Healthy Bivalves = Healthy Watersheds:

Rebuilding Bivalve Biodiversity, Populations and Ecosystem Services as a Basis for Ecosystem Restoration

Danielle Kreeger
Partnership for the DE Estuary

Rob Brumbaugh
The Nature Conservancy
To be discussed

The Delaware Estuary Watershed
- orientation, bivalve species
- status and trends
To be discussed

The Delaware Estuary Watershed
  - orientation, bivalve species
  - status and trends

Bivalve Natural Capital
  - biodiversity
  - biomass and ecoservices
  - bioindicators
  - commercial
  - cultural-historical
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Watershed Perspectives
- desired condition
- restoration for future steady states
- synergistic restoration/conservation
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Watershed Perspectives
- desired condition
- restoration for future steady states
- synergistic restoration/conservation

Future Needs
The Watershed

Upper Watershed:
undammed mainstem recreational area
water supply for NYC

Tidal River:
4th largest US urban center
world’s largest freshwater port
long freshwater tidal reach

Lower Estuary:
wetland dominated
water fowl, finfish, shellfish
horseshoe crabs

13,611 Square Miles
Seat of the Nation
History as a “Working River”

1762 map showing Philadelphia on the Delaware River

Slides adapted from Jonathan Sharp’s 2005
The Partnership for the Delaware Estuary

Non-Profit Organization, Established 1996

One of the 28 EPA National Estuary Programs

The only tri-state, multi-region NEP

**CCMP:** Watershed-based, coordination of outreach, education, restoration and science advancement

Along the shore of the Christina River
Wilmington, DE
Bivalves of the Delaware

- **Crassostrea virginica**
- **Elliptio complanata**
- **Geukensia demissa**
- **Corbicula fluminea**
- **Rangia cuneata**
- **Mya arenaria**
- **Mytilus edulis**
- **Ensis directus**
- **Mercenaria mercenaria**

11 Other Species of Freshwater Unionid Mussels
Bivalves of the Delaware

- Leptodea ochracea
- Mya arenaria
- Corbicula fluminea
- Ensis directus

Freshwater Tidal for 70 River Miles
Bivalves

Freshwater Mussel Status and Trends

Conservation Status of United States Taxa

Taxa

- Presumed/Possibly Extinct
- Critically Imperilled
- Imperilled
- Vulnerable

Source: The Nature Conservancy, 1997
Recent Loss of *Strophitus* from White Clay?

http://www.newgarden.org/whiteclay.htm
Mussel Surveys

White Clay

Big Elk

2000

2008

X

2000

2008
### Lower Delaware Watershed

#### State Conservation Status

<table>
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<tr>
<th>Scientific Name</th>
<th>Scientific Name</th>
<th>DE</th>
<th>NJ</th>
<th>PA</th>
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<td>Squawfoot</td>
<td>Extremely Rare</td>
<td>Species of Concern</td>
<td>Apparently Secure</td>
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</table>

Curated by Delaware Estuary Partnership Data andthe Delaware Estuary Partnership Data Portal (DEPDP)
State of the Delaware Estuary 2008

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

The Delaware Estuary is one of the most biologically diverse estuaries in the United States, supporting a wide variety of fish, wildlife, and plants. It is also an important economic resource, providing habitat for commercial and recreational fisheries. However, the estuary faces a number of challenges, including habitat loss, nutrient enrichment, and pollution. This report summarizes the current state of the Delaware Estuary and outlines the steps being taken to protect and conserve this valuable resource.

Freshwater Mussels

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 slowly, live longer (50 years or more), and have complex reproduction strategies dependent on fish hosts. Therefore, freshwater mussels cannot rebound quickly after they become impaired.

As they are sensitive, congeneric 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 suitable new areas following disturbances due to their complicated life history. The ratios of freshwater mussels provide different environmental information than macroinvertebrates, the latter of which are good indicators of short-term changes in conditions. The health, representativeness, and population density of the musselsemblage therefore represent an excellent biomarker of waterfished conditions over long periods of time.

