POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL

(Quadrula fragosa)

Monticello, Minnesota
5- 8 January 1998

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL
(*Quadrula fragosa*)

January 1998

Final Report
June 1998

A Collaborative Workshop:
United States Fish and Wildlife Service
United States National Park Service
Minnesota Department of Natural Resources
Wisconsin Department of Natural Resources
and
The Conservation Breeding Specialist Group (SSC/IUCN)

A contribution of the IUCN/SSC Conservation Breeding Specialist Group in collaboration with the United States Fish and Wildlife Service.

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Additional copies of *Population and Habitat Viability Assessment Workshop for the Winged Mapleleaf Mussel (*Quadrula fragosa*)*: *Final Report* can be ordered through the IUCN/SSC Conservation Breeding Specialist Group, 12101 Johnny Cake Ridge Road, Apple Valley, MN 55124.

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TABLE OF CONTENTS

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL (*Quadrula fragosa*)

January 1998

Final Report
June 1998

SECTION 1

EXECUTIVE SUMMARY

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL (*Quadrula fragosa*)

EXECUTIVE SUMMARY

Introduction

Reduction and fragmentation of wildlife populations and habitat are occurring at an accelerating rate world-wide. For an increasing number of taxa, these factors result in small and isolated populations that are at risk of extinction. A rapidly expanding human population, now estimated at 5.77 billion, is expected to increase to 8.5 billion by the year 2025. This expansion and the resulting utilization of resources has momentum that cannot easily be stopped, with the result being ever-decreasing capacity for all other species to exist simultaneously on the planet.

Human activities increasingly threaten the survival of natural environments and wildlife populations. As these populations are diminished, their ecological roles in ensuring a well-balanced, regulated, and sustainable ecosystem also are reduced. Species as the compositional unit of a community or ecosystem are a convenient and discrete unit of management, particularly when that taxon is threatened and requires species-specific management. Wildlife managers realize that management strategies designed to reduce the risk of species depletion must be adopted to ensure viable ecosystem functions. These strategies will include increased communication and collaboration in: habitat preservation; intensified information gathering in the field; investigating the ecological roles of key species; improving biological monitoring techniques; and, occasionally, scientifically managing captive populations that can interact genetically and demographically with wild counterparts. Successful conservation of ecosystems and wild species necessitates developing and implementing active management programs by people, governments, and non-government organizations (NGOs) that live alongside, and are responsible for, that ecosystem.

Single species management for threatened species can take a variety of forms:

- Protection from invasive organisms and pathogens
- Habitat modification and management
- Reintroduction or translocation
- Assisted reproduction
- *Ex situ* breeding or propagation

Status of the Winged Mapleleaf Mussel

The winged mapleleaf mussel (*Quadrula fragosa*) is listed as Endangered under the Federal Endangered Species Act of 1973 and under Minnesota and Wisconsin endangered species laws. One of only two known occurrences is in one segment of the lower St. Croix River, between Minnesota and Wisconsin. An extant population has been identified in the Ouachita River, Arkansas (Posey et al., 1996), which extends approximately 20 to 30 river miles, however density and age structure are not known (J. Harris, pers. comm.). According to the U.S. Fish and Wildlife Service's Winged Mapleleaf Mussel Recovery Plan (1997), the major factors of concern for the St. Croix River population are: 1) low reproduction; 2) low stream flow episodes; 3) high variation in stream flows caused by hydroelectric dam peaking operation during certain seasons; 4) toxic spills; 5) potential zebra mussel infestation; 6) habitat disturbance due to recreational or commercial activities; 7) human and non-human predation and disturbance; 8) water quality deterioration; 9) land-use changes in the watershed; and 10) lack of life history information.

