“Life Is Life,
and Fun Is Fun,
But it’s So Quiet
when the Goldfish
Die.”

Egyptian Coptic saying.
Cobbles with Gills and Guts: Conserving Freshwater Mussel Beds and Water Quality.
Seminar Agenda

- Biology
- Why Do We Care?
- What Can We Do?
- What We Need to Know . . .
- What Do We Know?
- Challenges
- Opportunities……the FUTURE!!!
Why Do We Care?

• Biodiversity

  72% imperiled (E, T, SC)
  43.2 % T and E
  27.7 % End
  7.1 % listed & possibly extinct

• Largest diversity in the world

  297 species in North America.
Why Do We Care?

• Economic Value
Why Do We Care?

- Abundance
Ecosystem Function

Photo courtesy of Matthew Patterson
Ecosystem Function

- Water Quality
- Riverbed Stability
- Ecosystem Stability

Shells 'R' Habitat

- Ctenidia pump large amounts of water
- Bioturbation - $O_2$ and $H_2O$ content
- Biotransformation of CPOM
- Nutrient Cycling

Bioturbation
In a reach of river 200 yards long (e.g. two football fields), a bed of 100,000 freshwater mussels is filtering 30,000 gallons of water per day FOR FREE!!!
No electricity, no fancy filters, no scrubbers, no chemical treatments.
Culprits

- Water Quality
- Habitat Degradation and Habitat Loss
- Exotic Species
What Can We Do?

- Culture and Propagation –
  - Augmentation or Stock Enhancement and Species Preservation.
  - Identify populations needing immediate attention.
  - Field surveys.
- Salvage and Refuge of T&E sp.
- Propagation of Commercial Sp.- pearls.
- Stream Habitat Restoration.
What We Know ...

Figure courtesy of Dan Graf
The Unionoida is unique among bivalves in that the larvae are parasitic. The host is almost always a fish. Larvae are brooded in the ctenidia. So... mussels are typical of freshwater bivalves in that they exhibit parental care.
The Suspension-Feeder Diet
What Do We Need To Know?

- Aquaculture Requirements.
  - How do we hold them?
  - What, How Much, and How Often?
  - Multispecies Management
- Habitat Requirements.
- Ecological Function, Role in Maintaining Water Quality.
Challenges to Captive Care: Diet Suitability

- **Food Quantity - mg/L**
  - Rate Functions - i.e. clearance, consumption, excretion, defecation.

- **Food Quality**
  - Physical - particle size, type
  - Biological
    - biochemical composition
    - caloric - energy value
    - Seasonal nutritional demands.
    - Scope for Growth.
Effect of algal ration on mean clearance rate in *Villosa iris*

![Graph showing the effect of algal ration on mean clearance rate.](image)

- 0.34 mg/L: 172.5 mL/h/gd tw
- 1.5 mg/L: 140.7 mL/h/gd tw
- 3.4 mg/L: 73.6 mL/h/gd tw

Clearance rate (mL/h/gd tw)

Algal ration (mg/L)
Assimilation efficiency in *Villosa iris* fed three rations of algae

- **Ration A**: 0.03 mg/L
- **Ration B**: 0.34 mg/L
- **Ration C**: 3.4 mg/L

The diagram shows the assimilation efficiency in percent (%) for different rations and treatments. The treatments are represented by the colors D+E (yellow) and T+R (red). The efficiency increases with higher rations.
Gut passage and gut purge time in *Villosa iris* fed three rations of algae

<table>
<thead>
<tr>
<th>Ration</th>
<th>Concentration (mg/L)</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PUMPER System

- Continuous-Flow-Through System
- 4, 100 L reservoir tanks
- 4, 20 L header tanks
- 40, 2 L test chambers
Questions
What is the effect of sediment on the clearance rate (CR) of mussels?