STATUS: North America has the world's greatest diversity of native freshwater mussels (more than 300 species). However, there is 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, enfeeble, and may prevent recolonization from adjacent tributaries following disturbances. Of the 12 omphalodes mussels in the Delaware Estuary, seven are considered rare or threatened. These mussels are patchy in abundance and may not be successfully reproducing across much of their range.

TRENDS: The most recent comprehensive mussel survey in the region was conducted in Pennsylvania between 1999 and 2009. Even by that time, dams and water-quality degradation may have impacted mussel communities. Nevertheless, the study provided an excellent benchmark for gauging mussel losses for the past 60 years. State surveys and recent anecdotal information suggest that all native mussel species in the region are in jeopardy, with many being severely depressed or extirpated altogether.

ACTIONS AND NEEDS: More proactive monitoring is needed to assess the species present and population trends of freshwater mussels across the entire Delaware River Basin. Improved coordination and data sharing among the 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 developing methods to transport freshwater mussels into waterways where they once flourished, like the Brandywine River, Chester Creek and White Clay Creek.
Bivalves

Oyster Trends

Oyster landings in Delaware Bay: 1880 - 1980s

http://www.epodunk.com/cgi-bin/genInfo.php?locIndex=25475
Delaware Estuary
Oyster Seed Beds

From Rutgers HSRL
Oyster Disease, Salinity & Climate Change

From Rutgers HSRL

Rutgers: “A 2 parts per thousand increase in salinity over the seed beds may push the oysters past a point of no return”
FMCS & NSA: Documenting the Decline

Biodiversity

Population Biomass

PROCEEDINGS OF THE WORKSHOP ON DIE-OFFS OF FRESHWATER MUSSELS IN THE UNITED STATES

June 23-26, 1986

Davenport, Iowa

Richard J.hers

EDDS

Sponsored by:

US Environmental Protection Agency
Upper Mississippi River Conservation Council

1987
Bivalve Natural Capital

Five Reasons Why We Value Them
1. Biodiversity

Species Loss:
↓ Intrinsic Losses
↓ Niches Filled
↓ Human Health
2. Biomass (Populations)

Biomass Loss:

↓ EcoServices
↓ Fish & Wildlife
↓ Human Health
Ecosystem Engineers
Ecosystem Engineers
Bivalve Ecological Services

1. Structure
   \[\uparrow\] Habitat Complexity
   \[\uparrow\] Binding of Bottom
   \[\uparrow\] Bottom Turbulence

2. Function
   \[\downarrow\] Suspended Particulates
   \[\downarrow\] Particulate N, P
   \[\uparrow\] Light
   \[\uparrow\] Sediment Enrichment
   \[\uparrow\] Dissolved Nutrients
Clean Water

Start

No mussels

8 adult mussels

Slide from Catherine Gatenby, USFWS
Biofiltration Potential

Later

No mussels

8 adult mussels

Slide from Catherine Gatenby, USFWS
Size Selection: seston particle sizes below a mussel bed in the John Day River, OR (see CTUIR talks)
Natural Diets and Particle Type Selection

Pennate Diatoms

Phytoplankton

Centric Diatoms

Detritus Complex

Heterotrophic Protists

Bacteria
Mussel Demands
Heterotrophic Protists
Benthic Microalgae
Nutritional Sources of N:
Bacteria
Phytoplankton

<table>
<thead>
<tr>
<th></th>
<th>Summer</th>
<th>Fall</th>
<th>Winter</th>
<th>Spring</th>
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<tr>
<td>Nitrogen Demand</td>
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<tr>
<td>Heterotrophic Matter</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Benthic Microalgae</td>
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<td></td>
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</tr>
<tr>
<td>Bacteria</td>
<td></td>
<td></td>
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<tr>
<td>Phytoplankton</td>
<td></td>
<td></td>
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</tbody>
</table>

µg N h⁻¹ [g DW]⁻¹
Water Quality & Grazing Impacts of Populations

Pennate Diatoms

Phytoplankton

Centric Diatoms

Detritus Complex

Bacteria

Heterotrophic Protists
Brandywine River
Studied 2000 - present

Map from The Brandywine River Conservancy

Elliptio complanata
To Understand EcoServices, Need...

