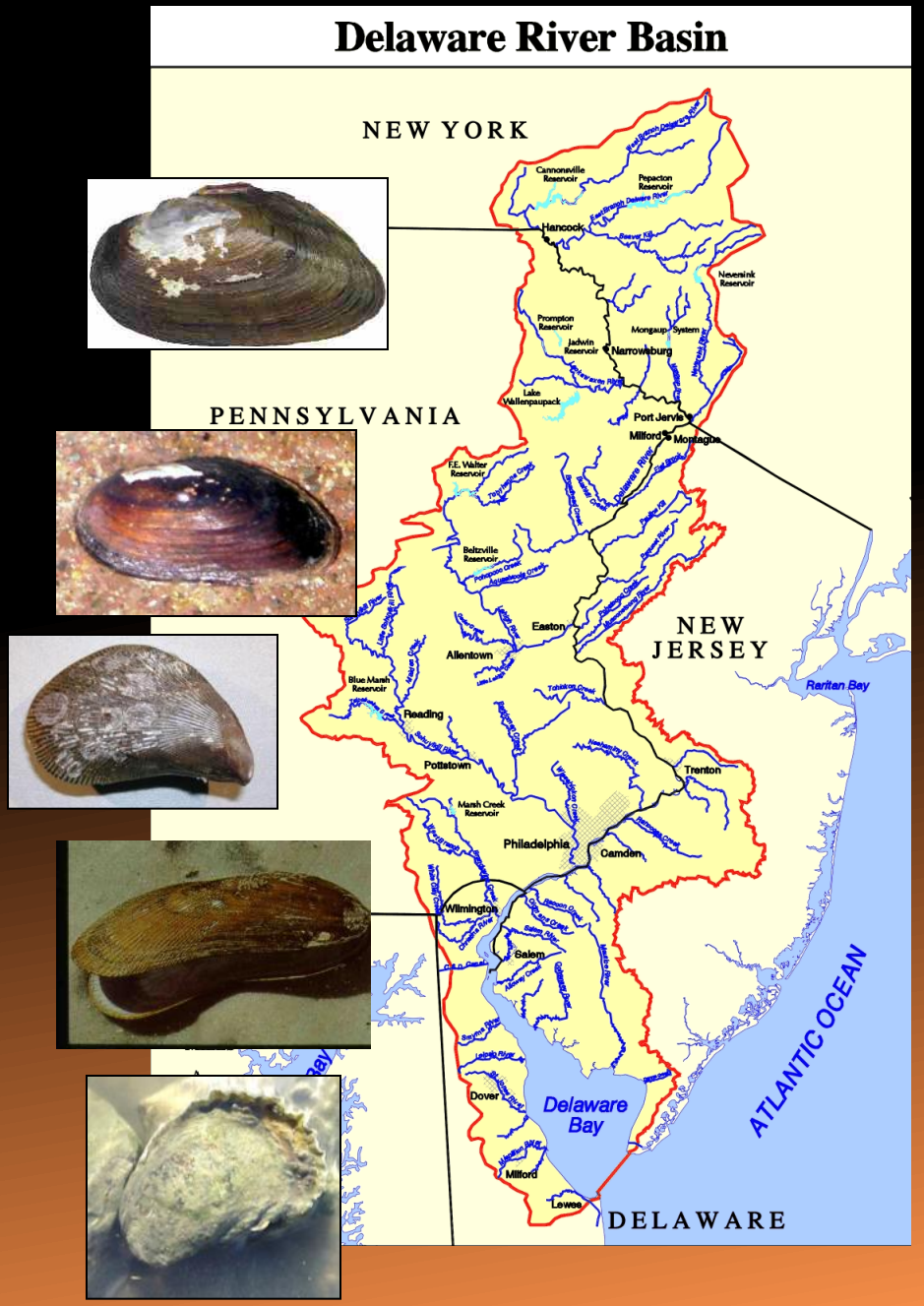
Bivalve Restoration From the Headwaters to the Coast: How Mussels Can Help Save our Great Waters



Danielle Kreeger

Partnership for the DE Estuary

Modeling Quarterly Review Meeting
January 11, 2012

The Delaware River Basin

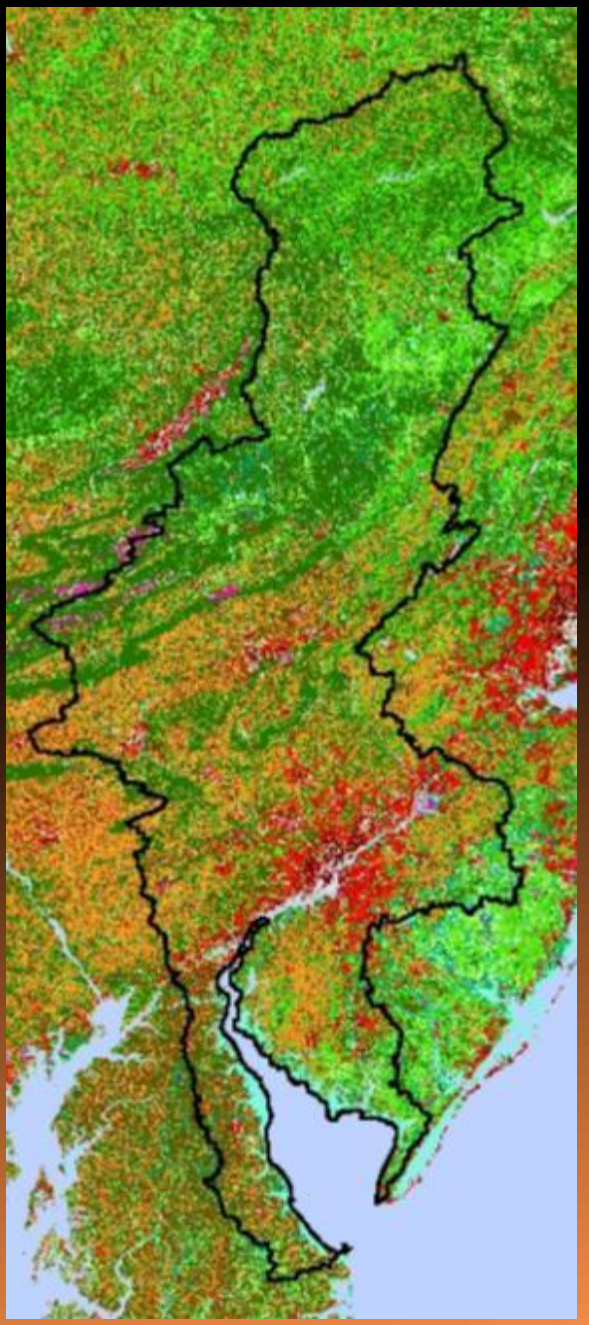
13,600 mi^2

4 States

9 million people

Delaware River
60% of fw inflow (11,700 ft^3/s)

Drinking water for 16 million people



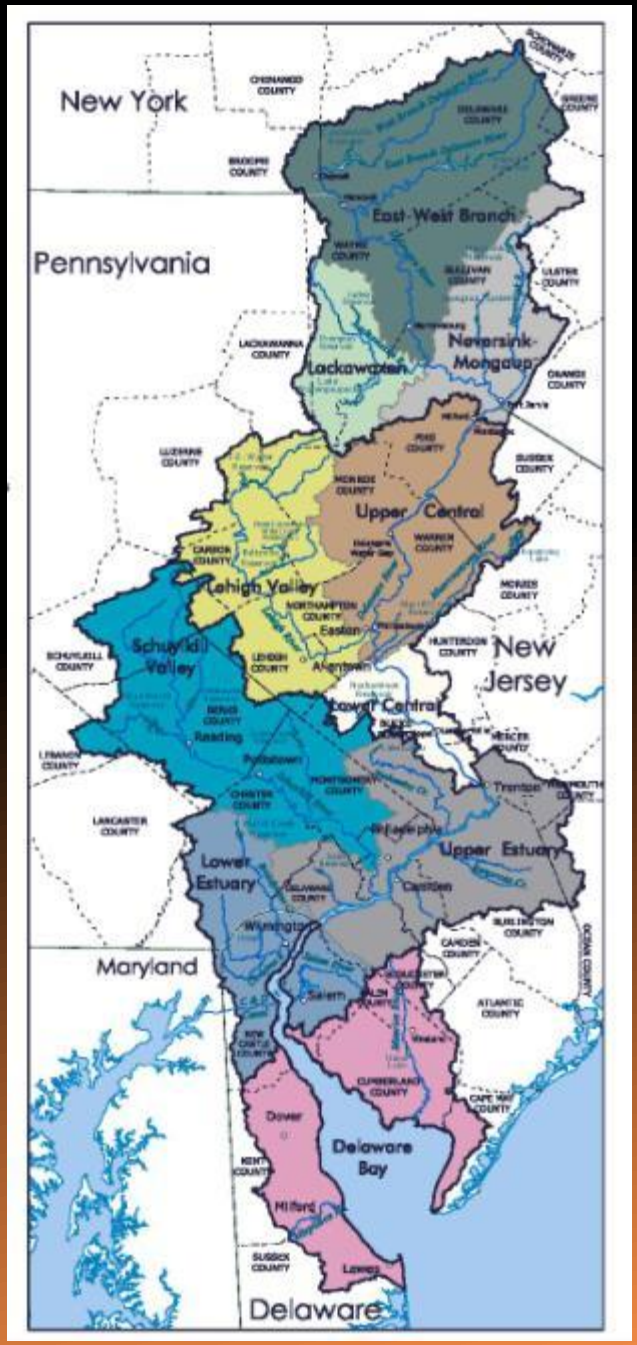
Delaware River Basin

Upper and Central Regions

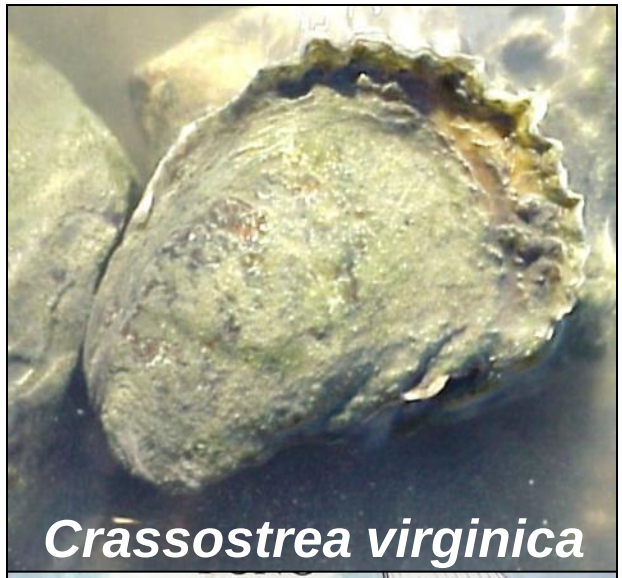
- above Trenton
- pristine, wild and scenic
- longest undammed river in east

Lower and Bay Regions

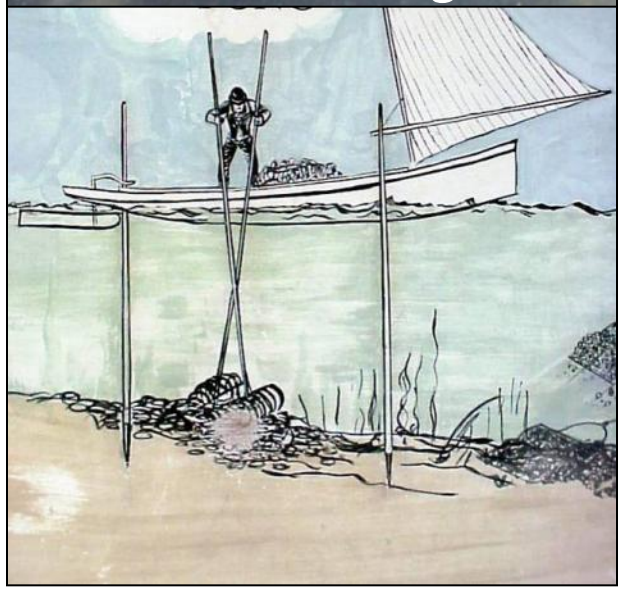
- >90% of people
- legacy contaminants
- historic and modern development
- rich estuarine resources

