UNIVERSITY OF MARYLAND CENTER FOR ENVIRONMENTAL SCIENCE
CHESAPEAKE BIOLOGICAL LABORATORY

HRF
HUDSON RIVER FOUNDATION

EDWARD A. AMES SEMINARS
6 March 2018

Intensified climate change effects on Hudson River white perch following zebra mussel invasion

Brian Gallagher
Dave Secor

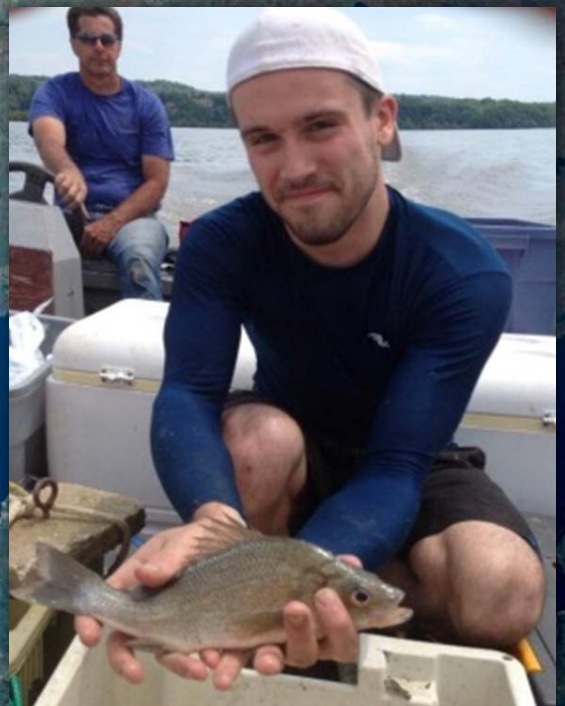

Image: NASA

HUDSON RIVER FOUNDATION
FOR SCIENCE AND ENVIRONMENTAL RESEARCH

Hudson River Fund: Call for Proposals

1993-2018!

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New York, New York 10004

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25 Years of support: Thanks!

The Hudson River Estuary maps past and ongoing human influences

- *navigation and ecological corridors to the Great Lakes and the Atlantic Ocean*
- *centuries of fishing, and industrial and urban degradation and clean up.*

Our purpose has been to investigate key species of the Hudson River as indicators of ecosystem health and change.

NRC Research Press

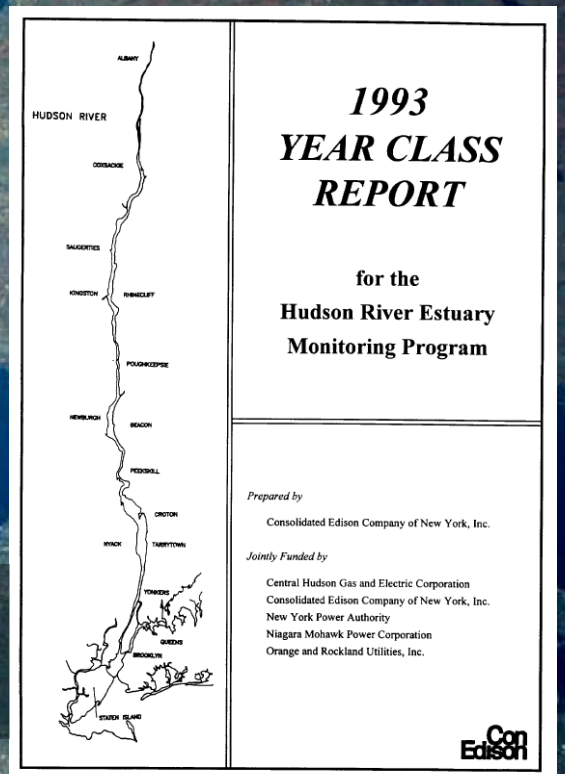
ARTICLE

Intensified environmental and density-dependent regulation of white perch recruitment after an ecosystem shift in the Hudson River Estuary

Brian K. Gallagher and David H. Secor

Canadian J. Fisheries and Aquatic Science

White perch as an indicator species



1993 YEAR CLASS REPORT

for the Hudson River Estuary Monitoring Program

Prepared by

Consolidated Edison Company of New York, Inc.

Jointly Funded by

Central Hudson Gas and Electric Corporation
Consolidated Edison Company of New York, Inc.
New York Power Authority
Niagara Mohawk Power Corporation
Orange and Rockland Utilities, Inc.

Con Edison

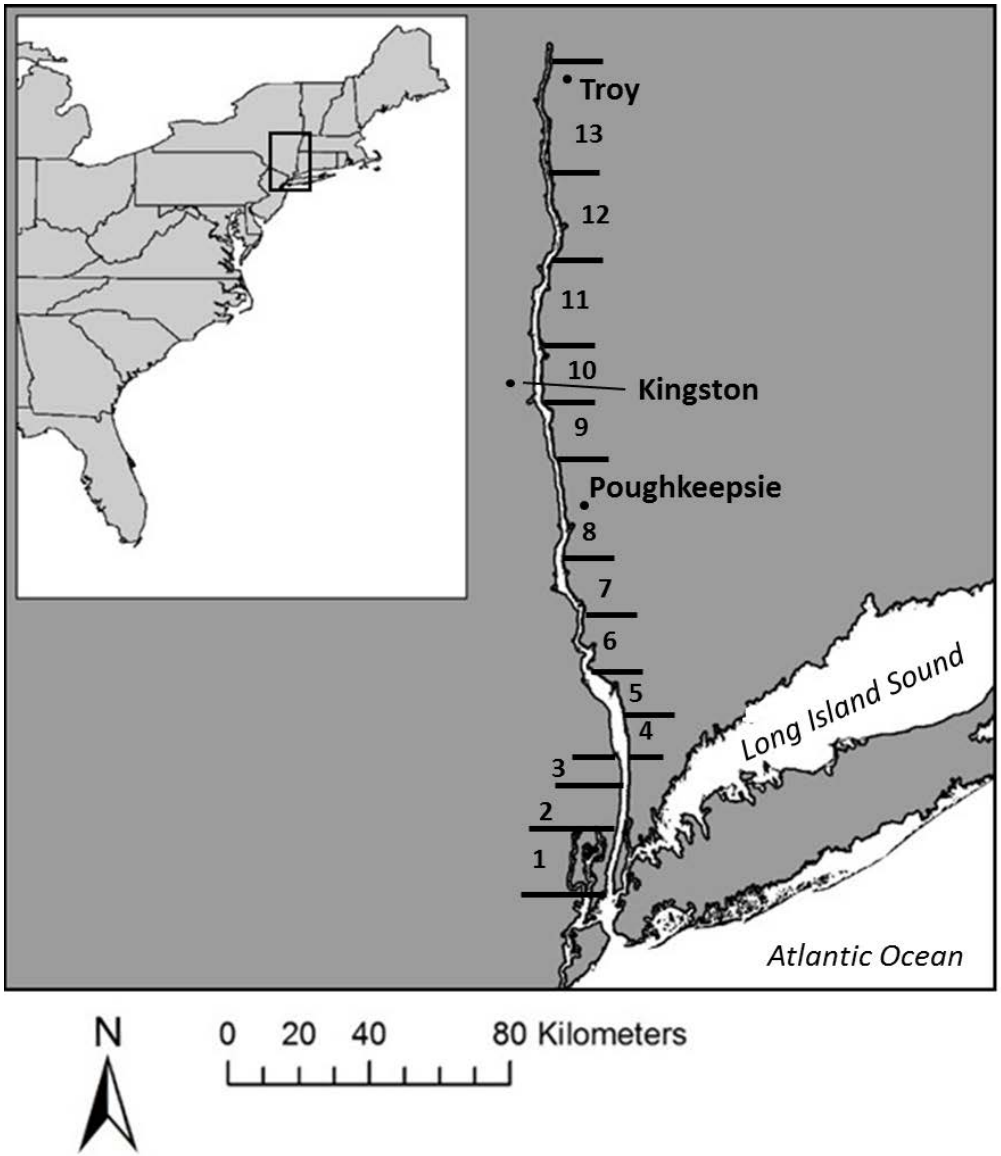
Hudson River Estuary Monitoring Program
Applied Science Associates, Inc.

Image: NASA

The Hudson River ecosystem

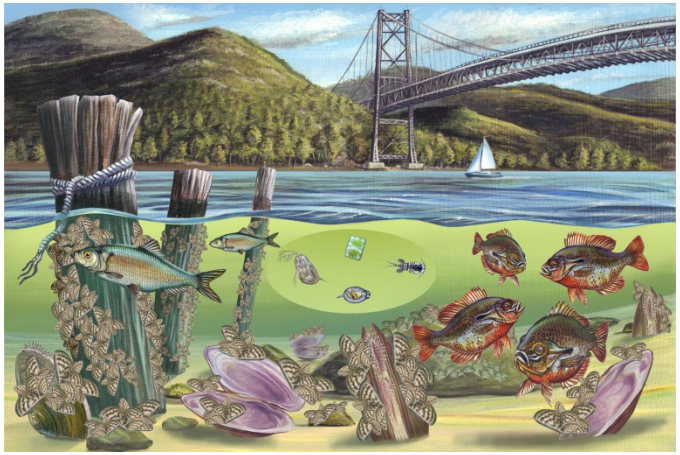
- Large, turbid estuary
  - Moderately productive

- Flume-like hydrology
  - Short residence times

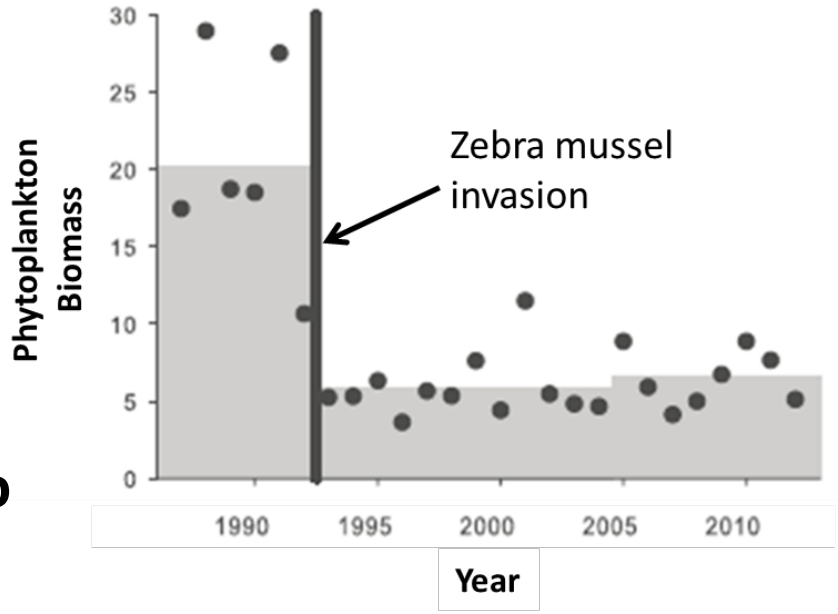


The Hudson River ecosystem

- Large, turbid estuary
  - Moderately productive
- Flume-like hydrology
  - Short residence times
- Zebra mussels invaded tidal freshwater in 1991
  - **Ecosystem shift: Grazing pressure depressed phytoplankton, carry over to zooplankton, benthic invertebrates**



Carey IES

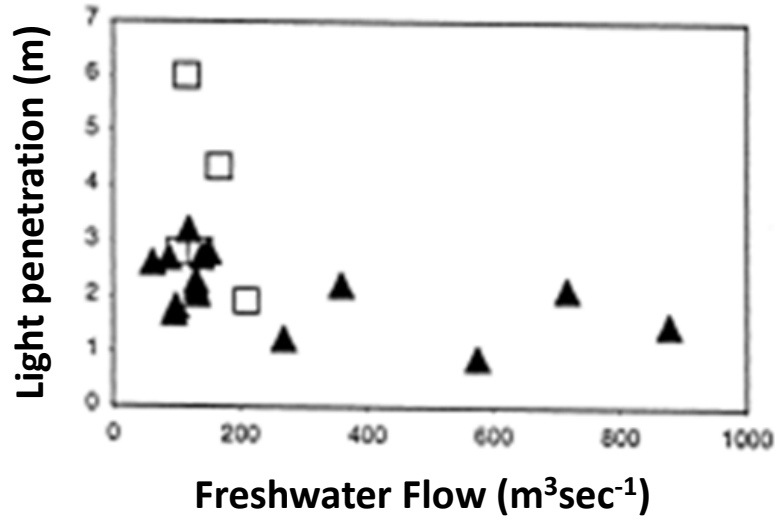


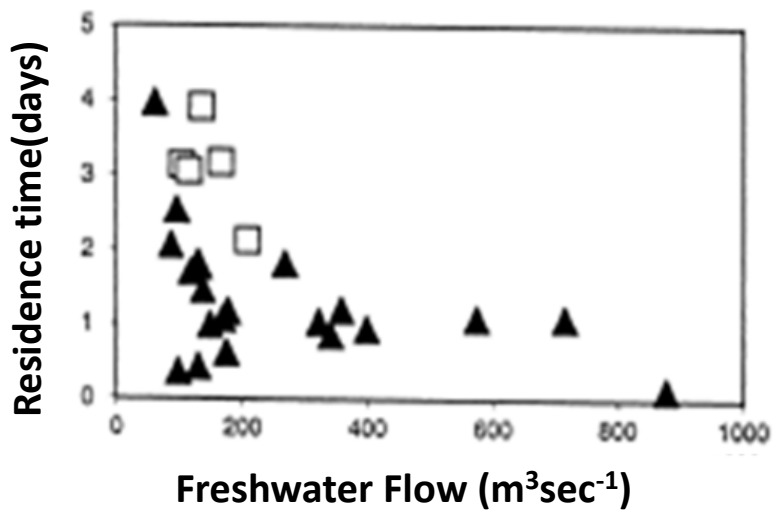
* Indexed by chlorophyll-a concentration (µg/L)

Figure: Strayer et al. (2014)

The Hudson River ecosystem

- Flow controls primary production
  - Limited by light and advection

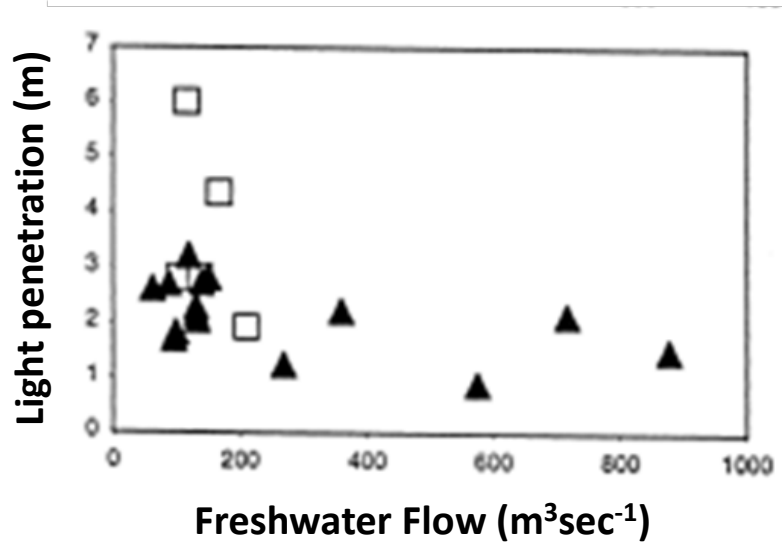


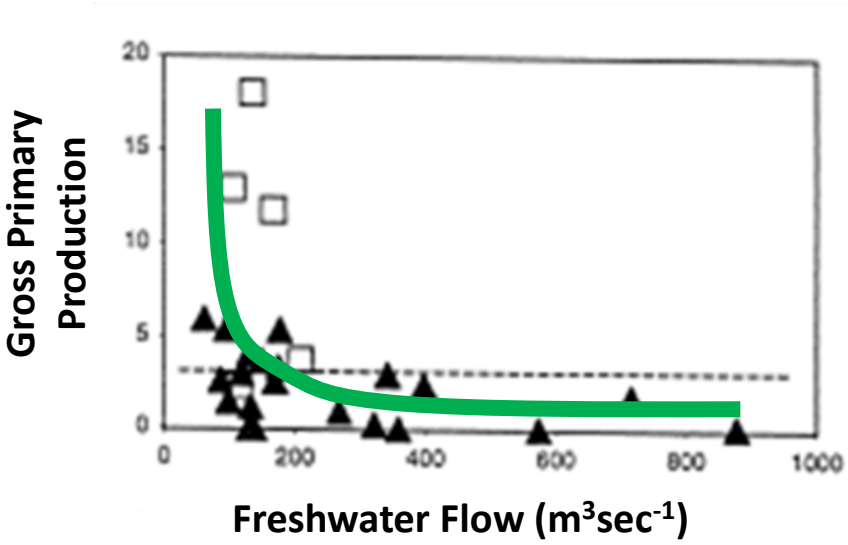


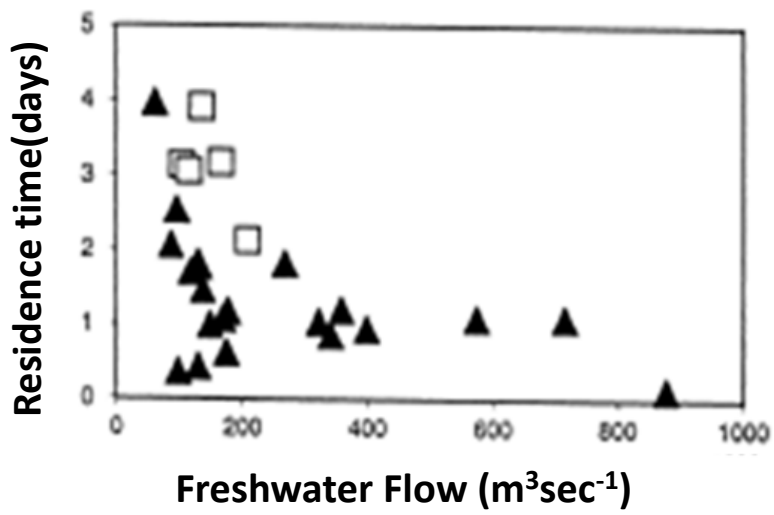
Figures: Howarth et al. (2000)

Importance of flow

- Flow controls primary production
  - Limited by light and advection
  - **Highest in low flow conditions**



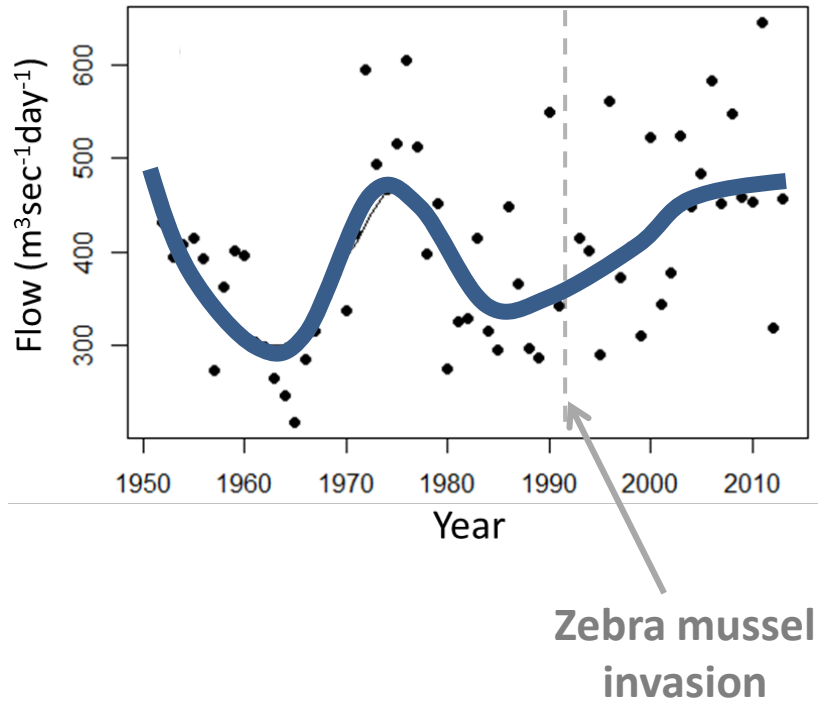


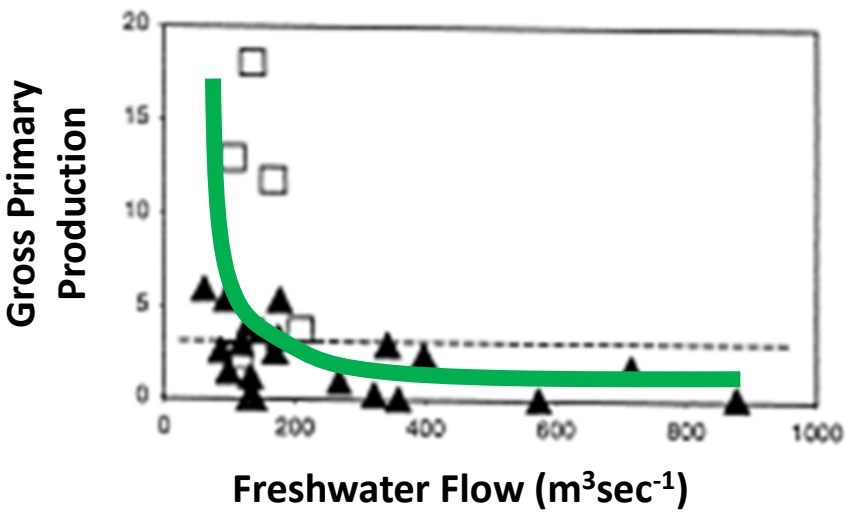


Figures: Howarth et al. (2000)

