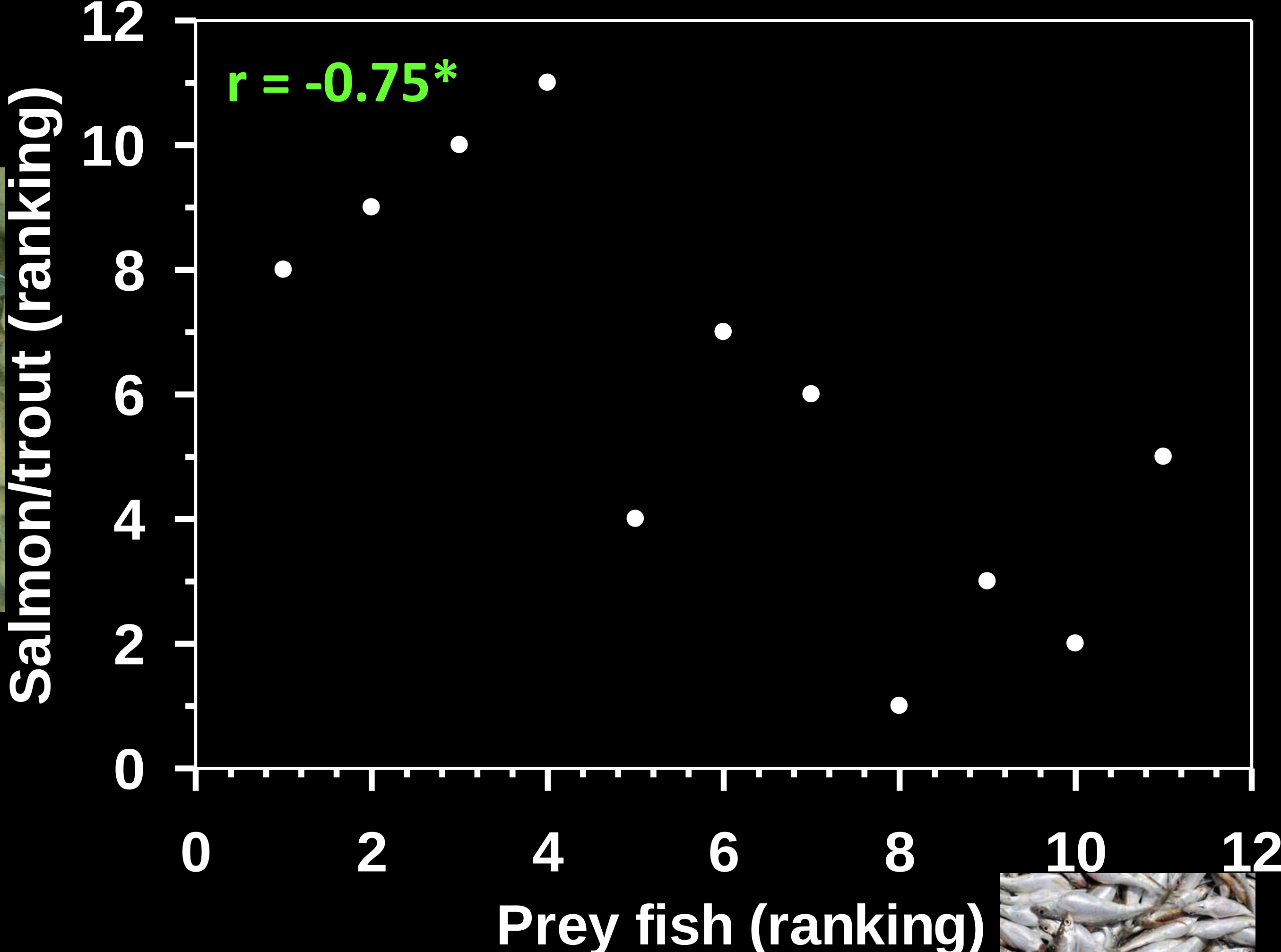
No significant pattern between ZP and prey fish



Bottom-up effect of benthos on prey fish (Lake Michigan)



Top-down effect of salmon/trout on prey fish (Lake Michigan)



Both drivers influence the Lake Michigan food web

	Bottom-up	Top-down
Phytoplankton	X	X*
Zooplankton	X	
Prey fish	X	X

Primary producers and secondary consumers are being squeezed in both directions….

Common trophic interactions across lakes

	Superior	Huron	Michigan	Western Erie	Central Erie	Ontario
Phytoplankton			B, T*			
Zooplankton			B			
Prey fish			B,T			
Piscivores						

B = Bottom-up
T = Top-down

Common trophic interactions across lakes

	Superior	Huron	Michigan	Western Erie	Central Erie	Ontario
Phytoplankton		B,T*	B, T*			
Zooplankton		B	B			
Prey fish	B	B	B,T			
Piscivores		B		B		B

B = Bottom-up

T = Top-down

Suggests pervasiveness of bottom-up regulation in the Great Lakes. Future mechanistic work required to test this hypothesis.

Today's talk:

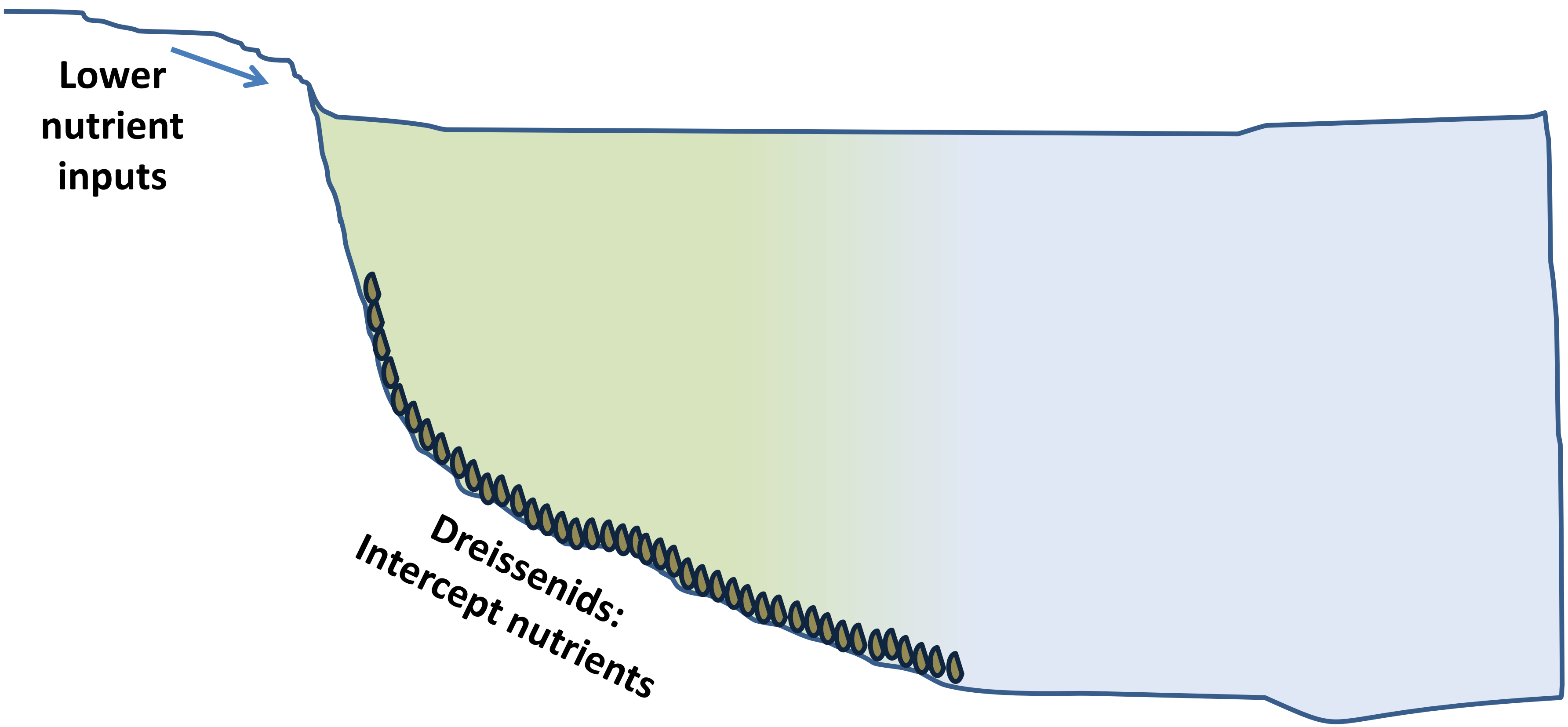
1. An ecosystem view of Lake Michigan (and other Great Lakes)

2. **Effects of lower trophic level changes on fishes.**

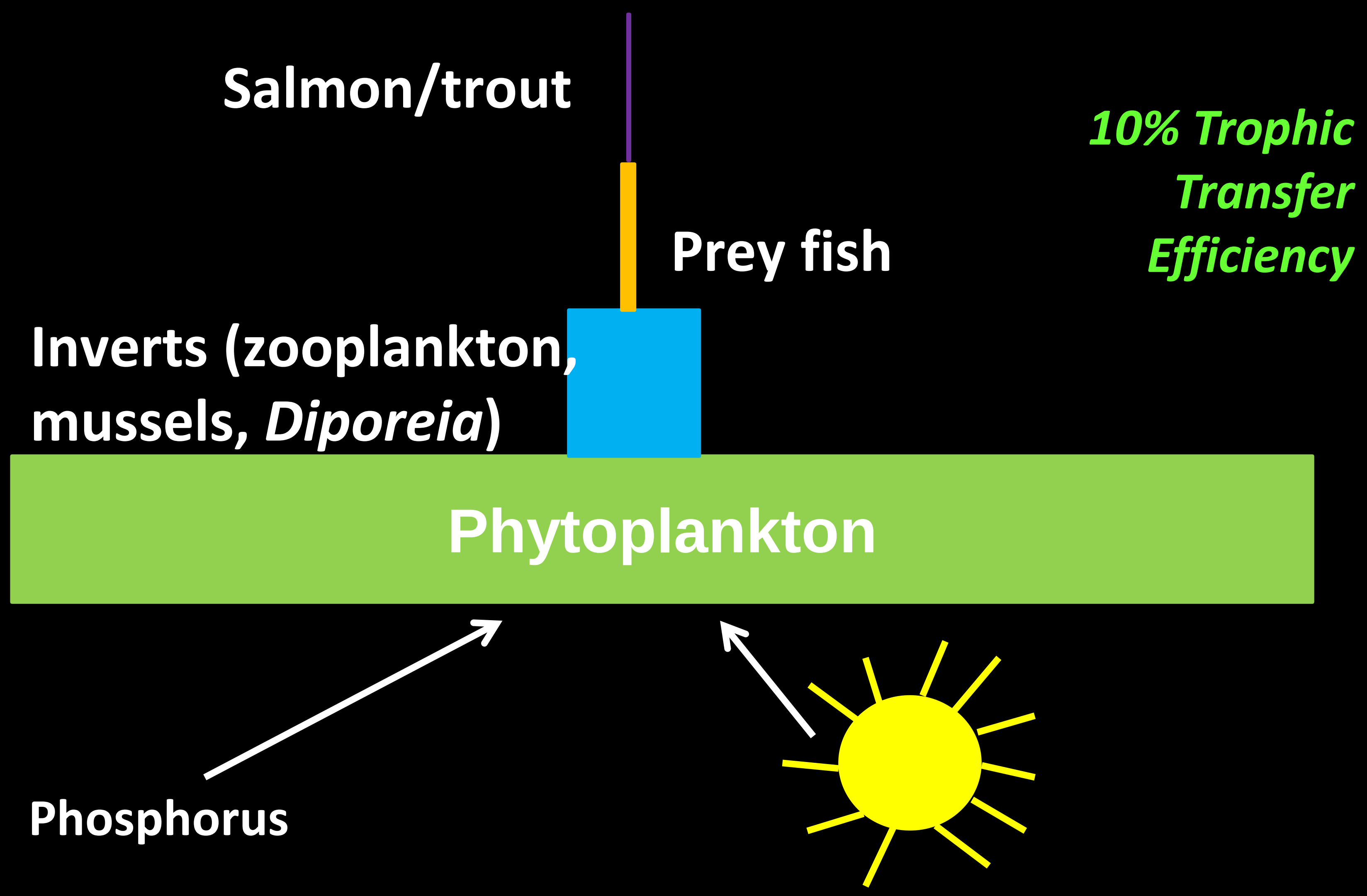
Bottom-up regulation?

- ✓ Base of the food-web is shrinking (less phosphorus, phytoplankton).
  - Long-term declines in phosphorus inputs.
  - Accelerated by dreissenid mussels sequestering phosphorus.