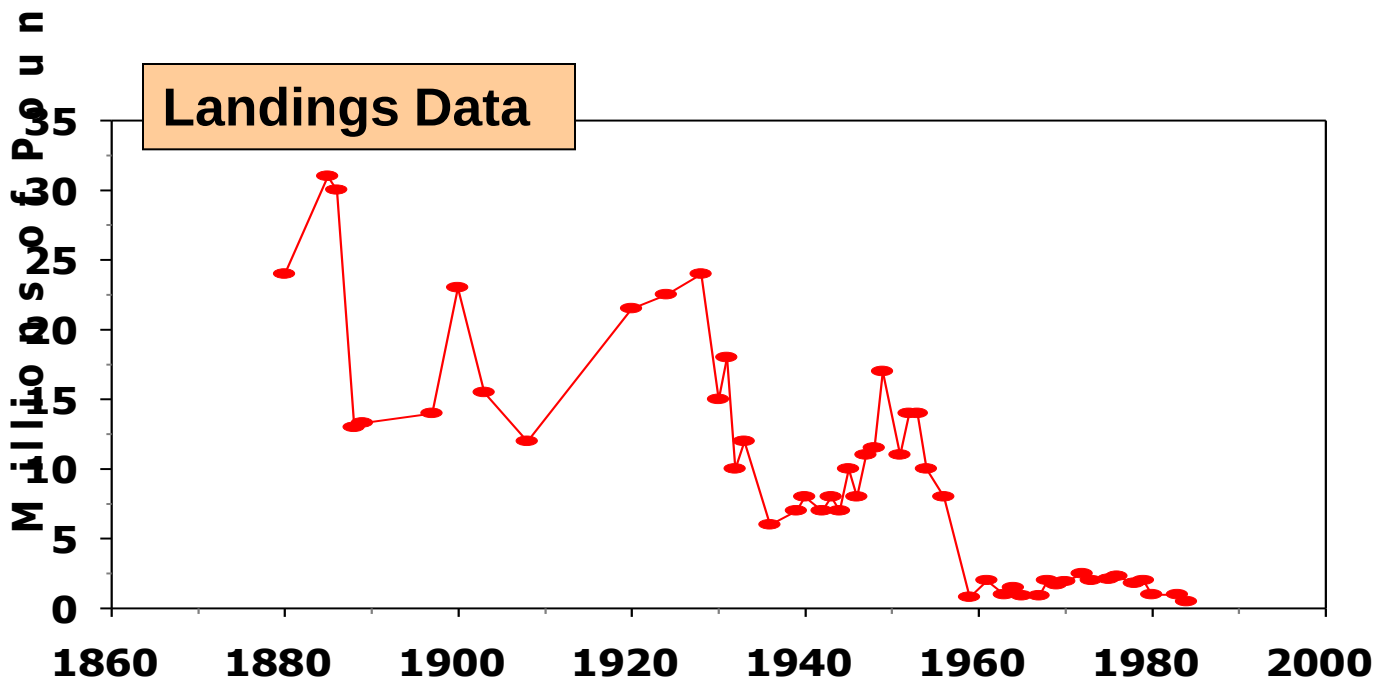


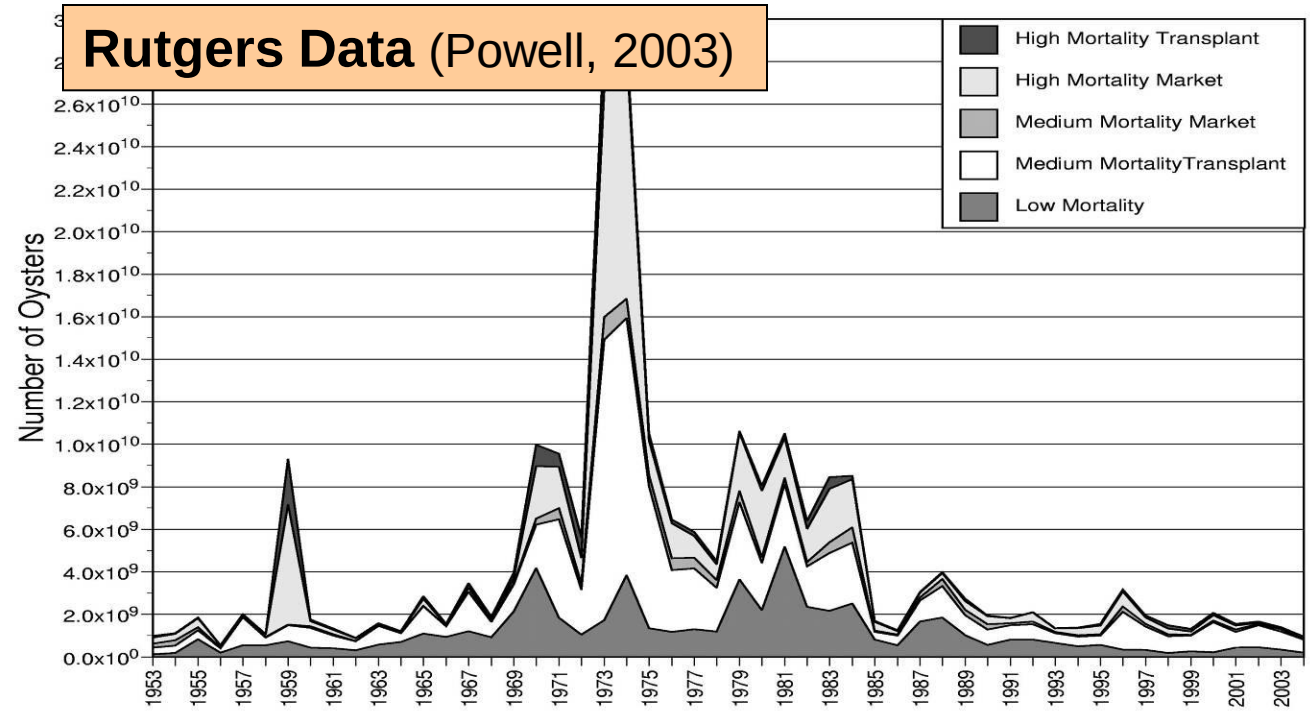
Oysters



Crassostrea virginica







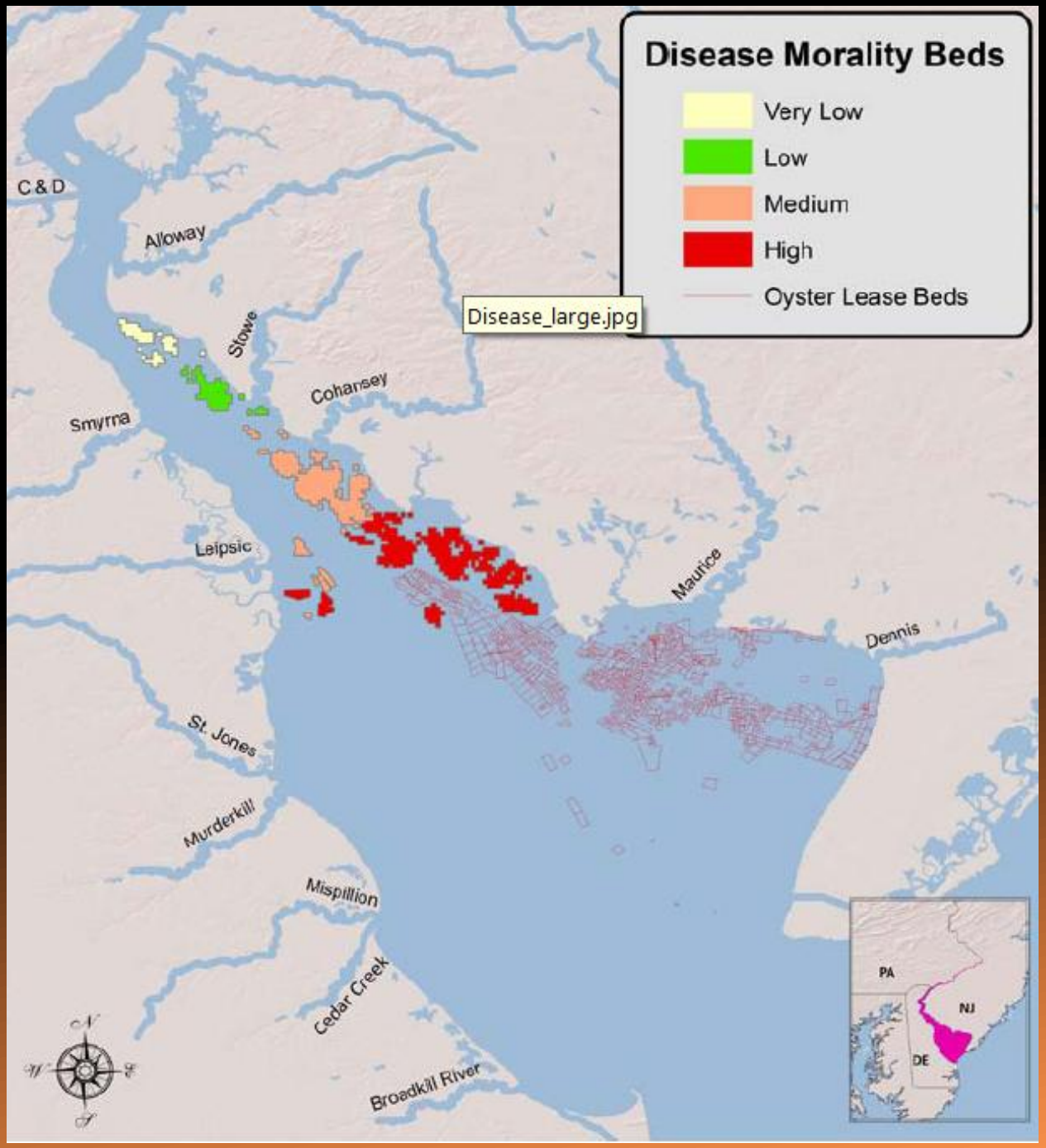
Oysters

Present Population:
~ 2 billion oysters

PDE Supports Oyster Restoration

<u>Challenges</u>:

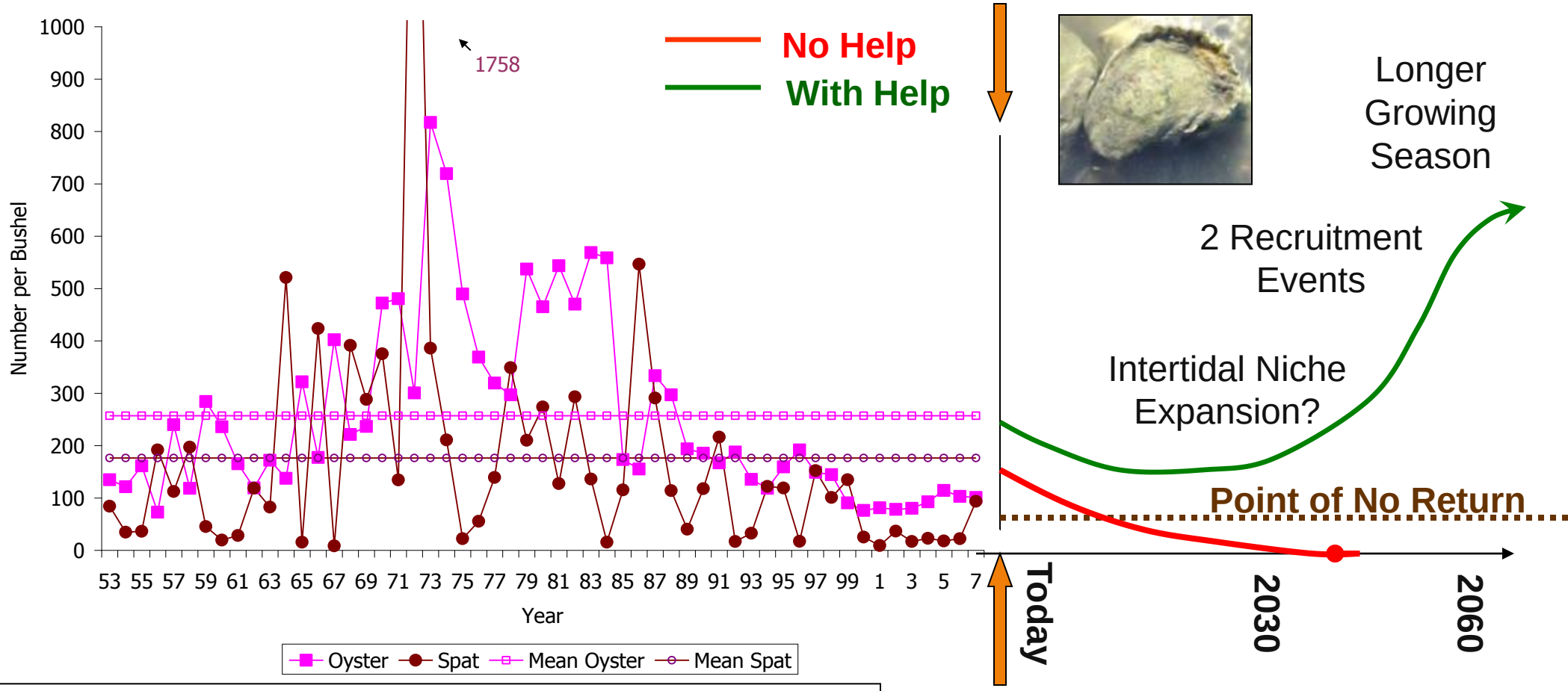
- Disease
- Industry Tradeoffs
- Human Health Mgt
- Climate Change
  - ↑ salinity
  - ↓ suitable bottom



Oyster Shellplanting Success

Bivalve Projections – Oysters

Can they be maintained until they might see better conditions?



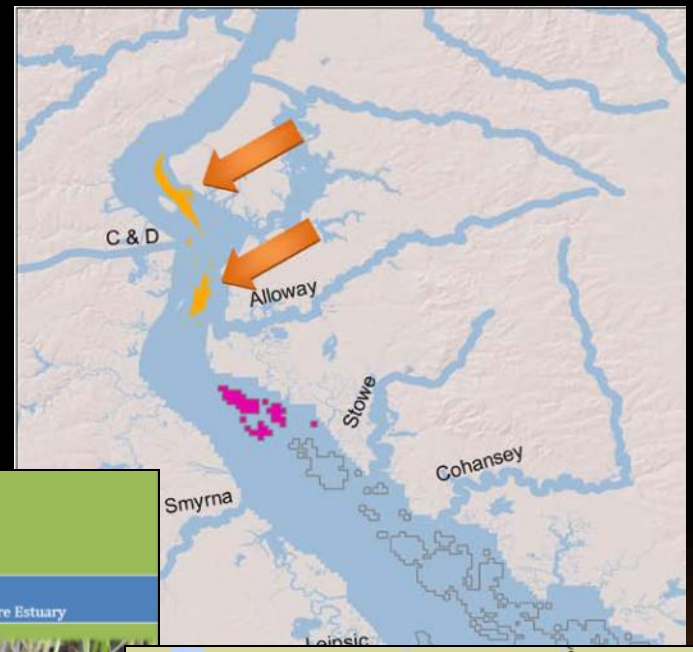
Historical data from Rutgers Haskin Shellfish Laboratory

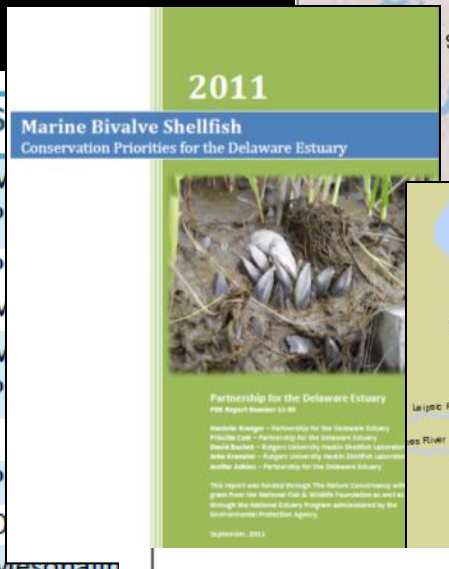
Oysters

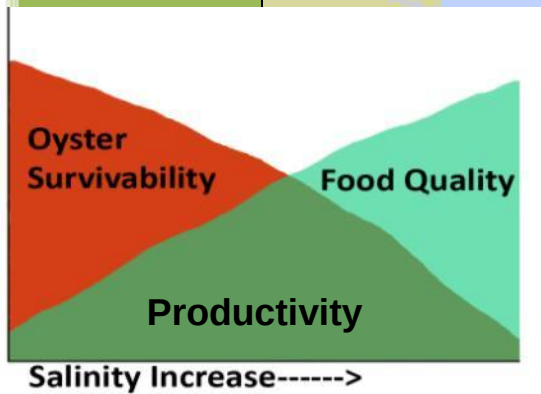
Restoration Planning:

Marine Bivalve Shellfish
Conservation Priorities for the Delaware Estuary
http://www.delawareestuary.org/science_reports_partnership.asp