Importance of flow

- Flow controls primary production
  - Limited by light and advection
  - **Highest in low flow conditions**
  - Flow has increased by over 20% since 1950

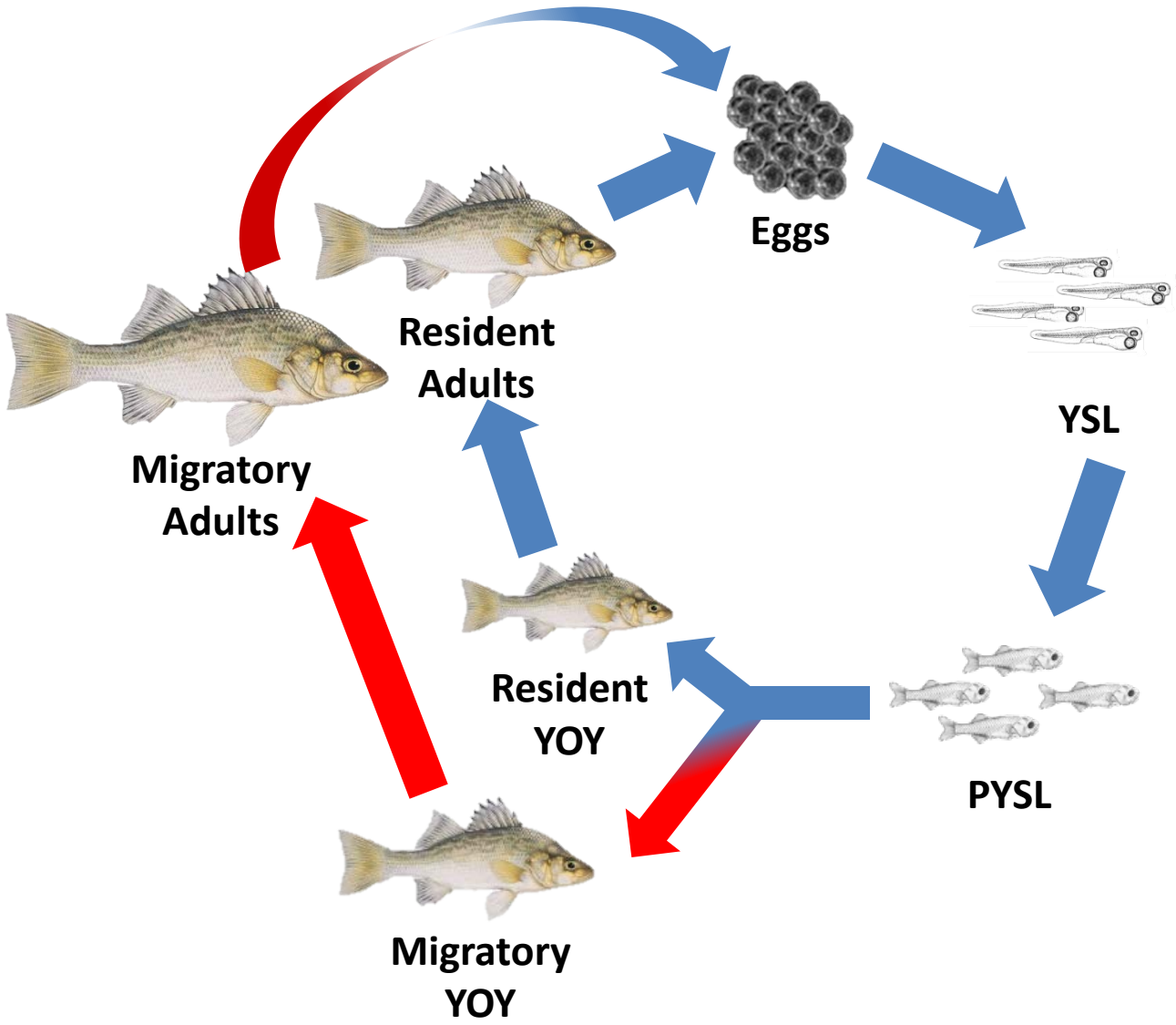




Figures: Howarth et al. (2000)

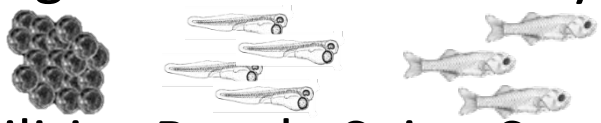
Hypothesis:

The ecosystem shift has altered white perch life-stage transitions and increased their environmental sensitivity



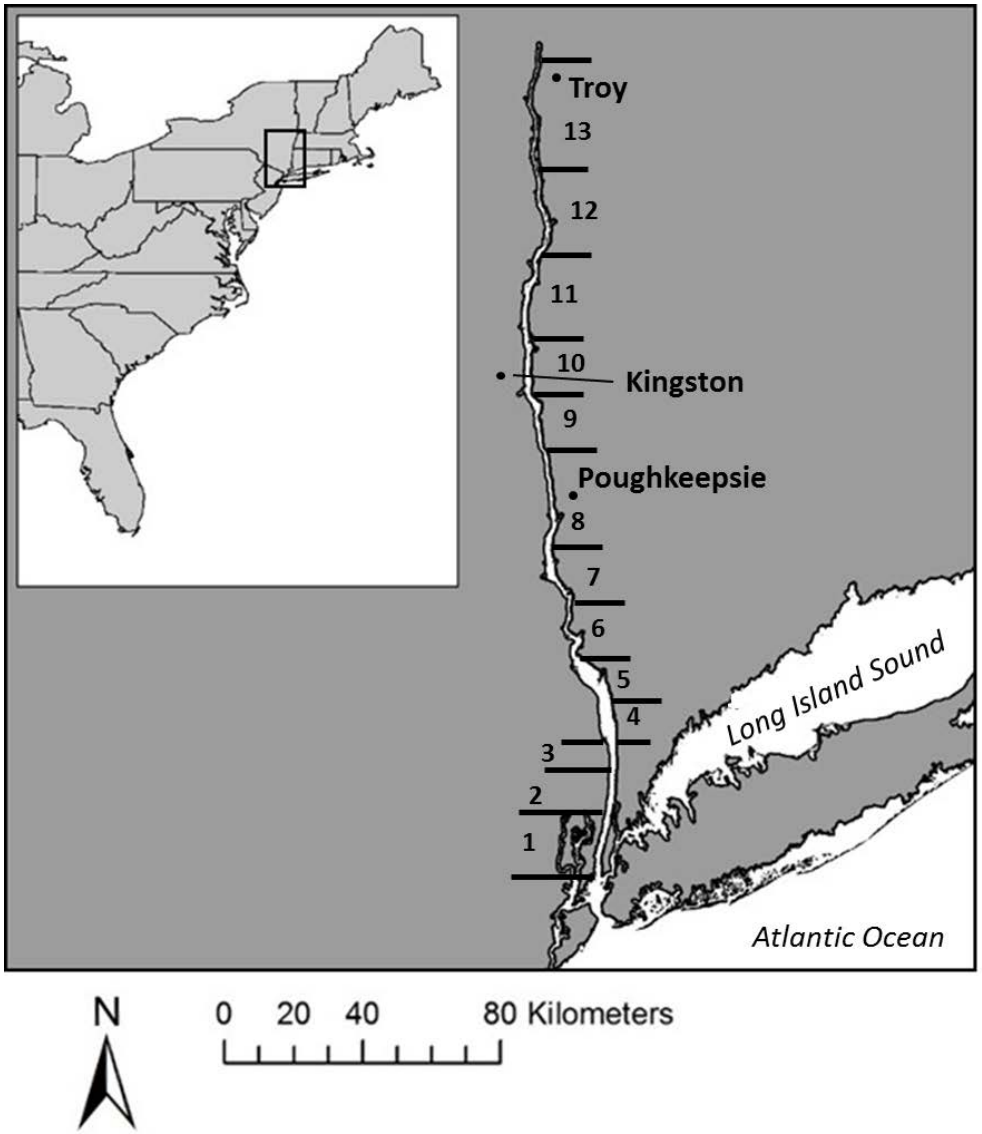
Hudson River monitoring

- Utility companies have sponsored fish monitoring programs since 1974
  - Estimate standing stocks
  - 13 river sections
  - stratified random design
  - c. 1000 samples yr^{-1}
- Three separate surveys
  - Longitudinal River Survey



  - Utilities Beach Seine Survey

  - Fall Juvenile Survey



Life cycle analysis

- Focusing on 1992-2013 (22 years)
  - After zebra mussel invasion

- Evaluate relationships between standing stocks of adjacent life-stages

Life cycle analysis

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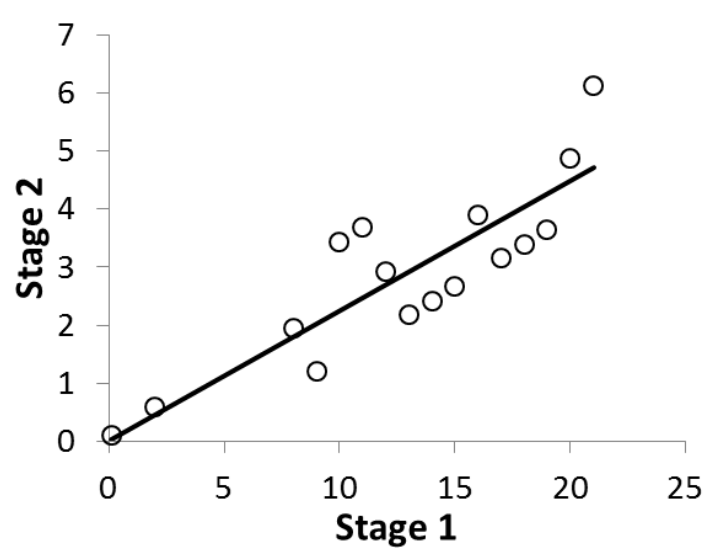
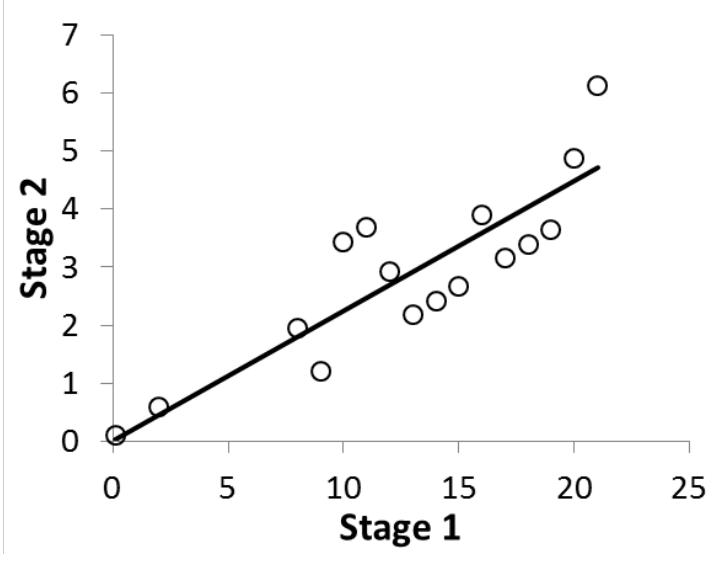
  - Linear regression (fixed intercept)

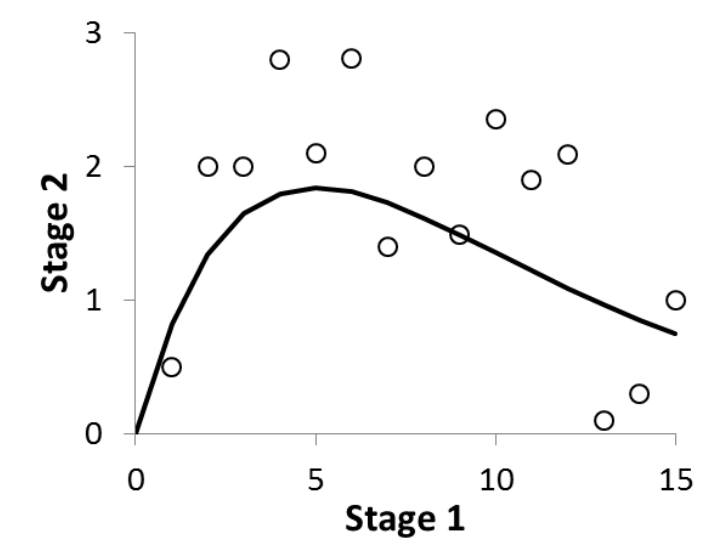


Life cycle analysis

- Focusing on 1992-2013 (22 years)
  - After zebra mussel invasion

- Evaluate relationships between standing stocks of adjacent life-stages
  - Linear regression (fixed intercept)
  - Ricker models (nonlinear) with environmental covariates

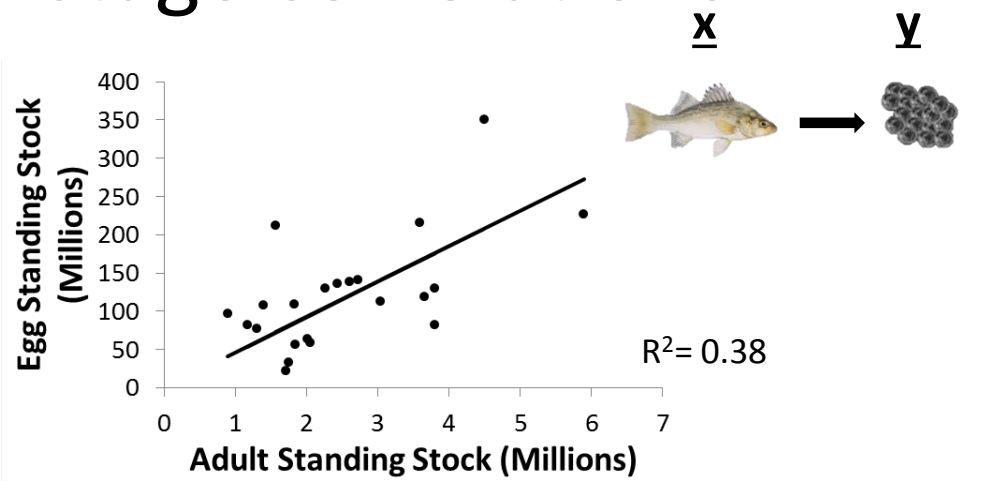


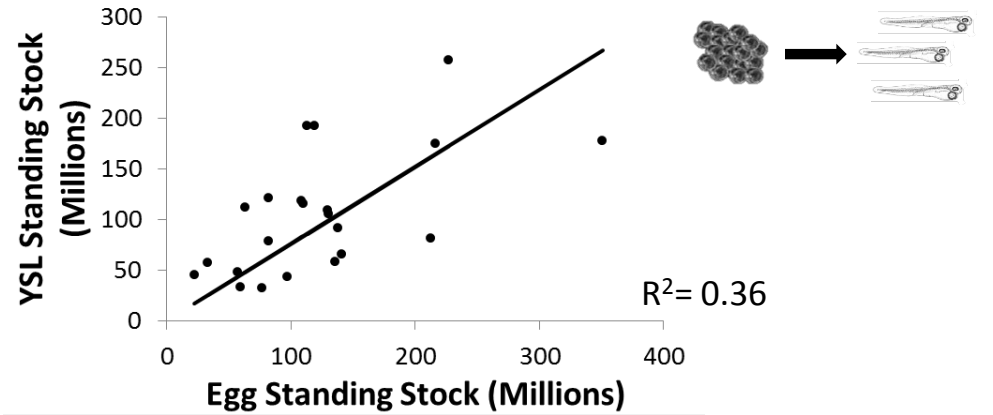


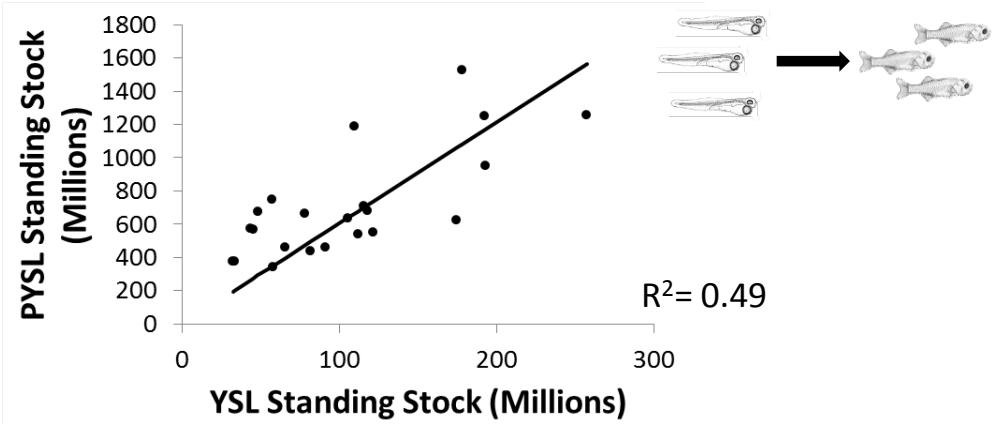
Recent Period: Early life-stage correlations

- Standing stocks of early life-stages were proportional to that of their previous stage

- All early life-stages were proportional to adults



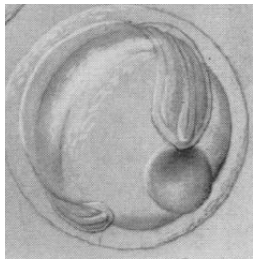


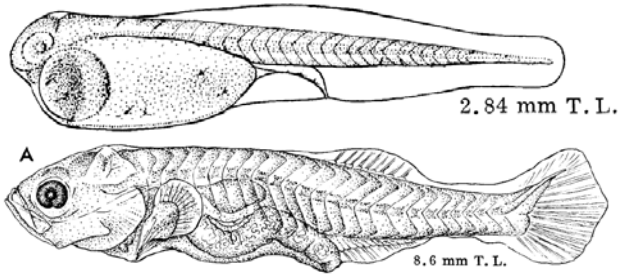


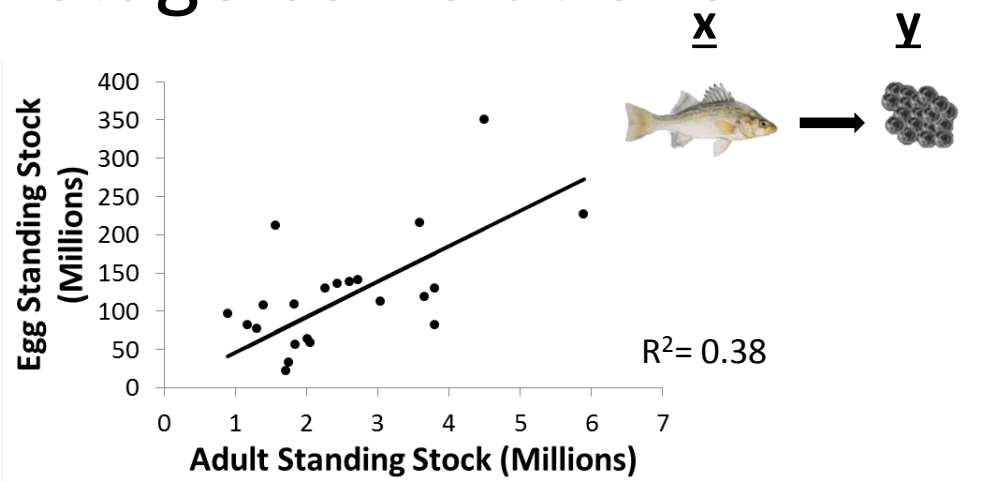
Recent Period: Early life-stage correlations