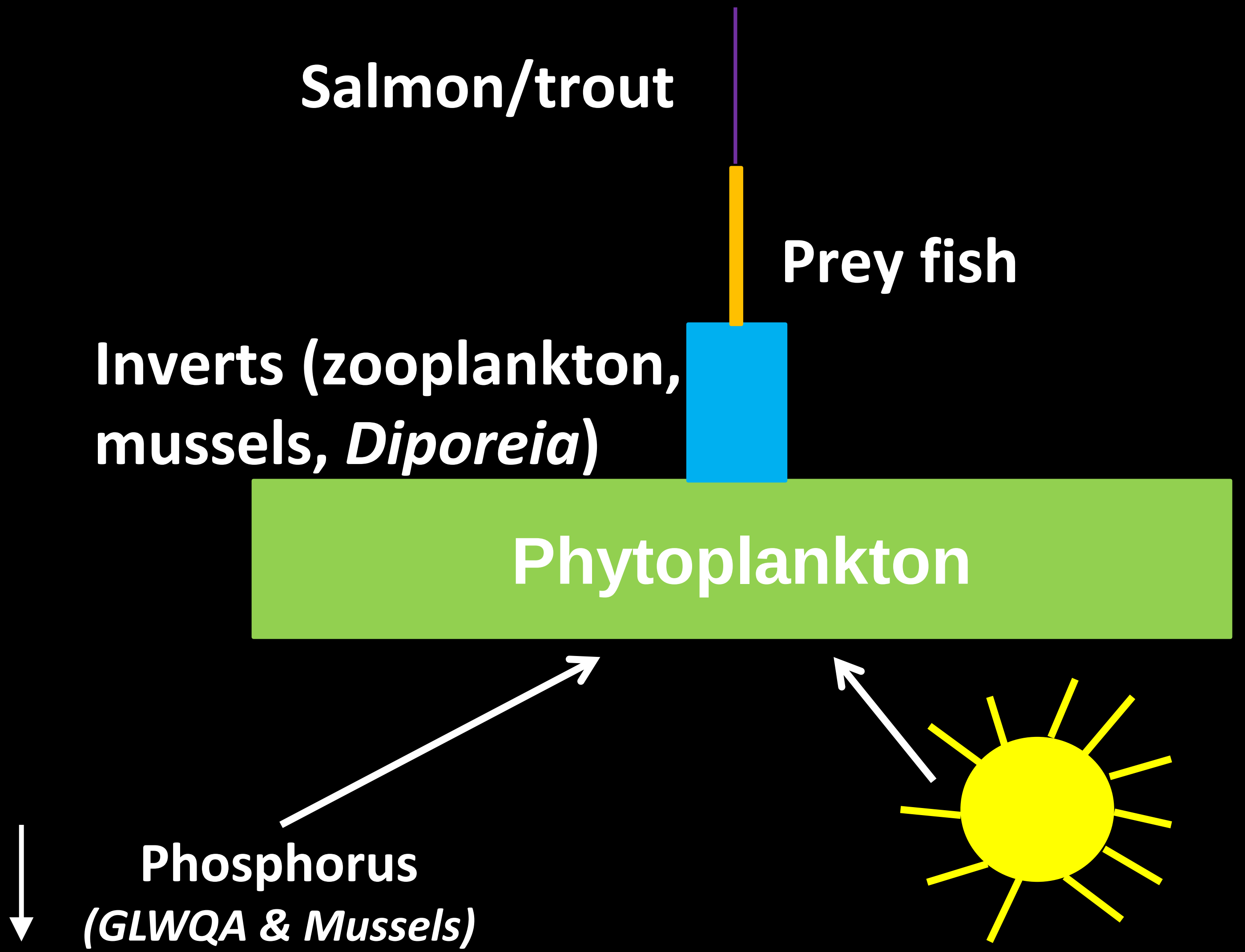
Reduction in pelagic productivity in Lake Michigan since 1970s.



Bottom-up regulation?

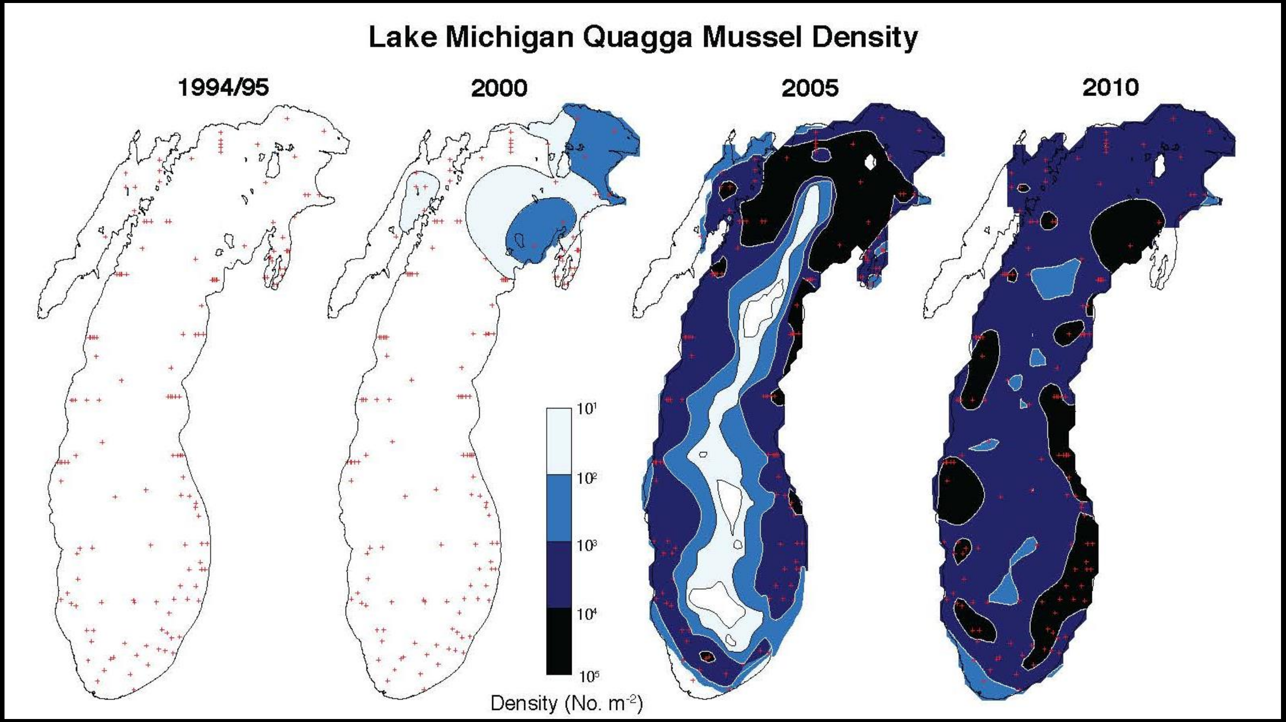


≥30% reduction in annual primary production since 1998 (Warner et al. 2015)



Quagga mussels carpet Lake Michigan

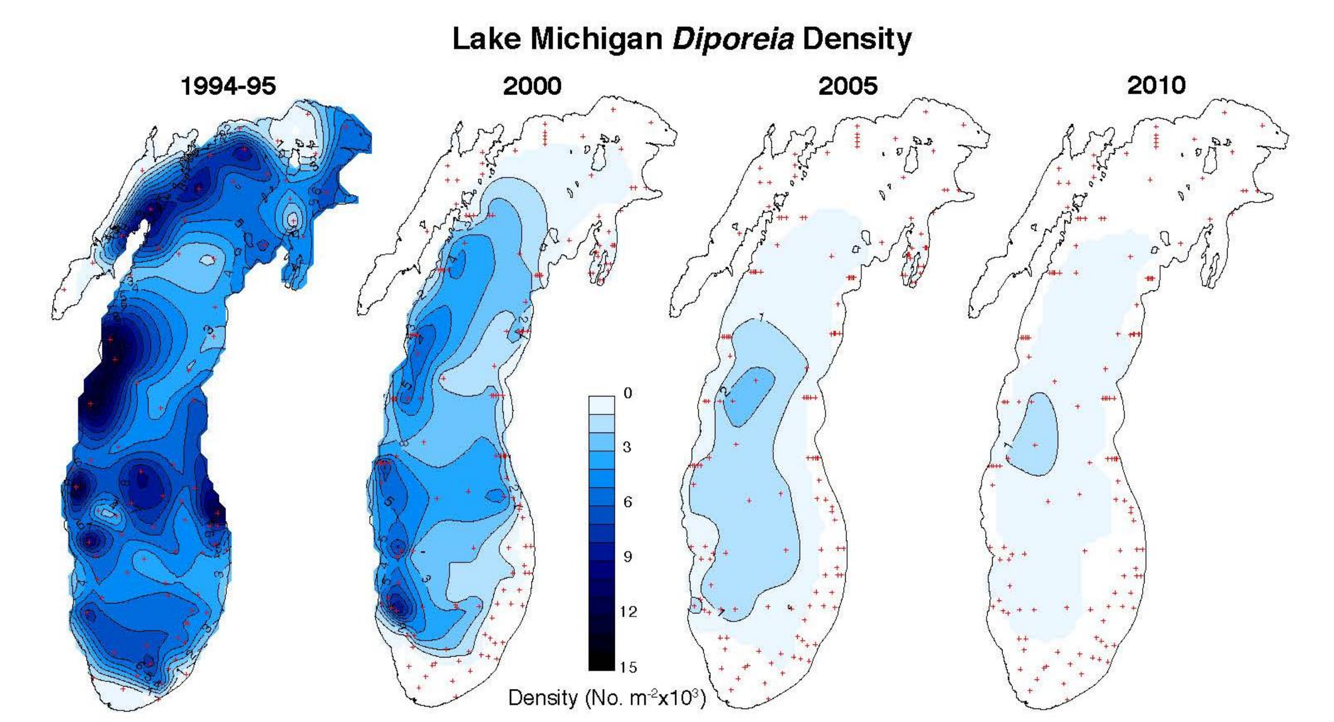
Quagga mussel



Nalepa et al. 2014

Juicy *Diporeia* are nearly gone

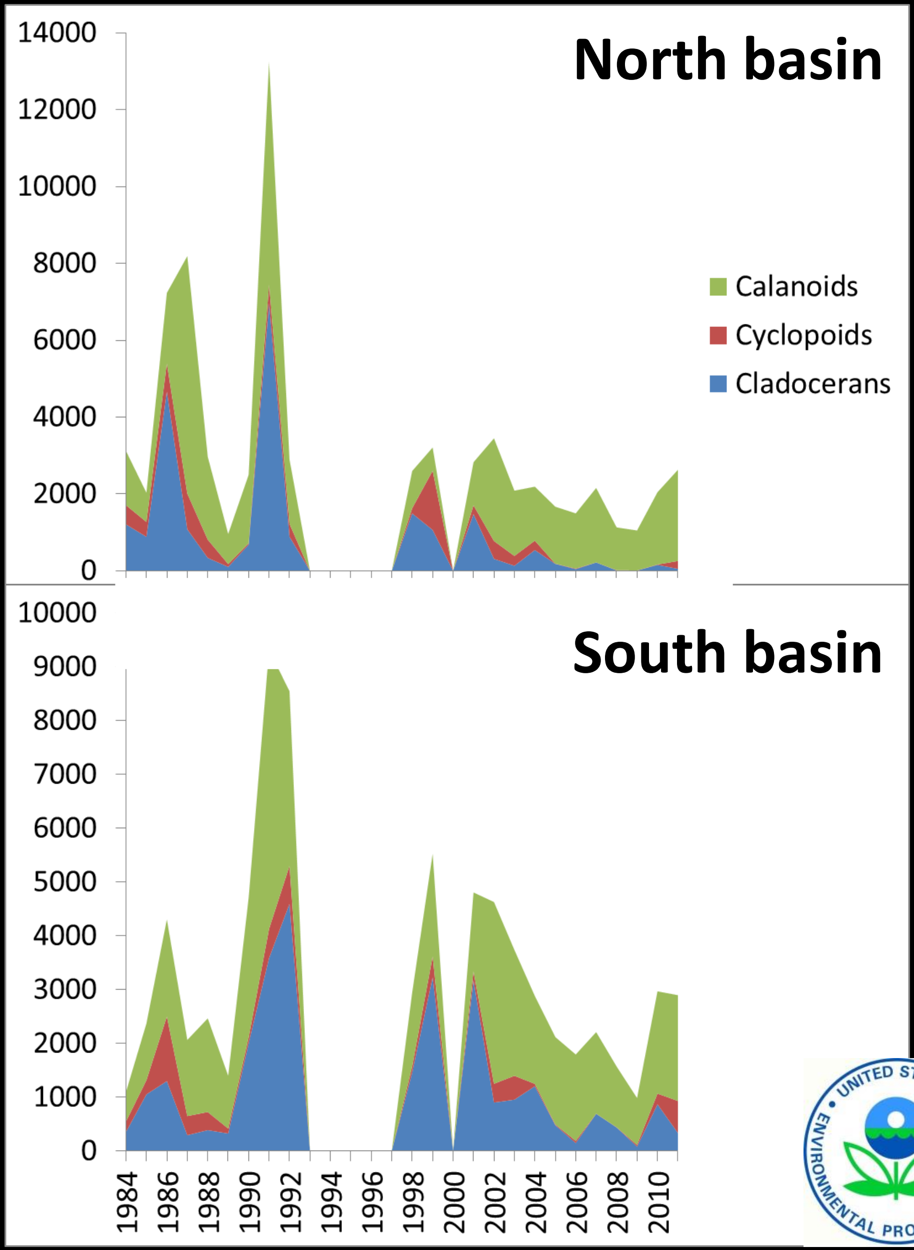
Diporeia
(amphipod)



Nalepa et al. 2014

What effect have declining nutrients and increasing mussels had on zooplankton?

Lake Michigan Zooplankton- offshore, lakewide in August

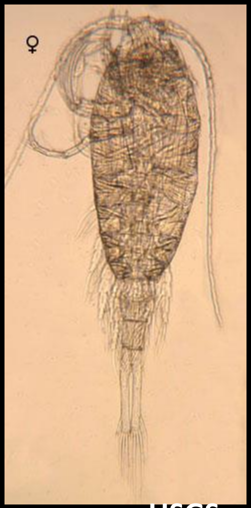


26-54% reduction in total ZP between 1984-1992 and 1998-2011.