- Ecology
- Physiology
- Population Surveys
- Monitoring, Variability
Physiological Rates

\[ I = F + U + R + T \]

\[ C = I + Ps \]

\[ AE = \frac{[U+R+T]}{I} \times 100\% \]
Physiology Measurements

E.g., Clearance Rate

In Lab

In Field
Population Measurements

Size Class Structure
Body Size
Abundance (# m⁻², # mile⁻¹)
Total Area (m², river miles)
Mussel Population Abundance

Spatial Heterogeneity

- 3 Sites (6 mile stretch)
- 3 Habitats (riffle, tail-out, run/pool)
- 3 Transects (per habitat)
- 3 Zones (left, middle, right bank)
- 4 Quadrats (up, down, up, down)
• **Density** = 1.67 mussels m$^{-2}$
• **Size** = 72.1 mm
• **Biomass** = 0.669 g

**Height:Weight Relationship**

\[
\text{LOG Hgt} = [0.201 \times \text{LOG Wgt}] + 4.359
\]

• **River Width** = 33.1 m

• **Per 100 m Reach:** 5527 mussels weighing 3.7 kg dry tissue
• **Clearance Rates** (Field) = 3.4 L h\(^{-1}\) g DTW\(^{-1}\) 
  = 301,800 L d\(^{-1}\) 100 m\(^{-1}\)

• **Base Flow** = 2.4 mg L\(^{-1}\) TSS and 200 cfs

• **TSS Upstream Inputs** = 978 kg d\(^{-1}\) per 6 mile

• **Bed Clearance** = 0.724 kg d\(^{-1}\) 100 m\(^{-1}\) 
  = 69.5 kg d\(^{-1}\) per 6 mile study stretch 
  = **25.4 metric tons** dry TSS per year

• **Estimated Removal** = **7.1 %**
Mass Balance Estimate

**Elliptio complanata**

- **Brandywine River**: 40,800 mussels/sq. mi
- **Upper Delaware River**: 125,100 mussels/sq. mi
  
  *Based on data from Bill Lellis*

- **Assumptions**: e.g., 25% of inhabitable area

- **Total Elliptio in Basin** (12,858 sq. mi):

  \[= 4.3 \text{ Billion } \text{Elliptio}\]
Basin–Wide Water Processing Potential

Elliptio complanata

4.3 Billion *Elliptio*

= 2.9 Million Kilos Dry Tissue Weight

= 9.8 Billion Liters per Hour
Brandywine River, PA

Delaware Estuary Marshes

Delaware Bay Oysters

Elliptio complanata

Geukensia demissa

Crassostrea virginica

Delaware River Basin
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

= 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
Water Processing per Unit Biomass

<table>
<thead>
<tr>
<th></th>
<th>Summer Clearance Rate (L h⁻¹ g⁻¹)</th>
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</thead>
<tbody>
<tr>
<td><em>Elliptio complanata</em></td>
<td>2</td>
</tr>
<tr>
<td><em>Geukensia demissa</em></td>
<td>5</td>
</tr>
<tr>
<td><em>Crassostrea virginica</em></td>
<td>6</td>
</tr>
</tbody>
</table>
Pound for Pound: Similar Ingestion

Clearance Rate (L h\(^{-1}\) g\(^{-1}\))

Mississippi

Atlantic

Pacific
**Pound for Pound: Similar Digestion**

Absorption Efficiency (mean % ±SE)

- **Spring**
  - Margaratifera falcata: n=31
  - Gonidea sp.: n=6
  - Anodonta sp.: n=11

- **Summer**
  - Margaratifera falcata: n=24
  - Gonidea sp.: n=12
  - Anodonta sp.: n=16

- **Fall**
  - Margaratifera falcata: n=20
  - Gonidea sp.: n=15
  - Anodonta sp.: n=15

CTUIR Project, Kreeger
Population Abundance

Elliptio complanata
Geukensia demissa
Crassostrea virginica
Population-Level Water Processing

Billions of Liters per Hour

<table>
<thead>
<tr>
<th>Species</th>
<th>Billions of Liters per Hour</th>
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</thead>
<tbody>
<tr>
<td><em>Elliptio complanata</em></td>
<td>0</td>
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<tr>
<td><em>Geukensia demissa</em></td>
<td>50</td>
</tr>
<tr>
<td><em>Crassostrea virginica</em></td>
<td>10</td>
</tr>
</tbody>
</table>
Restoration for Eco Services?