Common	Scientific Name	Bay Zone	S
Oyster	*Crassostrea virginica*	Subtidal	M P
Ribbed (Marsh) Mussel	*Geukensia demissa*	Intertidal	P M
Northern Quahog (Hard Clam)	*Mercenaria mercenaria*	Subtidal	M P
Blue Mussel	*Mytilus edulis*	Intertidal/Subtidal	P
Atlantic Rangia	*Rangia cuneata*	Subtidal	O
Hooked Mussel	*Ischadium recurvum*	Subtidal	Mesohalin Oligohalin
Softshell Clam	*Mya arenaria*	Subtidal	Polyhaline Mesohalin
Stout Tagelus (Stout razor clam)	*Tagelus plebeius*	Intertidal	Polyhaline
Atlantic Jackknife Clam (Razor Clam)	*Ensis directus*	Intertidal/subtidal	Polyhaline Mesohalin







>60 Species of Bivalves in the Delaware Estuary Watershed

Elliptio complanata

Geukensia demissa

Crassostrea virginica

11 Other Species of Freshwater Unionid Mussels

Corbicula fluminea

Rangia cuneata

Mya arenaria

Mytilus edulis

Ensis directus

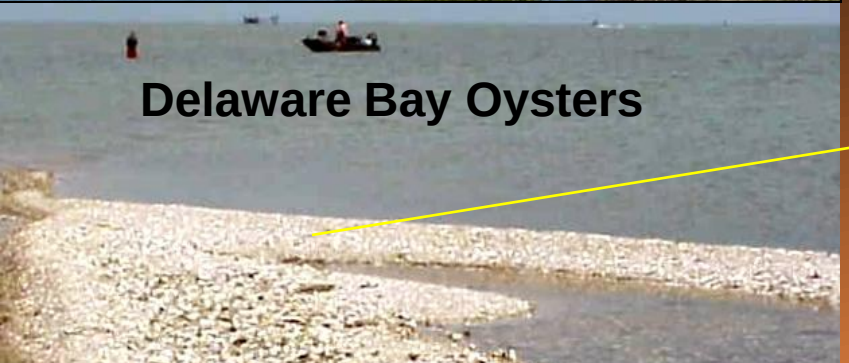
Mercenaria mercenaria

Watershed-wide bivalve restoration

- Bivalves can help reverse the effects of eutrophication. . .
  - Since pollution occurs everywhere, we can look at the whole watershed for remedies, including freshwater mussels, marsh mussels, and estuarine species (oysters)
  - Examples will focus on the Delaware Bay watershed, but the same species live in Chesapeake Bay
- *<u>Main issue</u>: how can we find the best species and locations to use bivalves for restoration?*

Elliptio complanata

Geukensia demissa



Crassostrea virginica

Kreeger

Nature's Benefits

Bivalve Shellfish are "Ecosystem Engineers"

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Mussel Beds

CTUIR Freshwater Mussel Project

Oyster Reefs

Kreeger

Nature's Benefits (Natural Capital)

Millennium Ecosystem Assessment Categories	Specific Services/Values	Oysters	Marsh Mussels	FW Mussels
		Relative Importance Scores		
Provisioning: Food & Fiber	Dockside Product	✓✓✓		✓
Regulating	Shoreline & Bottom Protection	✓✓		
	Shoreline Stabilization	✓✓	✓✓✓	✓✓
Supporting	Structural Habitat	✓✓✓	✓✓	✓✓
	Biodiversity: Imperiled Species			✓✓✓
	Bio-filtration	✓✓✓	✓✓✓	✓✓✓
	Biogeochemistry	✓✓	✓✓	✓✓
	Prey	✓	✓✓	✓
Cultural/ Spiritual/ Historical/ Human Well Being	Waterman Lifest Ecotourism	✓✓		
	Native American	✓✓		✓✓✓
	Watershed Indicator	✓✓✓	✓✓	✓✓✓
	Bio-Assessment	✓✓✓	✓✓	✓✓✓

Livelihoods

Lives

Health

Livelihoods

Health

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Example Ecological Services of Bivalves

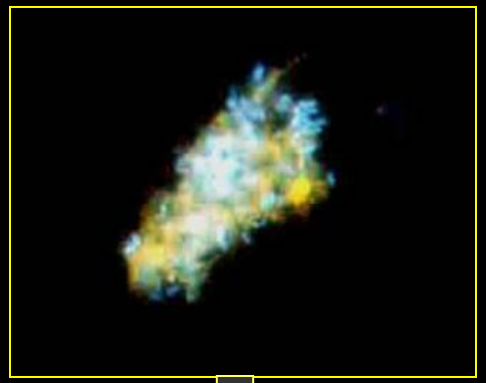
1. Structure

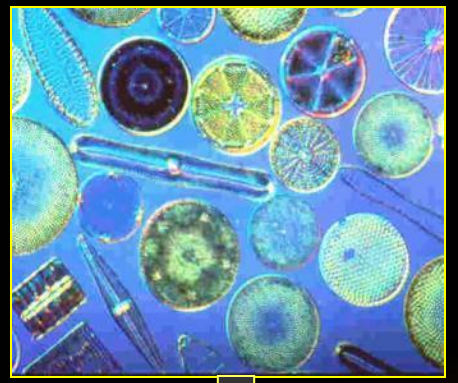
↑ Habitat Complexity

Bind Bottom

Stabilize Shorelines

↑ Bottom Turbulence





2. Function

↓ Suspended Particulates

↓ Particulate N, P

↑ Light reaching bottom

↑ Sediment Enrichment

↑ Dissolved Nutrients

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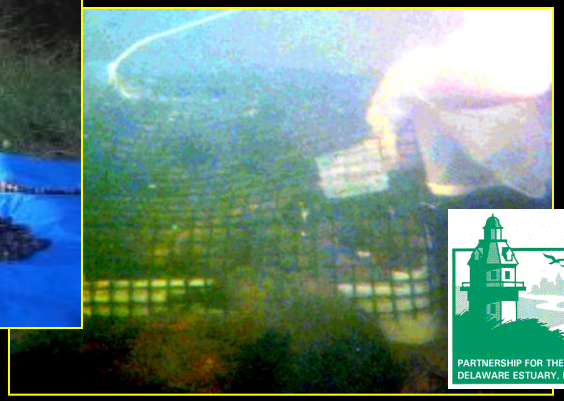
To Understand EcoServices, Need…

Ecology

Physiology

Population Surveys

Monitoring, Variability



Kreeger

Physiology Measurements

e.g., Clearance Rate

In Lab

In Field

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Kreeger

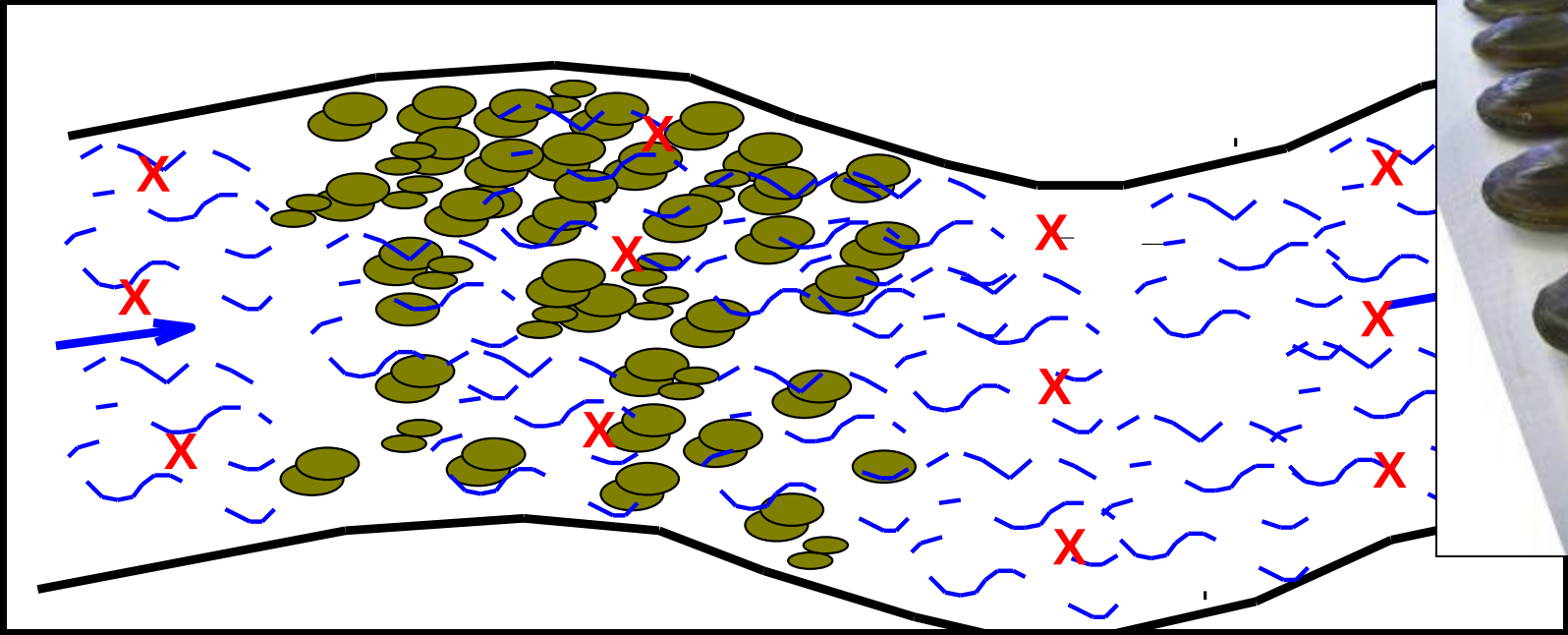
Population Measurements

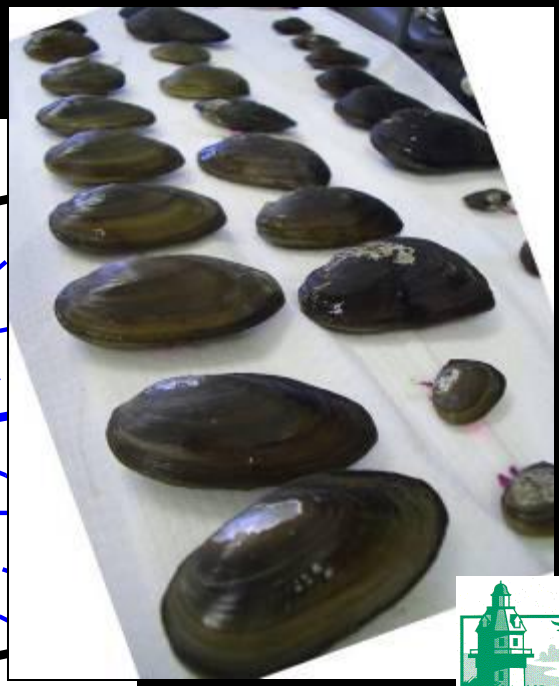
Size Class Structure

Body Size

Abundance (# m^{-2}, # $mile^{-1}$)

Total Area (m^2, river miles)





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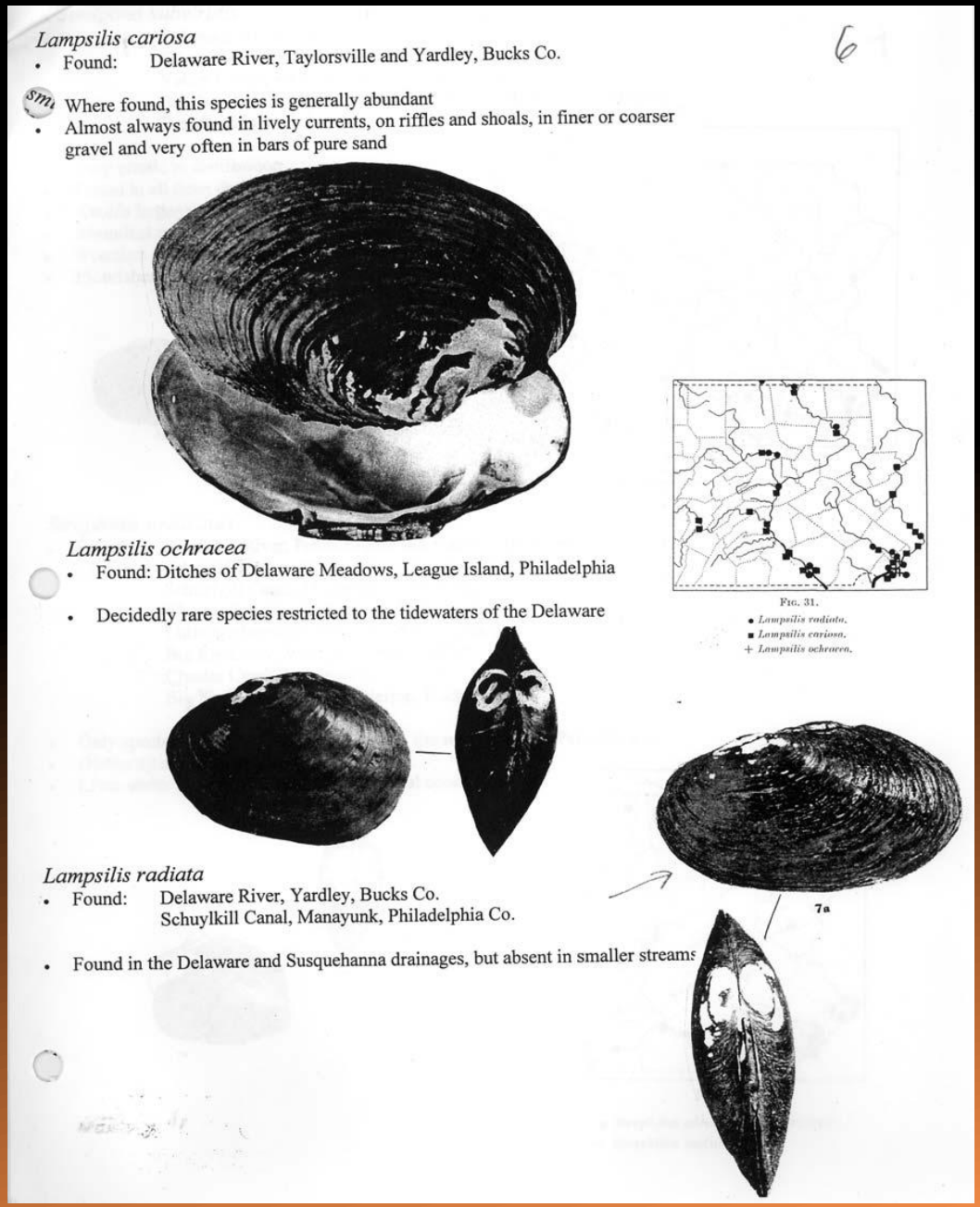
Kreeger

Bivalves

Freshwater Mussel Status and Trends

Ortmann, A.E. 1919.
A monograph of the naiades of Pennsylvania. Part III: Systematic account of the genera and species. Memoirs of the Carnegie Museum 8(1):



Lampsilis cariosa

- Found: Delaware River, Taylorsville and Yardley, Bucks Co.