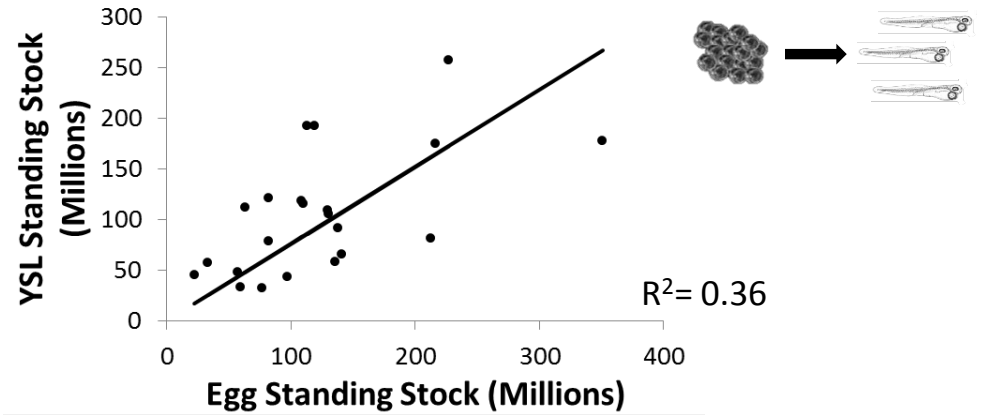
- Standing stocks of early life-stages were proportional to that of their previous stage
- All early life-stages were proportional to adults
- **Adult abundance controls larval abundance**

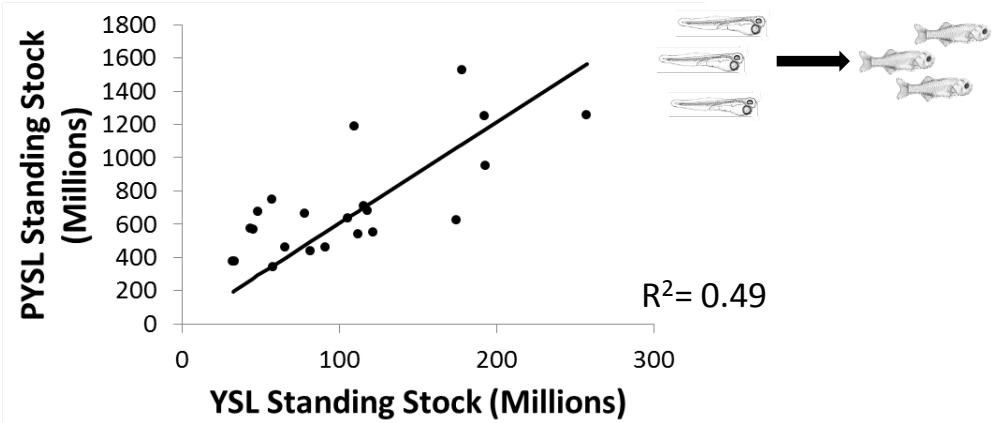
  - Density-independent





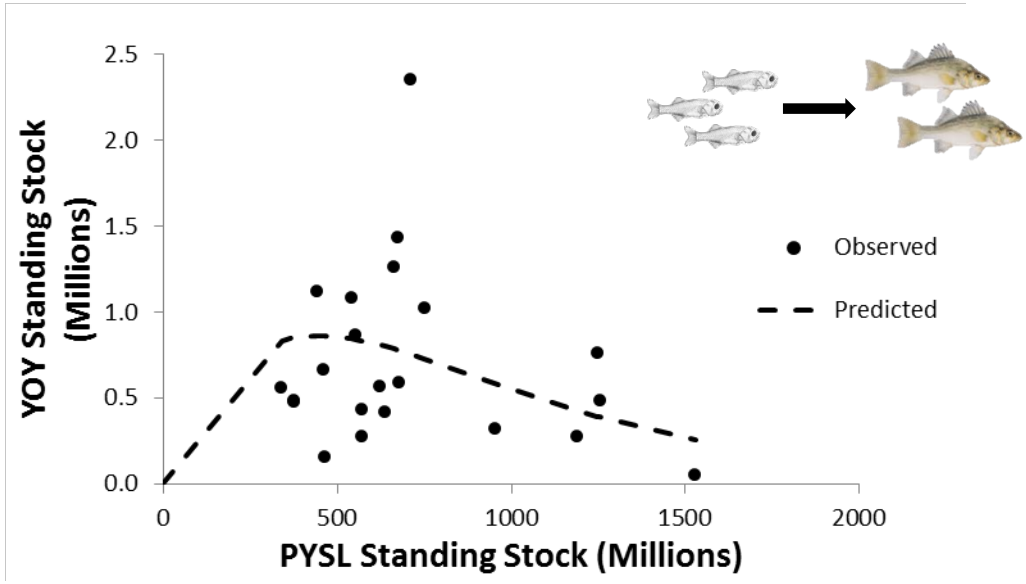






Recent Period: PYSL-YOY relationship

- **Strong density-dependence** at high PYSL abundance
  - Higher mortality



Recent Period: PYSL-YOY relationship

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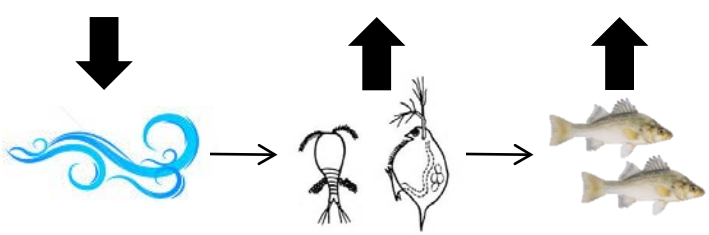
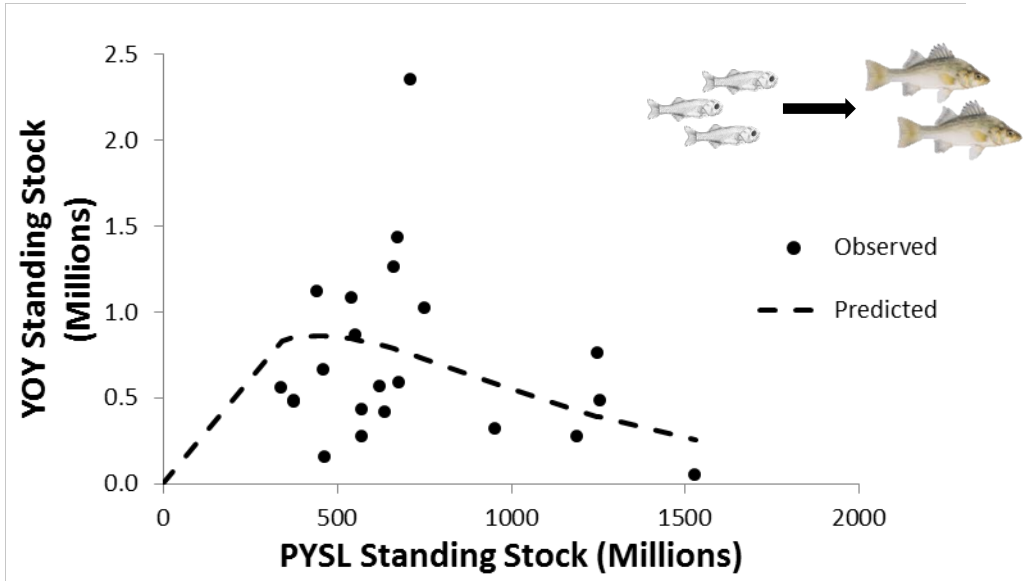
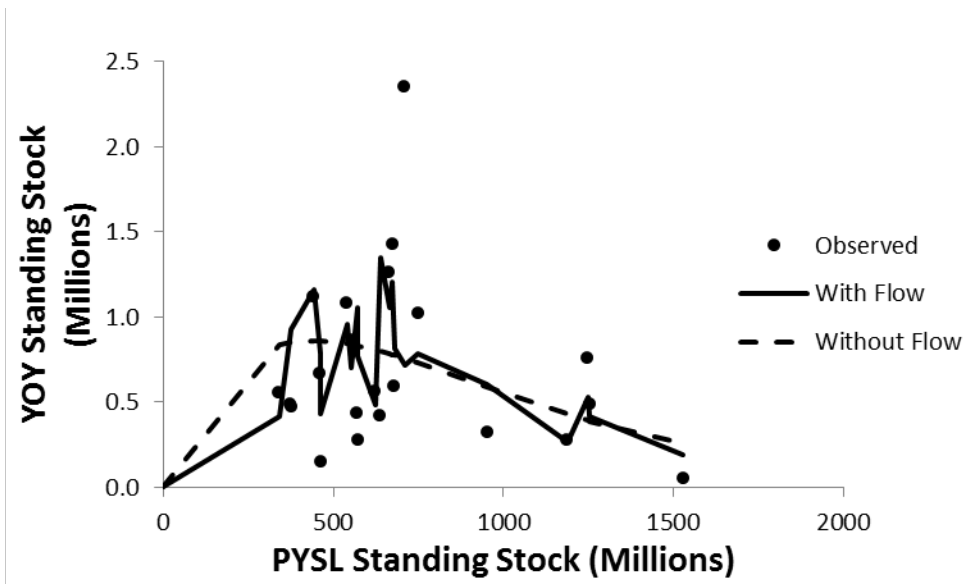
- Model selection supported the inclusion of freshwater flow during the PYSL period
  - **Negative effect**







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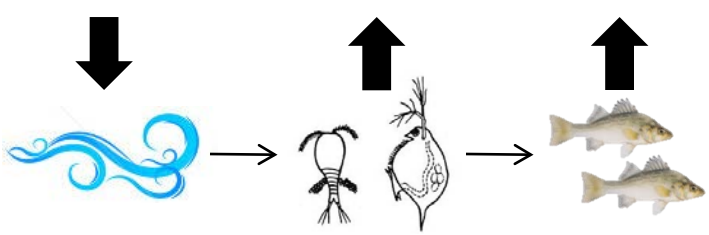
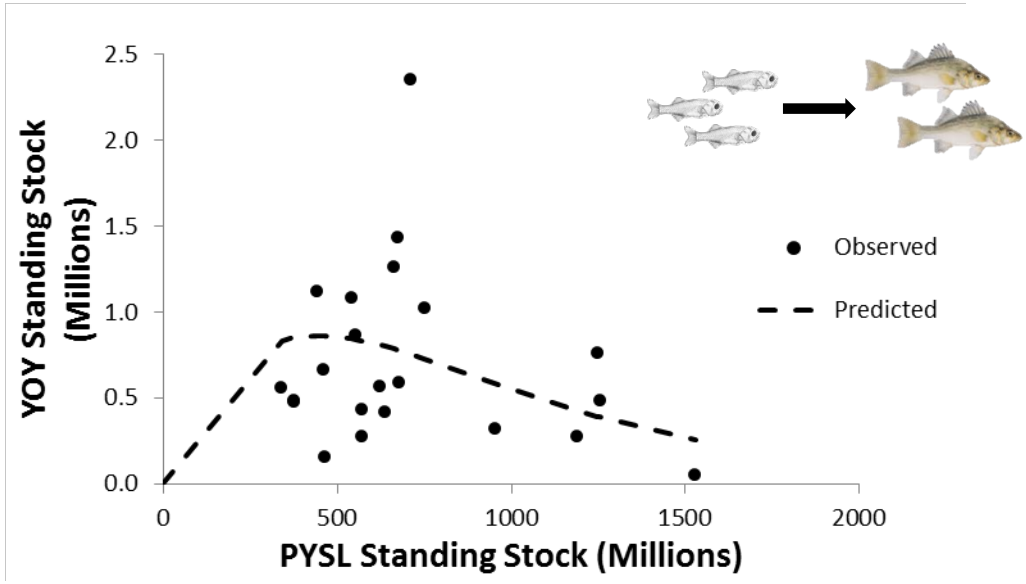
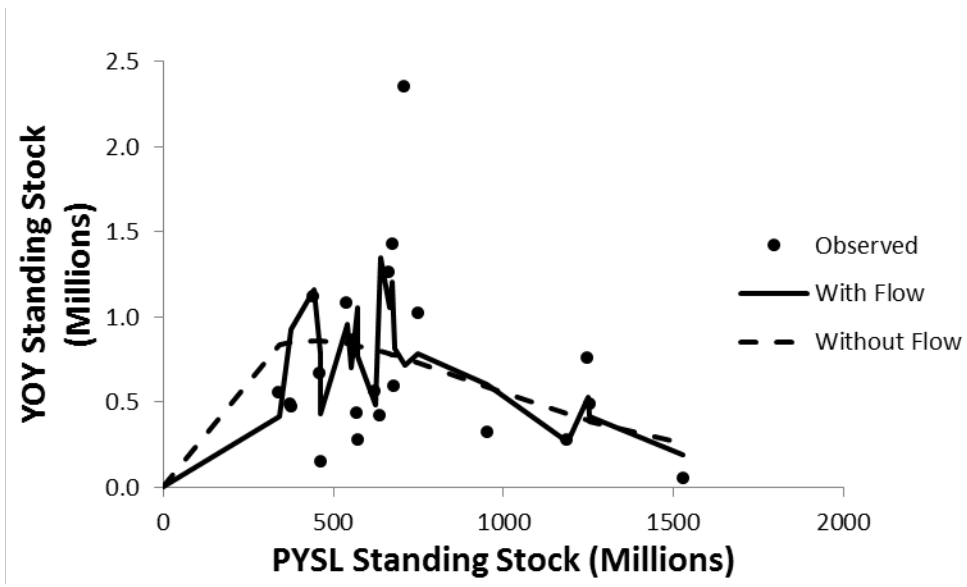
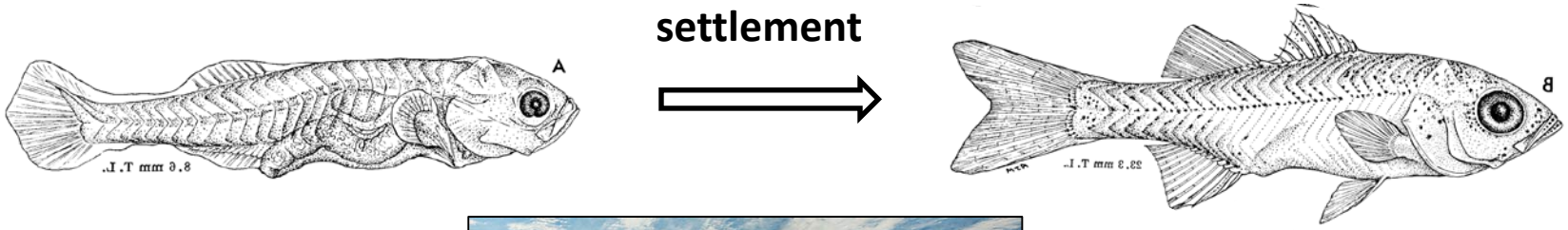




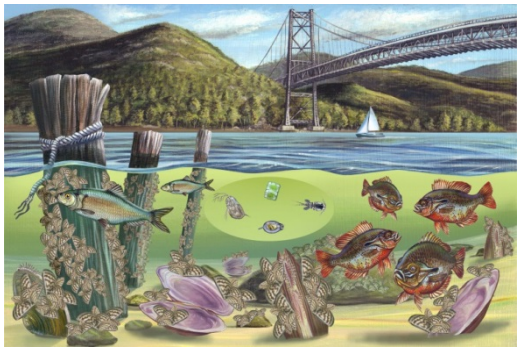


Life-stage transitions



Hypothesis:

The ecosystem shift has altered white perch life-stage transitions and increased their environmental sensitivity



Carey IES

- Compare findings to observations before the zebra mussel invasion (1974-1991)

- Two independent data sets
  - Pre-invasion and post-invasion **indices** of abundance (life-stage transitions)

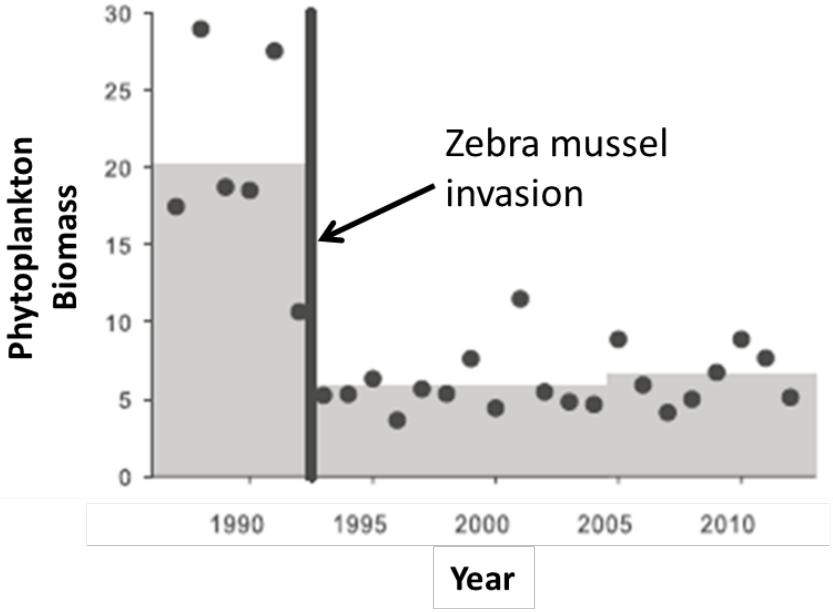
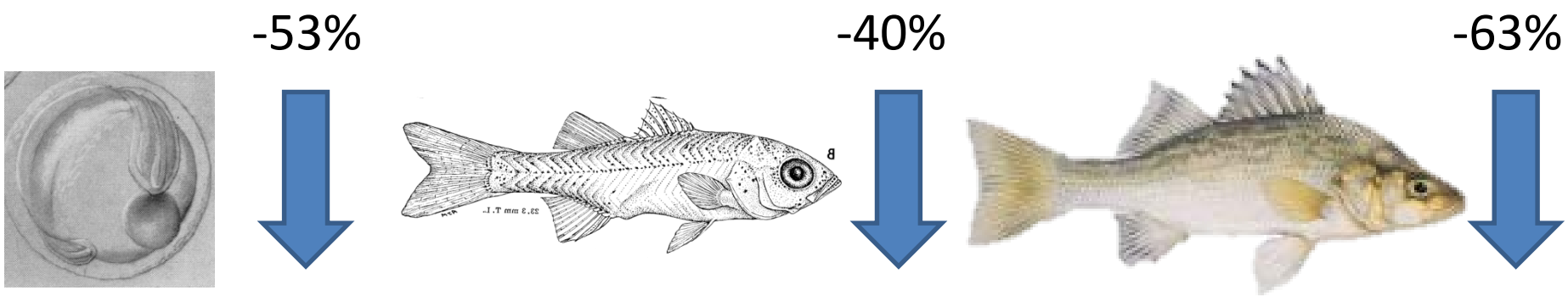


Table 5. Statistical comparisons of mean post-invasion (1992–2013) and pre-invasion (1974–1991) indices of abundance for white perch eggs, YSL, PYSL, YOY, and yearlings (age-1).