Billions of Liters per Hour

- **Elliptio complanata**: Present
- **Geukensia demissa**: Present
- **Crassostrea virginica**: Present

*Historic?*
Other Services – Marsh Shoreline Stabilization

Slide adapted from R. Brumbaugh’s, and Courtesy L. Coen, SCORE South Carolina
Delaware Estuary *Spartina* Marsh
Shoreline Erosion

Maurice River Mouth 2002 aerial photograph

1890 shoreline

Courtesy D. Bushek, Rutgers

Courtesy J. Gebert, ACOE
Living Shorelines
3. Bioindicator Value

International Mussel Watch
Freshwater Caging Studies
Contaminant and Site-Specific Testing, Monitoring
Tributary and Regional Bioassessment

Freshwater Mussels

**Indicator Description:** Freshwater mussels are filter-feeding invertebrates that live in lakes, ponds, and streams. Similar to systems, freshwater mussels benefit water quality in lakes, ponds, and streams. They are important ecosystem functions. Unlike marine species, freshwater mussels have water quality from the watches and monitoring studies. They have high biological diversity and are sensitive indicators of water quality and habitat conditions. Consequently, they lay dielectrically the most important water quality indices in the nation. These long-lived animals are often visible in water bodies following disturbances due to their complicated life history. The status of freshwater mussels provides different trend information than water-quality indices, the latter of which are used to indicate short-term changes in conditions. The health, reproductive status, population abundance, and species diversity of the mussel assemblage therefore represent excellent indicators of water quality in rivers over long periods of time.

**Status:** North America has the world’s greatest diversity of freshwater mussels (over 200 species), however, more than 50% have special conservation status. The leading causes of species declines include habitat and water-quality degradation, for example, damming. Many species may affect reproduction, growth, and may participate in predation and translocation following disturbance. Of the 25 mussel species in the Delaware, four are endangered, over the most common mussels are particularly vulnerable and may not be successfully reproducing in some of its range.

**Trends:** Most recent comprehensive survey data in the state was conducted in Pennsylvania between 1989 and 1991. These low taxonomic and water-quality degradation may have impacted mussel communities. Nonetheless, the study provided an excellent framework for ongoing mussel surveys for the past 30 years. Stream surveys and recent water-quality degradation suggest that several mussel species in the region are impacted to some degree, with many 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 partnerships for the Delaware River basin provide funding for the Delaware River basin's mussel surveys and other mussel restoration activities.

**Fast Fact:** The Delaware River is the 2nd most impacted river in the nation, with a number of sites listed as impaired. In addition, the river is home to a number of endangered species, including the Delaware Peninsula mussel.
4. Commercial Value

Shellfisheries
Jewelry
Pearl Shell Industry
5. Cultural-Historical

Native American Uses Waterman Lifestyle Ecotourism
Comparative Summary of Bivalve Natural Capital
# Importance of Bivalves to the Delaware Estuary Watershed

<table>
<thead>
<tr>
<th>Natural Capital Value</th>
<th>Commercial</th>
<th>Dockside Product + Secondary Value</th>
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<tr>
<td></td>
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<td>✅✅✅</td>
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- **Oysters**
  - *Crassostrea virginica*
# Importance of Shellfish to the Delaware Estuary Watershed

<table>
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<td></td>
<td></td>
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<td>✓ ✓ ✓</td>
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<tr>
<td>Ecological</td>
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<td>Structural Habitat</td>
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<td>biological hot spots</td>
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<td>Prey</td>
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<td>Biofiltration</td>
<td>✓ ✓</td>
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<td></td>
<td>top-down grazing, TSS removal, light</td>
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<td></td>
<td></td>
<td>Biogeochemistry</td>
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<td>enrichment/turnover, benthic production</td>
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<td>Shoreline Protection - nearshore reefs</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shoreline Stabilization - living edges</td>
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</tbody>
</table>
## Importance of Shellfish to the Delaware Estuary Watershed