6

- Where found, this species is generally abundant
- Almost always found in lively currents, on riffles and shoals, in finer or coarser gravel and very often in bars of pure sand

Lampsilis ochracea

- Found: Ditches of Delaware Meadows, League Island, Philadelphia
- Decidedly rare species restricted to the tidewaters of the Delaware

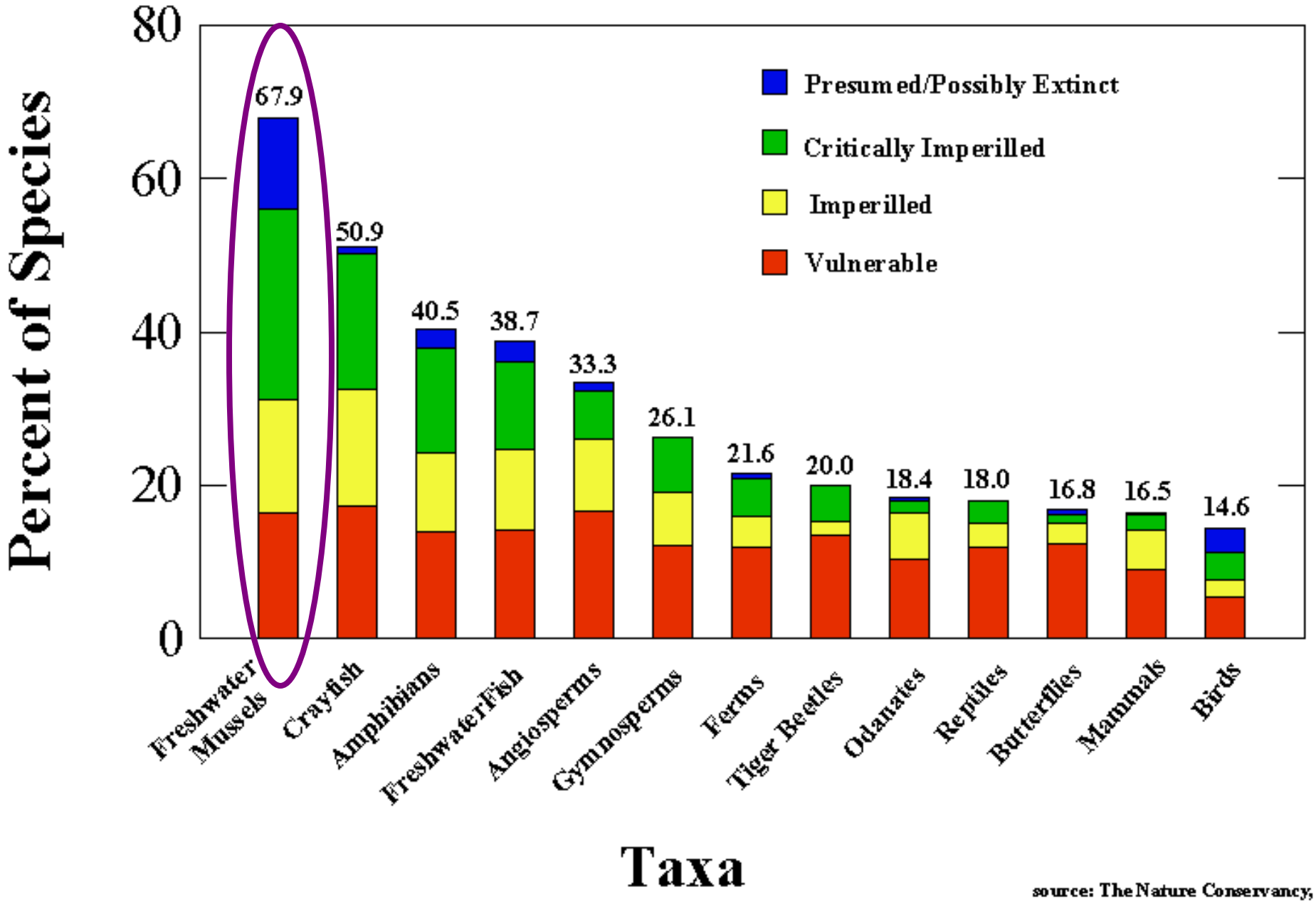
FIG. 31.
• *Lampsilis radiata.*
■ *Lampsilis cariosa.*
+ *Lampsilis ochracea.*

Lampsilis radiata

- Found: Delaware River, Yardley, Bucks Co.
  Schuylkill Canal, Manayunk, Philadelphia Co.
- Found in the Delaware and Susquehanna drainages, but absent in smaller streams

7a

Conservation Status of United States Taxa



source: The Nature Conservancy, 1997

Loss in Biodiversity

VOLUME 18 ★ ISSUE 3 ★ SUMMER 2008
PDE REPORT NO. 08-01

ESTUARY NEWS

A PUBLICATION OF THE PARTNERSHIP FOR THE DELAWARE ESTUARY: A NATIONAL ESTUARY PROGRAM

SPECIAL ISSUE

State of the Delaware Estuary 2008

By Jennifer Adkins, Executive Director, Partnership for the Delaware Estuary

Every three to five years, the Partnership for the Delaware Estuary works with outside experts to take a comprehensive look at the health of the Delaware Estuary and its watershed. This helps the National Estuary Program track the progress it is making implementing its long-term "Delaware Estuary Comprehensive Conservation and Management Plan." The results are presented here, for 2008, as a special issue of "Estuary News."

The Delaware River's dual identity as both a living river and a working river makes it an Estuary of many contrasts. On one hand it is a principal corridor for commerce that has sustained our region since America's Industrial Revolution, and it continues to be a major strategic port for national defense. On the other hand, it provides a wealth of natural and living resources, such as drinking water for millions of people, extensive tidal marshes that sustain vibrant ecosystems, and world-class habitats for horseshoe crabs, migratory shorebirds and more.

Given these contrasts, it should be no surprise that the 2008 State of the Estuary Report tells a story of mixed environmental conditions. In some ways, the Delaware Estuary is healthier than ever before, thanks largely to improvements in wastewater treatment and laws enacted over time. The condition of some species, like bald eagles and striped bass, for example, have remained stable or improved. Unfortunately, the status of other species appears to be getting worse. The total population of Atlantic sturgeon may number less than 1,000 — perhaps even less than 100. Freshwater mussels and brook trout now appear to be absent from much of the region's non-tidal waterways.

The Delaware Estuary has many important features that set it apart from other American estuaries. These include its freshwater tidal reach and extensive tidal marshes, which serve as the "kidneys" and "fish factories" of the Estuary. Less than five

continued on page 2

This report is being issued as a special summer edition of "Estuary News," as well as technical report number 08-01 of the Partnership for the Delaware Estuary. Additional supporting material's like references can be found at www.DelawareEstuary.org, and a list of key definitions can be found on page 34. This assessment complements the State of the Basin Report, which is currently being developed by a team led by the Delaware River Basin Commission (DRBC) that also includes the Partnership. For information on that report, please call the DRBC at (609) 883-9500.

Freshwater Mussels

Behold the squawfoot mussel, or *Strophitus undulatus*, one of the many once-abundant filter-feeders that is currently in decline in the Delaware Estuary's streams and rivers.

POSITIVE

NEGATIVE

INDICATOR DESCRIPTION: Freshwater mussels are filter-feeding bivalve mollusks that live in lakes, rivers, and streams. Similar to oysters, freshwater mussels benefit water quality, enrich habitats, and furnish other important ecosystem functions. Unlike marine species, freshwater mussels grow more slowly, live longer (50 years or more), and have complicated reproduction strategies dependent on fish hosts. Therefore, freshwater mussels cannot rebound quickly after they become impaired.

As they are sedentary creatures that filter large amounts of water, freshwater mussels are sensitive indicators of water quality and habitat conditions. Consequently, they lay claim to being the most imperiled taxonomic group in the nation. These long-lived animals are often unable to recolonize their habitats following disturbances due to their complicated life history. The status of freshwater mussels provides different environmental information than macroinvertebrates, the latter of which are good indicators of short-term changes in conditions. The health, reproductive status, population abundance, and species diversity of the mussel assemblage therefore represents an excellent bioindicator of watershed conditions over long periods of time.

Common Name	Scientific Name	State Conservation Status		
		DE	NJ	PA
Dwarf Wedgemussel	*Alasmidonta heterodon*	Endangered	Endangered	Critically Imperiled
Triangle Floater	*Alasmidonta undulata*	Extirpated	Threatened	Vulnerable
Brook Floater	*Alasmidonta varicosa*	Endangered	Endangered	Imperiled
Alewife Floater	*Anodonta implicata*	Extremely Rare	No Data	Extirpated ?
Eastern Elliptio	*Elliptio complanata*	Common	Common	Secure
Yellow Lampmussel	*Lampsilis cariosa*	Endangered	Threatened	Vulnerable
Eastern Lampmussel	*Lampsilis radiata*	Endangered	Threatened	Imperiled
Green Floater	*Lasmigona subviridis*	No Data	Endangered	Imperiled
Tidewater Mucket	*Leptodea ochracea*	Endangered	Threatened	Extirpated ?
Eastern Pondmussel	*Ligumia nasuta*	Endangered	Threatened	Critically Imperiled
Eastern Pearlshell	*Margaritifera margaritifera*	No Data	No Data	Imperiled
Eastern Floater	*Pyganodon cataracta*	No Data	No Data	Vulnerable
Squawfoot	*Strophitus undulatus*	Extremely Rare	Species of Concern	Apparently Secure

This chart shows the state conservation status of freshwater mussel species that were historically documented from the Delaware Estuary and River Basin. Gray-shaded cells indicate that these mussels may never have been found in that state. Note the different status descriptions used among the three states.

STATUS: North America has the world's greatest diversity of native freshwater mussels (more than 300 species), however, more than 75 percent have special conservation status. The leading causes of mussel decline are habitat and water-quality degradation. For example, dams that block fish passage can affect reproduction, gene flow, and may prevent recolonization from adjacent tributaries following disturbance. Of the 12 or more native species in the Delaware Estuary Watershed, even the most common mussel is patchy in abundance and may not be successfully reproducing across much of its range.

TRENDS: The most recent comprehensive mussel survey in the region was conducted in Pennsylvania between 1909 and 1919. Even by that time, dams and water-quality degradation may have impaired mussel communities. Nevertheless, the study provided an excellent benchmark for gauging mussel losses for the past 90-plus years. State surveys and recent anecdotal information suggest that all native mussel species in the region are impaired to some degree, with most being severely depressed or extirpated altogether.

ACTIONS AND NEEDS: More proactive monitoring is needed to assess the species presence and population health of freshwater mussels across the entire Delaware River Basin. Improved coordination and data sharing among states and the Partnership for the Delaware Estuary would greatly facilitate indicator development and watershed restoration planning.

Fast Fact

The Partnership for the Delaware Estuary is currently devising methods to reintroduce mussels into waterways where they once flourished, like the Brandywine River, Chester Creek and White Clay Creek.