Zooplankton community shifted to:

- “deeper” species
- Those associated with less productive waters
- More evasive species (especially for larval fish)

Calanoid copepods



USGS

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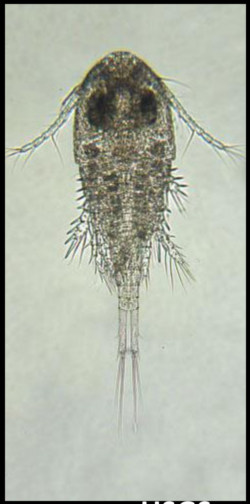
Cyclopoid copepods



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Daphnia

U. New Hampshire

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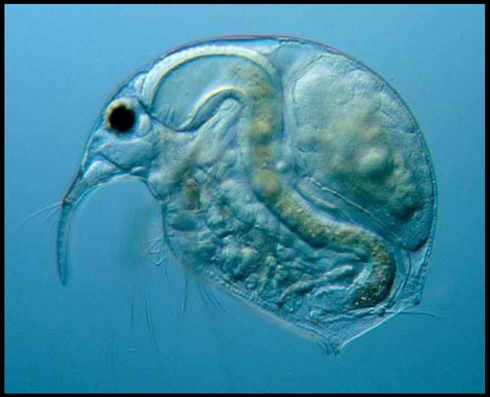
Bosmina



Florida Sea Grant

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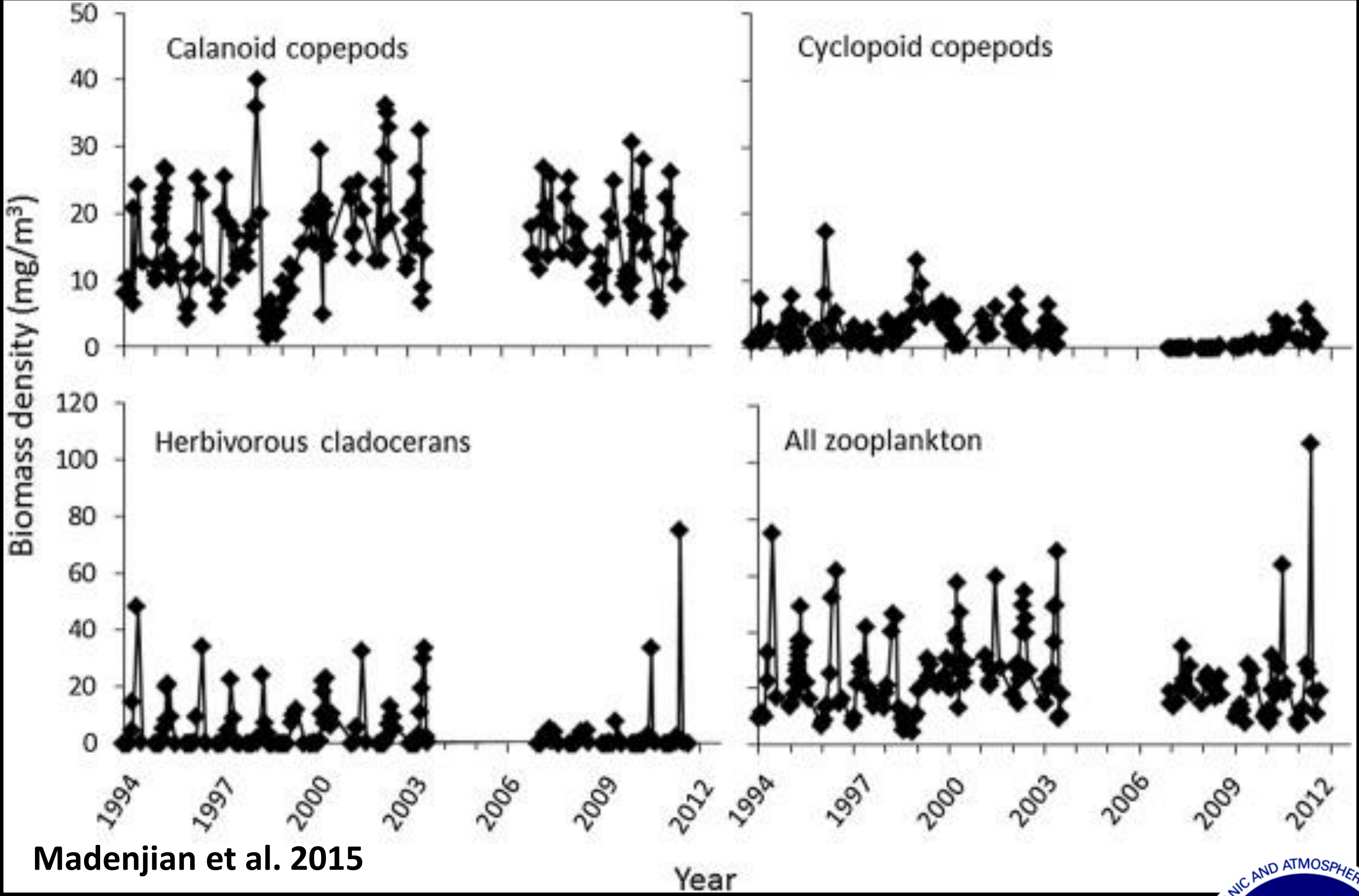
Not to scale

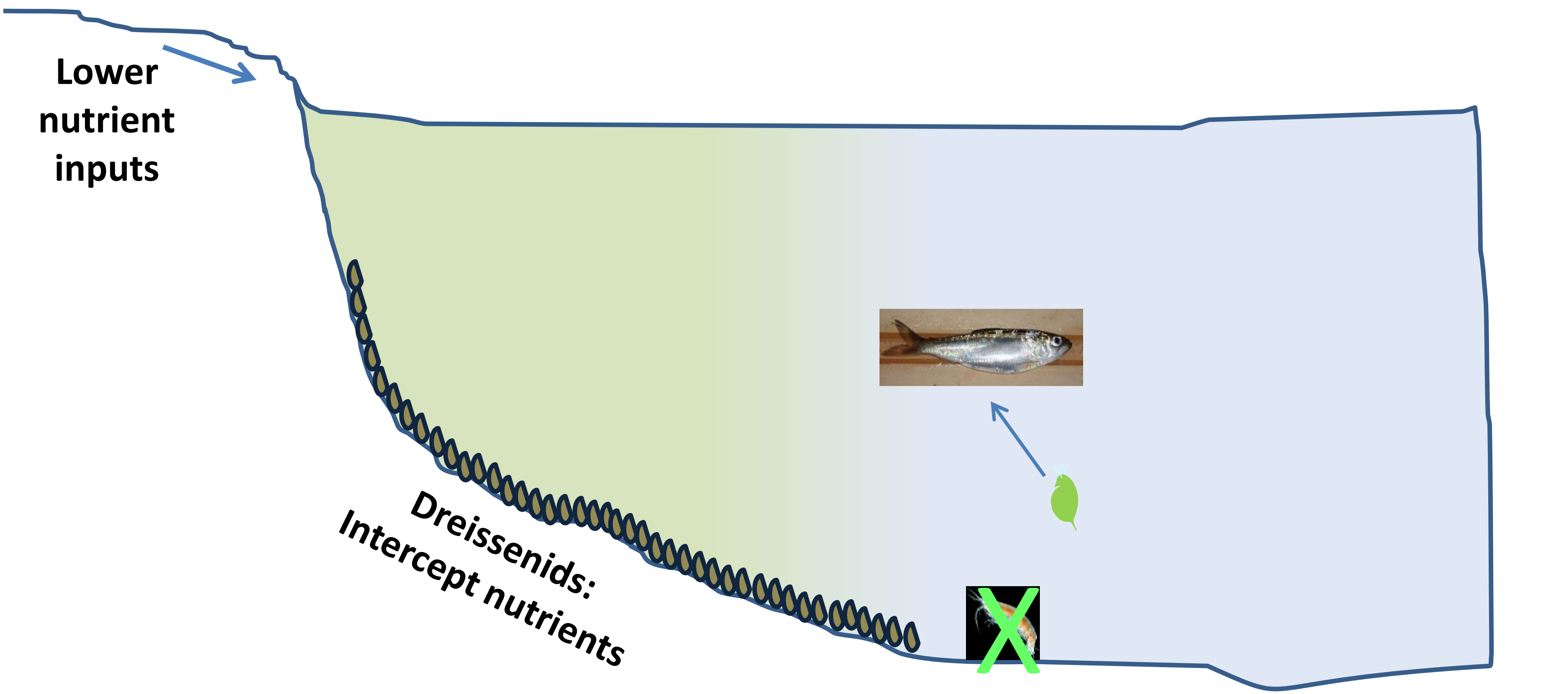
Lake Michigan Zooplankton- offshore, Muskegon monthly



Madenjian et al. 2015

- *No trend in total ZP from 1994-2011.*
- *Community composition trends similar.*

Reduction in pelagic productivity in Lake Michigan since 1970s.



Bottom-up regulation?

- ✓ **Are documented changes in lower primary production affecting fish?**
  1. **<u>Larval fish could be starving in 2010-2011</u>** **<u>(Withers et al. 2015).</u>**
     - **79-87% of larval alewife (post yolk-sac absorption) had empty stomachs.**

Photo: Eppehimer, USGS

Bottom-up regulation?

- ✓ Are documented changes in lower primary production affecting fish?
  1. Larval fish could be starving in 2010-2011 (Withers et al. 2015).
     - 79-87% of larval alewife (post yolk-sac absorption) had empty stomachs.
     - Those larvae with food were eating quagga mussel veligers or diatoms (not small zooplankton).
     - In 2001-2002, 43-87% of larval alewife had empty stomachs (Höök 2005).
     - 54% of larval yellow perch in 2010-2011 (post yolk-sac absorption) had empty stomachs.
  - Could limit larval survival and lead to lower numbers of alewife or yellow perch.

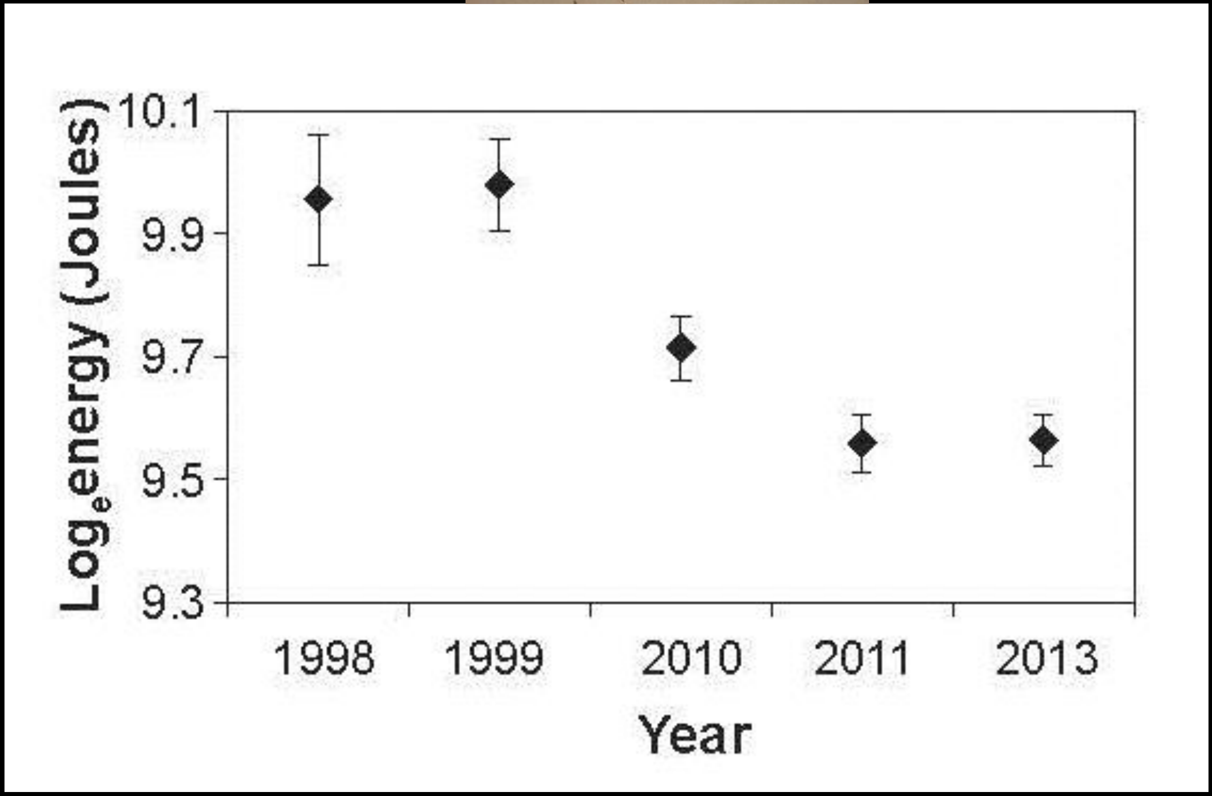
Bottom-up regulation?

- ✓ **Are documented changes in lower primary production affecting fish?**

  1. Larval fish could be starving in 2010-2011 (Withers et al. 2015).

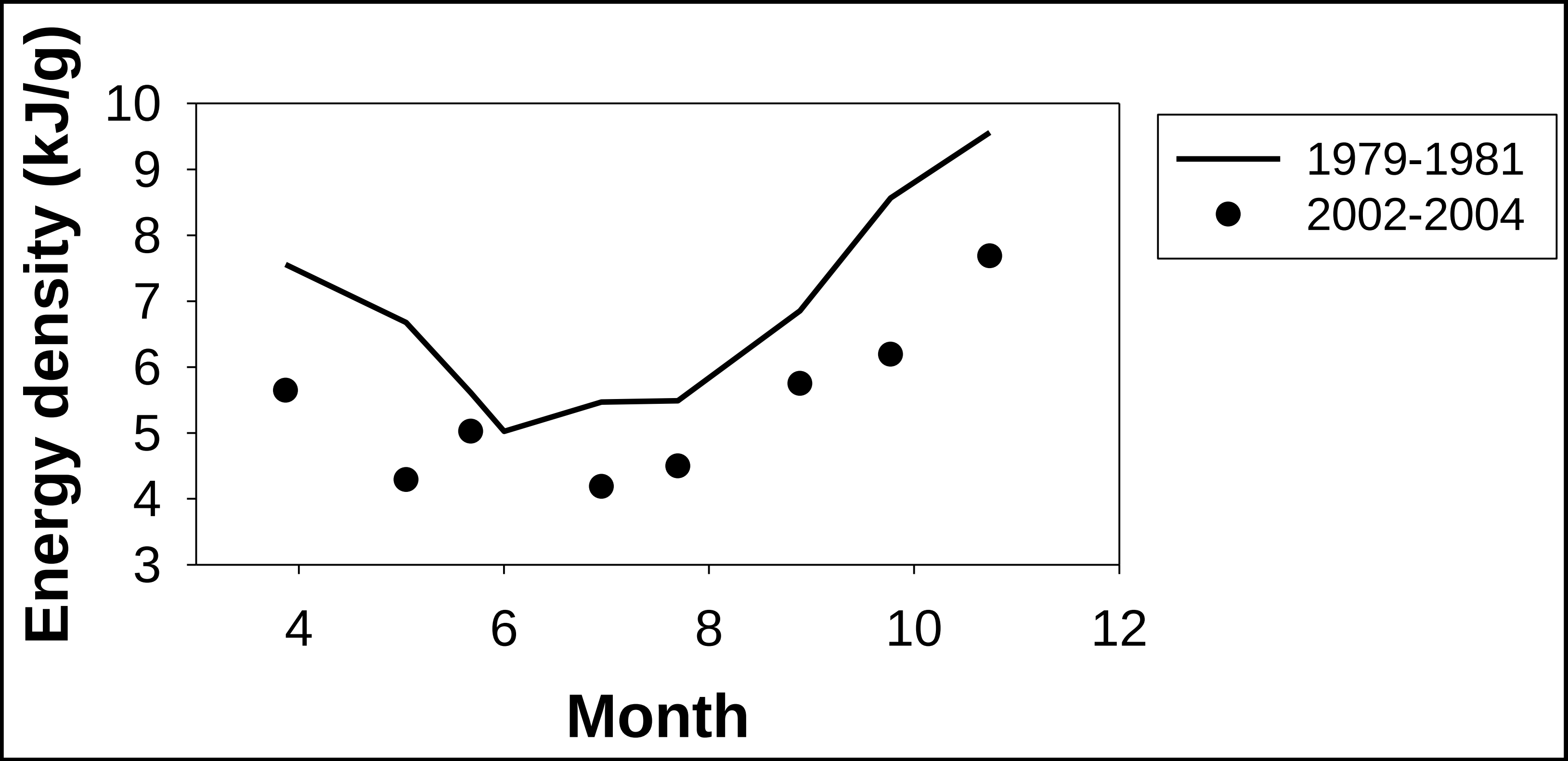
  2. Adult fish are in poorer condition, despite reduced numbers.