What particle size do mussels clear most efficiently?
Elliptio complanata

No Sediment
• seston

Sediment
• seston
• algae
Mussel chambers

Inflow

Middle

Outflow

water

air
# Mean CR of unionids held for 29d on four different feeding treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>CR (L/h)</th>
<th>SE</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.8</td>
<td>0.37</td>
<td>0.84 diet</td>
</tr>
<tr>
<td>2</td>
<td>2.3</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2.0</td>
<td>0.36</td>
<td>0.53 day</td>
</tr>
<tr>
<td>4</td>
<td>1.7</td>
<td>0.45</td>
<td></td>
</tr>
</tbody>
</table>

1 = Seston  
2 = Seston, NO SUBSTRATE  
3 = 0.5 pt Seston/ 0.5 pt Algae  
4 = Algae
Mean Clearance Rate of Mussels in the Allegheny River (Afternoon)

Species

1 = A. ligmentina
2 = E. dilatata
3 = L. costata

Clearance Rate (L/h)

1.53
1.12
1.10

p = 0.23 Spp
0.50 Test
Filtration Efficiency for Various Particle Sizes Over Time by *Elliptio complanata*

![Graph showing filtration efficiency for various particle sizes over time.](image)
Seston Concentration in the Brandywine River from June through December, 2001
Proportion of Particle Size Categories in the Brandywine River Seston Over Time

Proportion of Large Particles Over Time

Date: 6.29.01, 7.17.01, 8.1.01, 8.23.01, 10.16.01, 11.11.01, 12.11.01
QUALITY

- Successful growth and development of cultured species depends to a large extent on the **nutritional** value of the feed provided.
- If quantity does not limit growth, then **quality** is of increased importance in maintaining health of captive animals.
Dietary Protein

- Critical for maintaining **condition and breeding success** of cichlid fishes.
- Very important to marine mussels undergoing **reproductive development** (Kreeger 1993).
- Greatest effect on growth in juvenile hard clams; however, lipid had to be sufficient to support rapid growth.
- Important for tissue **growth and maintenance** in adults (Hawkins and Bayne 1991).
Dietary Carbohydrate

- Primary energy source for adults
  - immediate use in respiration
  - long-term storage as fuel for over-wintering and subsequent gametogenesis.
  - glycogen ~ 40-50% of CHO.

- Energy source for juveniles, however,
  - High CHO diet was of little use to juvenile oysters and adult mussels when protein became limiting.
Dietary Lipids

- Bivalves have limited abilities in:
  - FA elongation to UFA
  - Synthesis of cholesterol.
- Dietary requirement for sterols and the PUFA’s.
- Synthesis, transport, and regulation of hormones.
- Membrane function.
- Energy storage compounds - triglycerides.
  - Important for developing larvae and growing juveniles.
• 30 mussels / sp. /sample in Allegheny & Brandywine R., 1 y.
• 6 mussels/sp./sample in New R., 2 y.

Kreeger and Langdon, 1993
Breeding Strategies

• Short-term:
  – spawn April-**May**,
  – brood glochidia May-July,

• Long-term:
  – spawn July,
  – brood glochidia Sep-April,
  – release glochidia April-Jun.

**Ambleminae**: *Elliptio complanata*, *E. dilatata*, *Cyclonaias tuberculata*

**Anodontinae**, *Lasmigona costata*

**Lampsilinae**, *Actinonaias ligamentina*
Seasonal variation in energy substrates: long vs. short term brooders

Carbohydrate

Lipids

New River, VA

A. lig. NR 01
A. lig NR 02

C. tub. NR 01
C. Tub NR 02

= spawning
= Onset of Gametogenesis
Seasonal variation in energy substrates: short term brooders

New River, VA

PA Rivers, PA

Carbohydrate

Lipids


Gametogenesis initiated = spawning

C. tub. NR 01  -  C. Tub NR 02

C. tub. NR 01  -  C. tub. NR 02

% dry wt.

May  Jun  Jul  Sep  Nov  Dec  April

May  Jun  Jul  Sep  Nov  Dec  April
Seasonal variation in lipid and protein content: long term brooders, New River.

Lipid

Protein

[Graphs showing seasonal variation in lipid and protein content for different species and groups, with specific months and percentage dry weight values.]
Mean Absorption Efficiency (%): Mussels fed natural river seston.

- A. ligamentina = 60.0 ± 5.0
- E. dilatata = 63.0 ± 4.0
- L. costata = 66.5 ± 4.0
- p=0.5
- E. complanata = 75 ± 7.8
Discussion

• Seasonal timing and relative changes in BIOCHEM different between River systems.
  – Protein and lipid varied more than carbohydrate in mussels from the Allegheny River.
  – CHO may play a role in over-wintering conditioning in mussels in the New R. Whereas, lipids may play a more seasonal role in over-wintering, as well as gametogenesis and spawning in the New R.

• Lipid and PRO showed similar seasonal trends.
  – Increased in Fall - onset of **gametogenesis**, Declined in winter- quiessence, Increase in spring followed by sharp decline post- **spawning**.