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<thead>
<tr>
<th>Natural Capital Value</th>
<th>Oysters (Crassostrea virginica)</th>
</tr>
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<tbody>
<tr>
<td><strong>Commercial</strong></td>
<td>Dockside Product + Secondary Value</td>
</tr>
</tbody>
</table>
| **Ecological**        | Structural Habitat  
biological hot spots, bottom-binding | ✓ ✓ |
|                       | Prey | ✓ |
|                       | Biofiltration  
top-down grazing, TSS removal, light) | ✓ ✓ |
|                       | Biogeochemistry  
enrichment/turnover, benthic production | ✓ |
|                       | Shoreline Protection - nearshore reefs | ✓ |
|                       | Shoreline Stabilization - living edges | ✓ |
| **Cultural-Historical** | Waterman Lifestyle, Ecotourism | ✓ ✓ |
|                       | Native American - dietary staple | ✓ |
## Importance of Shellfish to the Delaware Estuary Watershed

<table>
<thead>
<tr>
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<td>Watershed Indicators</td>
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<td>Site-specific Bioassessment</td>
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<td>NS&amp;T, caged sentinels</td>
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### Importance of Shellfish to the Delaware Estuary Watershed

<table>
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<th>Marsh Mussels</th>
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<td>✓</td>
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<tr>
<td></td>
<td>Shoreline Stabilization - living edges</td>
<td>✓✓</td>
</tr>
<tr>
<td>Cultural-Historical</td>
<td>Waterman Lifestyle, Ecotourism</td>
<td>✓✓</td>
</tr>
<tr>
<td></td>
<td>Native American - jewelry, dietary staple</td>
<td>✓</td>
</tr>
<tr>
<td>Bioindicator</td>
<td>Watershed Indicators</td>
<td>✓✓</td>
</tr>
<tr>
<td></td>
<td>hallmark resource status/trends</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Site-specific Bioassessment</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>NS&amp;T, caged sentinels</td>
<td>✓</td>
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</table>
## Importance of Shellfish to the Delaware Estuary Watershed

<table>
<thead>
<tr>
<th>Natural Capital Value</th>
<th>Commercial</th>
<th>Ecological</th>
<th>Cultural-Historical</th>
<th>Bioindicator</th>
<th>Conservation</th>
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</thead>
</table>
|                       | Dockside Product + Secondary Value | Structural Habitat  
biological hot spots, bottom-binding | Ecological | Prey | Biofiltration  
top-down grazing, TSS removal, light) | Biogeochemistry  
enrichment/turnover, benthic production | Shoreline Protection - nearshore reefs | Shoreline Stabilization - living edges |
|                       | Oysters | Crassostrea virginica | Marsh Mussels | Geukensia demissa | FW Mussels | Elliptio complanata |
|                       |          | ✔️ ✔️ ✔️ | ✔️ ✔️ ✔️ | ✔️ ✔️ | ✔️ ✔️ | ✔️ |
|                       |          | ✔️ ✔️ | ✔️ ✔️ ✔️ | ✔️ ✔️ | ✔️ ✔️ | ✔️ ✔️ |
|                       |          | ✔️ ✔️ | ✔️ ✔️ ✔️ | ✔️ ✔️ | ✔️ ✔️ | ✔️ ✔️ |
|                       |          | ✔️ ✔️ | ✔️ ✔️ | ✔️ | ✔️ ✔️ | ✔️ ✔️ |
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|                       |          | ✔️ ✔️ | ✔️ | ✔️ | ✔️ | ✔️ ✔️ |
|                       |          | ✔️ | ✔️ | ✔️ | ✔️ | ✔️ ✔️ |
|                       |          | ✔️ | ✔️ | ✔️ | ✔️ | ✔️ ✔️ |

**Bioindicator**
- Watershed Indicators  
  hallmark resource status/trends
- Site-specific Bioassessment  
  NS&T, caged sentinels