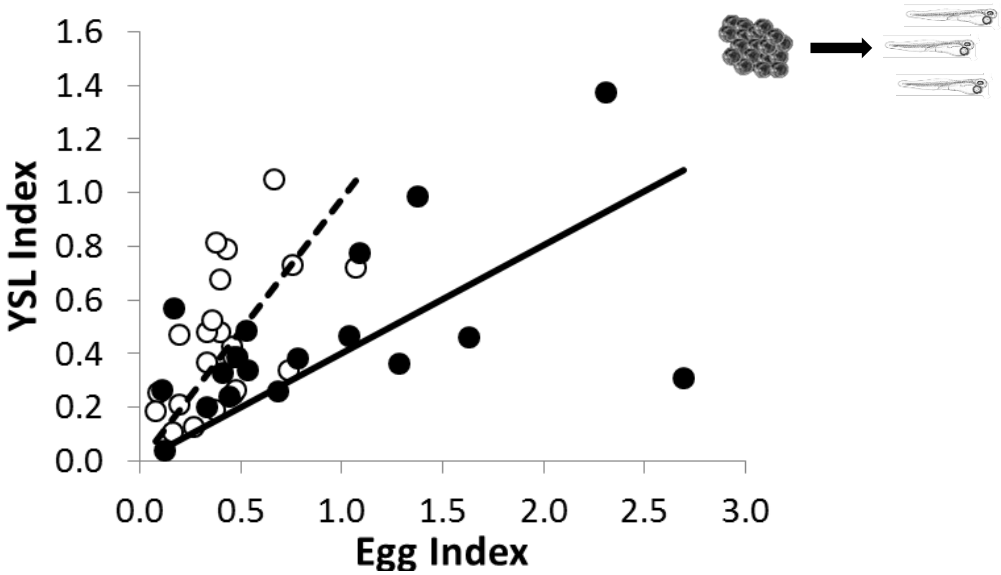
Life stage	Post-invasion mean	Pre-invasion mean	*t* statistic	% difference	*p* value
Egg	0.41	0.89	−2.66	−54	0.02*
YSL	0.45	0.46	−0.06	−1	0.95
PYSL	2.85	3.50	−1.30	−19	0.20
YOY	4.82	8.08	−2.83	−40	0.01*
Yearling	1.21	3.26	−3.95	−63	<0.01*

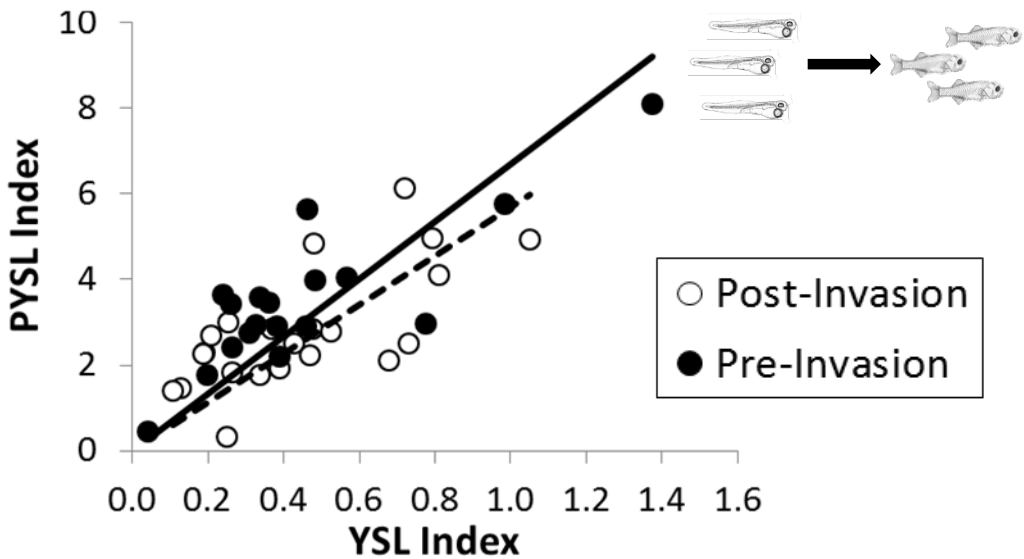
Note: The % difference metric is calculated as $(\text{mean}_{post} - \text{mean}_{pre}) \times \text{mean}_{pre}^{-1} \times 100$. Statistically significant *p* values (<0.05) are denoted by an asterisk.



Effects of the zebra mussel invasion

- Indices showed that **egg production decreased** by 53% after the invasion
- **Egg-YSL relationship became steeper**
  - Compensated for reduced egg production
- Little change in YSL-PYSL relationship





Effects of the zebra mussel invasion

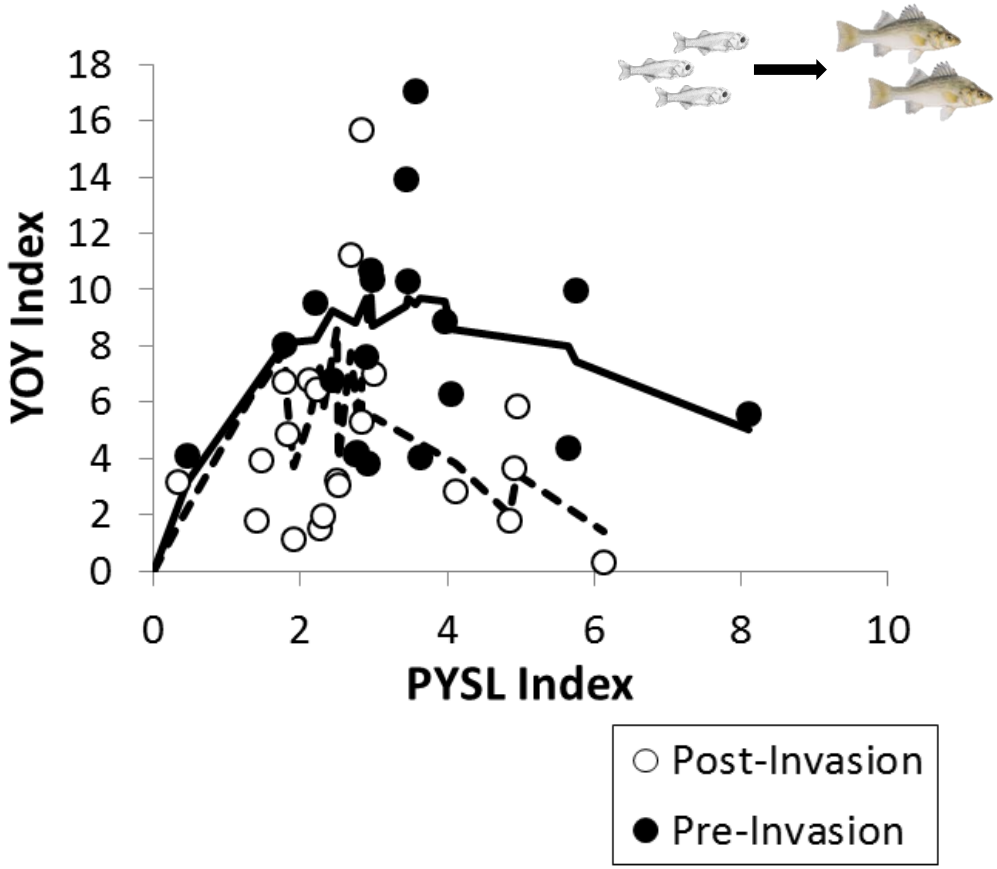
- PYSL-YOY relationship showed moderate density-dependence and no effect of flow (pre-invasion)

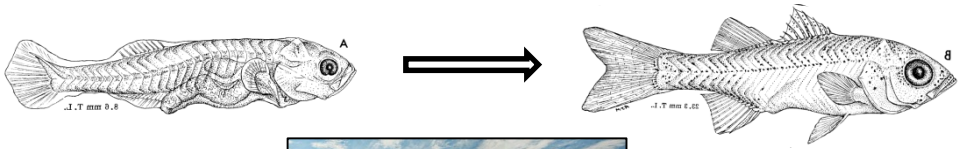
- **Changed considerably after the invasion**

  - Density-dependence

  - Strong, negative flow effect

- Resulted in 40% reduction in YOY abundance

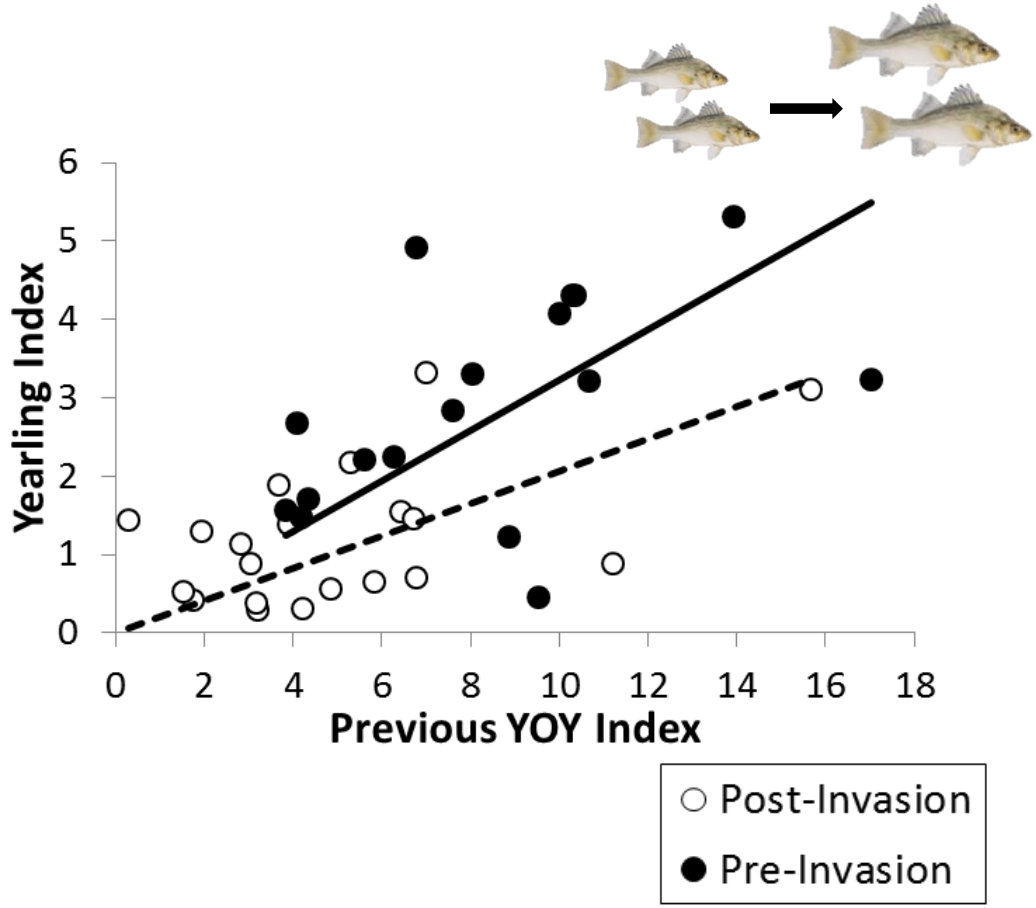




Effects of the zebra mussel invasion

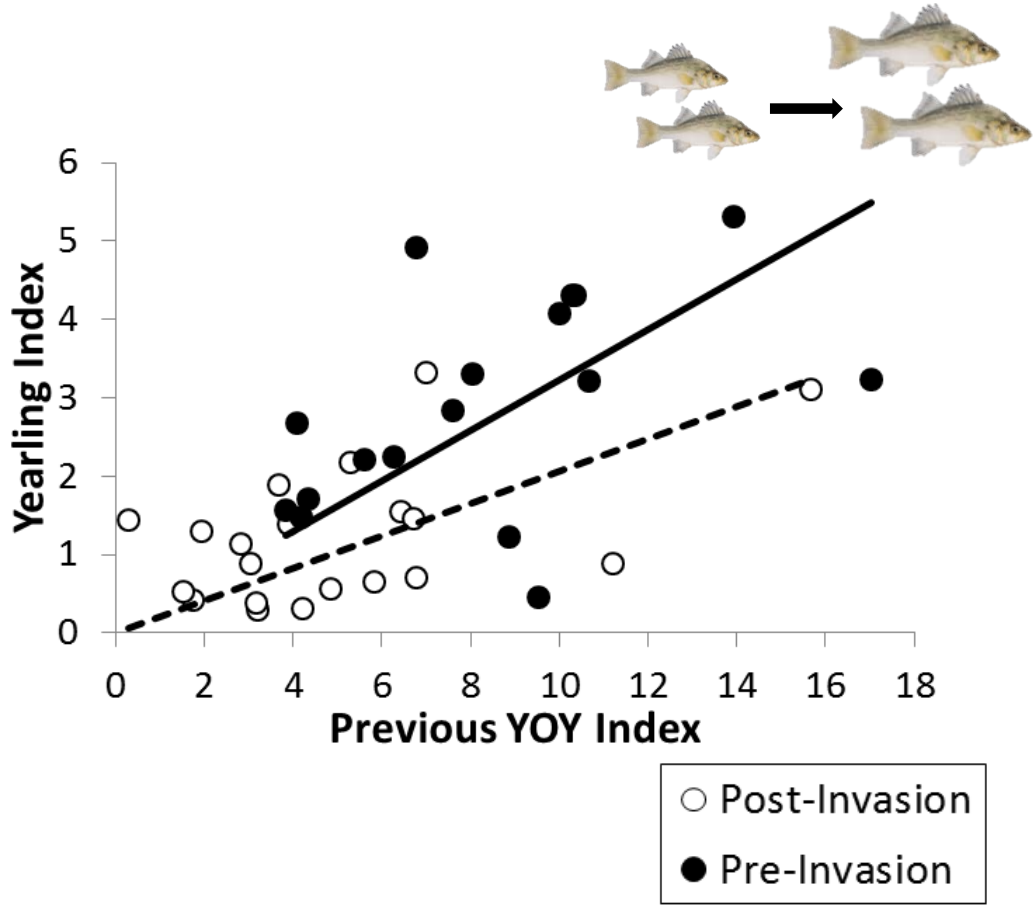
- Relationship between yearling (1-year old) and YOY abundance became **flatter after the invasion**

- Resulted in a 63% decline in yearling abundance



Effects of the zebra mussel invasion

- Relationship between yearling (1-year old) and YOY abundance became **flatter after the invasion**
- Resulted in a 60% decline in yearling abundance
- May explain decline in egg production



Change in PYSL-YOY transition

- After zebra mussels invaded:
  - Reduced food availability

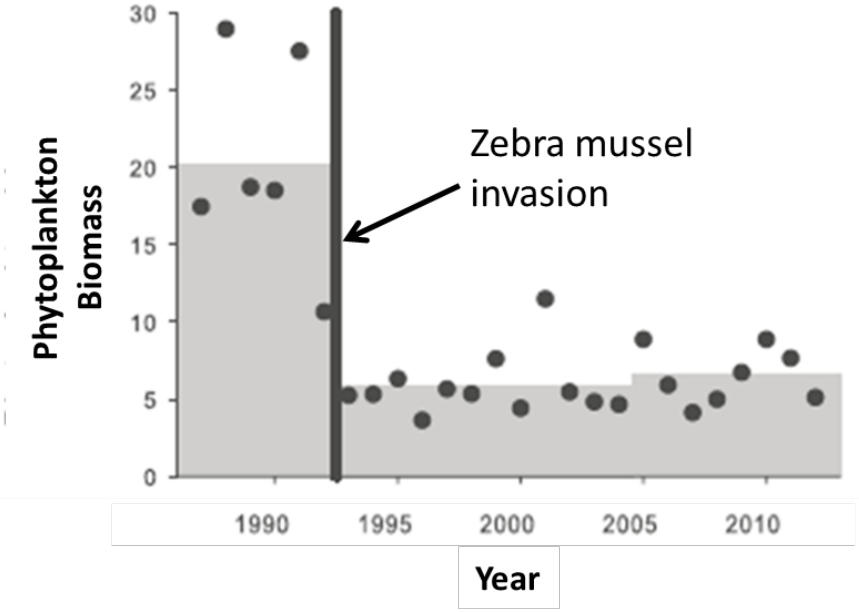
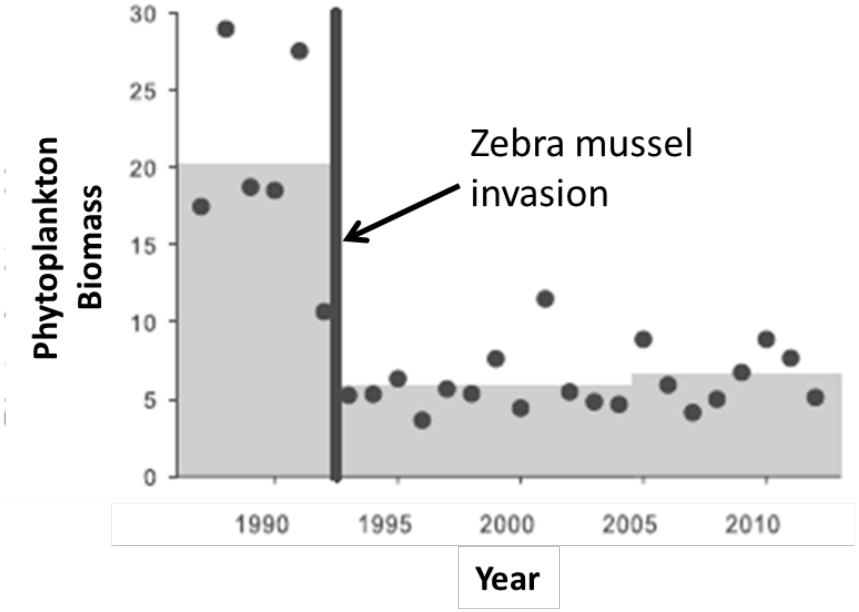


Figure: Strayer et al. (2014)

Change in PYSL-YOY transition

- After zebra mussels invaded:
  - Reduced food availability
  - **Increased sensitivity to flow throughout the food web**