- Age-1 alewife energy density declined 33% between 1998-1999 and 2010-2013 (Pothoven et al. 2014)- Muskegon transect.



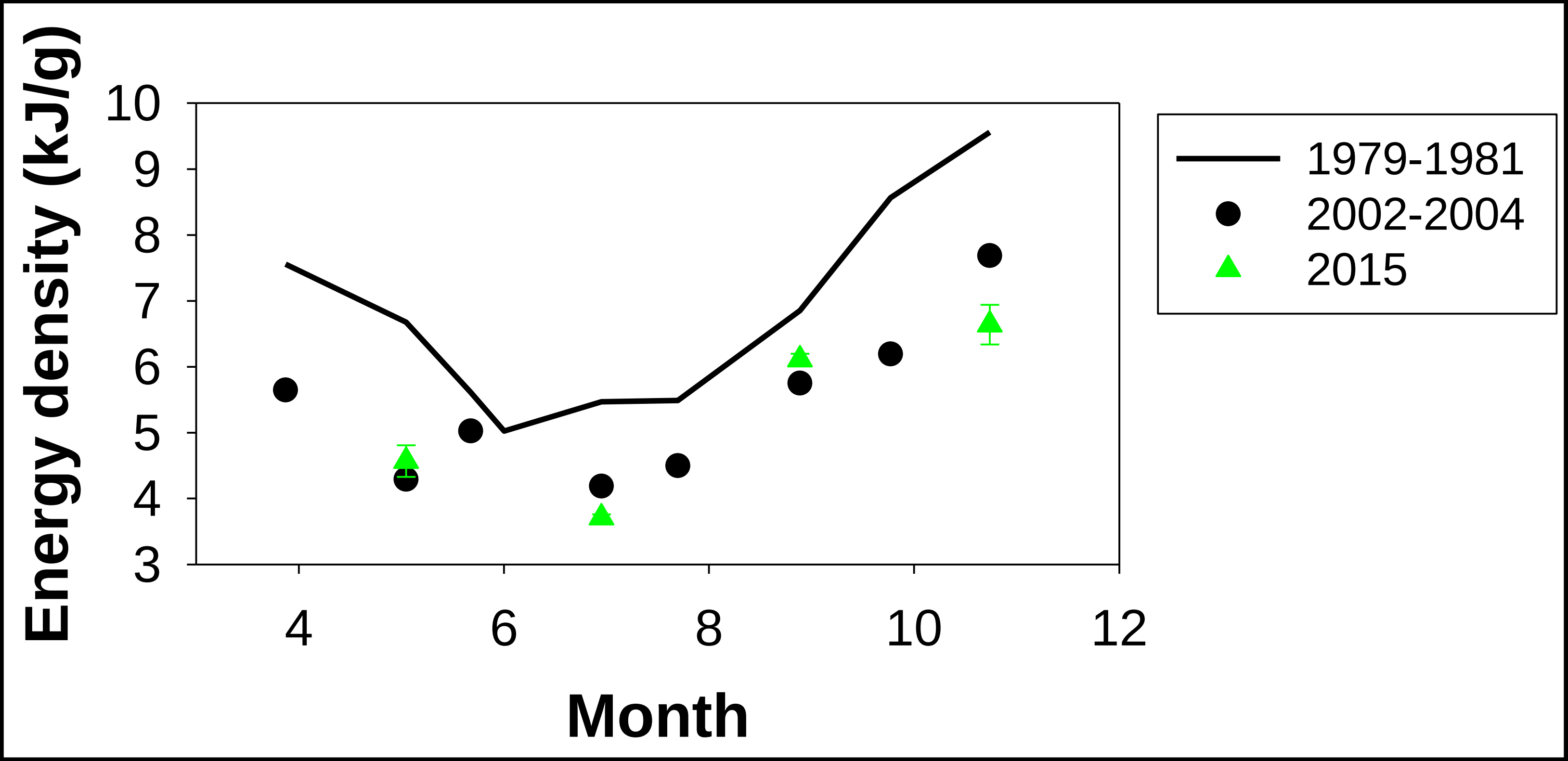
Pothoven et al. 2014

- Alewife (>5 inches) energy density declined <u>23%</u> in 2002-2004 relative to 1979-1981 (Madenjian et al. 2006)- lakewide.



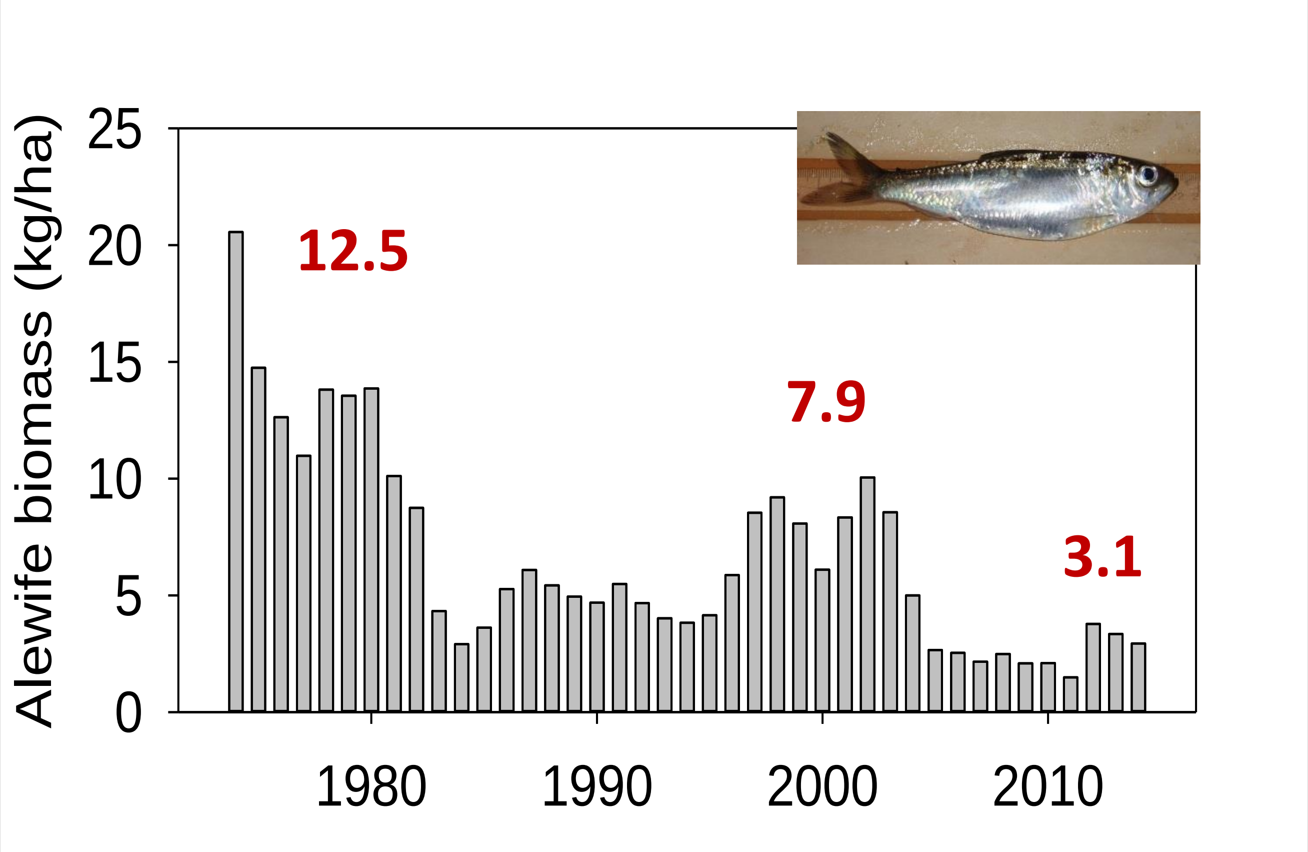
Madenjian et al. 2006

- **Alewife (>5 inches) energy density declined 23% in 2002-2004 relative to 1979-1981 (Madenjian et al. 2006)- lakewide.**
  ……and 2015 similar to 2002-2004