**Conservation**
- Biodiversity  
  fw mussels most critically impaired biota

**Ecological**
- Structural Habitat  
  biological hot spots, bottom-binding
- Prey
- Biofiltration  
  top-down grazing, TSS removal, light)
- Biogeochemistry  
  enrichment/turnover, benthic production
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- Native American  
  jewelry, dietary staple

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- Watershed Indicators  
  hallmark resource status/trends
- Site-specific Bioassessment  
  NS&T, caged sentinels

**Conservation**
- Biodiversity  
  fw mussels most critically impaired biota
Watershed Perspective
Others?

- *Elliptio complanata*
- *Geukensia demissa*
- *Crassostrea virginica*

12+ Other Species of Freshwater Unionid Mussels

- *Corbicula fluminea*
- *Rangia cuneata*
- *Mya arenaria*
- *Mytilus edulis*
- *Ensis directus*
- *Mercenaria mercenaria*
Desired Watershed Condition:
A diverse and robust assemblage of native bivalve shellfish living in all available tidal and non-tidal ecological niches and providing maximum possible natural capital goods and services.
Future Needs to Reach this Desired State
1. More Survey Data

Still limited in many freshwater and marsh areas

Important for all conservation, restoration and management needs
2. Ecosystem Role

Watershed Mass Balance Studies

- How much population biomass is needed to make a real difference for water quality?

Estimate of Water Filtration by 10,000 juvenile *Elliptio*
2. Ecosystem Role

Watershed Mass Balance Studies

- How much population biomass is needed to make a real difference for water quality?
- Quantitative studies needed, with physiological ecologists, hydrodynamics experts and geomorphologists, modelers
Actual Water Processing and Water Quality Effects Also Depend on Hydrologic Conditions

Shellfish Affect Water Quality

No Water Quality Benefits

Residence Times
SF Bay: 11
Ches Bay: 22-45
Narragansett: 27
Delaware Bay: 97

2. Ecosystem Role

**Watershed Mass Balance Studies**
- How much population biomass is needed
d- Quantitative interdisciplinary studies

**Linkages Between Bivalves and Other Biota**
- How much do macroinvertebrates, fish, benthic algae, depend on bivalves?
e.g., Biodeposits

- Ingestion (I)
- Absorption (A)
- Defecation (F)
- Excretion (U)
- Respiration (R)
- Production (T)
- Gametic (Tg)
- Somatic (Ts)
- Clearance (C)
- Pseudofeces (Ps)
2. Ecosystem Role

**Watershed Mass Balance Studies**
- How much population biomass is needed?
- Quantitative interdisciplinary studies

**Linkages Between Bivalves and Other Biota**
- Linkages with macroinvertebrates, fish, benthic algae

**Linkages Between Non-Tidal and Tidal Systems**
- Interception of pollutants in non-tidal waters
- Enhancement of diadromous fish (hosts) by reefs
System Linkages

11 Other Species of Freshwater Unionid Mussels

Elliptio complanata

Geukensia demissa

Crassostrea virginica

Corbicula fluminea

Mya arenaria

Rangia cuneata

Mytilus edulis

Ensis directus

Mercenaria mercenaria
The Other Filter Feeders: Mussels, Clams, & More

A Few Good Filter Feeders

From Headwater to Bay

Clear Water through Clam Culture?
3. Human Health Links

Pathogen Removal

- bacteria and protist grazing and assimilation
Some Bivalves are Bacterivorous

- Pennate Diatoms
- Phytoplankton
- Centric Diatoms
- Bacteria
- Detritus Complex
- Heterotrophic Protists

Some Bivalves are Bacterivorous.
3. Human Health Links

Pathogen Removal

- bacteria and protist grazing and assimilation

- capacity for antimicrobial resistance transference
3. Human Health Links

Pathogen Removal
- bacteria and protist grazing and assimilation
- antimicrobial resistance transference

Model Organisms
- for medical sciences (e.g. cancer research)

www.livingclassrooms.org/lbo/dermo/oyster2.jpg
3. Human Health Links

**Pathogen Removal**
- bacteria and protist grazing and assimilation
- antimicrobial resistance transference

**Model Organisms**
- for medical sciences (e.g. cancer research)

**TMDL applications**
- can reassembled bivalve communities help managers address TMDL’s?
4. Restoration for Future Steady States