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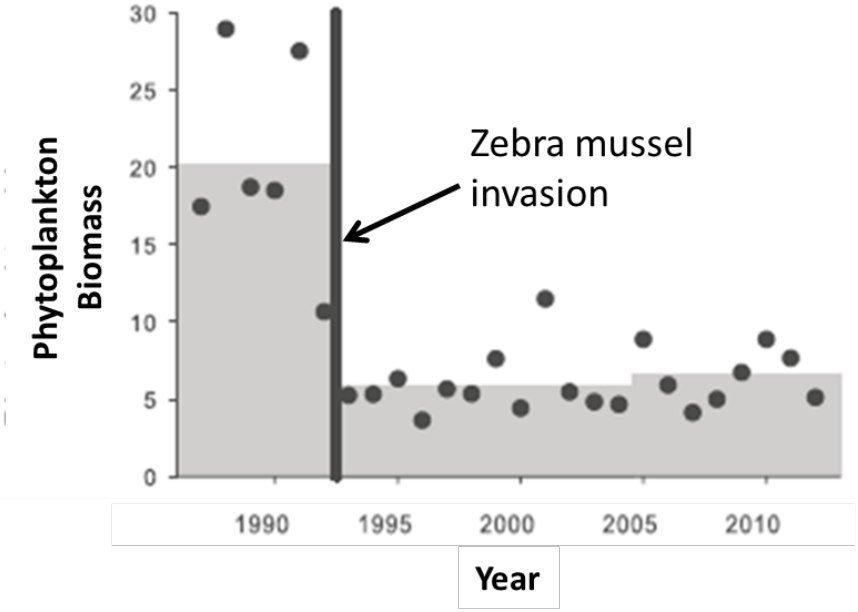
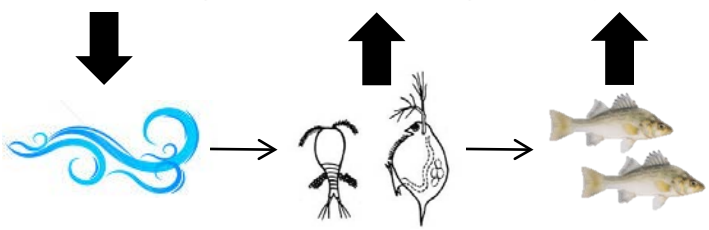
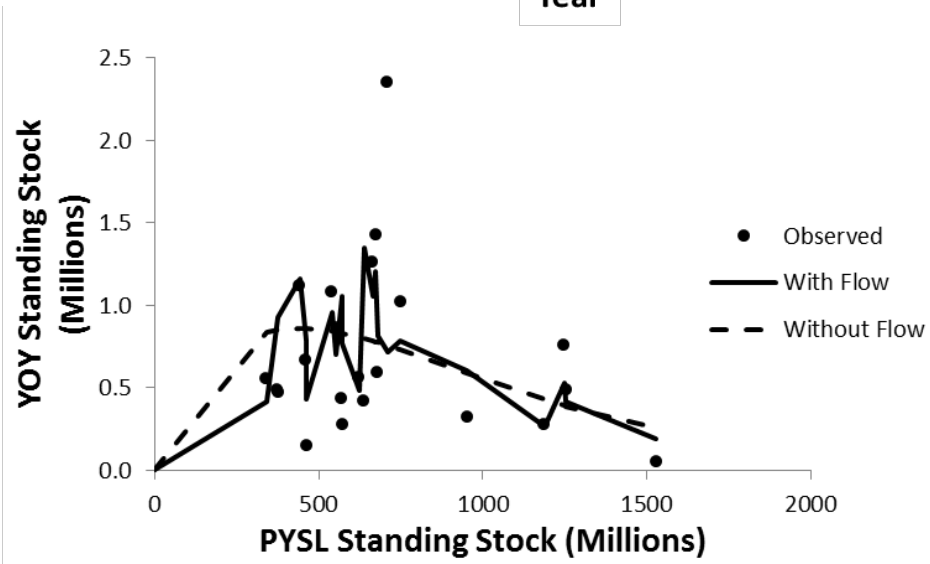


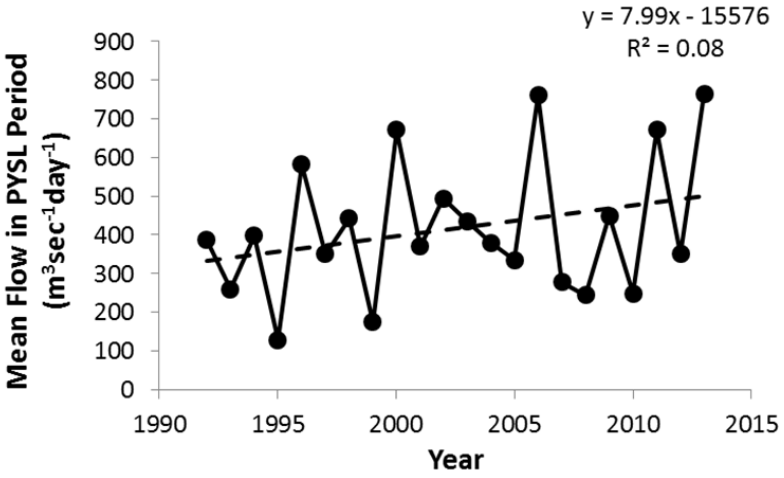
- At high densities, mortality of PYSL and newly-settled YOY increases due to starvation, lower growth, higher predation

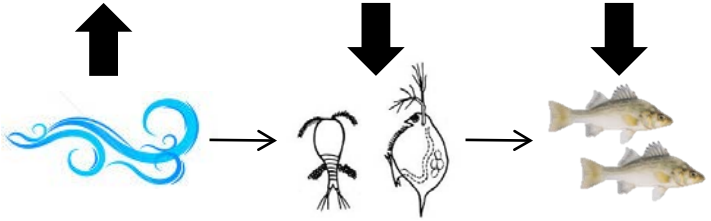




Conclusions

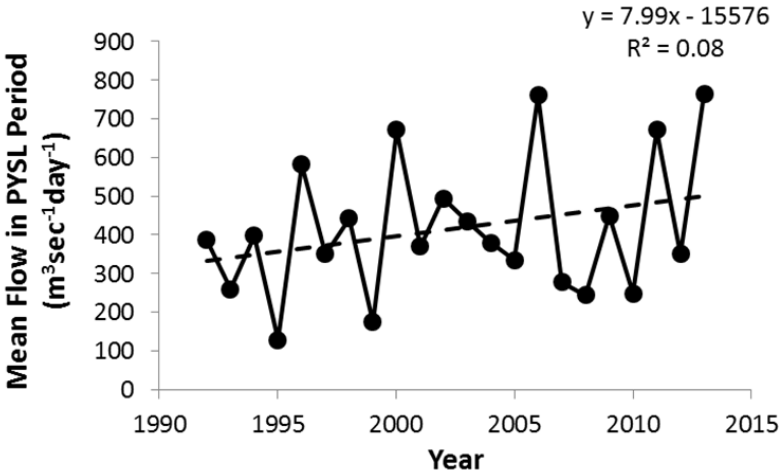
- Life-stage transitions are now less successful and more sensitive to freshwater flow
  - Diminished population productivity
  - Flow during PYSL period increased by 2% per year from 1992-2013



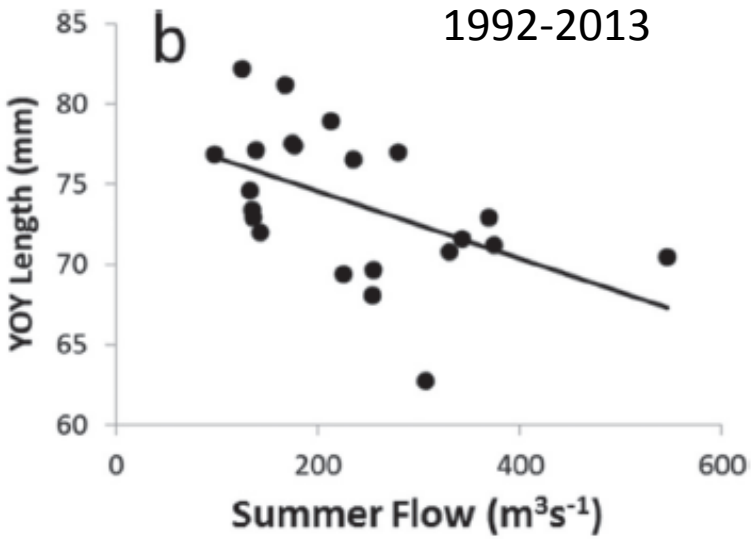


Conclusions

- Life-stage transitions are now less successful and more sensitive to freshwater flow
  - Diminished population productivity
  - Flow during PYSL period increased by 2% per year from 1992-2013



- Will likely influence how white perch respond to climate change in the Hudson River
  - Flow to increase by 10-15% by 2100



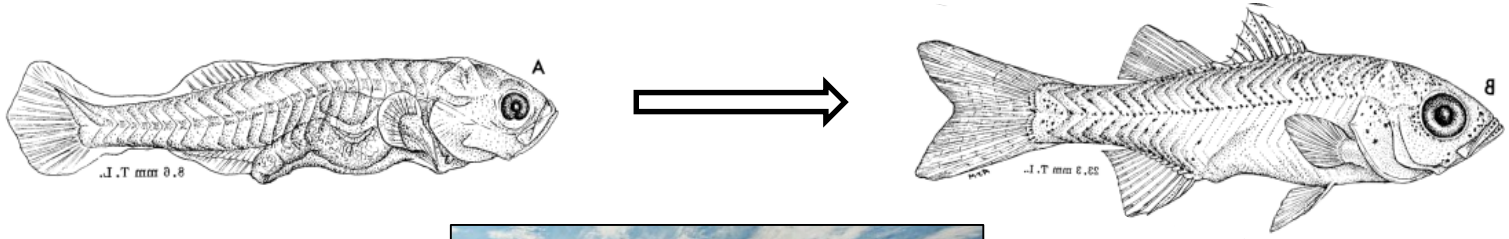
Citation: Najjar et al. (2009)

Overall Conclusion

Zebra mussel forced WP production into alternate state:

- Abrupt and long term changes in production
- Lower spawning stock
- Reduced juvenile production
- Increased sensitivity to environmental variation (flow)

Future Research: Density-dependent production in HR littoral habitats



Estuarine, Coastal and Shelf Science 200 (2018) 277–288

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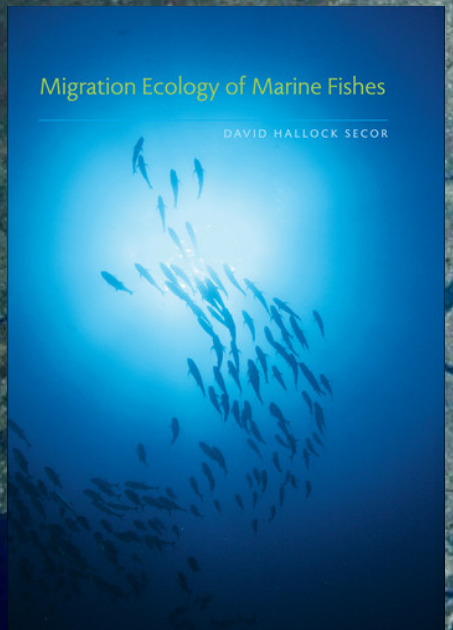
journal homepage: www.elsevier.com/locate/ecss

Ecological carryover effects associated with partial migration in white perch (*Morone americana*) within the Hudson River Estuary

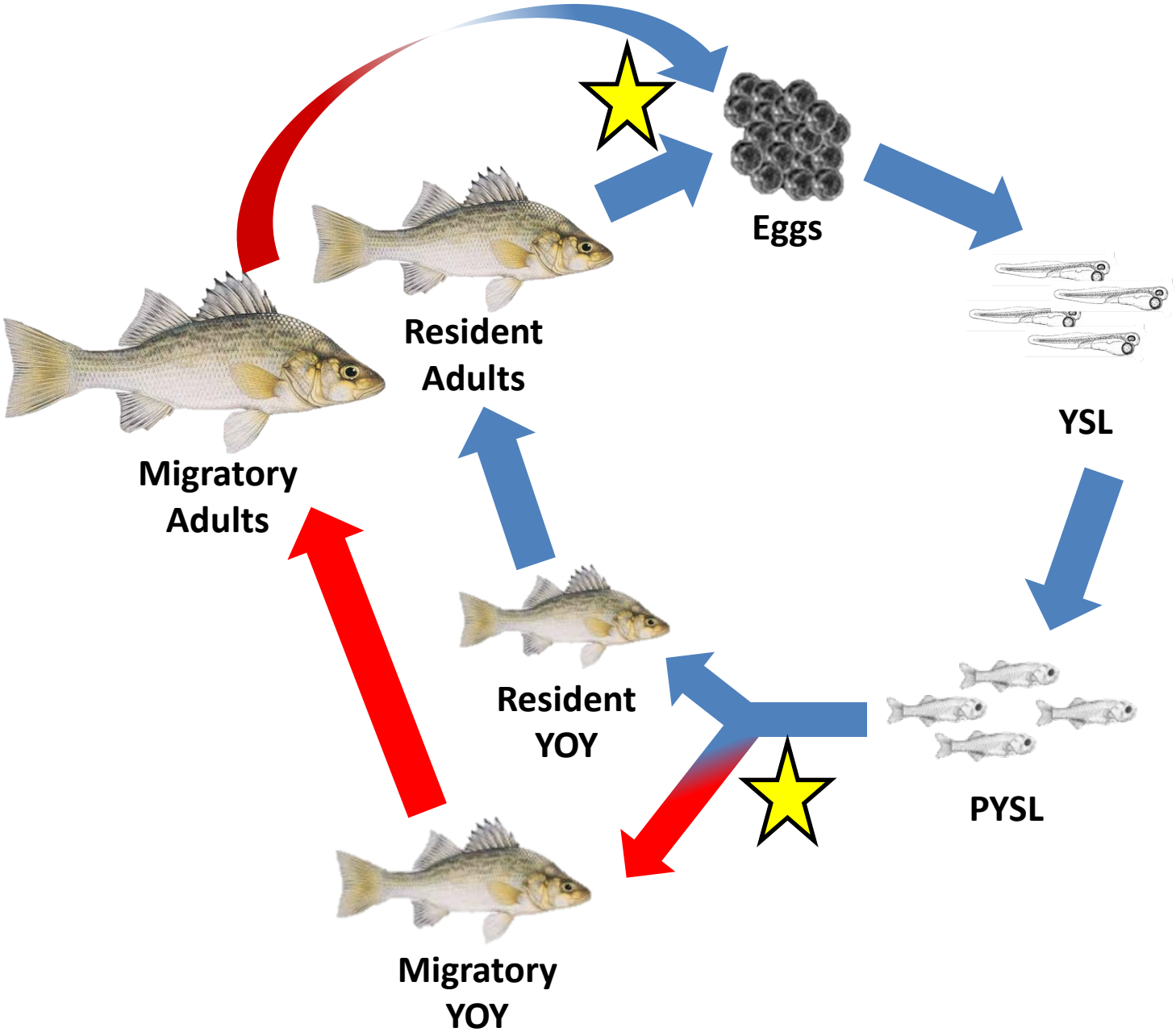
Brian K. Gallagher [a,*,1], Philip M. Piccoli [b], David H. Secor [a]

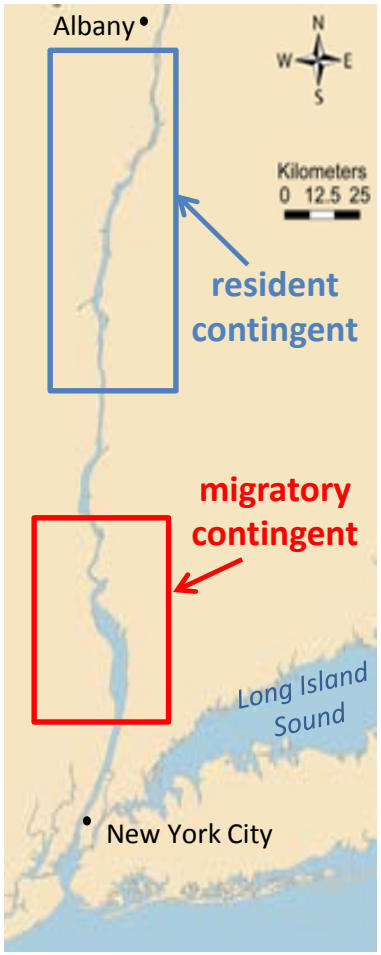
[a] University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, P.O. Box 38, Solomons, MD 20688, USA
[b] Department of Geology, University of Maryland College Park, 237 Regents Drive, College Park, MD 20742, USA

Partial migration: presence of multiple groups with different migration behaviors within a single population



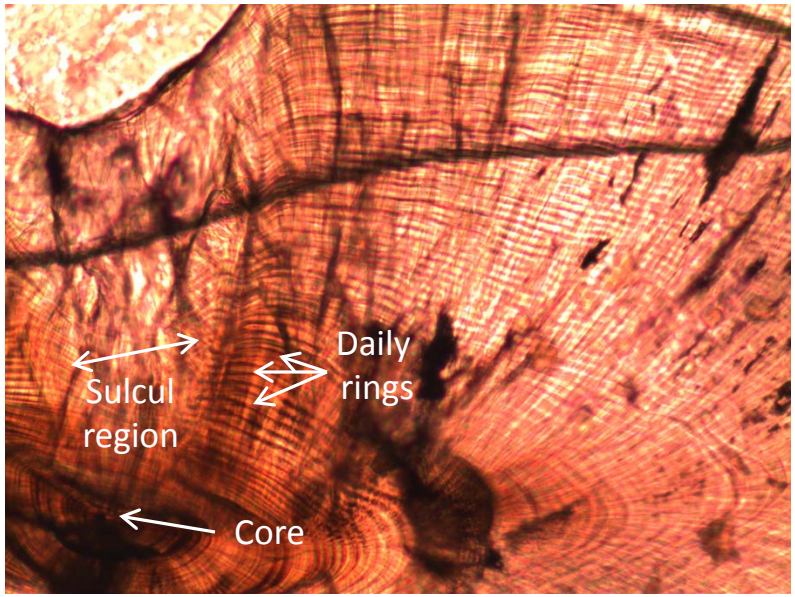
Background: partial migration

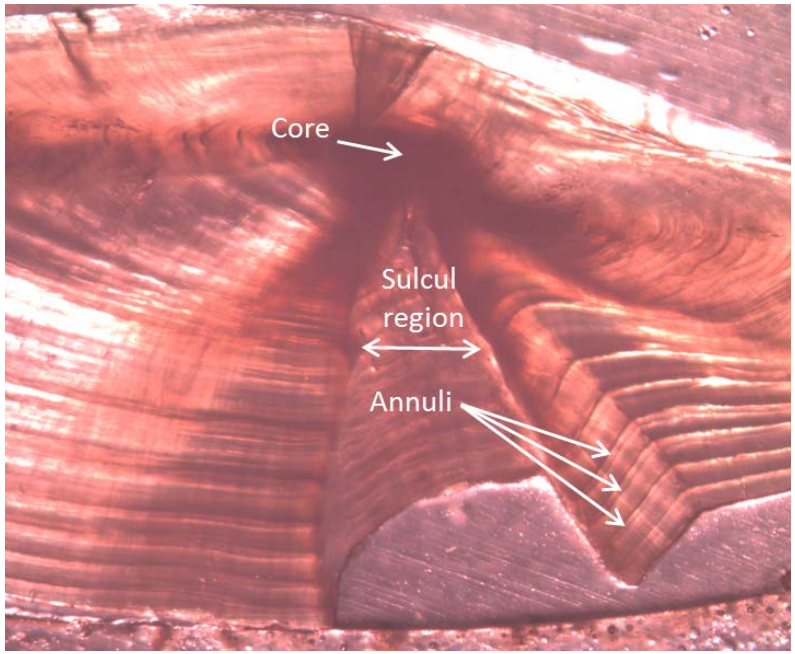




Otolith (ear-stone) analysis

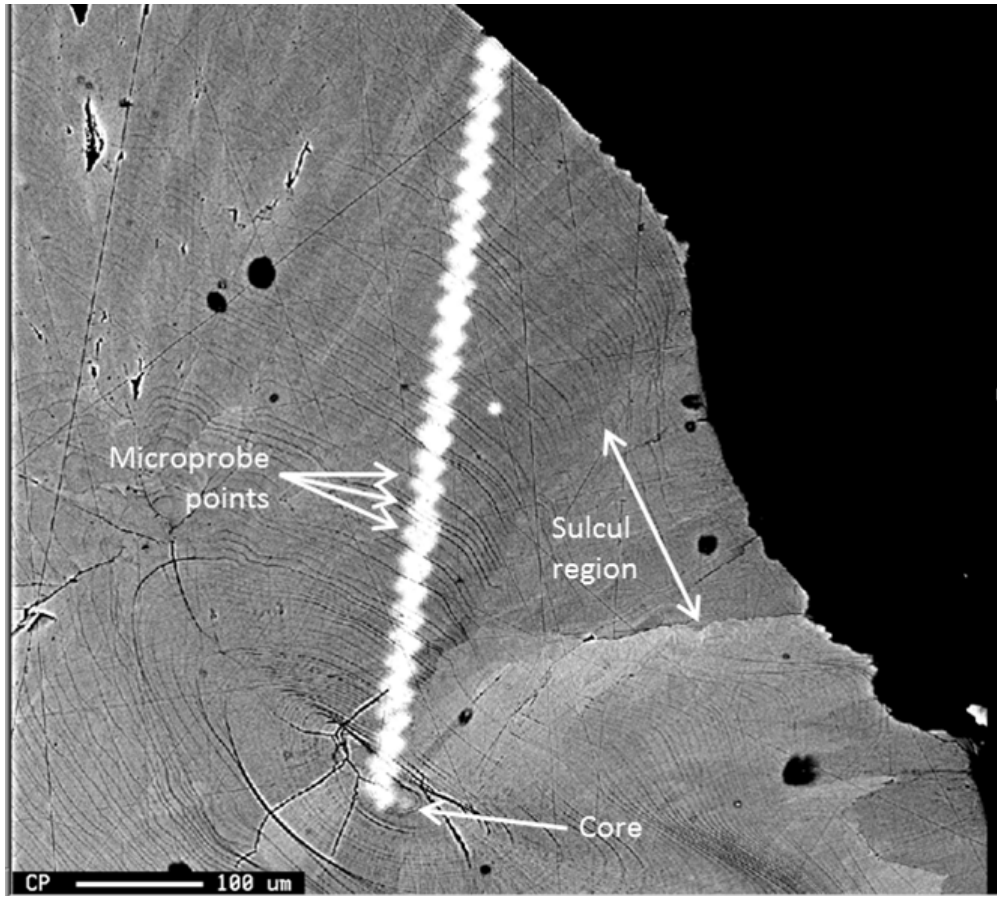
- Ear-stones ($CaCO_3$) grow in concentric rings
- Enables precise age determination in YOY (daily) and adults (annual)