NEP Study Area

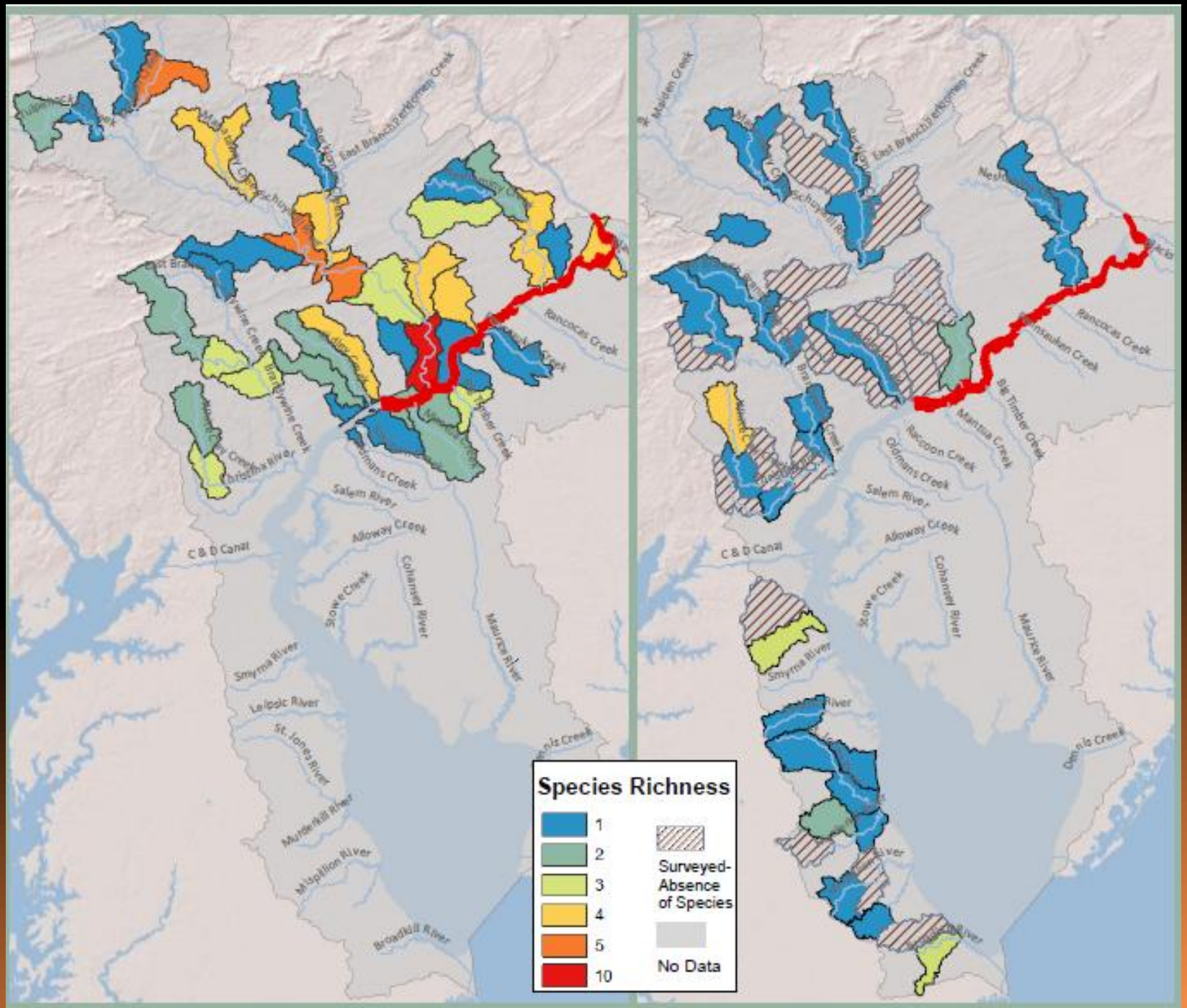
Patchy, Impaired

Rare

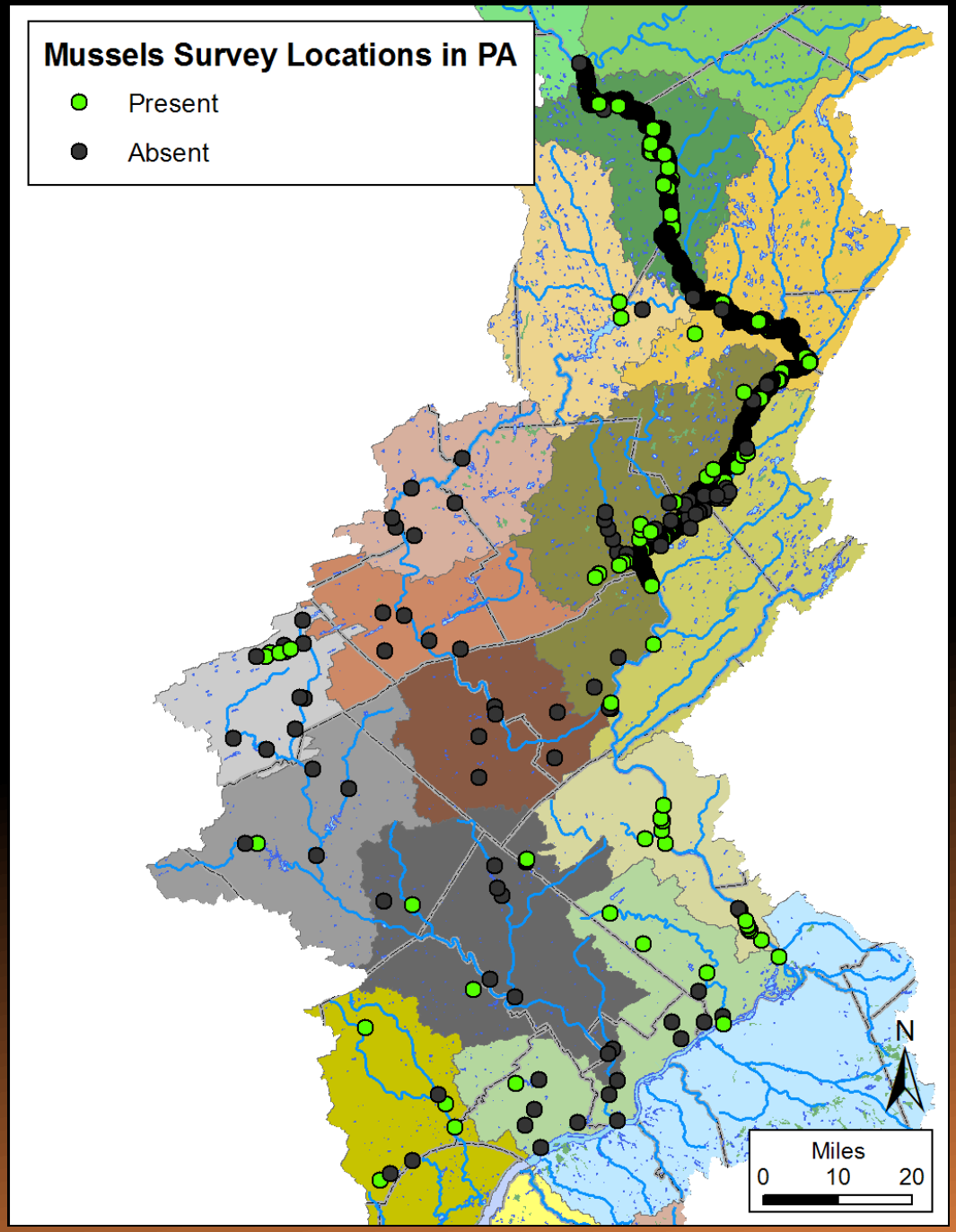
Extirpated

		State Conservation Status		
Scientific Name	**Scientific Name**	**DE**	**NJ**	**PA**
ALASMIDONTA HETERODON	DWARF WEDGEMUSSEL	**Endangered**	**Endangered**	**Critically Imperiled**
ALASMIDONTA UNDULATA	TRIANGLE FLOATER	**Extirpated ?**	**Threatened**	**Vulnerable**
ALASMIDONTA VARICOSA	BROOK FLOATER	**Endangered**	**Endangered**	**Imperiled**
ANODONTA IMPLICATA	ALEWIFE FLOATER	**Extremely Rare**	**no data**	**Extirpated ?**
ELLIPTIO COMPLANATA	EASTERN ELLIPTIO	**common**	**common**	**Secure**
LAMPSILIS CARIOSA	YELLOW LAMPMUSSEL	**Endangered**	**Threatened**	**Vulnerable**
LAMPSILIS RADIATA	EASTERN LAMPMUSSEL	**Endangered**	**Threatened**	**Imperiled**
LASMIGONA SUBVIRIDIS	GREEN FLOATER	**no data**	**Endangered**	**Imperiled**
LEPTODEA OCHRACEA	TIDEWATER MUCKET	**Endangered**	**Threatened**	**Extirpated ?**
LIGUMIA NASUTA	EASTERN PONDMUSSEL	**Endangered**	**Threatened**	**Critically Imperiled**
MARGARITIFERA MARGARITIFERA	EASTERN PEARLSHELL	**no data**	**no data**	**Imperiled**
PYGANODON CATARACTA	EASTERN FLOATER	**no data**	**no data**	**Vulnerable**
STROPHITUS UNDULATUS	SQUAWFOOT	**Extremely Rare**	**Species of Concern**	**Apparently Secure**

1919

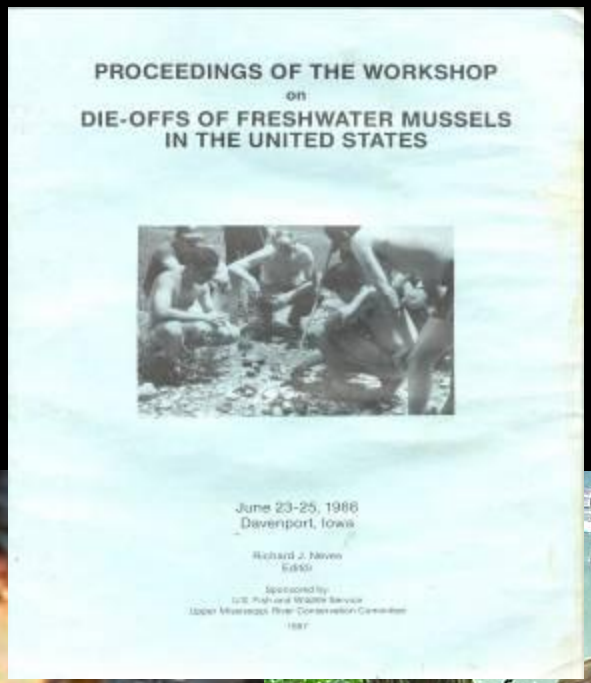


Since 1996


Mussels Survey Locations in PA
Present
Absent
N
Miles
0
10
20

Documenting the Decline

Biodiversity



Population Biomass

Culprits

Water Quality

Habitat Loss and Degradation

Photo by D. Kreeger

Exotic Species

Freshwater Mussel Larvae Require Fish Hosts

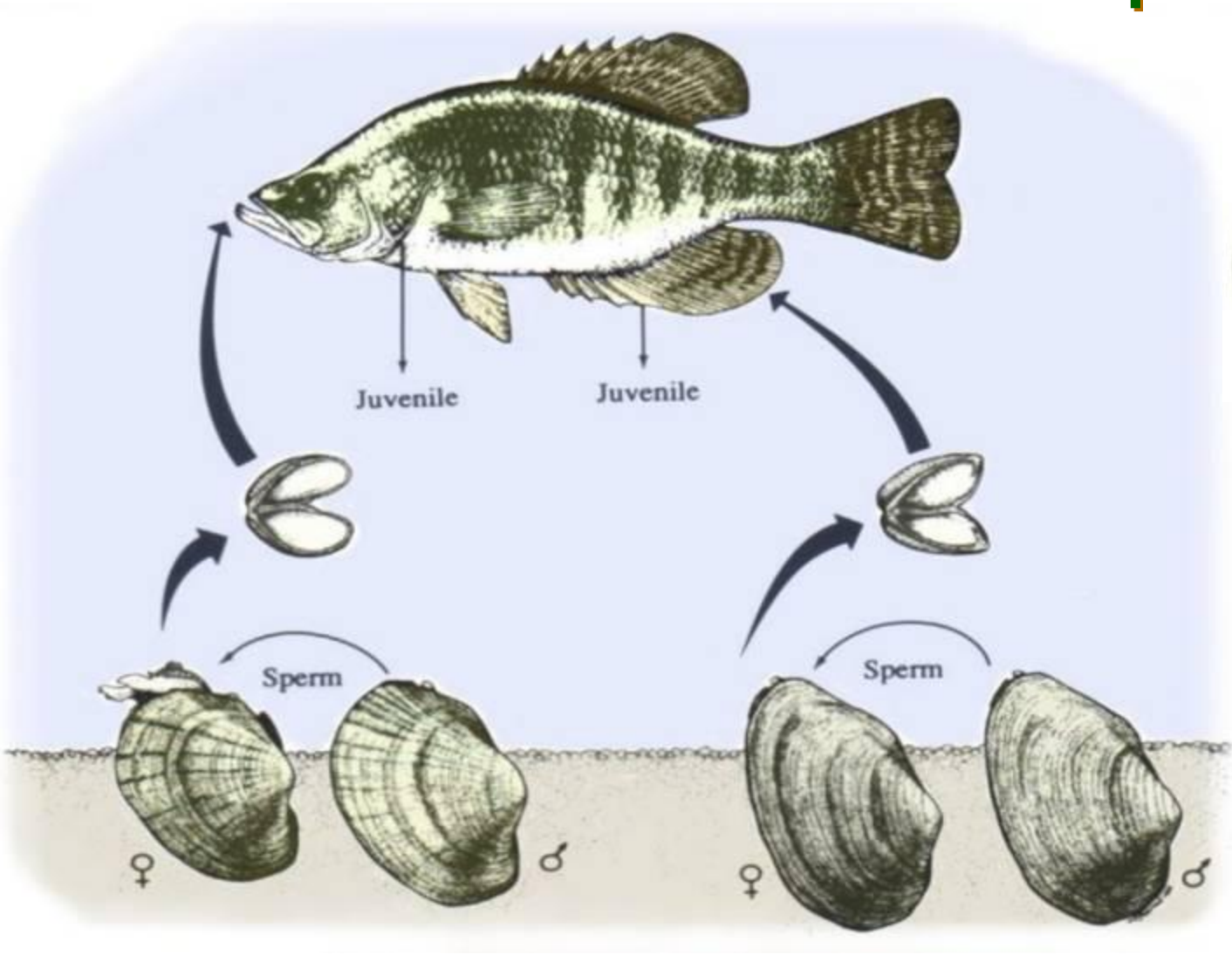
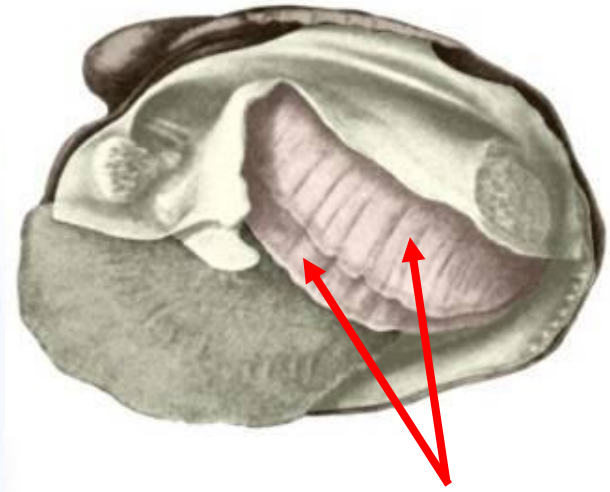


Figure from Cummings and Mayer (1992).