• As lipid (and protein) increased, CHO decreased.
• Long-term brooders may be considered dabblers.
Conclusions

• Until empirical data become available, a diet high in protein and lipid is recommended for all mussels, especially in the Fall.
• Carbohydrates, however, should not be ignored. Indeed, carbohydrate may be linked to late summer conditioning in some short-term brooders.
• We recommend the following diet for captive freshwater mussel: ~10-15% carbohydrate, ~20-40% protein, ~30% lipid, and ash ~ 20%.
• Focus on identifying seasonal patterns to enable the development of “smart” diets that will maintain fitness of brood stock and the progeny.
• Consider base feeding level of 1-1.5 mg/L or 20,000 c/mL.
Challenges to Propagation: Fish Host

What is it?
How do we hold it?
How do we maintain disease-free brood stock stations?
Other contamination issues?
Challenges to Reintroduction

Genetics!!!

- Source Population.
- Where and which source population.
- Is it really a species?
  - Occurs only in VA . . .hmmmm.
Challenges to Reintroduction:

- Who Wants An Endangered Species? 
  .... in their backyard ....
The Juggling Act

• Begin setting the stage –
  – ES-USFWS, State, others …
• Identify species in need.
• Identify Interest Groups . . .
  and priorities.
• Identify reintroduction sites.
• Identify source populations.
• On the ground working with
  the public. . . . OUTREACH.
Challenge . . .

Juvenile Survival Bottleneck
OPPORTUNITIES

• CLEAN WATER!
  - Restore mussels = Restore streams.
  - Species Preservation and Restoration
• National Collaborations - Regions.
• International Collaboration.
• NGO Conservation Partnerships.
  – Raise Public Awareness.
OPPORTUNITIES

• National and International Collaboration.

  – *Margaritifera falcata* - Species of concern. Disappearing at alarming rates on the west coast.

  – *Margaritifera margaratifera* - Disappearing at alarming rates throughout Europe. Ireland, Scotland interested in propagation.


  – *Margaritifera auricularia* – was presumed extinct; population found in Spain; propagation program developing.
Propagation: population augmentation and species preservation
Salvage and Refugia: adult holding and maintaining brood stock.
Imperiled Species Aquaculture Center
Bunkbeds for Bivalves
Freshwater Mussel Culture System
Longitudinal View
Glycogen results

**Actinonaias ligamentina**

- **River**
- **Relocated 8/01**
- **Relocated 8/02**

Glycogen results for Actinonaias ligamentina are shown for different sample dates from June 2001 to June 2003. The graph indicates fluctuations in glycogen levels with specific annotations for relocated samples in August 2001 and August 2002.
Future Opportunities - Applied

• Salvage and Refuge

• Biomonitoring
The Future > Conservation Aquaculture for the Recovery of Endangered and Imperiled Species (CARES)

Cambarus (Hiaticambarus) elkensis

460 turtles harvested in 2000 to over 23,000 harvested in 2002

Cheat Mountain Salamander Plethodon nettingi

GETT INTO and CRAYFISH FARMING

Greg Barron
Sustainable Aquaculture Opportunities

International Food Trade - Turtles

Freshwater Pearl Industry

Many hundreds of adult Southeast Asian box turtles in a holding pen in Sumatra, Indonesia, awaiting international export. This represents an average day’s volume in the trade of this species at this site.
Summary

• Where present, mussels likely perform **ecological services** that are key to maintaining water quality and ecosystem stability.

• Culture and **propagation** of endangered species may be the last hope for reversing the current downward trend in diversity and abundance of aquatic species and aquatic habitats.
Healthy Mussels = Healthy Streams = Healthy Fish = Healthy Economy = Healthy People.
Acknowledgements

- Mussel Mitigation Trust Fund.
- American Zoological and Aquarium Association.
- Academy of Natural Sciences.
- United States Fish and Wildlife Service.
- Biological Resources Division, USGS.
- Virginia Tech.
Effect of Substrate on Clearance Rates Over Time When Ration Effect Removed

**Particles over 20,000**

- MANOVA, p=0.64, treat 0.62, day 3.1 (L/h)

**Particles under 20,000**

- MANOVA, p=0.22, treat 0.78, day 1.9 (L/h)

- MANOVA, p=0.64, treat 0.62, day 1.4 (L/h)