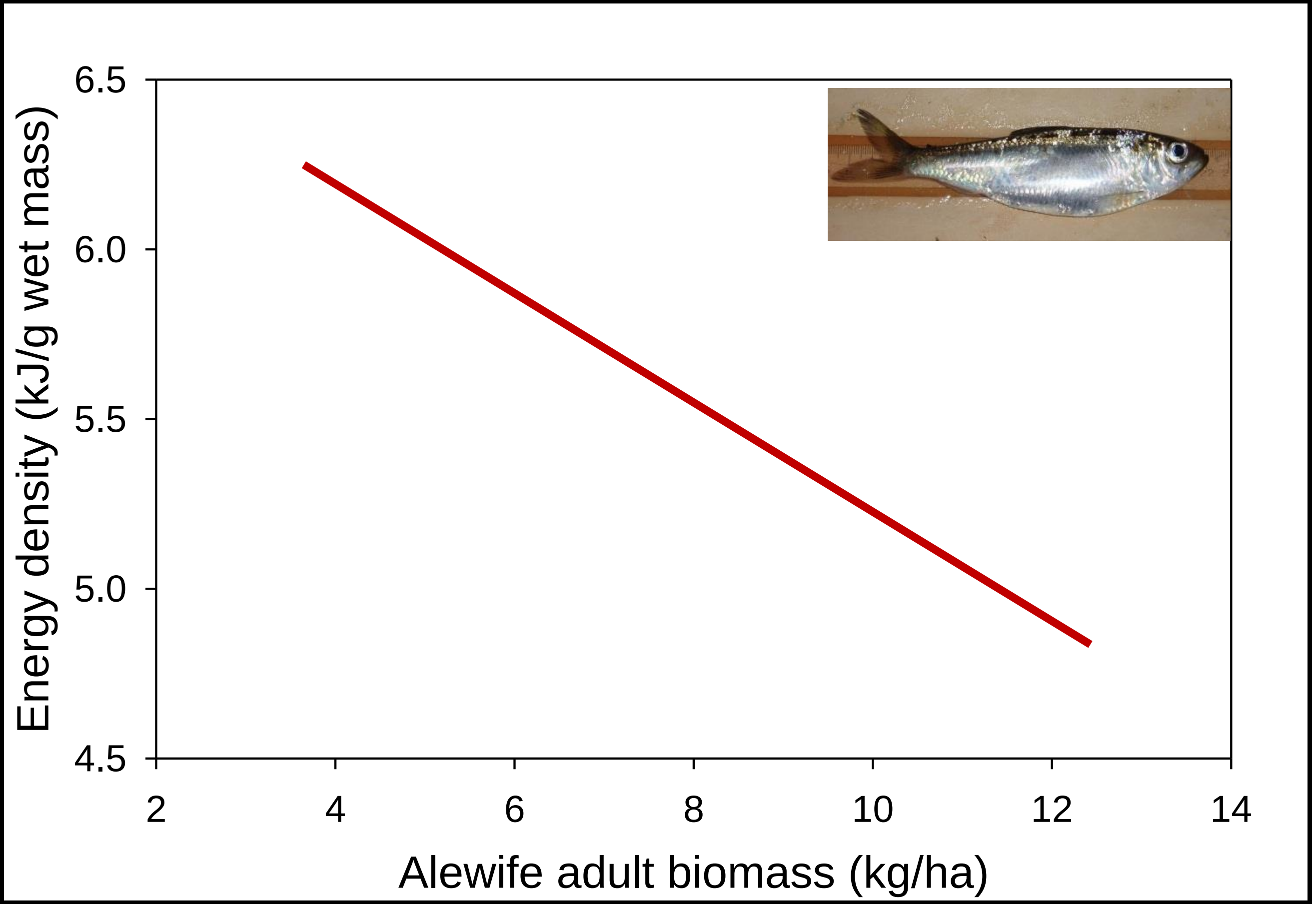


Madenjian et al. 2006, USGS unpublished data

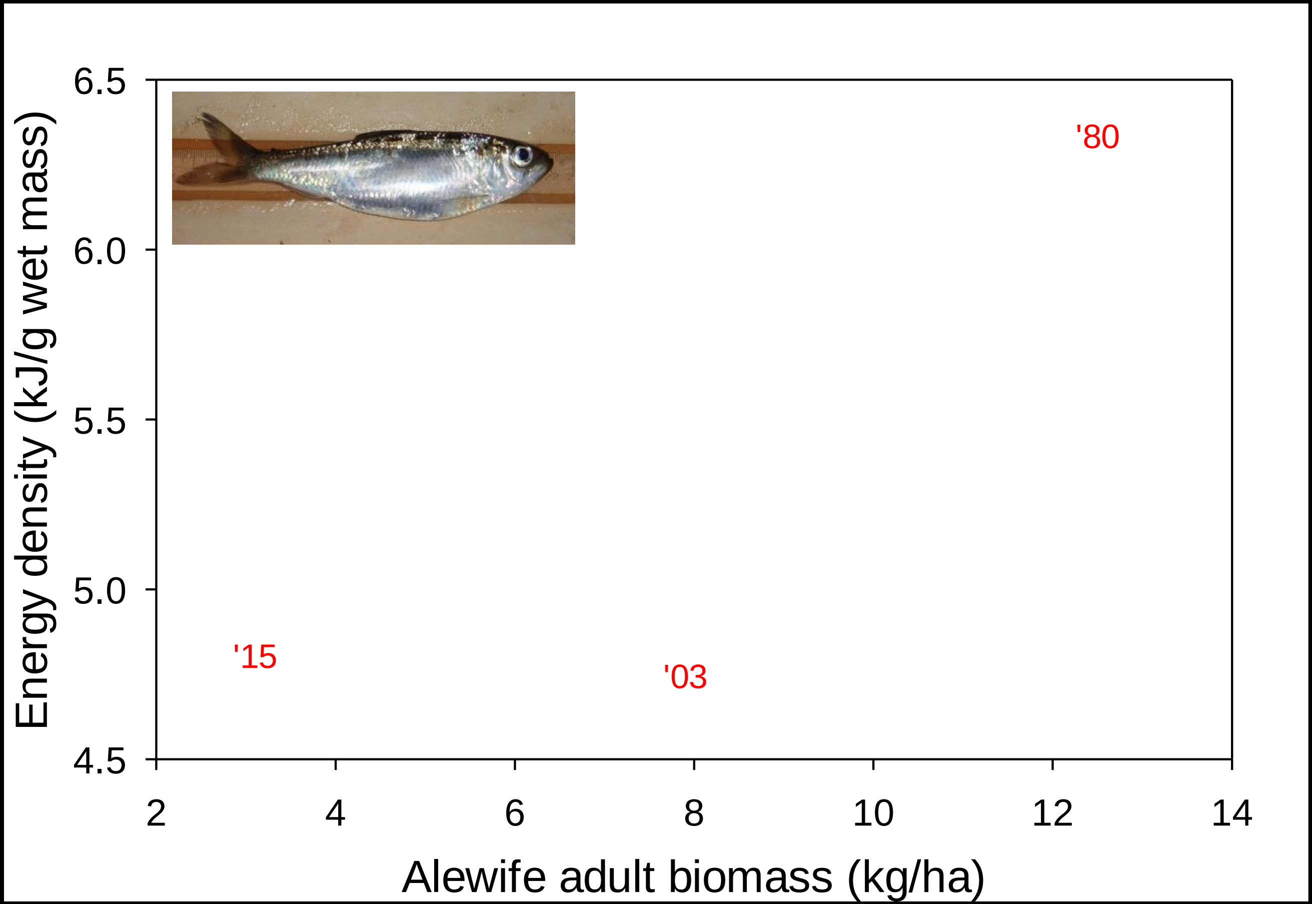
Alewife biomass is lower in 2015 than in earlier time periods.



Would expect physiological condition to decline with increasing population size.

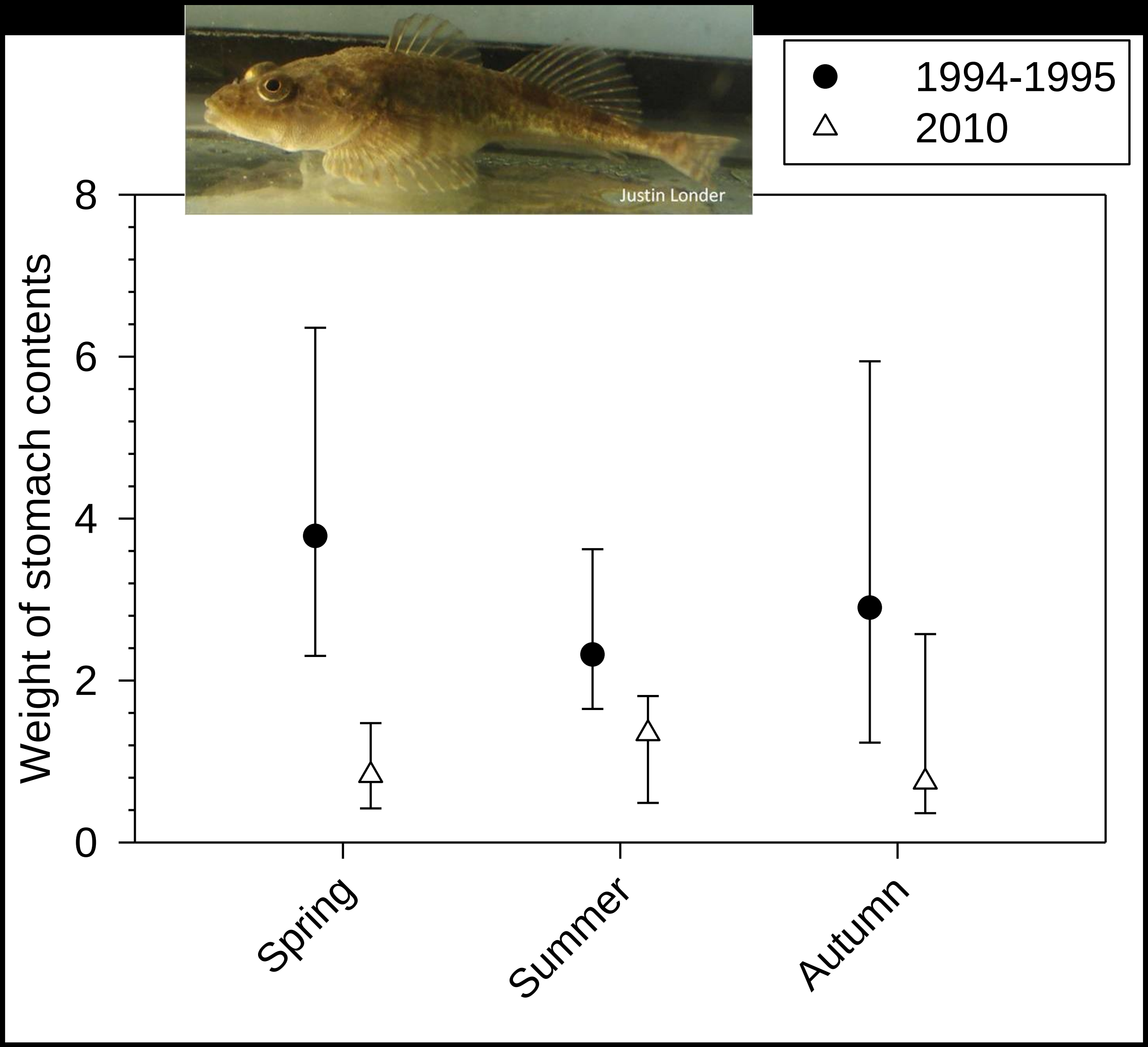


Physiological condition is unrelated to population size.

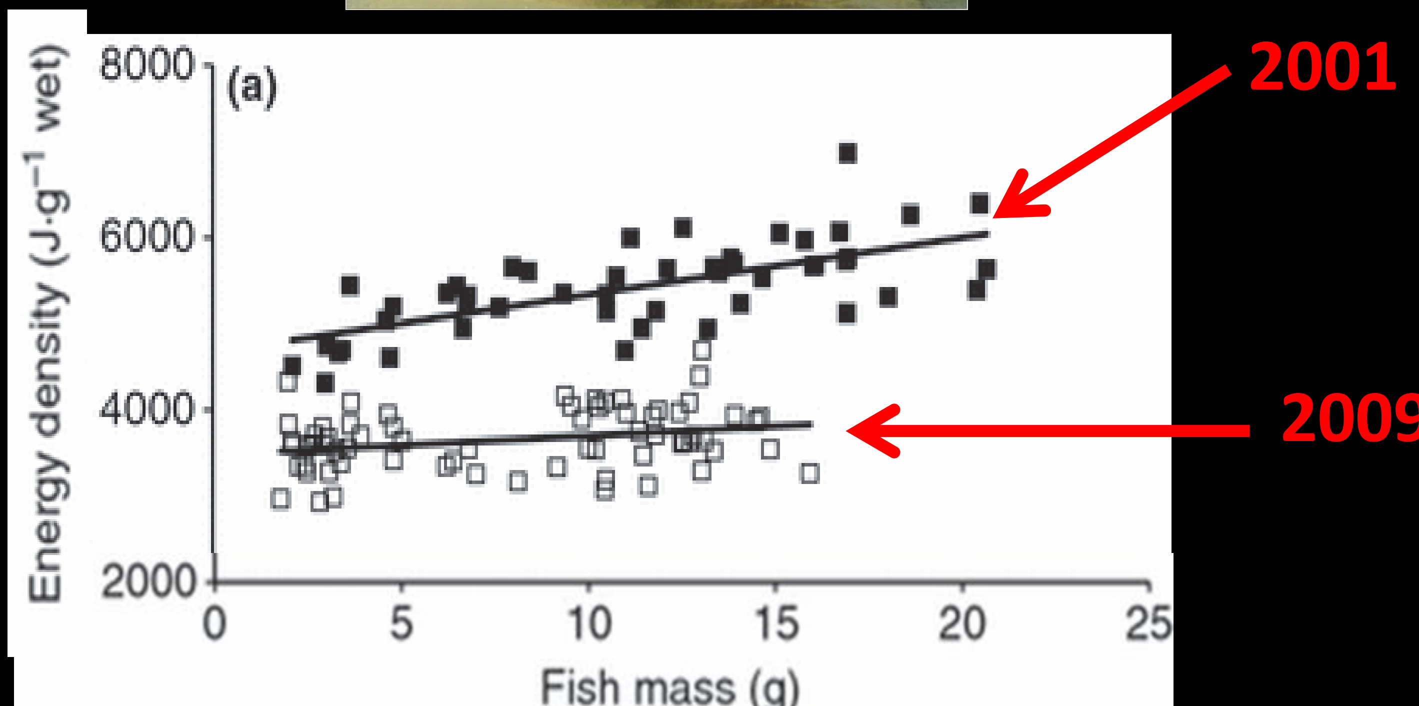


Madenjian et al. 2006, USGS unpublished

- Deepwater sculpin had <u>65% less food in their stomachs</u> in 2010 than in 1994-1995 (Bunnell et al. 2015)



- Deepwater sculpin energy density declined <u>29%</u> between 2001 and 2009 (Pothoven et al. 2011)



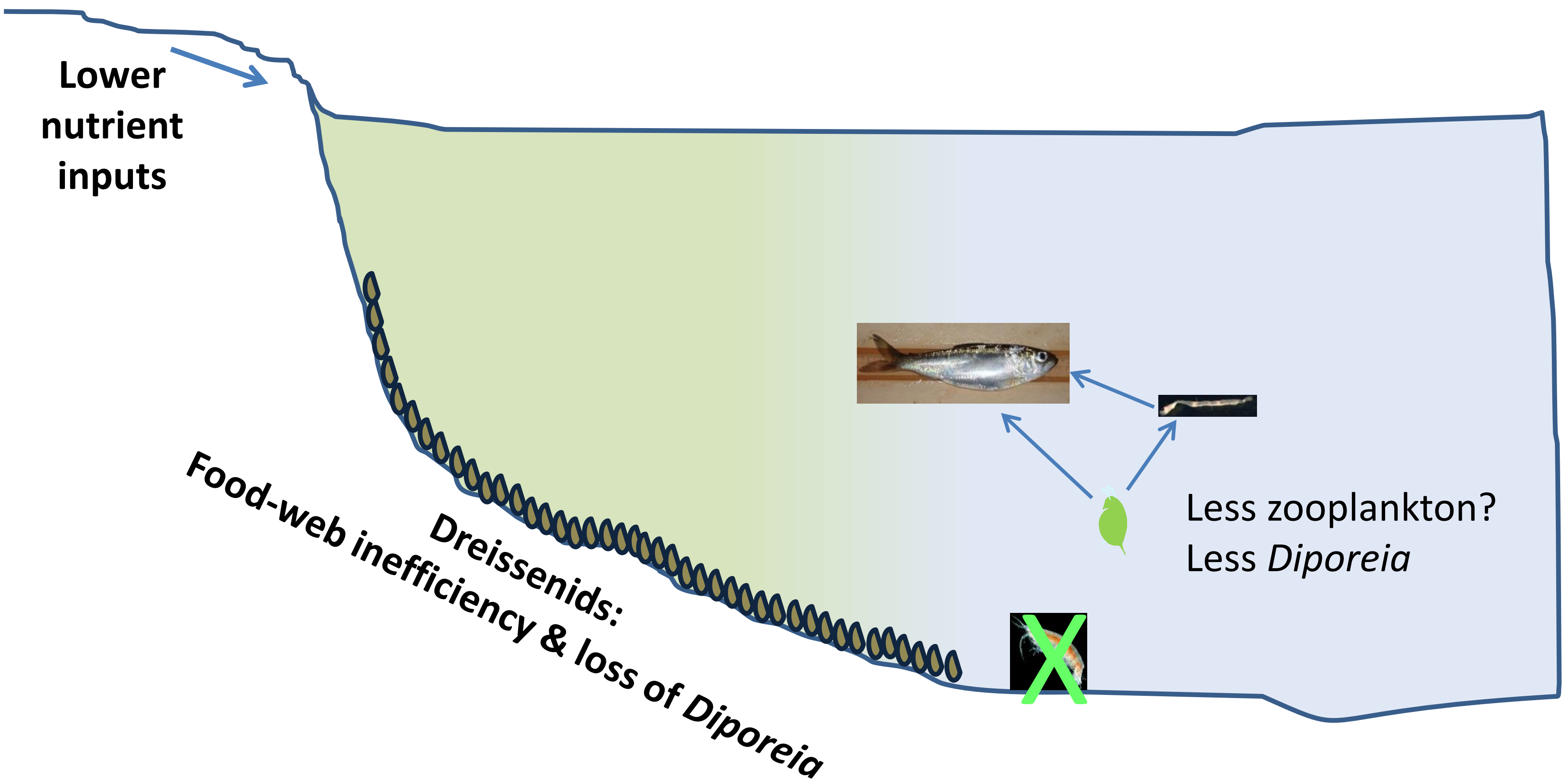
Pothoven et al. 2011

- **Deepwater sculpin energy density declined 29% between 2001 and 2009 (Pothoven et al. 2011)**