Initiation of the PHVA Process for the Winged Mapleleaf Mussel

To address these and other problems facing the winged mapleleaf mussel, a Population and Habitat Viability Assessment (PHVA) Workshop for was held at the Riverwood Conference Center in Monticello, Minnesota, from 5-8 January 1998. Seventeen people attended the workshop (Section 7), which was a collaborative effort between and the United States Fish and Wildlife Service, United States National Park Service, Minnesota Department of Natural Resources, Wisconsin Department of Natural Resources and the Conservation Breeding Specialist Group (CBSG). The goals of the PHVA were to investigate the viability of the species and to develop practical conservation measures that public and private Riverway stakeholders can support. Researchers, agency representatives, landowners, and other stakeholders were invited to present and analyze information on the winged mapleleaf mussel, its conservation needs, stakeholder considerations, and other issues relevant to its survival.

The PHVA Process

Effective conservation action is best built upon critical examination and use of available biological information, but it also very much depends upon the actions of humans living within the range of the threatened species. Motivation for organizing and participating in a PHVA comes from fear of loss as well as a hope for the recovery of a particular species.

At the beginning of each PHVA workshop, there is agreement among the participants that the general desired outcome is to prevent the extinction of the species and to maintain a viable population(s). The workshop process takes an in-depth look at the species' life history, population history, status, and dynamics, and assesses the threats putting the species at risk.

One crucial by-product of a PHVA workshop is that an enormous amount of information can be gathered and considered that, to date, has not been published. This information can be from many sources; the contributions of all people with a stake in the future of the species are considered.

To obtain the entire picture concerning a species, all the information that can be gathered is discussed by the workshop participants with the aim of first reaching agreement on the state of current information. These data then are incorporated into a computer simulation model to determine: (1) risk of extinction under current conditions; (2) those factors that make the species vulnerable to extinction; and (3) which factors, if changed or manipulated, may have the greatest effect on preventing extinction. In essence, these computer-modelling activities provide a neutral way to examine the current situation and what needs to be changed to prevent extinction.

Complimentary to the modelling process is a communication process, or deliberation, that takes place during a PHVA. Workshop participants work together to identify the key issues affecting the conservation of the species. During the PHVA process, participants work in small groups to discuss key identified issues. Each working group produces a brief report on their topic, which is included in the PHVA document resulting from the meeting. A successful PHVA workshop depends on determining an outcome where all participants, coming to the workshop with different interests and needs, "win" in developing a management strategy for the species in question. Local solutions take priority. Workshop report recommendations are developed by, and are the property of, the local participants.

At the beginning of the workshop, the 17 participants worked together in plenary to identify the major issues and concerns affecting the conservation of the winged mapleleaf mussel. These identified issues centered around three main topics, which then became the focus of the working groups: Species Biology; Threats, Habitat and Management; and Simulation Modelling.

Each working group was asked to:

- Examine the list of problems and issues affecting the conservation of the species as they fell out under each working group topic, and expand upon that list, if needed.
- Identify and amplify in text the most important issues.
- Develop recommendations to address the key issues.
- Amplify and specify the actions or strategies that might improve each of the priority problems or issues in detail.

Each group presented the results of their work in plenary sessions to make sure that everyone had an opportunity to contribute to the work of the other groups and to assure that issues were carefully reviewed and discussed by all workshop participants. The recommendations coming from the workshop were accepted by all participants, thus representing a consensus. Working group reports can be found in Sections 2-4 of this document. Recommendations resulting from each of the 3 working groups are presented below. Recommendations are listed according to priority and, within a particular working group, those recommendations with the same number are considered to be of equal importance.

Recommendations

Species Biology Working Group

1. Determine quantitative and qualitative sample sizes needed to estimate changes in population density and species richness at various precision levels (5 to 25% with 95% confidence). From this analysis modify the existing (Hornbach, Heath) long term monitoring strategy such that monitoring results can be used to trigger management action. To monitor change, overall community characteristics (density, richness, dominant species, age structure) will be used as a surrogate for *Q. fragosa*.

2. Identify fish host and determine if the availability of fish host or its habitat is limiting, and if increasing fish abundance is prudent, manage for host fish enhancement.