Otolith chemistry

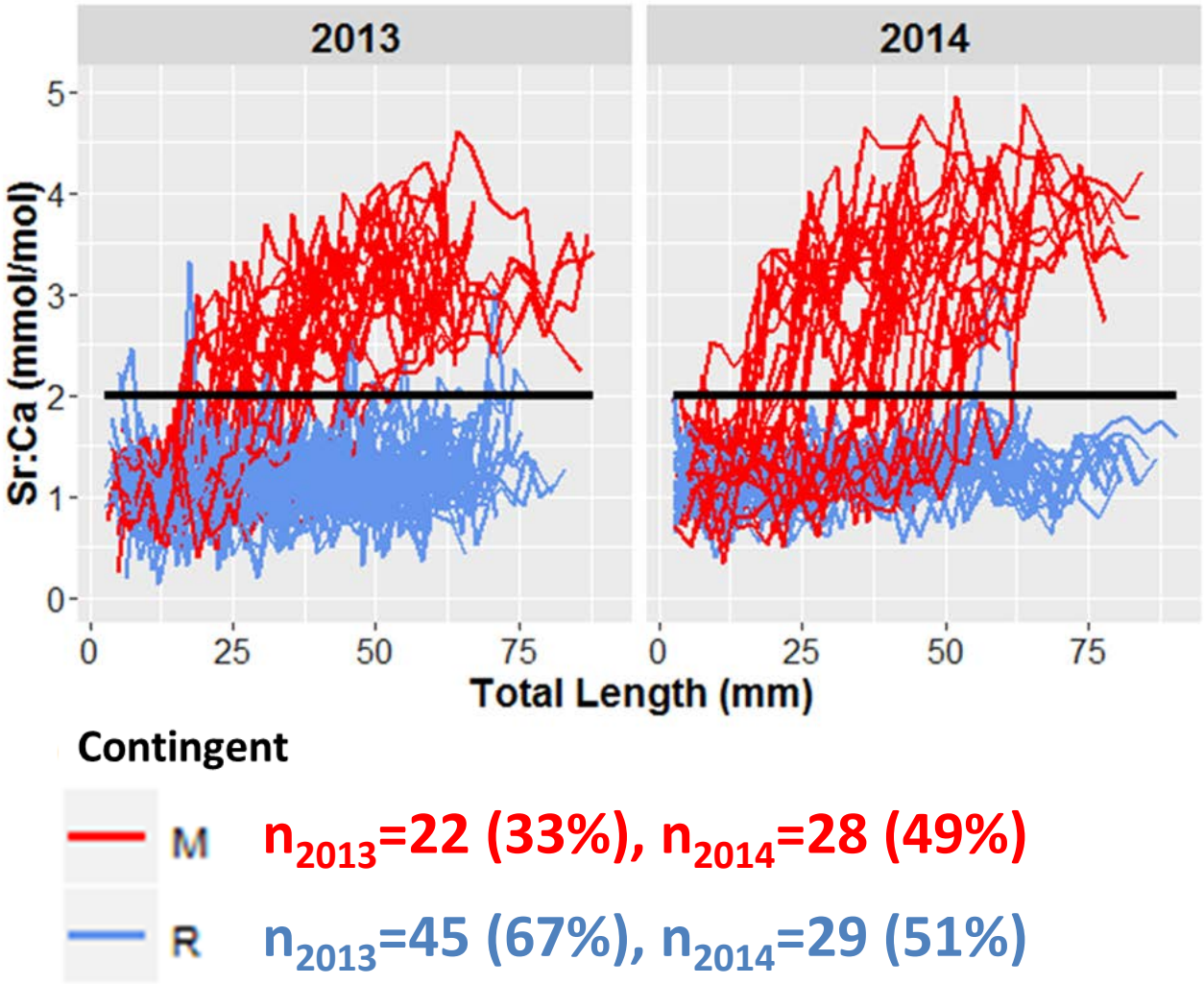
- Strontium:Calcium (Sr:Ca) measured within first annulus of otoliths
- Sr:Ca positively related to salinity
- X-ray spectrometry
- Points every ~20µm (YOY) or ~25µm (adults)



Reference: Kraus and Secor (2004b)

YOY contingents

- 2 mmol/mol threshold
- Identified two contingents in each year class
- Greater YOY abundance and higher percent migrants in 2014



n_{2013}=22 (33%), n_{2014}=28 (49%)

n_{2013}=45 (67%), n_{2014}=29 (51%)

Are adults recruiting from freshwater or brackish water nurseries?

- Compare adult characteristics between contingents:

  <u>Classify adult migrations</u>

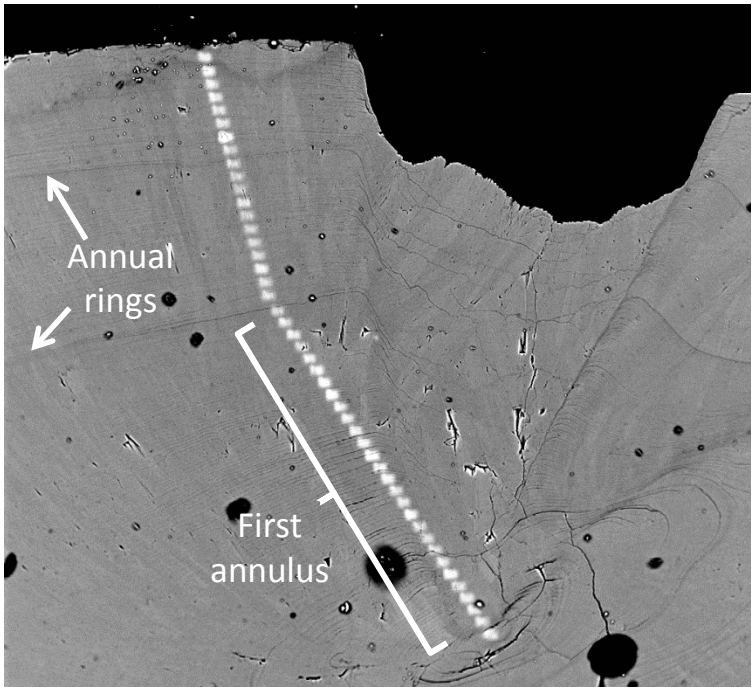
  - *first annulus Sr:Ca profiles*
  - *lifetime Sr:Ca profiles*

  <u>Age-length relationships</u>

  - *von Bertalanffy growth models*

  <u>Fecundity and maturity</u>

  - *functions of length*



What about adults?

- Compare adult characteristics between contingents:

  <u>Classify adult migrations</u>

  - *first annulus Sr:Ca profiles*

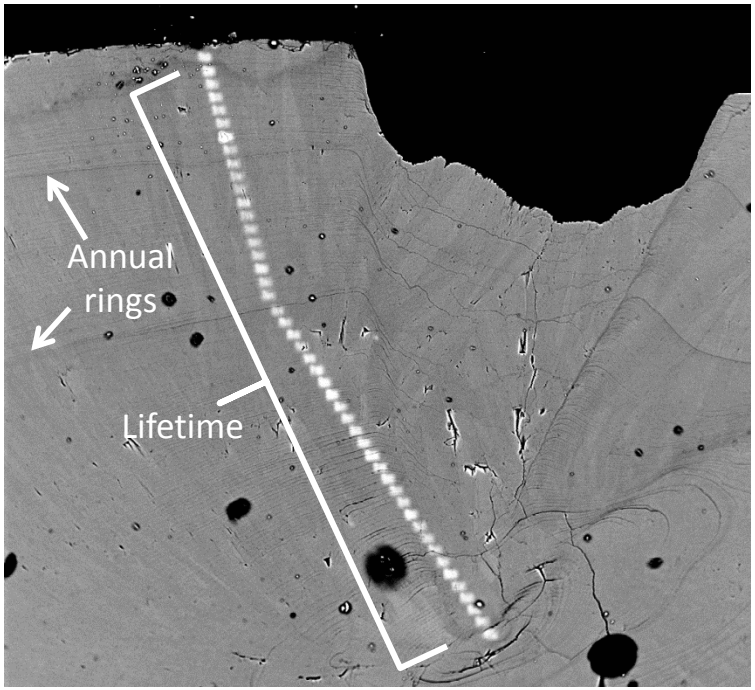
  - *lifetime Sr:Ca profiles*

  <u>Age-length relationships</u>

  - *von Bertalanffy growth models*

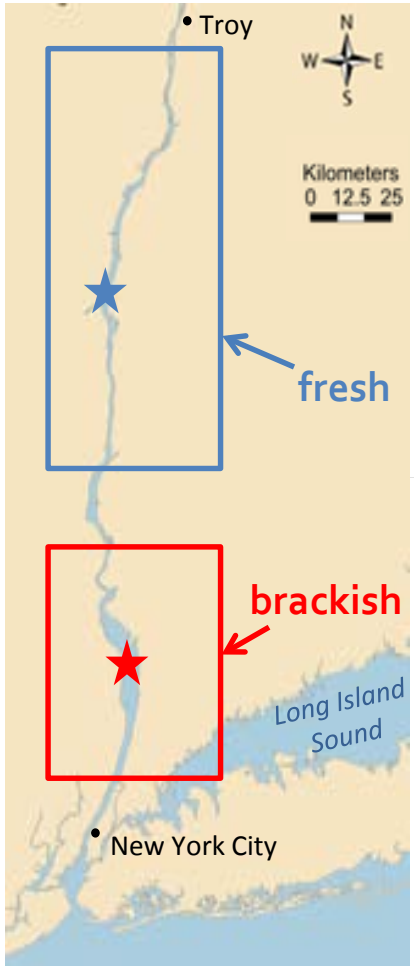
  <u>Fecundity and maturity</u>

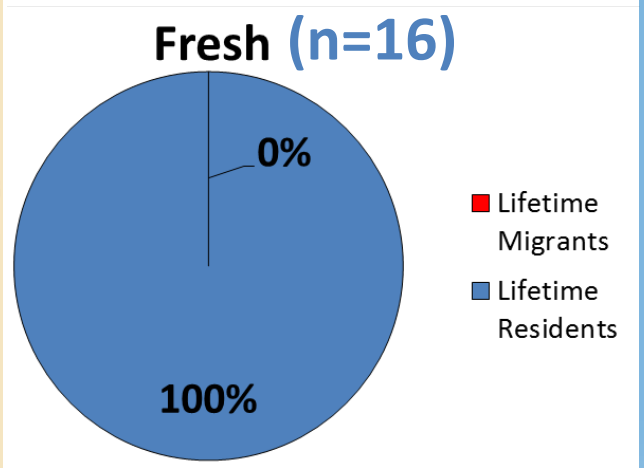
  - *functions of length*

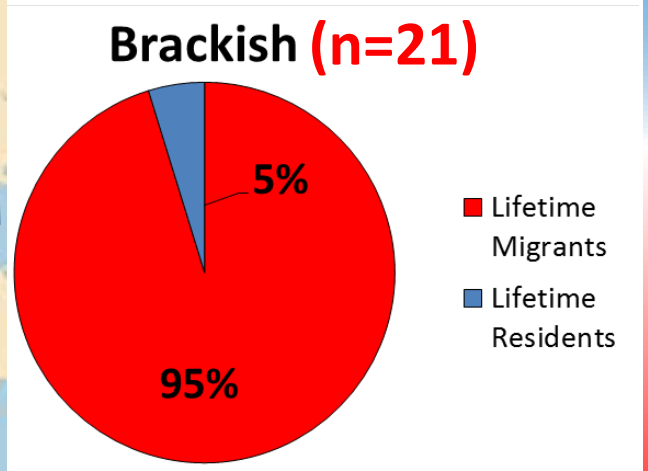


Lifetime Sr:Ca profiles

- For adults captured in the fall:
  - All fish caught in freshwater were lifetime residents
  - Most fish caught in brackish water were lifetime migrants

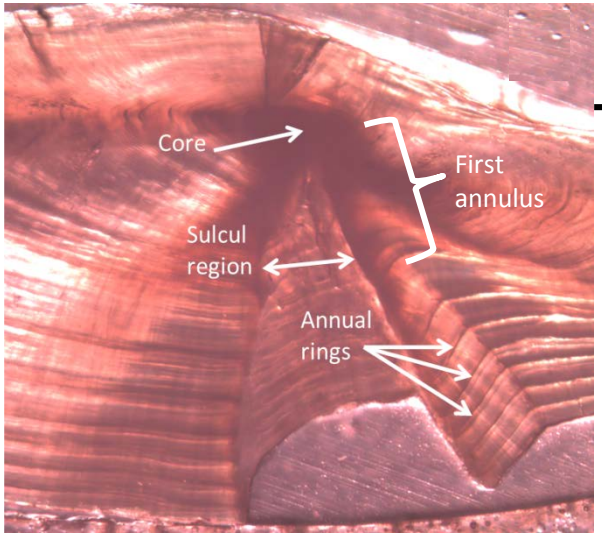






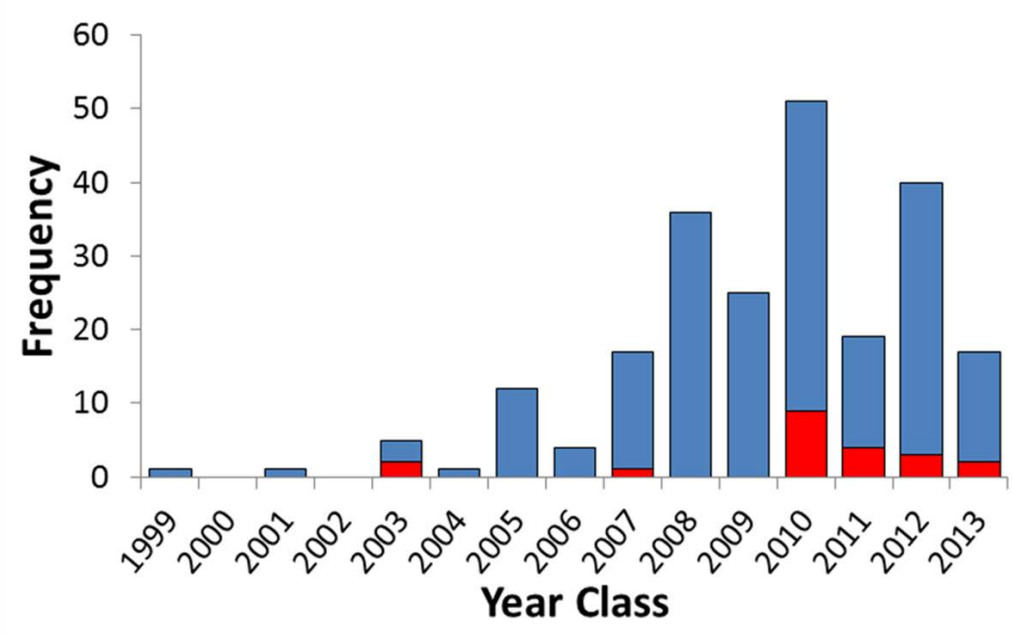
Contingent proportions

- Tested for differences in contingent proportions across year-classes
  - Compared to direct estimate based on surveys of YOY



Age + Year-1 Sr:Ca → Cohort + Contingent

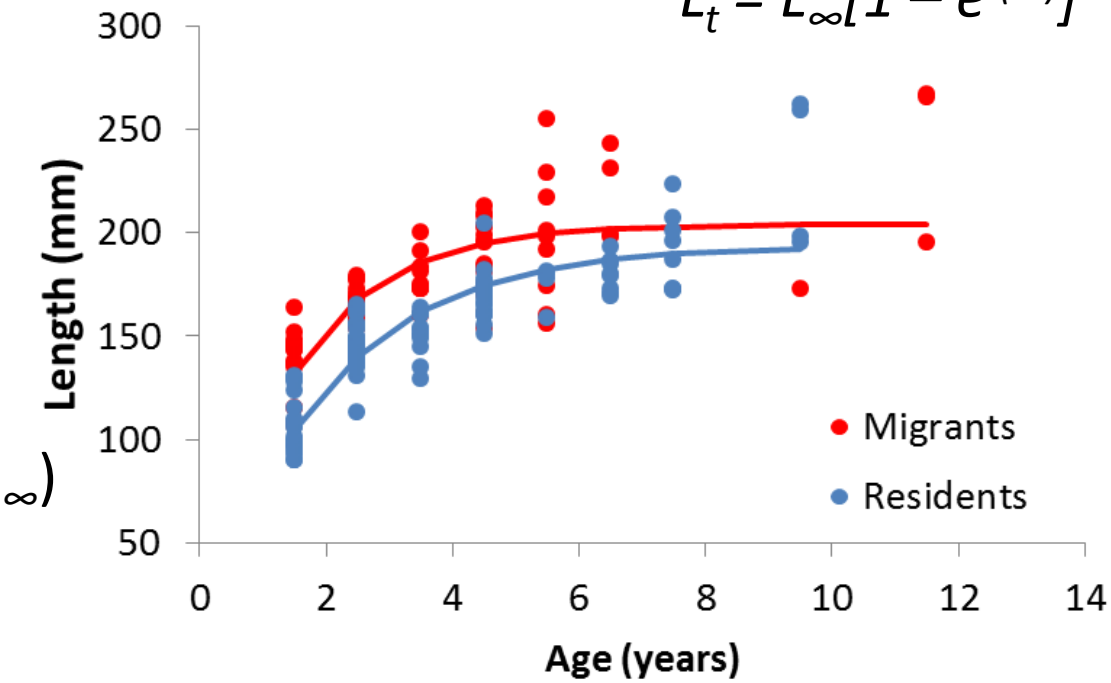
- Migratory contingent was underrepresented in adult sample (~9%) compared to YOY sample (~43%)



Adult growth

- Contingents based on location of capture
- Migrants had higher growth rate (*k*) and larger maximum size (L_∞)
- Carryover effect

$$L_t = L_\infty[1 - e^{-(kt)}]$$



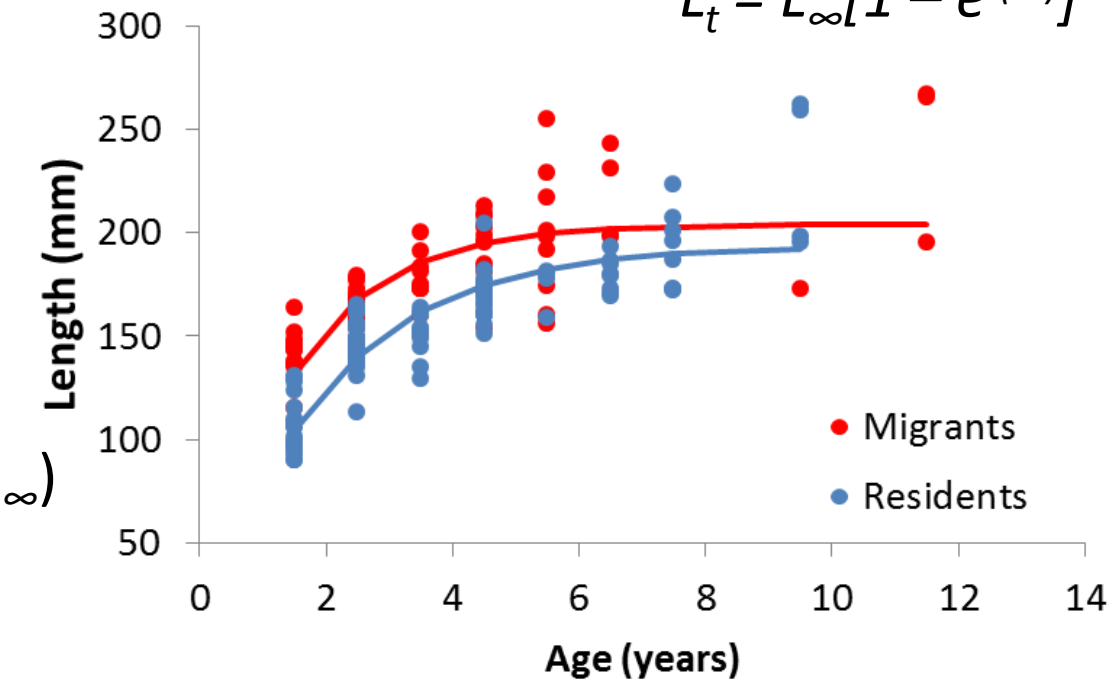
Migratory Contingent		
Parameter	Estimate	95% CI
k	0.69	0.62-0.76
L_∞	204	201-207

Resident Contingent		
Parameter	Estimate	95% CI
k	0.52	0.48-0.56
L_∞	194	191-196

Adult growth

- Contingents based on location of capture
- Migrants had higher growth rate (*k*) and larger maximum size (L_∞)
- Carryover effect
  - Migrants likely mature faster, spawn more eggs

$$L_t = L_\infty[1 - e^{-(kt)}]$$



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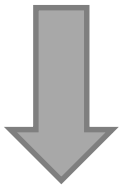
k	0.52	0.48-0.56
L_∞	194	191-196

Summary

- Identified two primary contingents
  - Residents and migrants

Early-life environment



?