Climate Change

Natural Resource Responses

- Disruption - species or community
- Disconnects - de-coupled interactions
- Thresholds - non-linear bio responses
- Synergisms - climate effects + other changes

Temp
Salinity
Sea Level Rise
Storms
Species Range Shifts

- Sweetgum
- Liquidambar styraciflua

Legend:
- Range
- FIA Imp Value
- 0: No Range
- 1-5: 1-20
- 6-10: 21-50
- 11-20: 51-100

Habitat in 2100
- Low Emissions
- High Emissions
Opportunistic Invasive Species
**Thresholds** *(Non-linear Responses)*

**Organisms, Populations**: Example: Hypoxia mortality

**Species**: Extinction is an Abrupt, irreversible Change

*Slide adapted from Carlos Duarte*
Ecological Thresholds

- Non linear shifts in ecosystem status
- Tipping points or breaking points of the system
- Once breached, "recovery" may be slow or unlikely

Knowing where these tipping points are will be extremely valuable to set policy targets (Climate-driven Thresholds) and for determining who the survivors might be.
4. Restoration for Future Steady States

Climate Change + Watershed Change
“... The interaction between climate change and habitat loss might be disastrous. During climate change, the habitat threshold occurs sooner. Similarly, species suffer more from climate change in a fragmented habitat.”
Not All Doom and Gloom?

Can oysters be maintained until they might see more optimal conditions?

Historical data from Rutgers Haskin Shellfish Laboratory
Oyster Reef Revitalization
“Smart” Restoration

Targeted Restoration
- species that can self-sustain
- sites that are suitable
Freshwater Mussel Recovery Program

see posters by Padeletti, Gray
Need to Prioritize Streams for Restoration
Reciprocal Transplants and Condition Monitoring

Tagging Mussels
Reciprocal Transplants and Condition Monitoring

Cage Deployment
Mussel Survivorship Over 1 Year

<table>
<thead>
<tr>
<th>Site</th>
<th>Survivorship %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandywine</td>
<td>100</td>
</tr>
<tr>
<td>Ridley</td>
<td>100</td>
</tr>
<tr>
<td>MB White Clay</td>
<td>100</td>
</tr>
<tr>
<td>EB White Clay</td>
<td>100</td>
</tr>
<tr>
<td>Red Clay</td>
<td>100</td>
</tr>
<tr>
<td>WB Brandywine</td>
<td>75</td>
</tr>
<tr>
<td>Chesler</td>
<td>75</td>
</tr>
</tbody>
</table>

Matt Gray thesis research (Drexel)
Condition Index Over 1 Year

Sampling Periods Oct 2007 - October 2008

Important for Overwintering ➔

- Brandywine
- Ridley
- MB White Clay
- EB White Clay
- Red Clay
- WB Brandywine
- Chester

Matt Gray thesis research (Drexel)
Smart Restoration

Targeted Restoration
- species that can self-sustain
- sites that are suitable

Conservation-Minded Propagation
- genetic studies
- shell middens
- develop uniform policies for when and how to permit interbasin transfers
White Sulphur Springs NFH

Re-circulating System

“Bivalve Bunkbeds”
Fish Infestation
Propagation and Reintroduction

Cheyney Hatchery
Propagation and Reintroduction

2009 Goal: Propagated Juveniles (but *Elliptio*)

*Photos, R. Neves, VA Tech*
Set Goals Based on Eco Services

Not including progeny

 Millions of Liters Processed

Years After Planting

0 200 400 600 800 1,000 1,200 1,400 1,600 1,800 2,000
Future Needs recap

Survey Data

Ecosystem Role

Human Health Links

“Smart” Restoration for Future States
Conclusions

• Both freshwater and marine bivalves provide multiple goods and services

• Fresh and brackish water mussels can be sufficiently abundant to affect water quality at least as much as oysters

• Both biodiversity and population biomass of bivalves represent important natural capital in American watersheds

• Bivalves represent excellent targets for ecosystem-based management, conservation and restoration

• Efforts to maintain and improve water quality and ecological health would benefit from a holistic approach to conserve and restore bivalves throughout whole basins.