3. Examine *Q. fragosa* adults every two weeks to find gravid females and determine the timing and duration of the brooding period.

4. Since fertilization of *Q. fragosa* may be dependent on the proximity of males and females and few gravid *Q. fragosa* have been located, determine the density and spatial relationship of *Q. fragosa* to one another in existing populations.

5. Develop molecular reference standard for identification of *Q. fragosa* glochidia. Collect fish in areas of existing *Q. fragosa* habitat. Examine fish for glochidial infection and identify glochidia by use of molecular genetics methodology.

6. Contact local unionid experts and review survey reports from each state with historical records of *Q. fragosa*, to determine sites that currently support unionid mussels and might support *Q. fragosa*. Conduct qualitative sampling at sites with species-rich unionid communities with an emphasis on sites in the St. Croix River.

7. Since *Q. fragosa* is not sexually dimorphic, develop a non-lethal technique (such as fiber optics) for determining sex of adult mussels. Use methodology to determine sex of *Q. fragosa* adults in extant populations.

8. Compile and analyze all available information on water quality, chemistry and water flow (USGS-WRD, NAWQA data; MPCA; other sources?) for streams with existing *Q. fragosa* populations. Unionid distribution is affected by water quality and flow. Historical events of fluctuations may partially explain current distribution and community characteristics, given the long generation time of unionids.

9. Collect tissue, using non-lethal techniques (see Berg or Naimo) from extant populations of *Q. fragosa* and from other *Quadrula* species. Compare genetic structure of species using standard molecular genetic techniques to verify species status.

10. Model or simulate, in a working lab model, various hydrological scenarios to test lethal and sub-lethal effects on *Q. fragosa* and its hosts/or a suitable surrogate species. The surrogate should be as close to *Q. fragosa* as possible with respect to physical and behavioral characteristics (i.e. another *Quadrula* species or *Ambleminae* species.)

Threats Working Group

The five threats determined to be most significant to the survival of the winged mapleleaf mussel are listed below followed by specific recommendations addressing these threats.

1. *Zebra mussels*

   a) Continue and expand existing aggressive zebra mussel encroachment prevention and education programs of St. Croix Zebra Mussel Task Force
   b) Continual findings of jeopardy for the winged mapleleaf mussel under Section 7 Fish and Wildlife Service consultations for federal activities that will result in the introduction of zebra mussels in the St. Croix River
   c) Develop and implement a pro-active, contingency strategy to prevent extinction of winged mapleleaf mussels in the St. Croix River from an infestation of zebra mussels
   d) Determine a threshold of zebra mussel demographics (density, biomass, reproduction) that triggers implementation of the contingency strategy

2. *Instream Flow*

   a) Increase the minimum flow from the Northern States Power dam during winter peaking operations from 800 cfs to 1,600 cfs; monitor the response of the mussel community to 1,600 cfs in terms of changes in mussel densities and based on the response of the mussel community to 1,600 cfs, evaluate the need to adjust the minimum flow.
   b)

3. *Point and nonpoint source pollution*

   a) Establish a policy of no net increase in pollutant loading in the St. Croix watershed. The purpose of this recommendation is to prevent additional pollution loading through implementation of programs designed to increase water quality monitoring, insuring compliance with existing regulations, and adoption of voluntary Best Management Practices (BMPs). This recommendation is not intended to limit further development in the watershed.

4. *Direct human disturbance*

   a) To address the threats of Direct Human Disturbances on *Quadrula fragosa*, actions are needed to restrict the impact of people. We recommend that all stakeholders be engaged in a process to develop creative, mutually satisfactory solutions to the problems of direct harm to the winged mapleleaf mussel and its habitat, particularly by boating, and the currently illegal use of mussels for fish bait and food.