YOY migration behavior

Summary

- Faster growth rate and larger maximum size in migratory adults

- **Early migration behaviors have carryover effects on growth and maturity**

Early-life environment

?

YOY migration behavior

✓

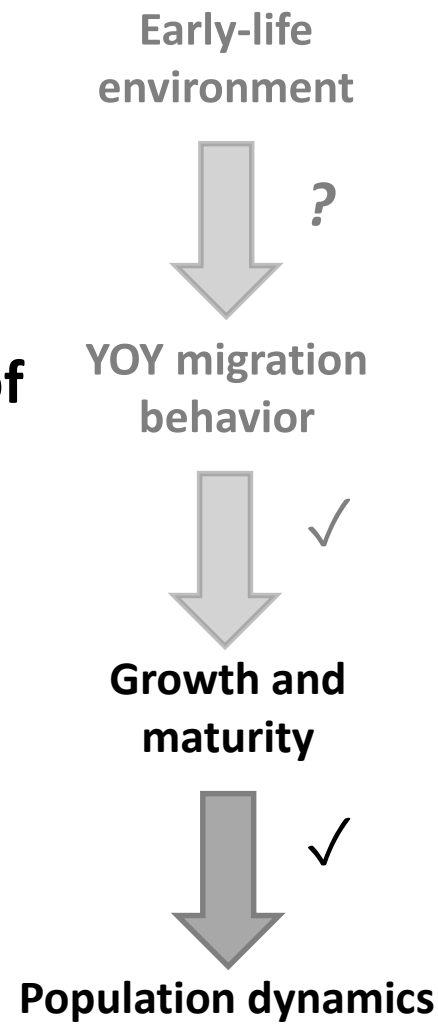
Growth and maturity

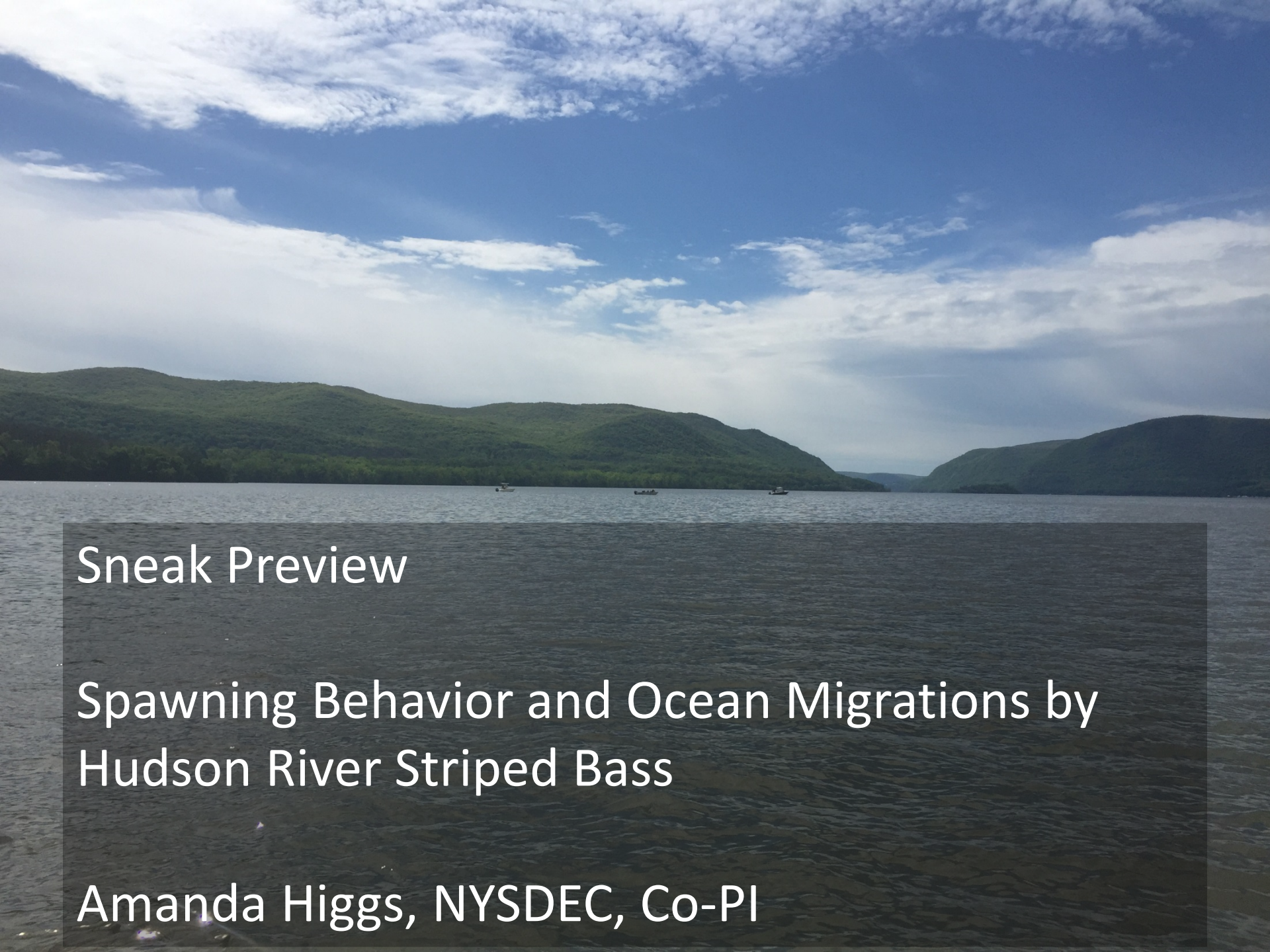
Summary

- **Some evidence that migrants may experience higher mortality**

  - Related to "predatory gauntlet"

  (Limburg. 2001. Ecology)
- **Future work will explore a broader range of scenarios in an age-structured population model**





Sneak Preview

Spawning Behavior and Ocean Migrations by Hudson River Striped Bass

Amanda Higgs, NYSDEC, Co-PI

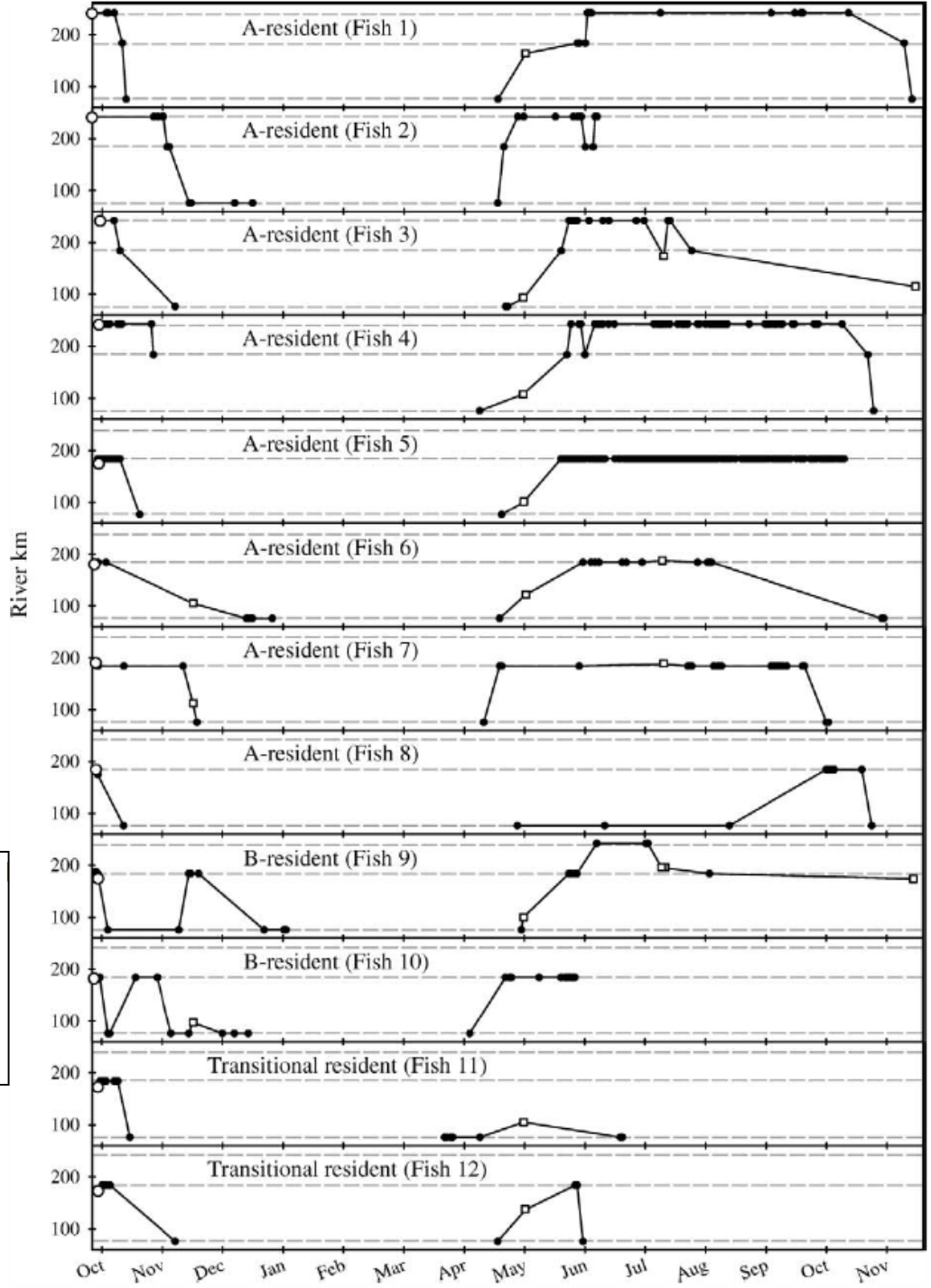
Striped bass spawning run(s): Single or multiple?

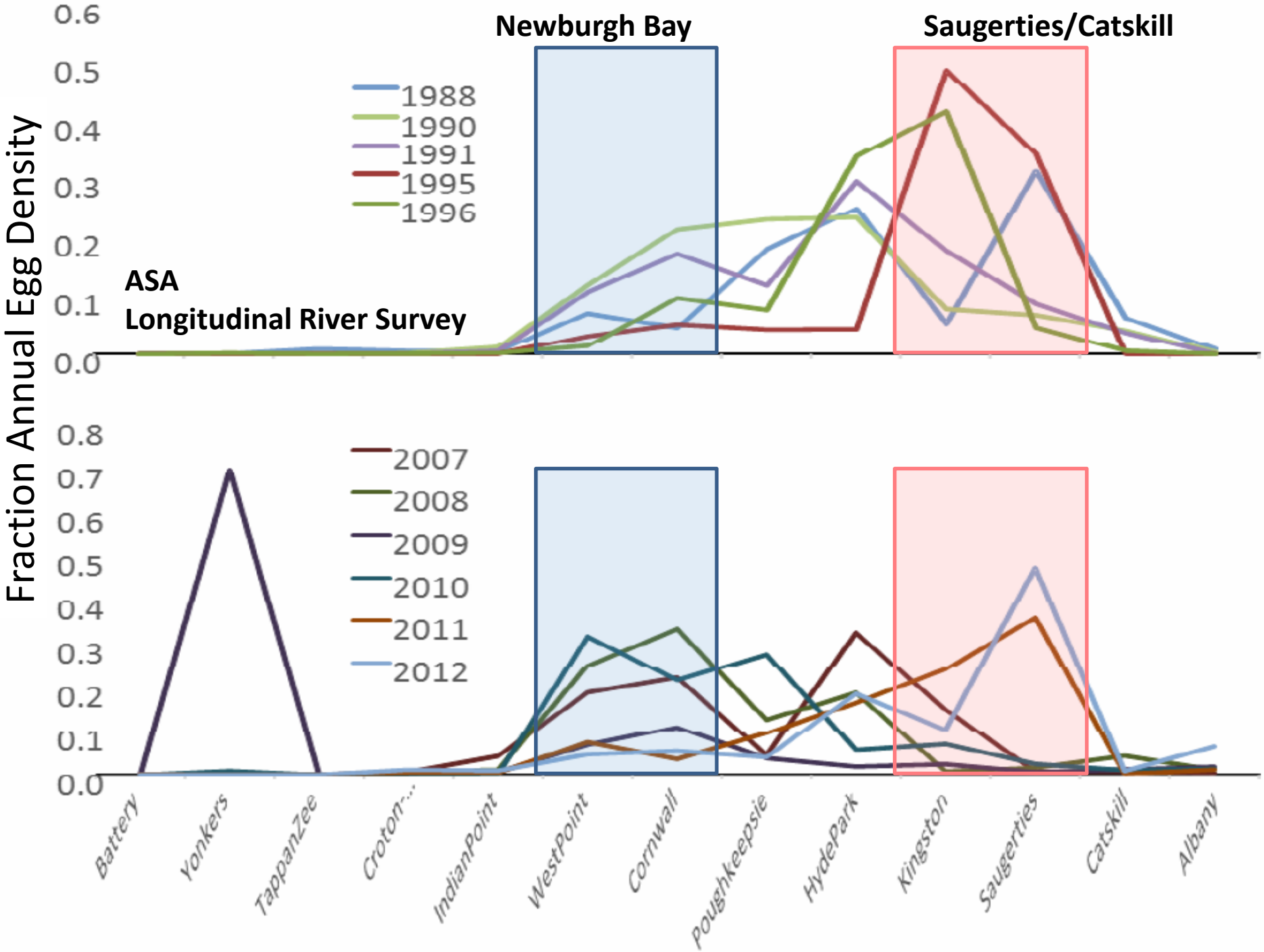
Transactions of the American Fisheries Society 136:95–104, 2007

DOI: 10.1577/T06-056.1

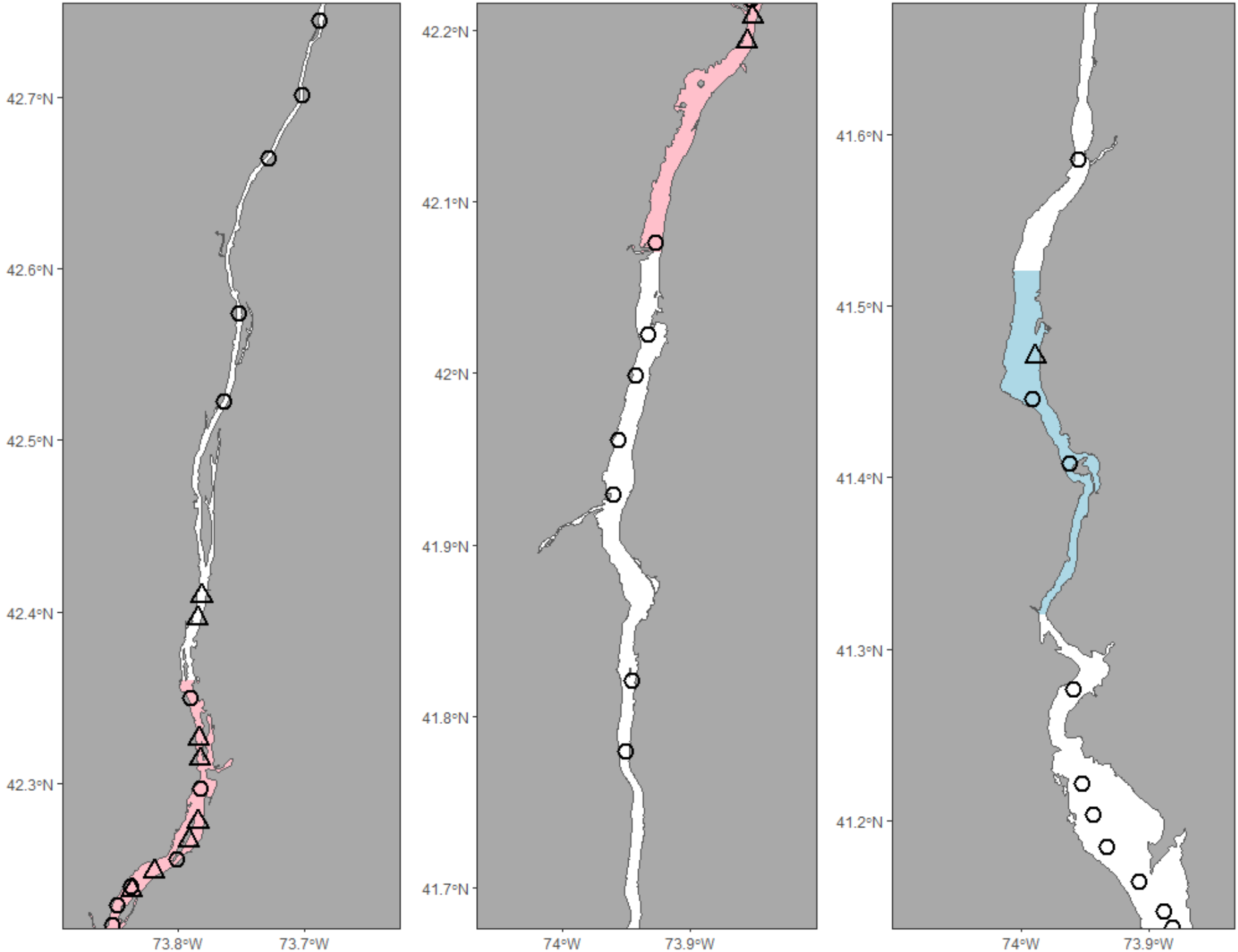
Intercept Telemetry of the Hudson River Striped Bass Resident Contingent: Migration and Homing Patterns