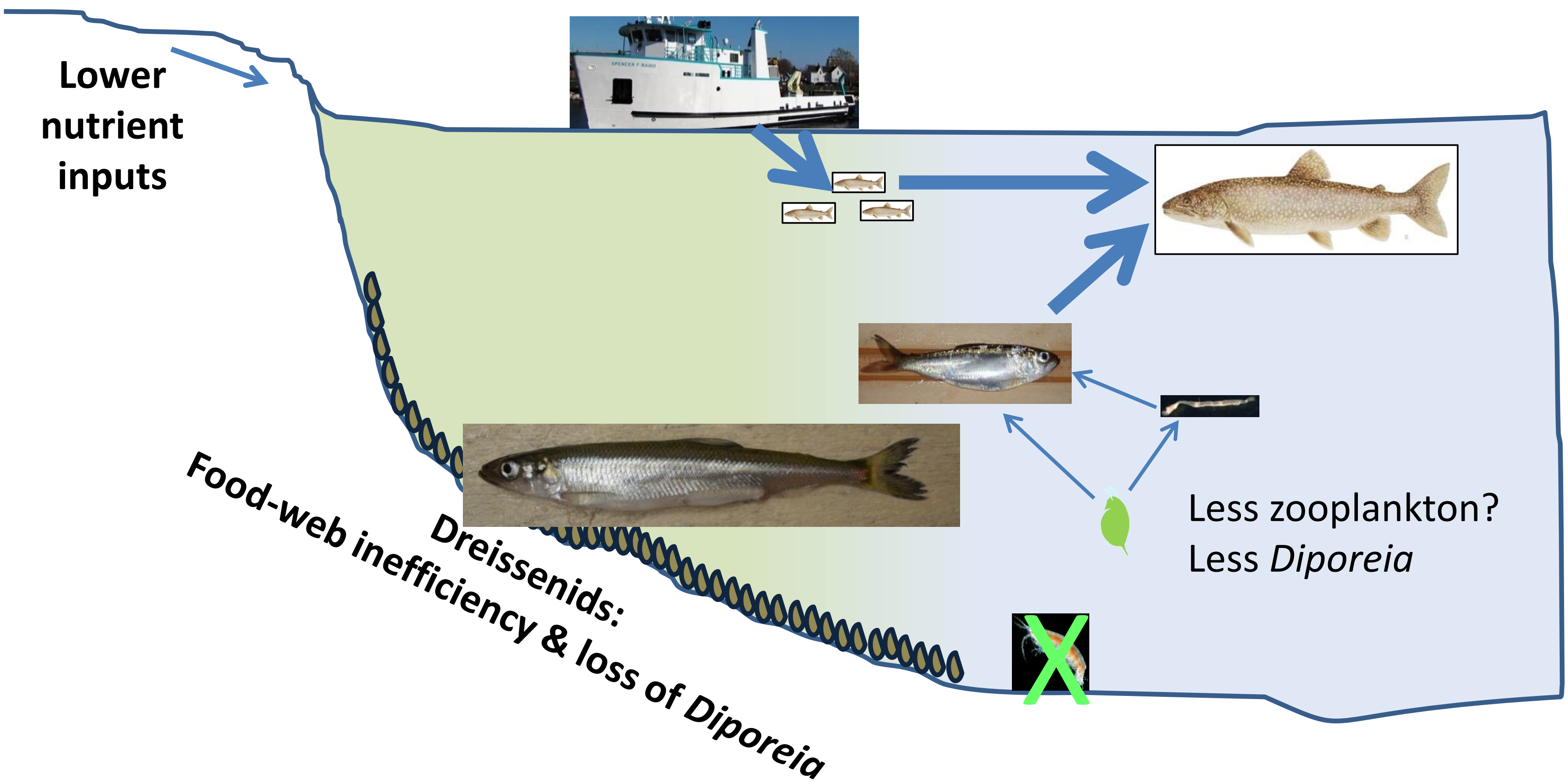
- **Deepwater sculpin were 80% more abundant in 2001 than 2009, so not driven by density-dependence.**

- **Loss of *Diporeia* as high-calorie prey item is most likely explanation for declining physiological condition.**

Changing Lake Michigan food web (since 1970s)



Changing Lake Michigan food web (since 1970s)



Today's talk:

1. Ecosystem-level trends across the Great Lakes

2. Effects of lower trophic level changes on fishes.

3. Impacts of climate change-
   "Synchronize" production of fish (or good and bad years)

Spatial synchrony occurs within Great Lakes fish populations

- ✓ Bloater- Lakes Superior, Huron, Michigan (~800 km): Bunnell et al. 2010

- ✓ Cisco- Lake Superior and inland lakes (~400 km): Myers et al. 2015

- ✓ Yellow perch- Lakes Erie, Huron, Michigan, Ontario (~150 km): Honsey et al. in review

What synchronizes animal populations?

1. <u>Moran effect</u> - spatially autocorrelated climate synchronizes disparate populations that have a similar density-dependent structure

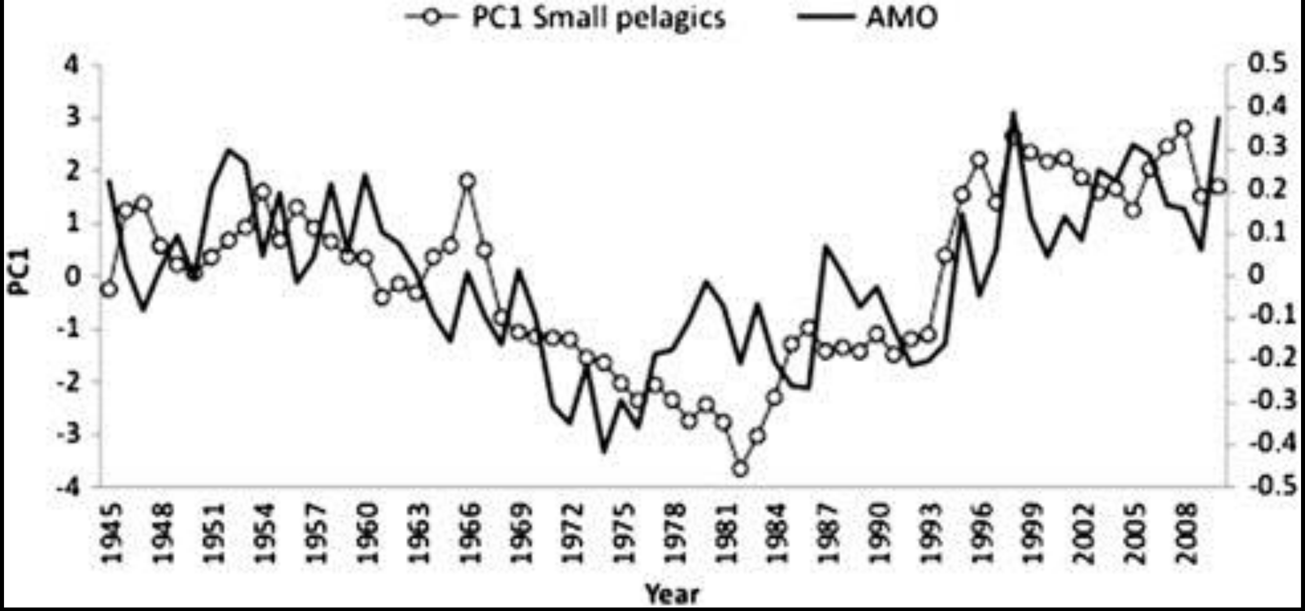
2. <u>Dispersal</u> – locally strong year-classes disperse to synchronize disparate populations

3. <u>Predation</u> – mobile predators synchronize disparate prey populations

Synchrony across species has been documented

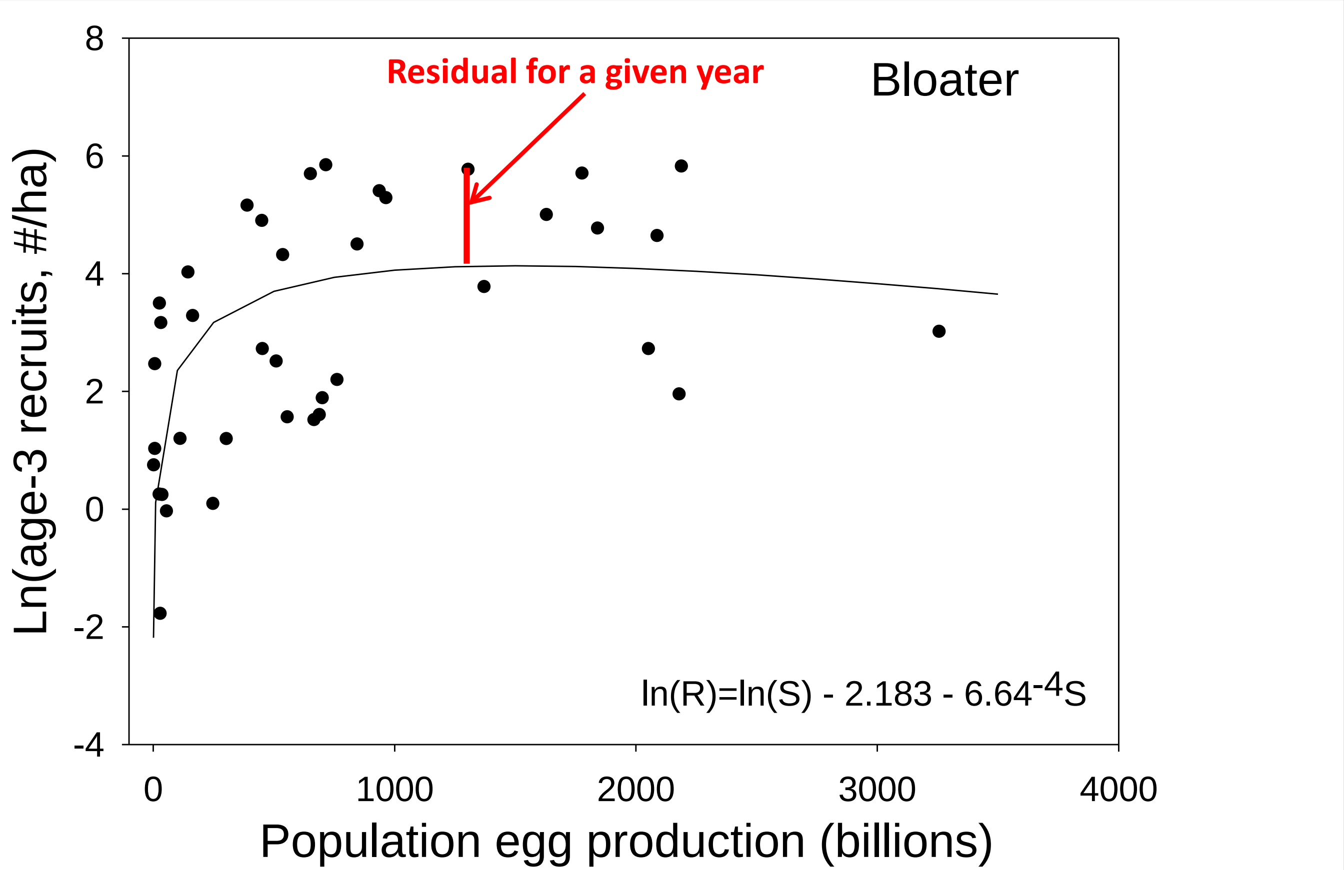
- ✓ **Georges Bank groundfish- common "exceptional" years related to North Atlantic Oscillation (Brodziak and O'Brien 2005).**
- ✓ **Small pelagic fish in eastern Atlantic Ocean related to Atlantic Multidecadal Oscillation (Alheit et al. 2014).**

+ correlated with herring, anchovy, sardine landings



Approach to evaluating synchrony across species in Lake Michigan to detect a climate signal

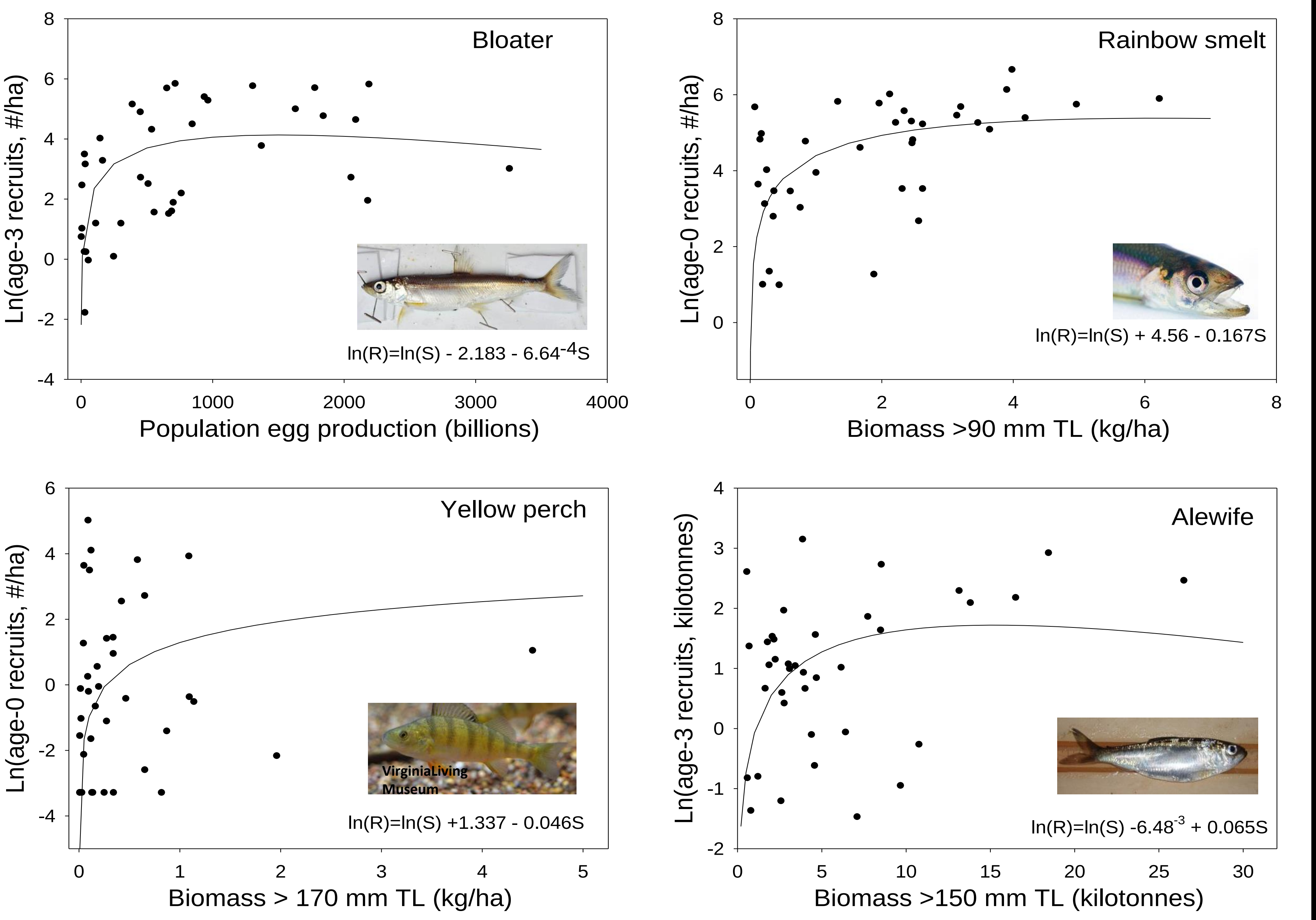
1. Estimate stock-recruit relationship for each species. Estimate the residual- unexplained variation due to environmental factors or measurement error.