5. *Corridor construction*

   a) Involve appropriate state and Federal agencies early in project planning prior to initiating the following Environmental Impact Statement (EIS) process: inventory candidate construction/ construction impact corridors for winged mapleleaf mussels, evaluate the feasibility of mussel relocation, relocate all project impact area mussels if state or Federal threatened or endangered species are present and, take all necessary measures during construction to maintain water quality and exclusion of zebra mussels.

b) Project impact reduction should include consideration of improving the status of the species via "off site" research and management. Off site research and management could be developed in coordination with experts in the winged mapleleaf mussel and related areas; for example, determine the amount of fragmentation related to corridor impacts that would cause the winged mapleleaf population to collapse.

Simulation Modeling Working Group

Ranking criterion used: Recommendation will lead to a better model.

1. Develop more precise estimates of juvenile and subadult mortality for *Q. fragosa* i.e., those in the 0-7 year age classes. Sediment traps could be employed to obtain estimates of the number of juvenile mussels settling in a given area of substrate in a given year. Furthermore, Surber and related sampling methodologies can be used to look for juvenile age classes for all mussel species in the same area repeatedly through time. Ideally, a surrogate species in this context would be another *Quadrula sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

2. Focus our understanding of the nature and extent of the interaction between *Q. fragosa* and the zebra mussel, particularly with respect to the following parameters: at what density/biomass of zebra mussels do measurable impact(s) on winged mapleleaf mussel demography begin to occur, how rapidly would a zebra mussel population reach this specified level on the St. Croix and grow beyond it, and which aspects of winged mapleleaf life history would be most seriously affected at these various levels of zebra mussel infestation. Ideally, a surrogate species in this context would be another *Quadrula sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

3. Improve estimates of annual rates of juvenile production per breeding female of *Q. fragosa*, primarily through more detailed analysis of literature on unionid mussels where available. Ideally, a surrogate species in this context would be another *Quadrula sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

4a. Review and improve estimates of adult winged mapleleaf (or surrogate) mussel mortality rates. This could be done through mark-recapture studies. Ideally, a surrogate species in this context would be another *Quadrula sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

4b. Improve our understanding of the nature and extent of direct and indirect anthropogenic factors on mussel habitat and by extension, winged mapleleaf mussel demographic rates, particularly those involving juveniles and breeding adults. Direct experimentation on related unionid mussels may prove useful toward this goal. Ideally, a surrogate species in this context would be another *Quadrula sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

5. Improve estimates of environmental variance associated with adult winged mapleleaf (or surrogate) mussel mortality rates. Again, mark-recapture studies would prove useful in pursuit of this goal. Ideally, a surrogate species in this context would be another *Quadrula sp.*; if this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

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SECTION 2

SPECIES BIOLOGY WORKING GROUP REPORT

SPECIES BIOLOGY WORKING GROUP REPORT

Introduction

The species biology working group reviewed the list of sixty problem statements identified by workshop participants and selected twenty-six of them as being appropriate for the working group to address. These problems were grouped into four categories of analysis. The participants then used a paired-ranking technique to identify the priority problems within each category. The criterion used for ranking problem statements was the importance of the knowledge to the ultimate survival of the species. Priority recommendations are marked with an * within the text below.

A. Life History (individual)
1. host fish
2. breeding cycle
    a) long term vs. short term
    b) periodicity
    c) time of year
3. minimum viable population
4. critical life history stages
5. age of sexual maturity
6. determining age/rings
7. ability to identify all life stages
8. nutrient requirements
9. life history relationship to other *Quadrula* (surrogate sp.)
10. propagation (a. cryopreservation b. captive)

B. Demographics
- 1. current/historical pop size
- 2a. taxonomic status - is it a species?
- 2b. demographic parameters (modeling group)
- 4a. genetic diversity within a population
- 4b. sex ratio (a. optimal b. what is it)
- 5. Other problem statements
    - a) disease susceptibility
    - b) life span of a mussel bed - n/a
    - c) predation
    - d) what constitutes a population

C. Distribution
1. taxonomic status - are the two or three known populations all *Q. fragosa*?
2. current/historical population size
3. current range limitations
4. fragmentation as it relates to mussel population

D. Habitat

1. Abiotic (water quality, substrate requirements, environmental variability)
2. Biotic
   a) community structure/competition
   b) fish community data
   c) potential sites for reintroduction
   d) other organisms on which species depends
   e) predation

LIFE HISTORY

Problems concerning the life cycle completion of individuals were addressed by this working group. The participants identified questions related to the fish host, the breeding cycle of *Q. fragosa*, determining a viable population size and the critical life history stages as priorities.