REBECCA L. WINGATE AND DAVID H. SECOR

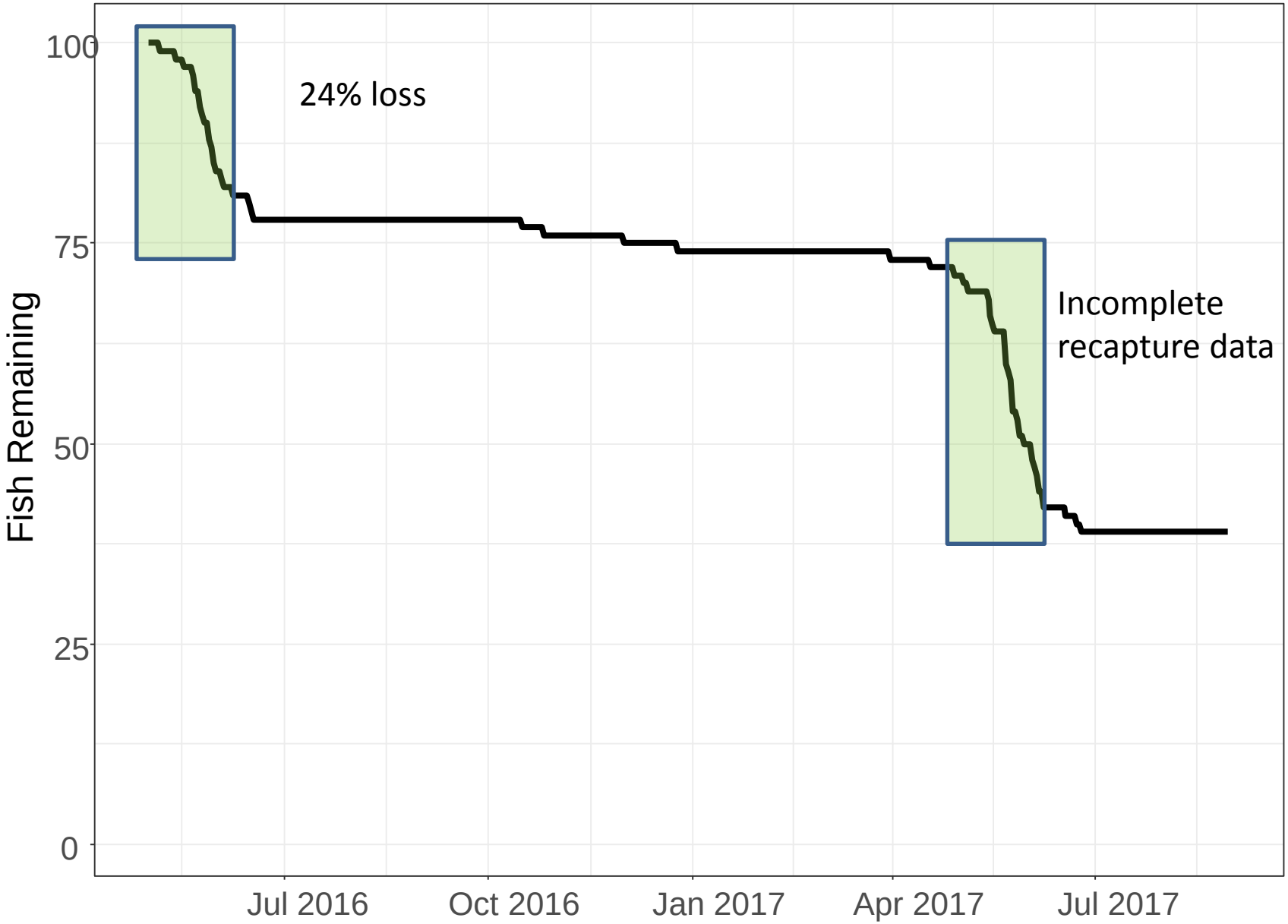



Newburgh Bay
Saugerties/Catskill
Fraction Annual Egg Density
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1988
1990
1991
1995
1996
ASA
Longitudinal River Survey
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2007
2008
2009
2010
2011
2012
Battery
Yonkers
TappanZee
Croton-...
IndianPoint
WestPoint
Cornwall
Poughkeepsie
HydePark
Kingston
Saugerties
Catskill
Albany

NYSDEC Spawning stock survey
Spring 2016: 100 Adults implanted with acoustic tags

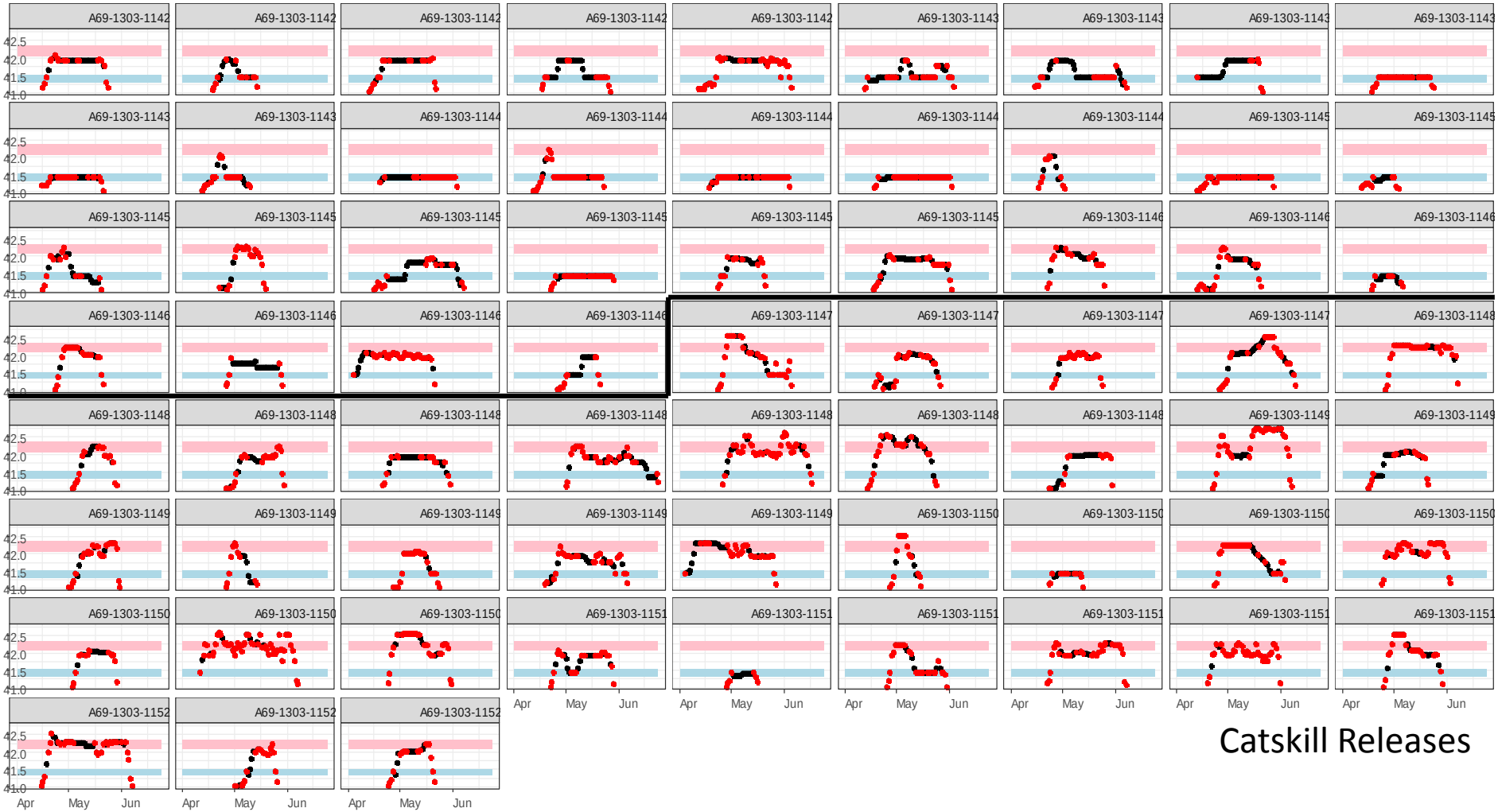

42.7°N
42.6°N
42.5°N
42.4°N
42.3°N
73.8°W
73.7°W
42.2°N
42.1°N
42°N
41.9°N
41.8°N
41.7°N
74°W
73.9°W
41.6°N
41.5°N
41.4°N
41.3°N
41.2°N
74°W
73.9°W

Loss Rate of Tagged Spawners

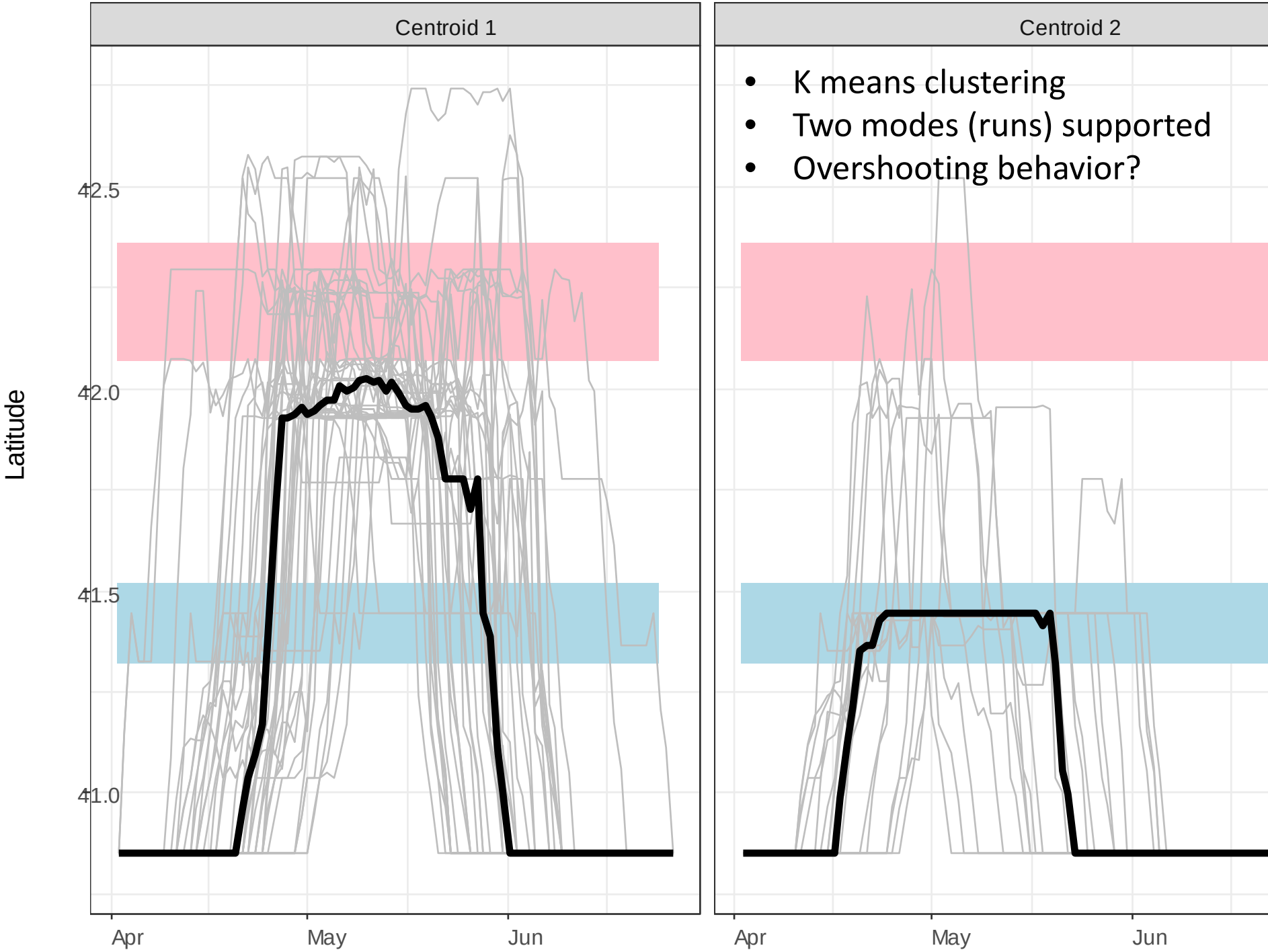


Spring 2017 Striped Bass Spawning Run

Newburgh Releases



Catskill Releases



- K means clustering
- Two modes (runs) supported
- Overshooting behavior?

Data providers:

- John Young
- David Strayer

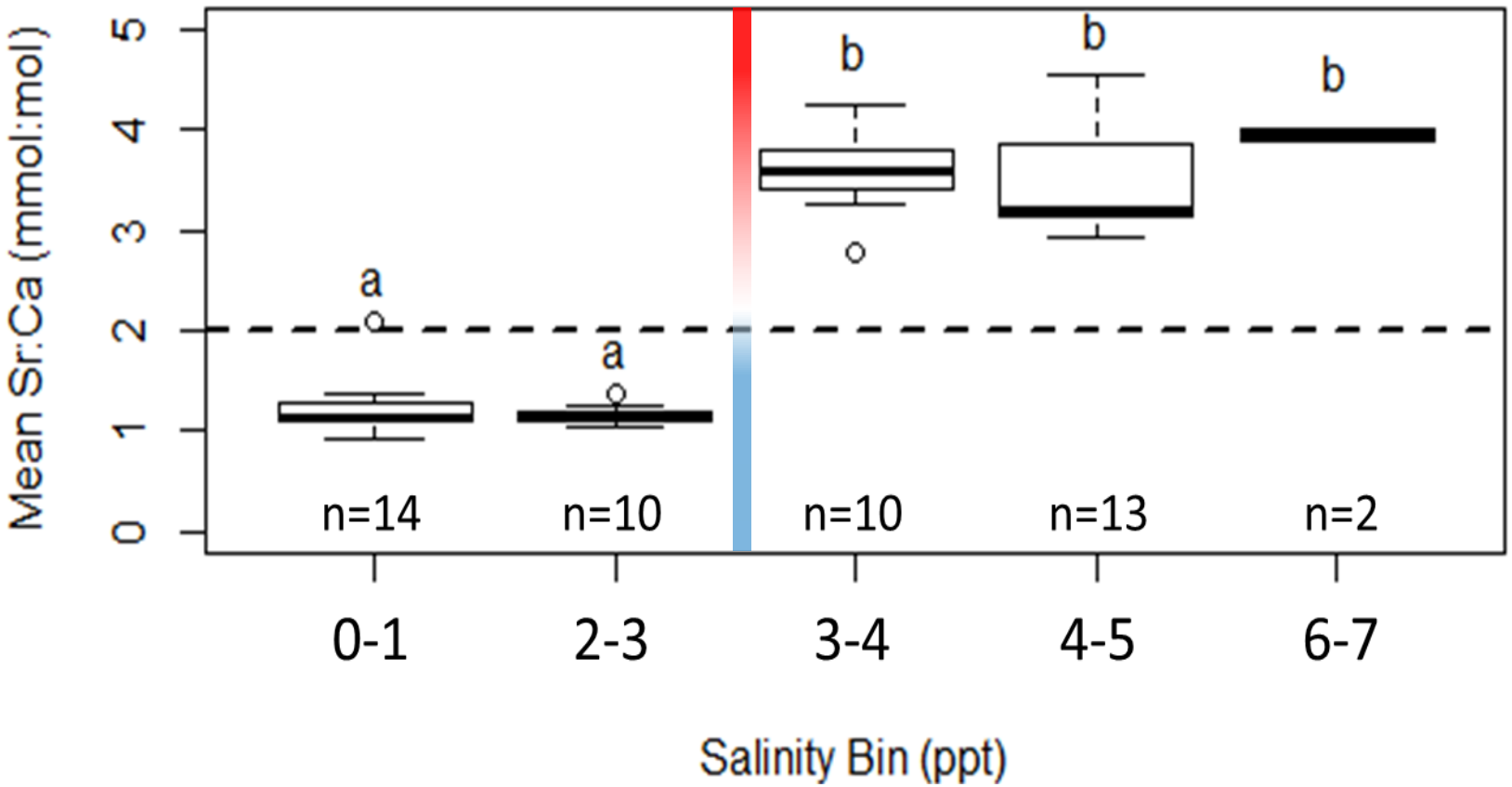
HUDSON RIVER FOUNDATION

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

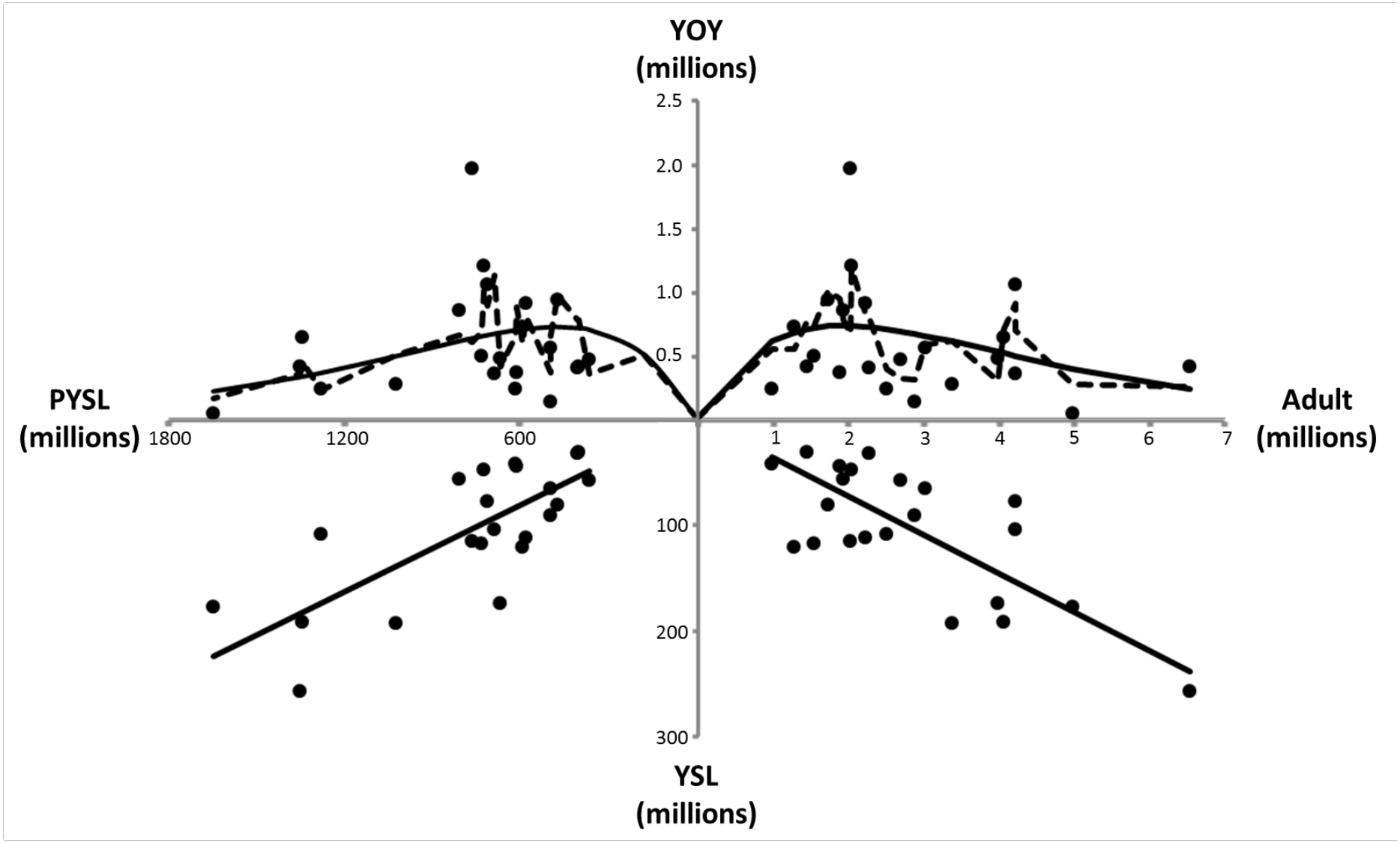
Sneak Preview: Striped bass spawning runs

- Spawning run mortality ~25%
- Two discrete spawning runs (locations)
- HR fish overwinter off Ocean City MD
- Come here more at AFS, Atlantic City, 9/2018

Sr:Ca vs salinity



Putting it together: Paulik diagram



Changes in zebra mussels

- Zebra mussel survival has decreased over time
- Many benthic and pelagic invertebrates have recovered
- Quagga mussels also invaded in 2008