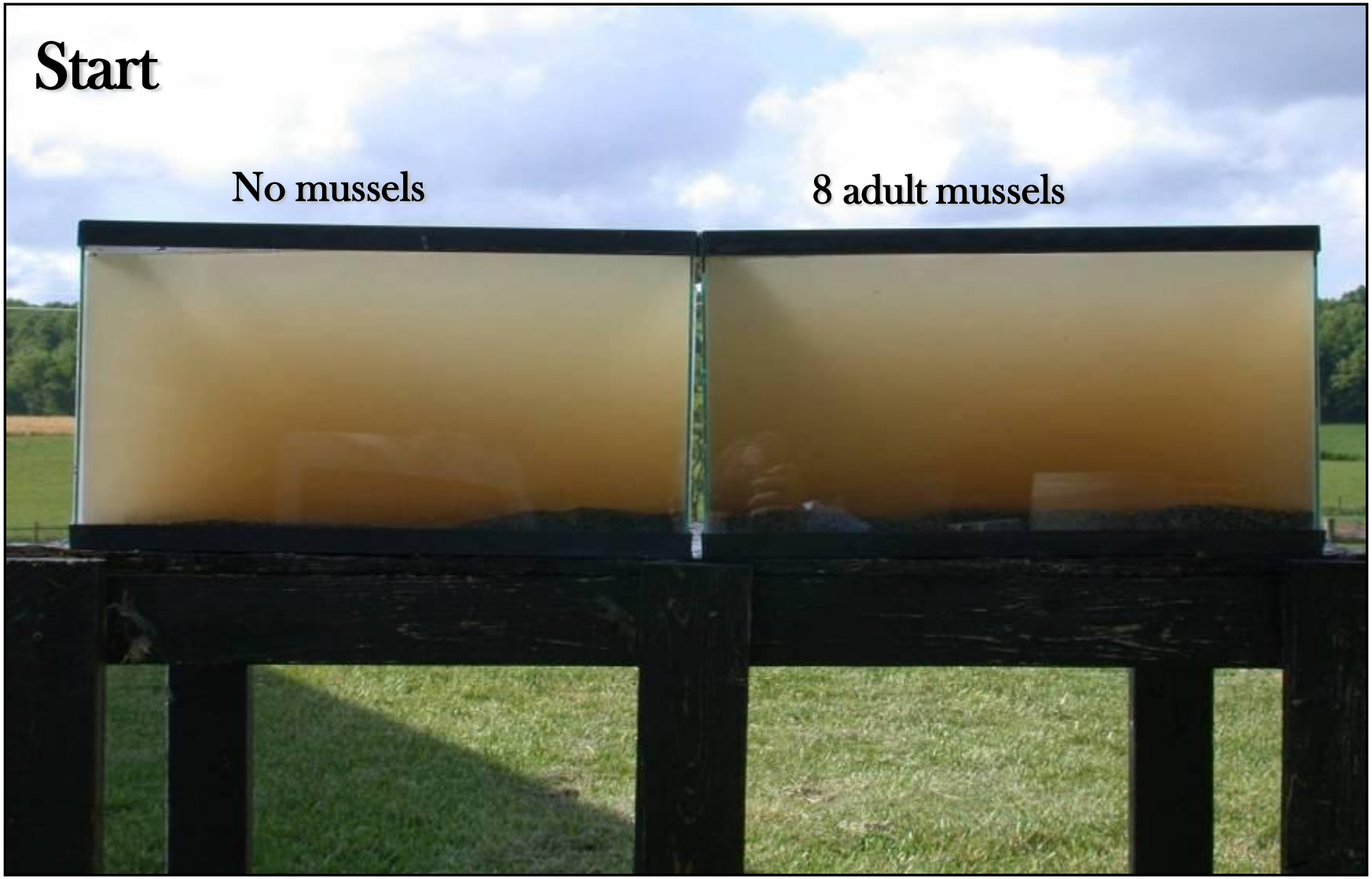
Larvae are brooded in the ctenidia

Most mussels depend on particular fish species


Nature's Benefits
Bivalve Shellfish are
"Ecosystem Engineers"
CTUIR Freshwater Mussel Project
PARTNERSHIP FOR THE DELAWARE ESTUARY, INC

Mussels Are Habitat
INITIATIVE
Restoring Our Nation's Water Quality

Biofiltration Potential



Slide from Dick Neves, VA Tech

Mussels Are Habitat
INITIATIVE
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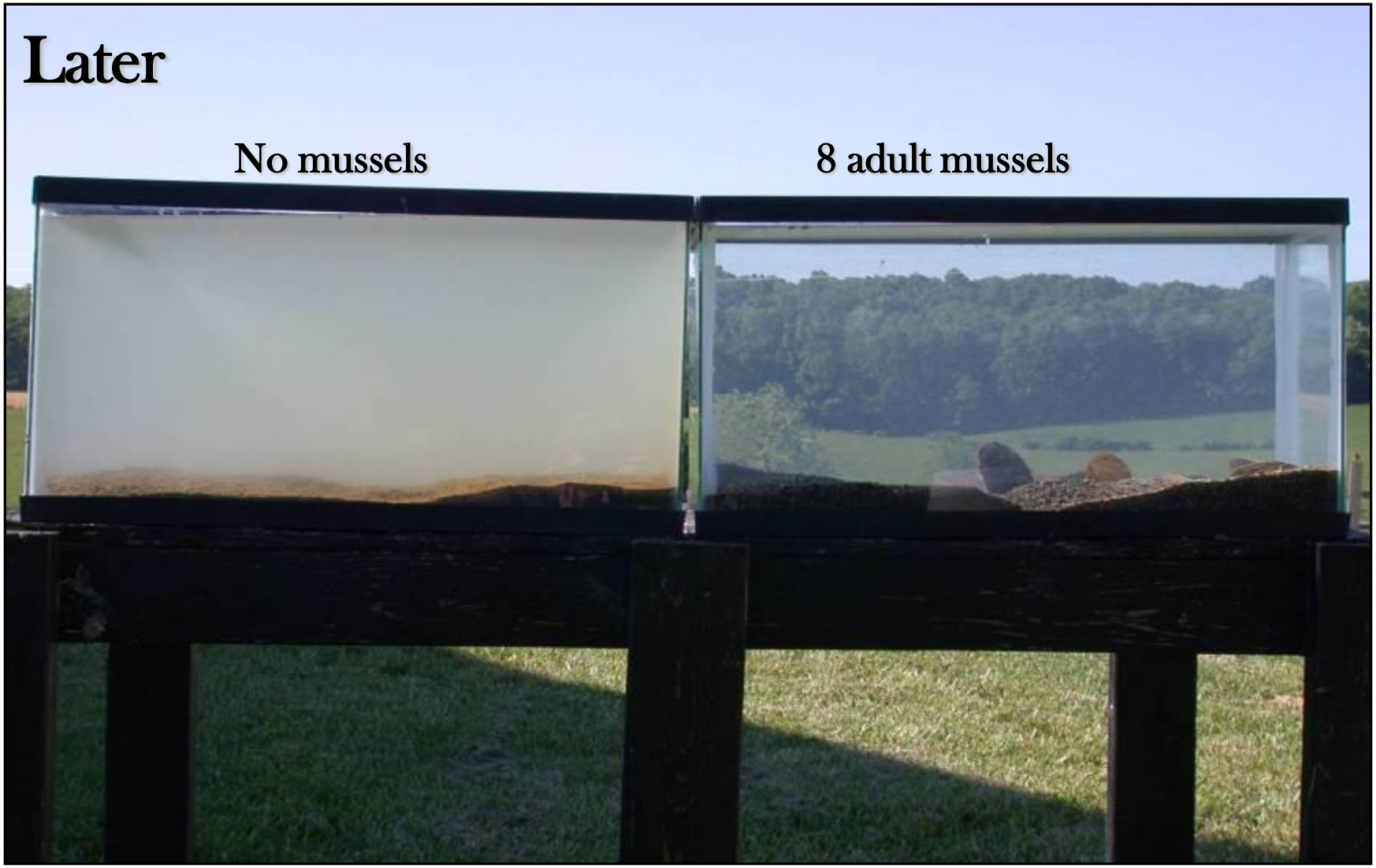
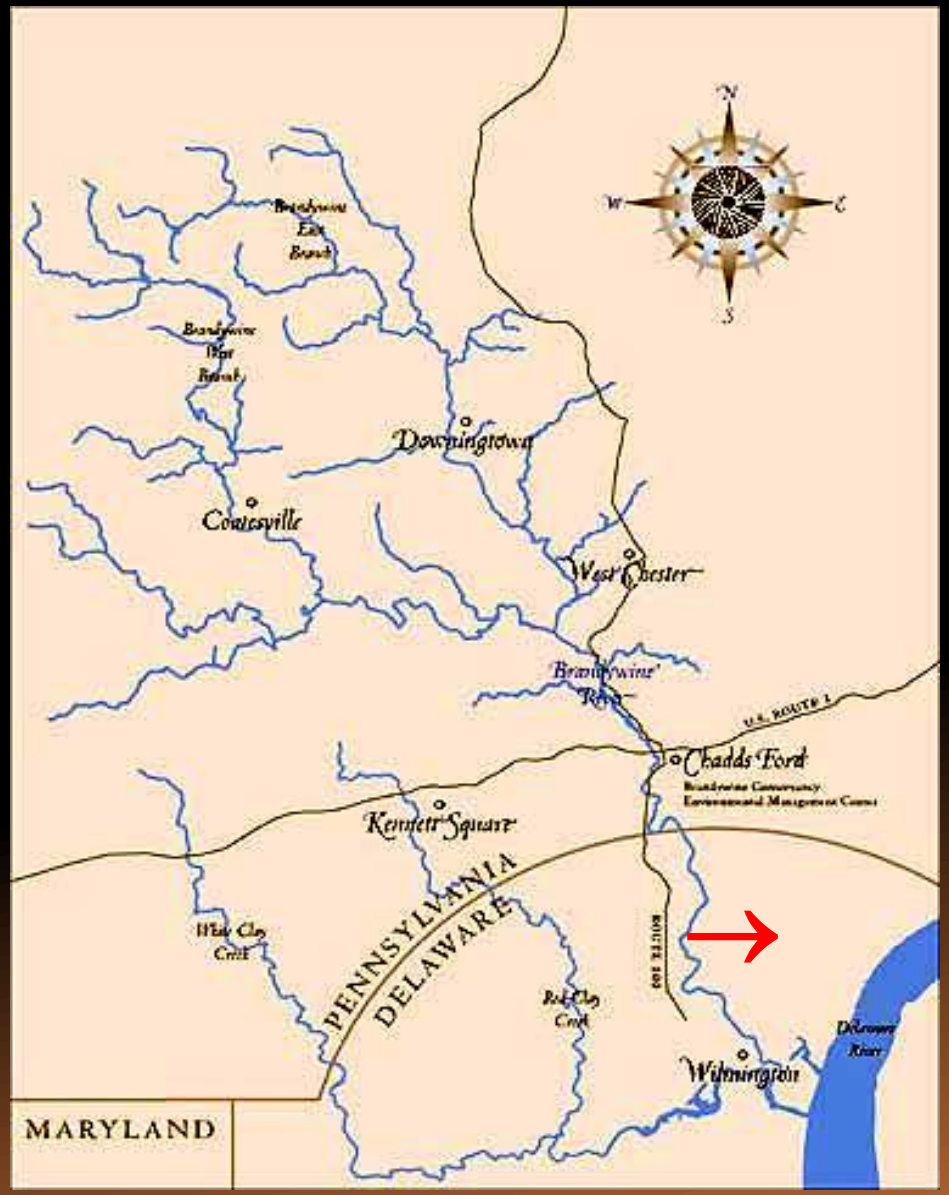


Slide from Dick Neves, VA Tech

Brandywine River

Studied 2000 - present

Elliptio complanata



Map from The Brandywine River Conservancy

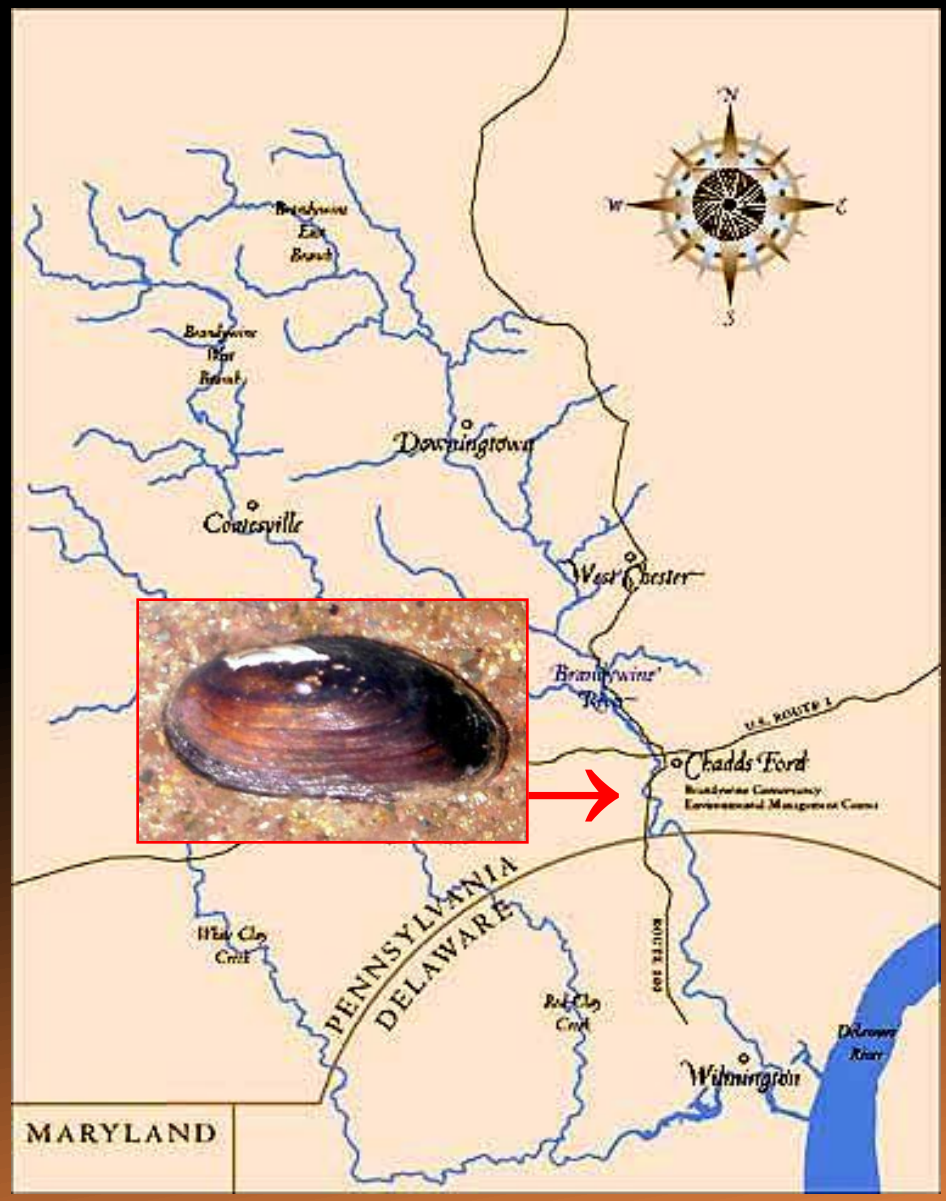
Elliptio complanata

Photos by Kreeger

One Mussel Bed in a 6 mile reach of the Brandywine River

Filters >25 metric tons dry suspended solids per year

Estimated Removal = 7.1 %



Map from The Brandywine River Conservancy

Data from Kreeger, 2006

Water Processing Estimate

4.3 Billion *Elliptio* *(DK estimate)*

2.9 Million Kilos Dry Tissue Weight *(DK)*

= 9.8 Billion Liters per Hour

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Bivalve Projections – FW Mussels