Approach to evaluating synchrony across species in Lake Michigan to detect a climate signal

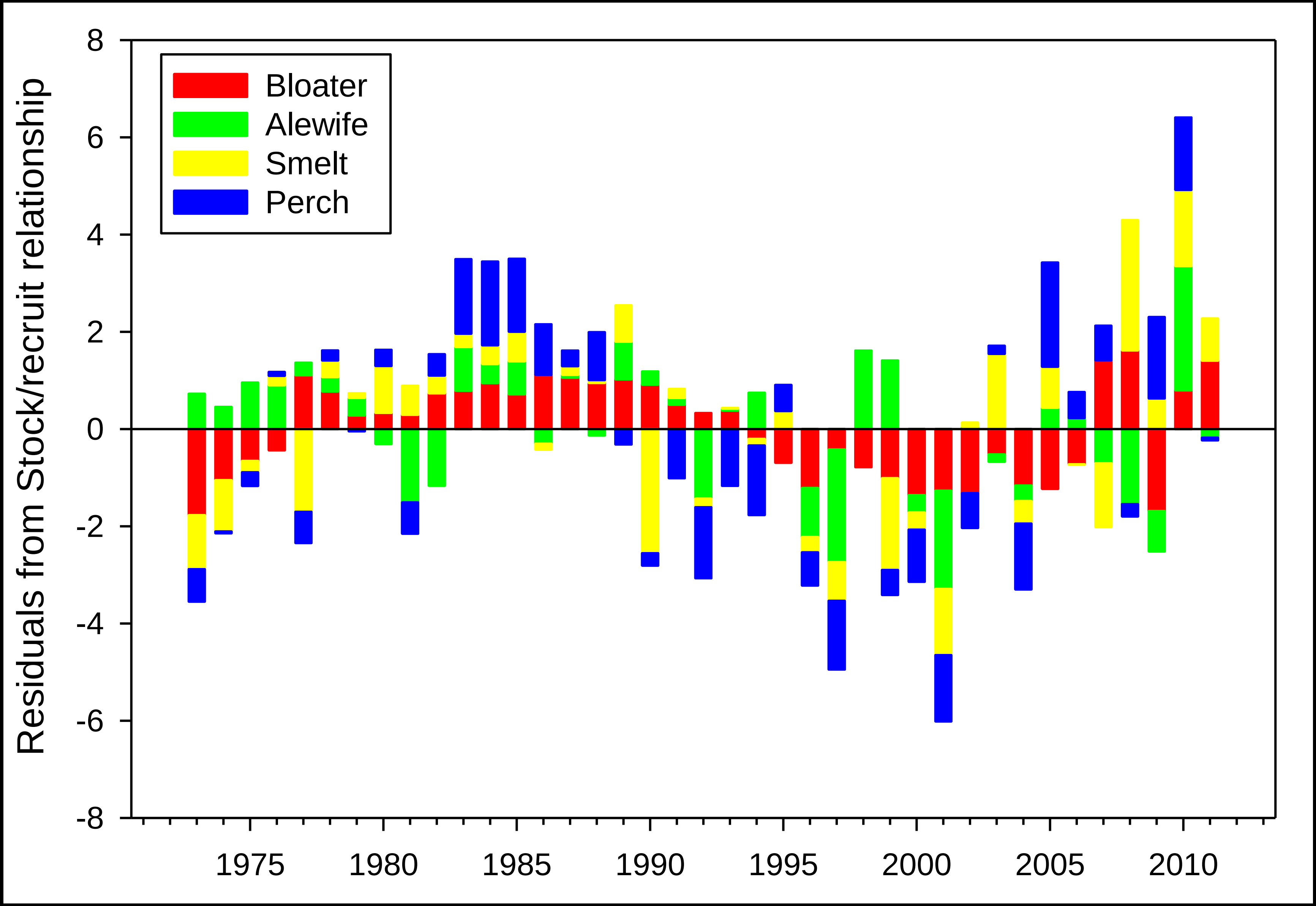
1. Estimate stock-recruit relationship for each species. Estimate the residual- unexplained variation due to environmental factors or measurement error.

2. Do residuals reveal common patterns between species? If so, use a generalized additive model (GAM) to determine whether the residuals correspond with environmental or climate variables.

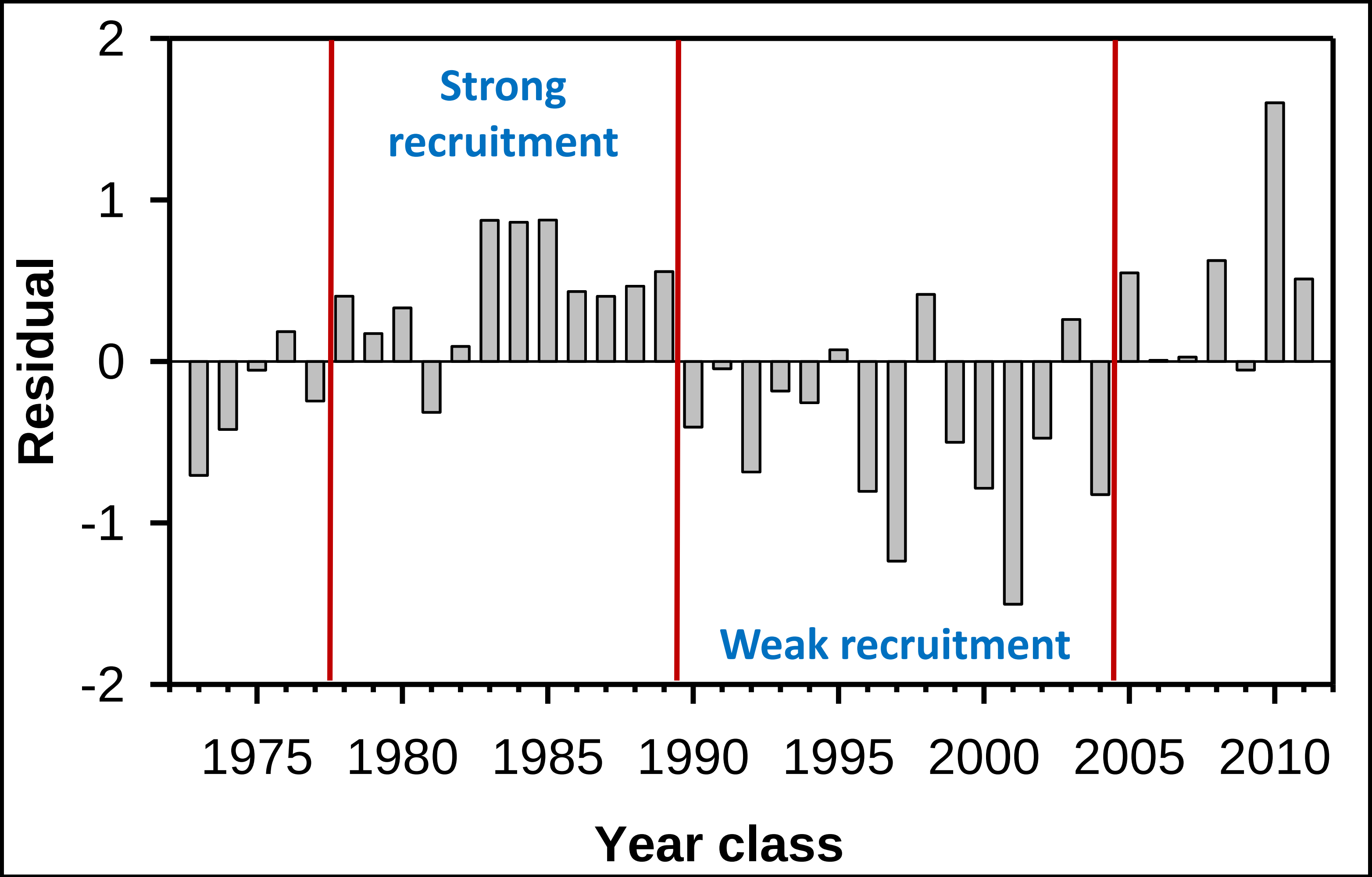


Bloater
Ln(age-3 recruits, #/ha)
Population egg production (billions)
ln(R)=ln(S) - 2.183 - 6.64-4S
8
6
4
2
0
-2
-4
0
1000
2000
3000
4000
Rainbow smelt
Ln(age-0 recruits, #/ha)
Biomass >90 mm TL (kg/ha)
ln(R)=ln(S) + 4.56 - 0.167S
8
6
4
2
0
0
2
4
6
8
Yellow perch
Ln(age-0 recruits, #/ha)
Biomass > 170 mm TL (kg/ha)
VirginiaLiving Museum
ln(R)=ln(S) +1.337 - 0.046S
6
4
2
0
-2
-4
0
1
2
3
4
5
Alewife
Ln(age-3 recruits, kilotonnes)
Biomass >150 mm TL (kilotonnes)
ln(R)=ln(S) -6.48-3 + 0.065S
4
3
2
1
0
-1
-2
0
5
10
15
20
25
30