Shifting Species Ranges, But No Dispersal

Patchy, Impaired

Elliptio complanata

Rare

Strophitus undulatus

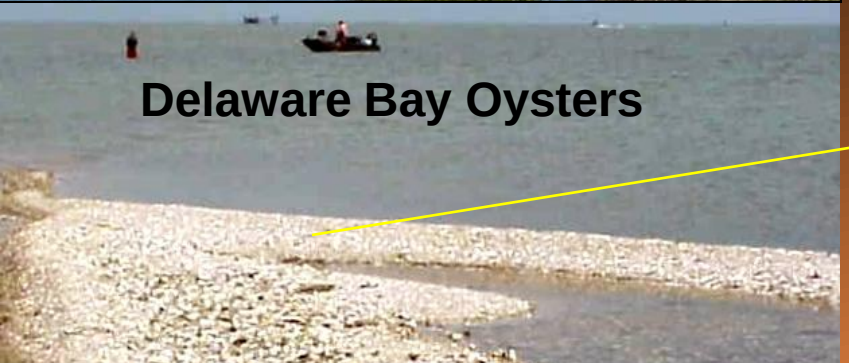
Extirpated

Alasmidonta heterodon

		State Conservation Status		
Scientific Name	**Scientific Name**	**DE**	**NJ**	**PA**
ALASMIDONTA HETERODON	DWARF WEDGEMUSSEL	Endangered	Endangered	Critically Imperiled
ALASMIDONTA UNDULATA	TRIANGLE FLOATER	Extirpated ?	Threatened	Vulnerable
ALASMIDONTA VARICOSA	BROOK FLOATER	Endangered	Endangered	Imperiled
ANODONTA IMPLICATA	ALEWIFE FLOATER	Extremely Rare	no data	Extirpated ?
ELLIPTIO COMPLANATA	EASTERN ELLIPTIO	common	common	Secure
LAMPSILIS CARIOSA	YELLOW LAMPMUSSEL	Endangered	Threatened	Vulnerable
LAMPSILIS RADIATA	EASTERN LAMPMUSSEL	Endangered	Threatened	Imperiled
LASMIGONA SUBVIRIDIS	GREEN FLOATER	no data	Endangered	Imperiled
LEPTODEA OCHRACEA	TIDEWATER MUCKET	Endangered	Threatened	Extirpated ?
LIGUMIA NASUTA	EASTERN PONDMUSSEL	Endangered	Threatened	Critically Imperiled
MARGARITIFERA MARGARITIFERA	EASTERN PEARLSHELL	no data	no data	Imperiled
PYGANODON CATARACTA	EASTERN FLOATER	no data	no data	Vulnerable
STROPHITUS UNDULATUS	SQUAWFOOT	Extremely Rare	Species of Concern	Apparently Secure

Elliptio complanata

Geukensia demissa



Crassostrea virginica

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Ribbed Mussels in Salt Marshes

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Ribbed Mussels

Intertidal

No Disease

Non- commercial

Living Shorelines

Ribbed Mussels in Salt Marshes

208,000 per hectare on average

10.5 Billion *Geukensia*

Clearance Rate = 5.1 L h-1 g-1 *(DK data)*

11.7 Million Kilos Dry Tissue Weight *(DK)*

= 59.0 Billion Liters per Hour

Oysters on Seed Bed Reefs

2.0 Billion *Crassostrea* *(Powell, 2003 data)*
Mean size = 0.87 g dry tissue weight *(DK data)*
Clearance Rate = 6.5 L h-1 g-1*(Newell et al 2005)*
= 11.2 Billion Liters per Hour

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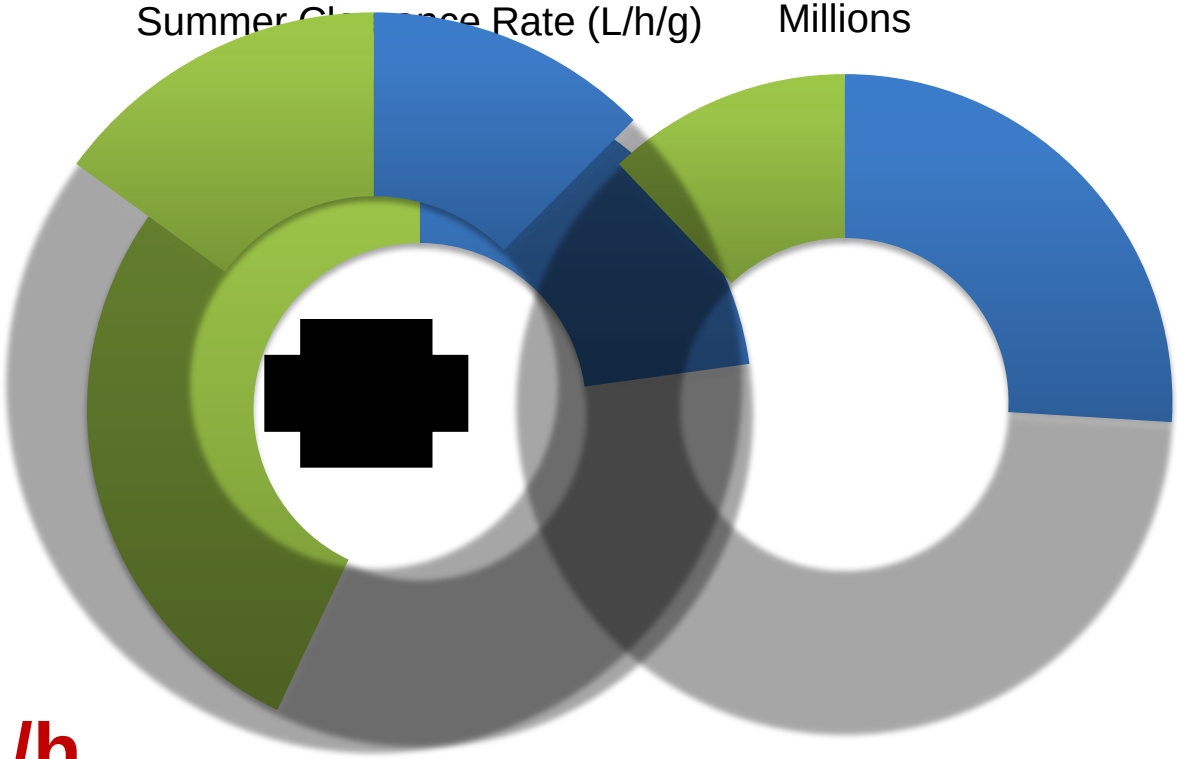
Population-level Water Processing

Water Processing per Unit Biomass

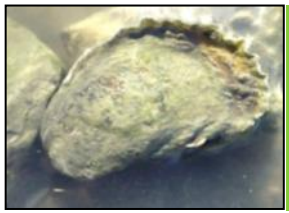
Population Abundance



= 80 Billion L/h

Freshwater Mussel

Marsh Mussel



Oyster

Bio-filtration

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Considerations

- Total filtration capacity for one fw mussel species (~10 billion L/hr) is >250X freshwater inflow from the Delaware River and other tributaries (not total volume)
- Total filtration capacity of oysters and ribbed mussels in Delaware Bay (~70 billion L/hr) is ~8% of tidal volume per day (100% in 11.5 days)
- Water processing potential is estimated based on current abundances
- Although historical abundances can be informative, current and future carrying capacities are poorly understood

Residence time is one key to impacts

Refiltration

Hydrodynamic contact

More study is also needed:

- Net Benefits
  - Physiological rate functions
  - Population processing
- Carrying Capacity
  - Which areas can support restoration
  - Optimal population biomass

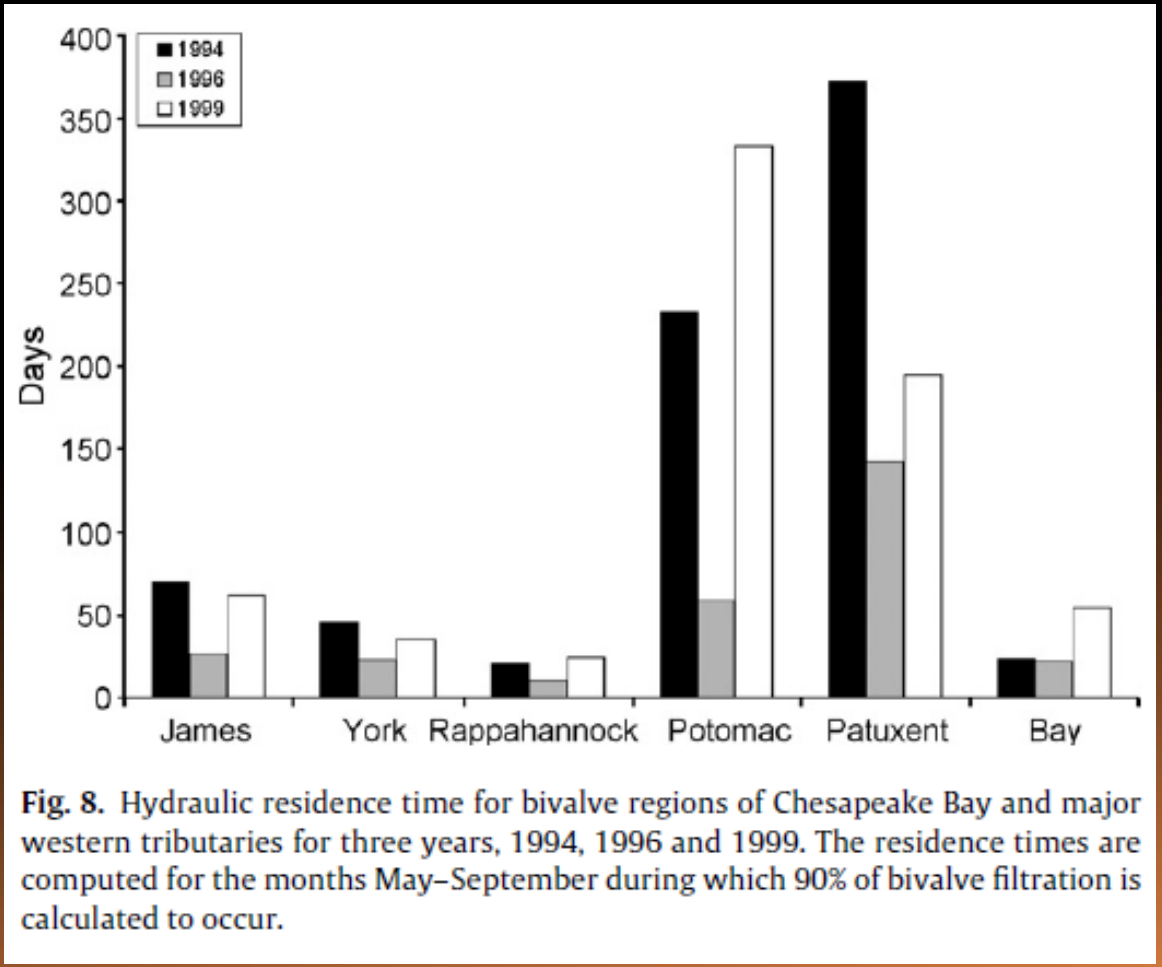


Fig. 8. Hydraulic residence time for bivalve regions of Chesapeake Bay and major western tributaries for three years, 1994, 1996 and 1999. The residence times are computed for the months May–September during which 90% of bivalve filtration is calculated to occur.