Residual patterns across the four species



Average residuals across the four species

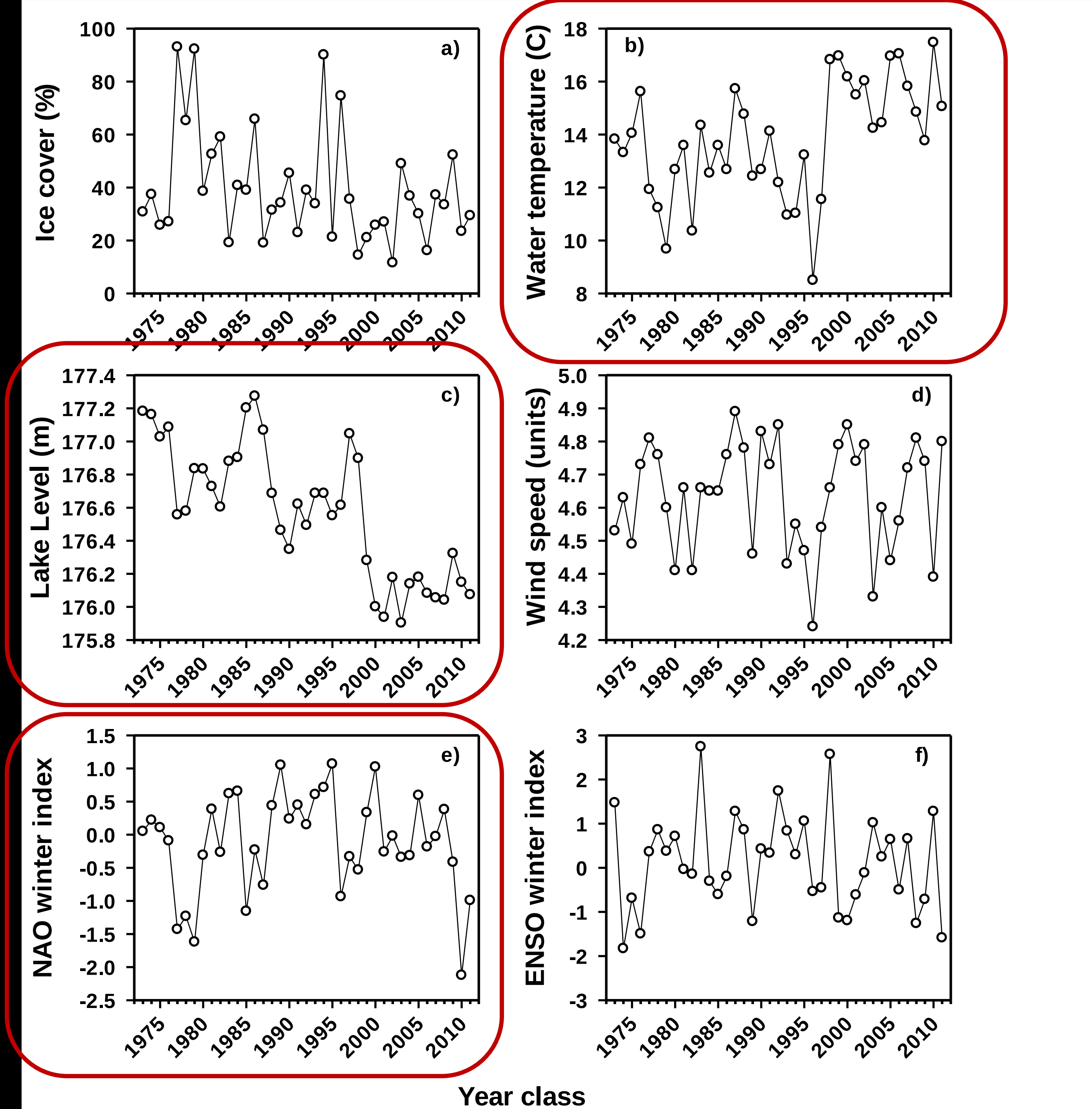


Climatic or environmental variables

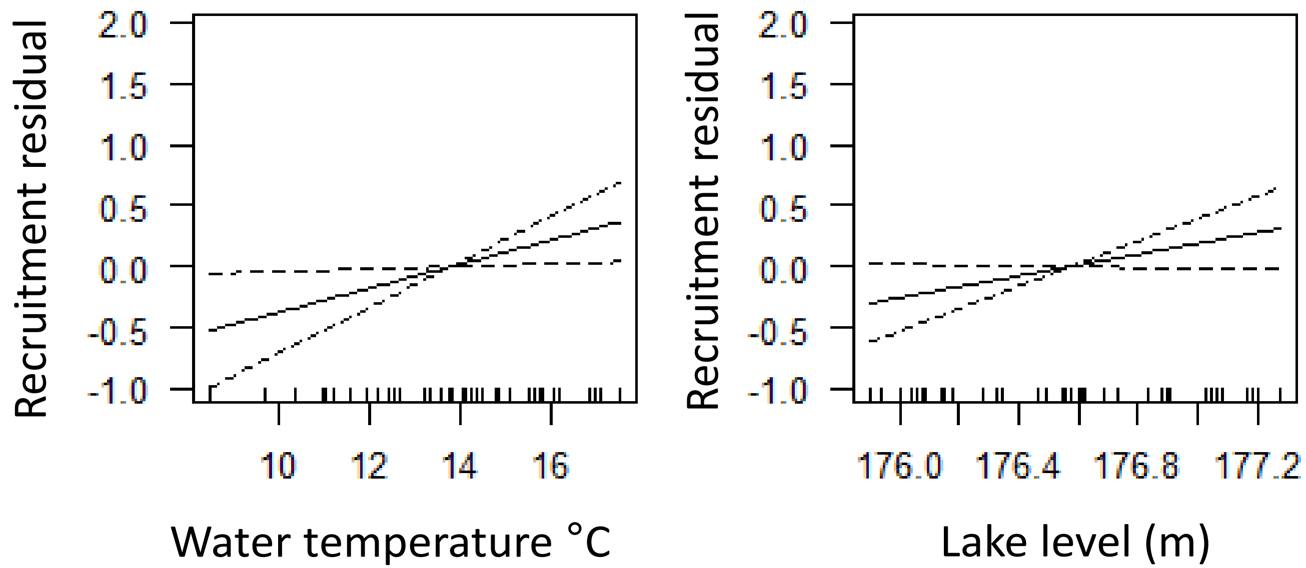
Variable	Mechanism
Annual maximum ice cover	Timing and magnitude of plankton blooms
April-July lake level	Affect nearshore spawning habitat
May-Aug wind speed	Transport of fish larvae
May-Aug epilimnetic water temperature	Growth rates of fish larvae
ENSO index (El Niño)	Regional climate indices that may influence regional Great Lakes climate
North Atlantic Oscillation index	
Lake level X water temperature interaction	Effect of water temperature on growth could depend on spawning habitat

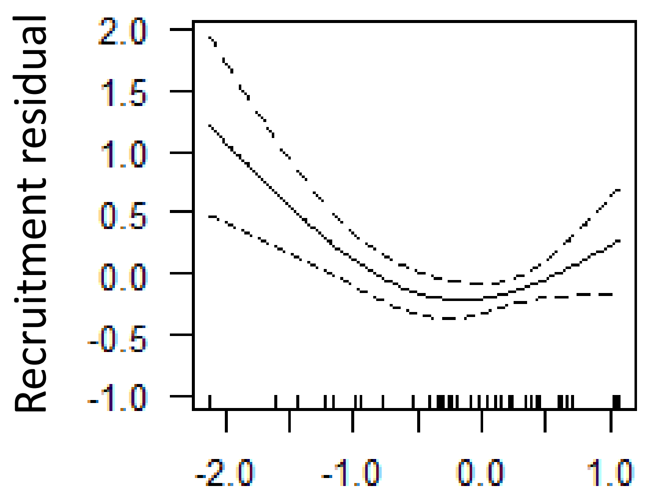
Only lake level, water temperature, and NAO had temporal autocorrelation.

But does the timing of the "regimes" match with the fish patterns?



Top-ranked model





Cold, dry NAO winter index **Warm, wet**

Higher recruitment in extreme NAO years.

Effect of climate on fish recruitment

- **Climate signals are difficult to detect when paired with biotic variables. Factors such as predation or density-dependence can be more important.**

- **Some evidence of "regimes" of good and bad recruitment in Lake Michigan fish community. But future research will be required to identify whether some climatic characteristic underlies those regimes.**

Today’s talk:

1. **Ecosystem-level trends across the Great Lakes**
   -Declining nutrients could be limiting production at higher trophic level.
2. **Effects of lower trophic level changes on fishes.**
   -Larval fish could be starving & juveniles and adults are skinnier.
3. **Impacts of climate change**

   -Climate (lake level, water temperature) is changing. Difficult to discern effect on fish so far.

Great Lakes: Learn to expect the unexpected

- ✓ Stocking: After 46 years, native lake trout are just now starting to reproduce in the wild. Non-native chinook salmon are > 50% of wild origin.
- ✓ Zebra mussels are effectively extirpated.
- ✓ Quagga mussels (far worse) have replaced them.
- ✓ New fisheries in Lake Michigan are causing excitement…

Native cisco caught while trawling for trout and salmon in Grand Traverse Bay.

World Record Brown Trout

2009: Manistee River, Michigan (41.5 lbs)

http://www.jsonline.com/blogs/sports/58634057.html

2010: Racine- (41.5 lbs)

http://www.jsonline.com/sports/outdoors/107105798.html

2012: Milwaukee harbor fish recognized as world record

http://www.jsonline.com/blogs/sports/160297845.html

Slide: John Janssen

Green Bay Lake Whitefish

Slide: John Janssen

http://www.icefishgreenbay.com/

http://www.greenbaywhitefish.com/

http://whyknotguideservice.com/galleries/whitefish/#viewimage-102

Will Chinook salmon collapse in Lake Michigan?

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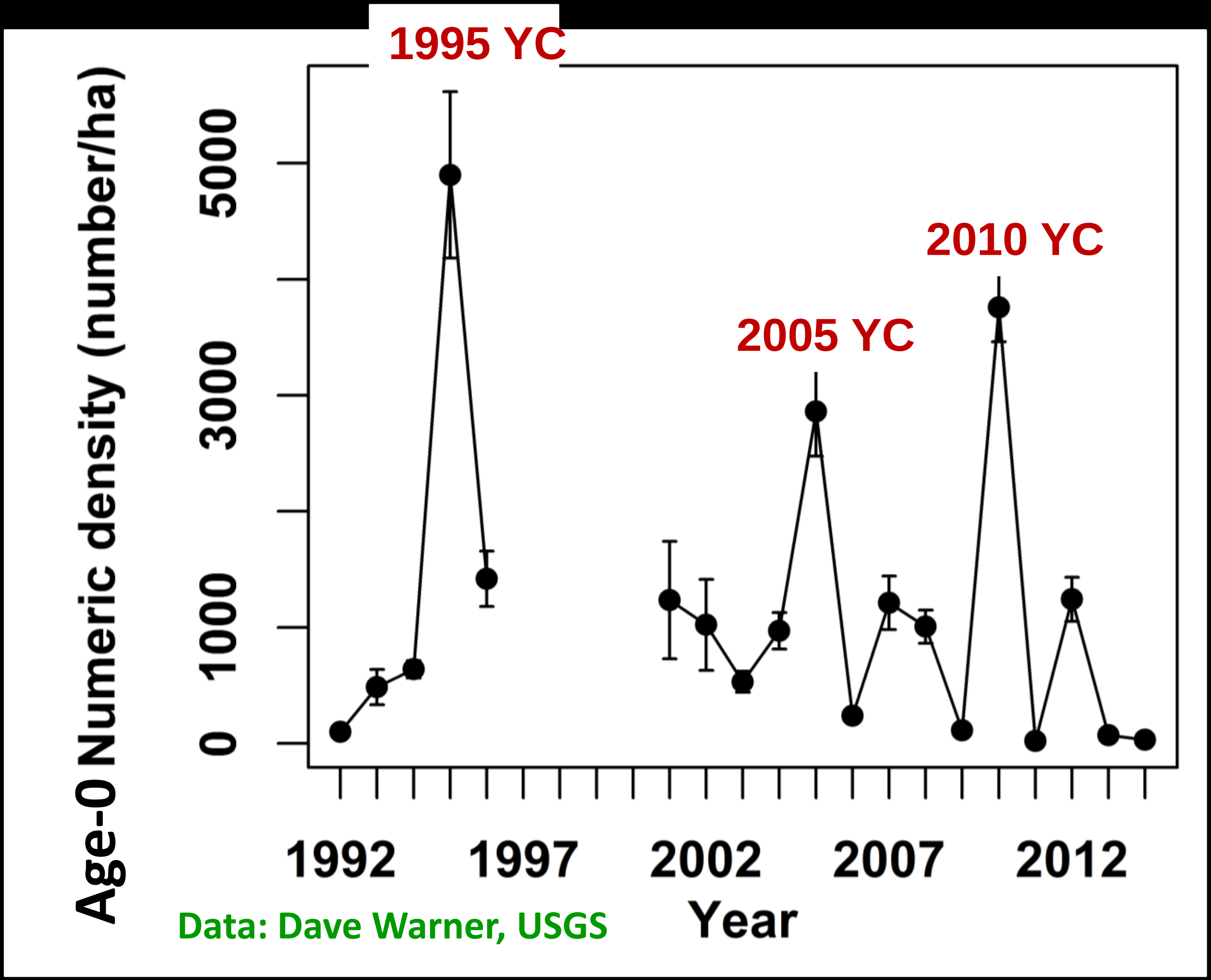
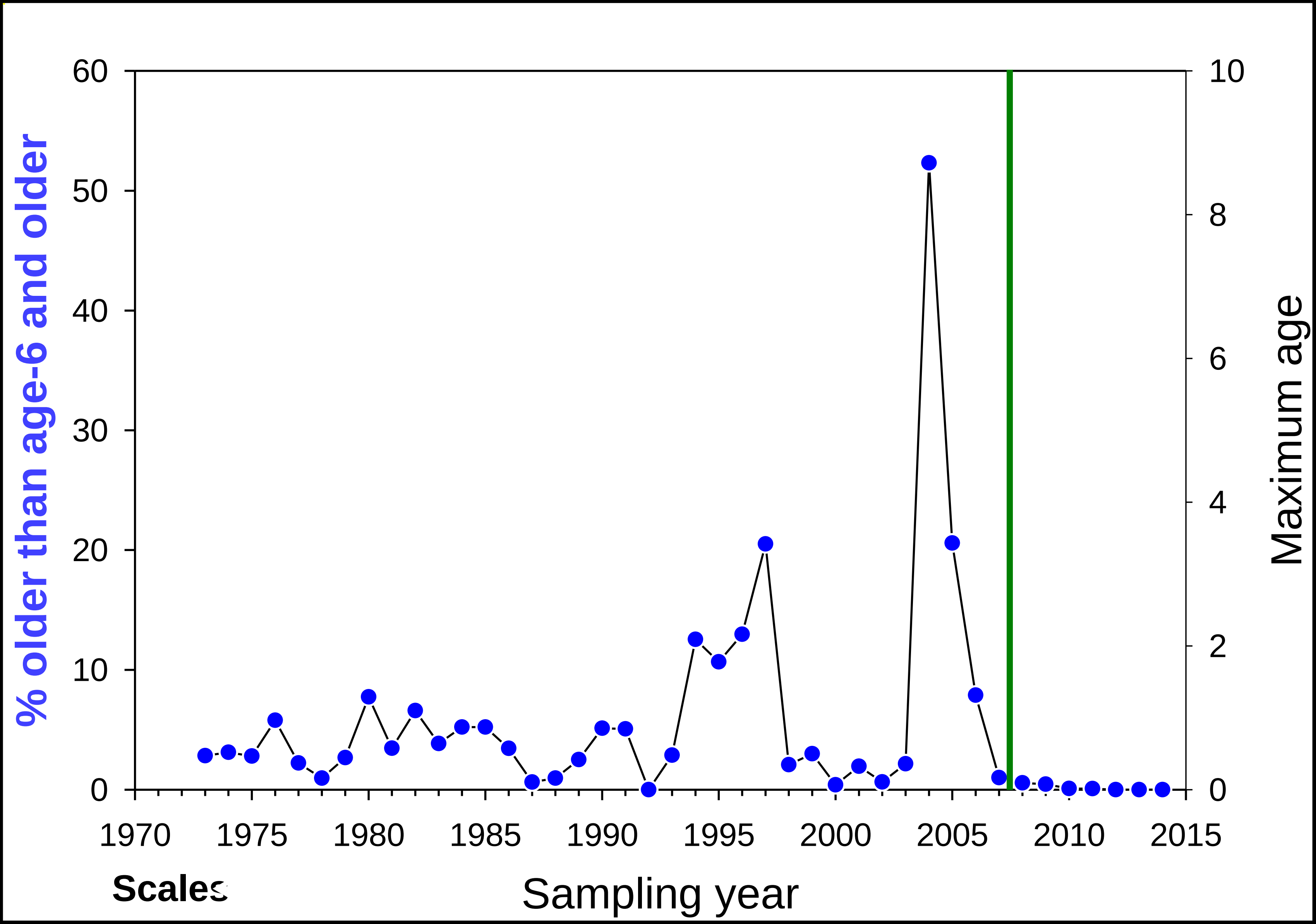
✓ No strong alewife year-classes in 2013, 2014, 2015.



Will Chinook salmon collapse in Lake Michigan?

- ✓ No strong alewife year-classes in 2013, 2014, 2015.
- ✓ Alewife are not surviving as long as they used to.

Alewife age truncation since 2007



Will Chinook salmon collapse in Lake Michigan?

- ✓ No strong alewife year-classes in 2013, 2014, 2015.

- ✓ Alewife are not surviving as long as they used to.

- ✓ The 2015 year-class was critical.
  - By 2016, the 2012 year-class will be 4 years old and the 2010 year-class will be gone.
  - Strong year-class recipe = relatively low salmon densities, warm spring, sufficient spawning stock size.

- ✓ Lake Huron lesson: if alewife collapse, Chinook salmon diet strategies is inflexible, and Chinook salmon crash will likely follow.

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