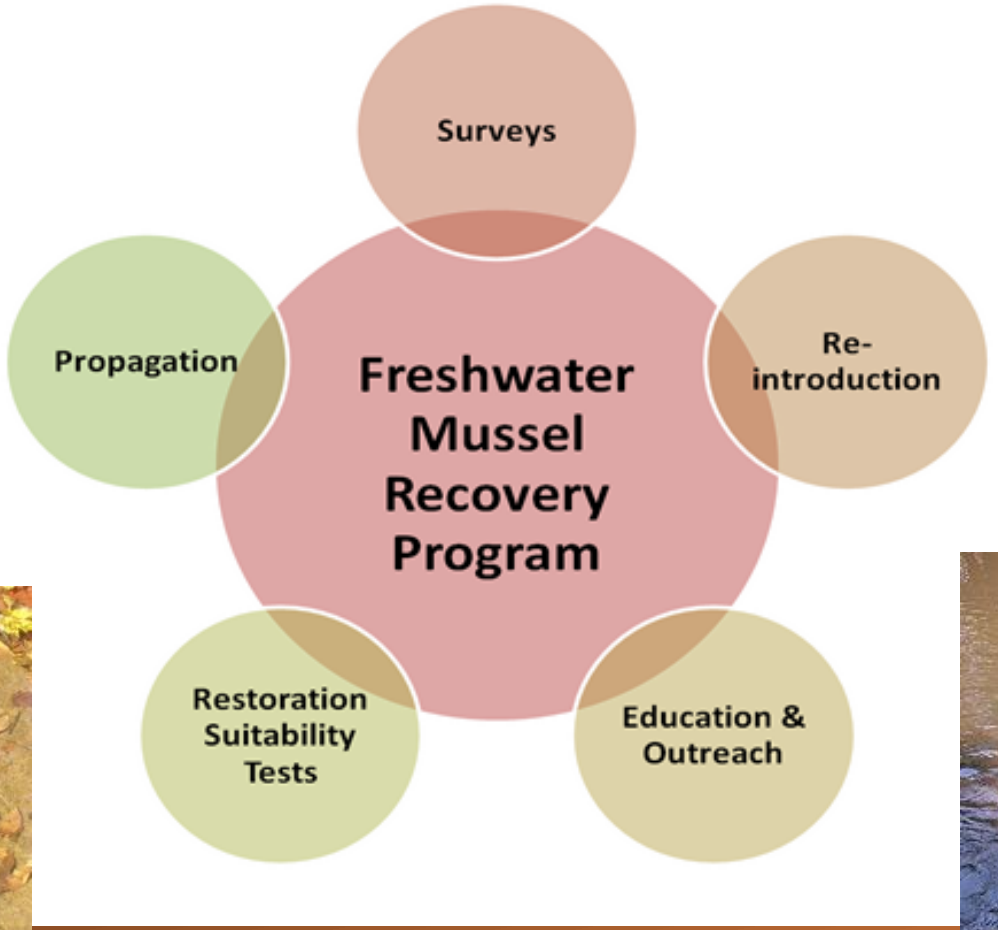
From Cerco and Noel 2010

Options for Making Shellfish More Resilient

Water Quality &
Flow Management

Freshwater Mussel Recovery Program

Freshwater Mussel Recovery Program



http://www.delawareestuary.org/science_projects_mussel_restoration.asp

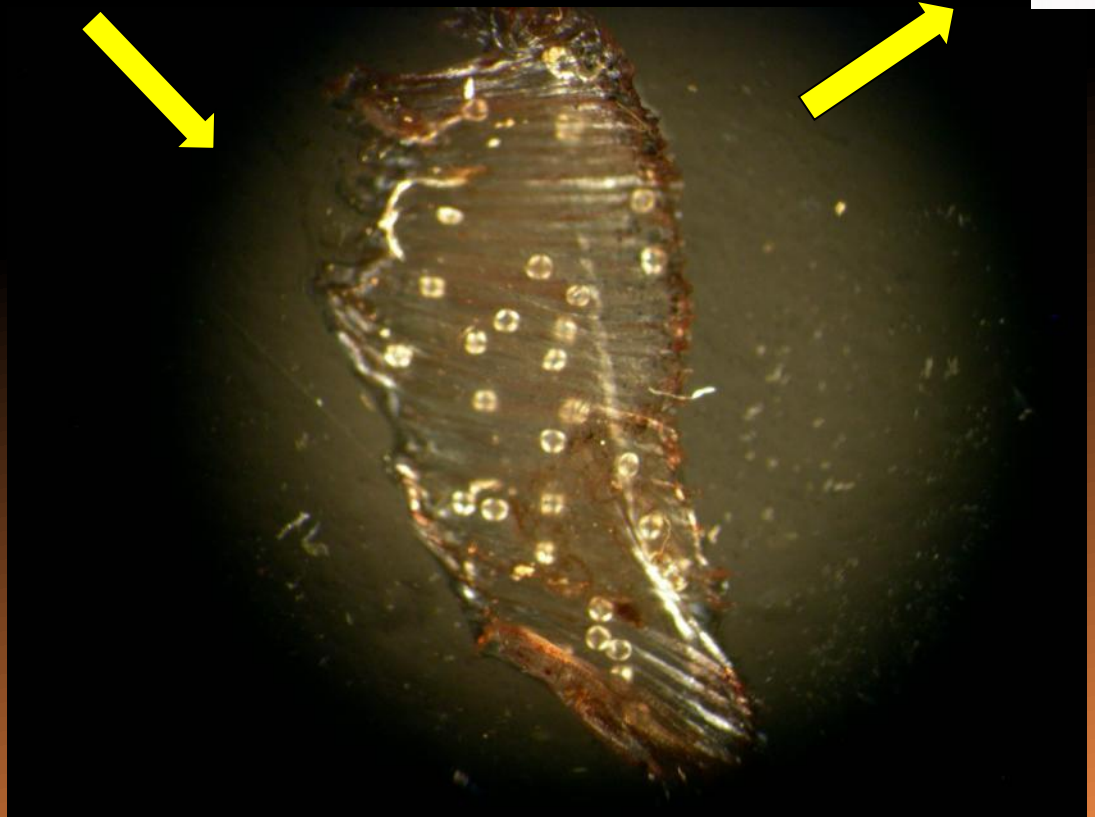
Propagation and Reintroduction

USFWS & Cheyney Hatcheries

Fish Infestation

Fish from USGS, Academy of Natural Sciences

Larval Transformation Into Juveniles



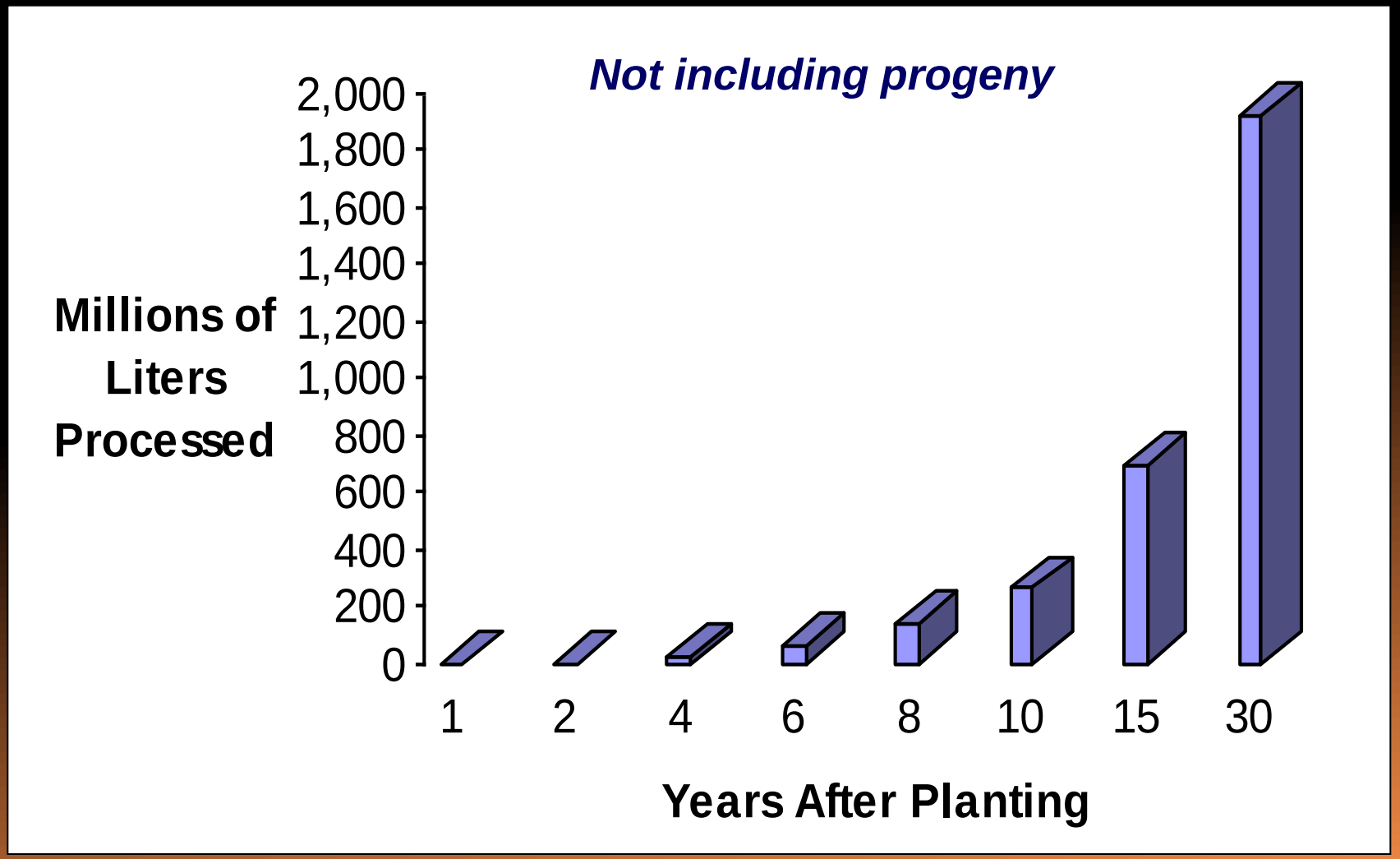
Propagation and Reintroduction

Propagated Juveniles

Photos, R. Neves, VA Tech

Freshwater Mussel Recovery Program

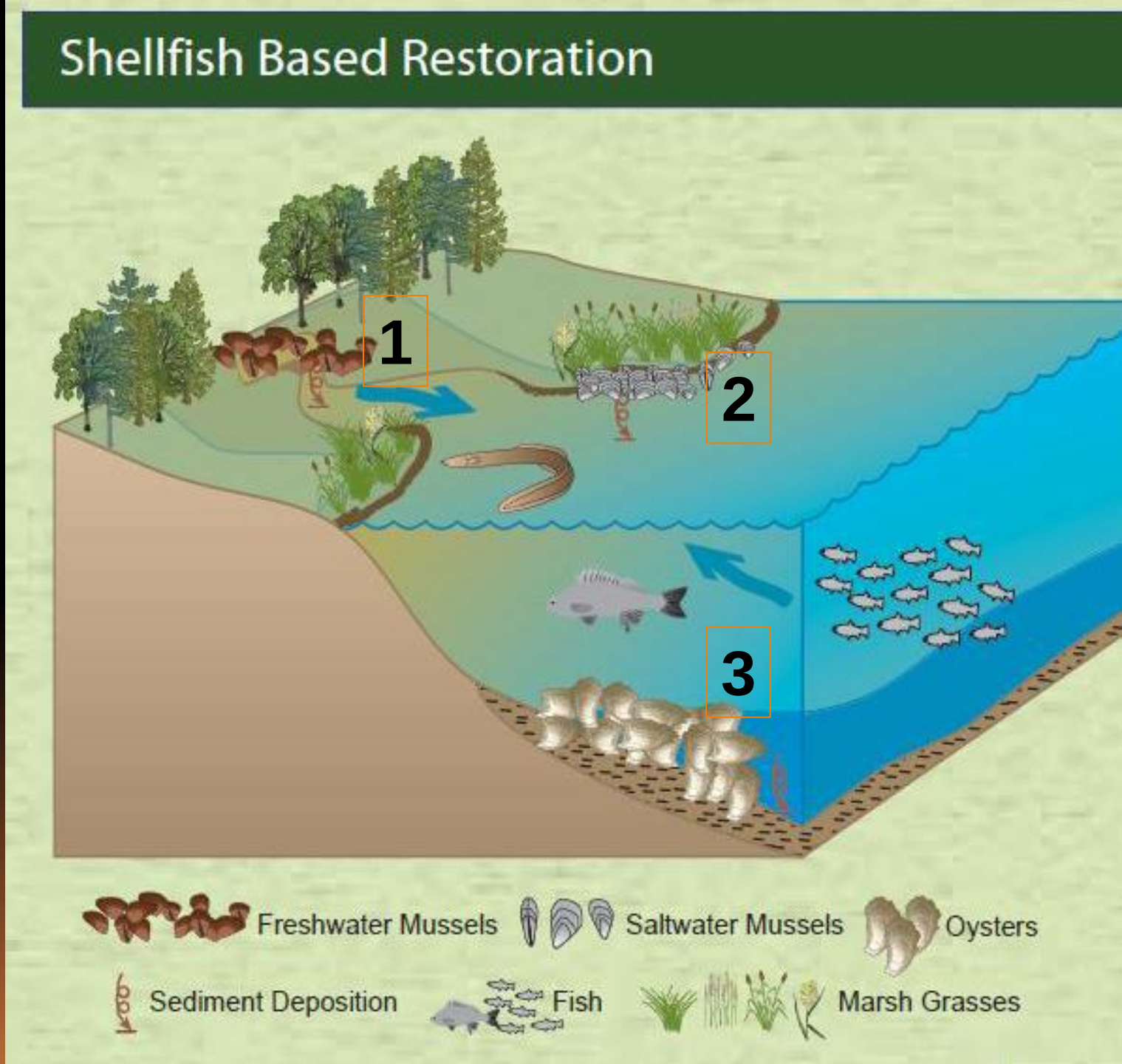
Goals Based on Ecosystem Services



Conceptual model:

Three-pronged approach to bivalve restoration to improve water quality

1. Non-tidal
2. Intertidal
3. Subtidal



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System Linkages ?

11 Other Species of Freshwater Unionid Mussels

Elliptio complanata

Corbicula fluminea

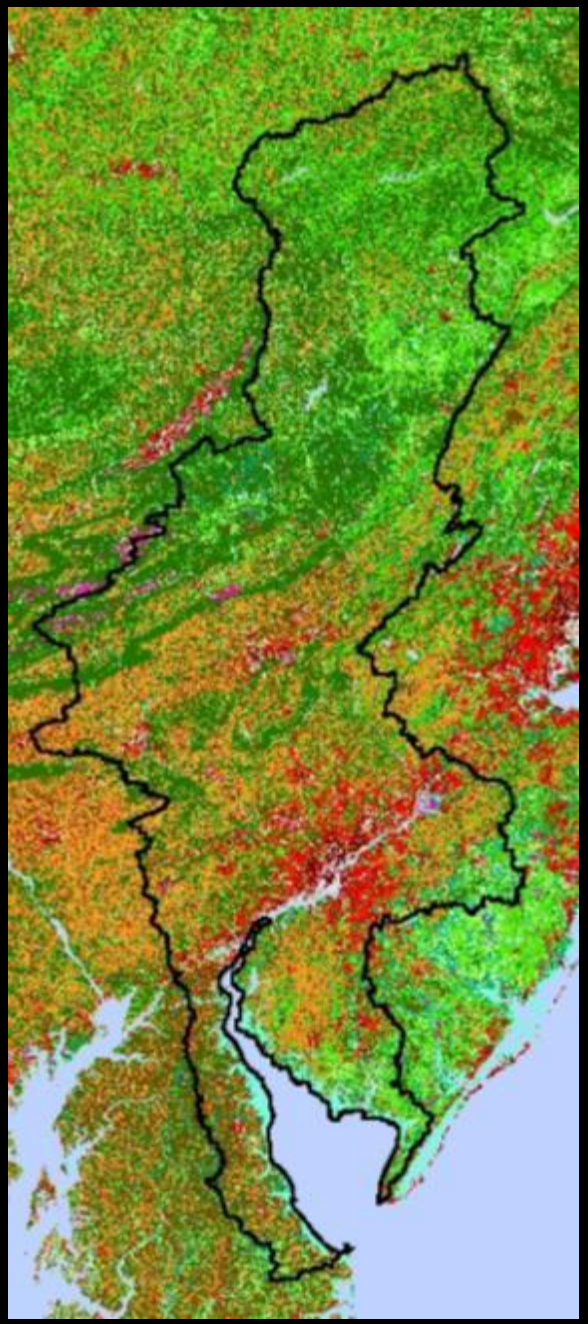
Geukensia demissa

Ensis directus *Mytilus edulis*

Crassostrea virginica

Mercenaria mercenaria

DRBC



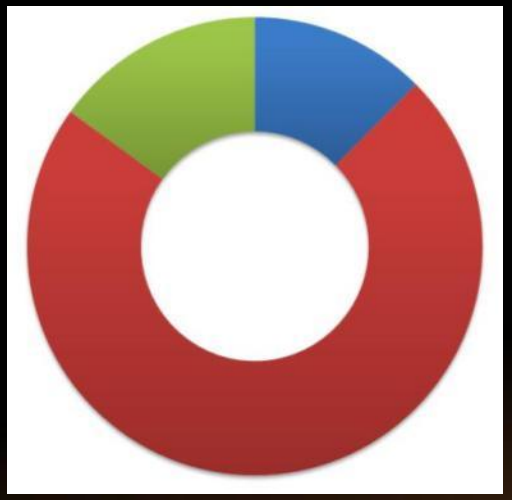
Desired Watershed Condition:

A diverse and robust assemblage of native bivalves living in abundance in all available tidal and non-tidal ecological niches and providing maximum possible natural benefits.

Kreeger

CONCLUSIONS 1

- Diverse bivalve species should help reverse eutrophication under the right conditions
- Current bivalve populations help sustain water quality, and they deserve protection
- Populations of many species are below carrying capacity and could be augmented
- Protection and restoration of diverse species can augment restoration and promote positive feedbacks via ecosystem linkages



CONCLUSIONS 2

- Conditions that support sustainable bivalve populations need more study
- Spatial and temporal variation in gross and net bivalve services should be measured and modeled in relation to system residence and physiology
- Research & modeling should be used to identify ecologically significant species that best achieve water quality goals
- Chesapeake Bay and Delaware Estuary
- partnering would be fruitful

– End –

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