Fish host

Known:

We know that other *Quadrula* species use Ictalurids, and may use Centrarchids and Percids, (based on field observations, Coker et al. 1921; Howard, 1914). *Q. cylindrica* metamorphosed on Cyprinids in the lab (Yeager and Neves 1986). We suspect that the glochidia are gill parasites based on observations of *Q. fragosa* and other *Quadrula* spp.

Need:

a) What is the fish host?
b) Availability of fish host - is it in the area, seasonality, density. Are appropriate life stages available at the right time of year?
c) Population dynamics of host fish
d) Habitat requirements of all life stages of host fish, including spawning habitat, diurnal and nocturnal, juvenile nursery area, over-wintering habitat
e) Alternative hosts for captive propagation - species that do not co-occur with *Q. fragosa* in its habitat, but could be used for captive propagation, if the host fish is rare or is sensitive to laboratory holding conditions.

Actions:

- Identify fish host and determine if the availability of fish host or its habitat is limiting, and if increasing fish abundance is prudent, manage for host fish enhancement.** This action requires a step-wise process of investigation. Conduct a thorough review of the literature and contact experts (WIDNR, Heath; MNDNR) to develop a list of potential fish species, demographics, and habitat present near *Q. fragosa* habitat. Obtain gravid female *Q. fragosa*. Obtain fish species for laboratory infection trials. Conduct laboratory trials of host specificity. Secondary action: If glochidia are available, test alternative hosts for use in captive propagation programs.
- Conduct a seasonal fish survey around and within *Q. fragosa* populations (with the objective of identifying spawning habitat, diurnal and nocturnal habitat, juvenile nursery area, overwintering habitat). Measure length-frequency of fish to determine population structure. Measure habitat parameters for fish.
- Develop management actions to enhance fish host attraction to *Q. fragosa* during time of glochidial release.

Breeding Cycle

Known:

One *Q. fragosa* female was gravid in late September 1997, but glochidia were not mature. Other *Quadrula* species are short-term brooders, and release glochidia from May-July. *Quadrula* spp. breed once a year.

Need:

a) Are they short- or long-term brooders? How long do females brood glochidia?
b) What time of year do they release glochidia?
c) How often do they breed?
d) What proportion of the population spawn annually? (Frequency of spawning)

Actions:

- Examine *Q. fragosa* adults every two weeks to find gravid females and determine the timing and duration of the brooding period. We recommend beginning at ice out in the spring and if gravid females are not found by ice cover, continue sampling as long as practically possible.*
- From this data, recommend limitations on disturbance (e.g., collections, paddleboats, water fluctuations) during the brooding period.
- Determine availability of fish during period of brooding using data from this action and actions under host fish section.

Viable Population

What is the number of individuals and density needed to a) maintain a stable population and b) have a growing population over a period of 100 years?

Known:

a) Observations suggest that some species of Ambleminae actively move only a few meters (ESI 1996 & 1997) and some species clump.
b) Downing et al. (1993) reported that, for *E. complanata*, fertilization failed completely at densities $<10/m^2$, and was 100% successful only in patches where densities exceeded $40/m^2$.
c) Neves (1997) suspects hermaphroditism is important in historically rare species.

Need:

a) What number and density of individuals are needed for fertilization to occur?
b) What is the density needed to maintain a stable population for 100 years?
c) What density is needed for a population to grow over a period of 100 years?
d) What is the ideal proximity of males and females for fertilization to occur?

Actions:

- Determine quantitative and qualitative sample sizes needed to estimate changes in population density and species richness at various precision levels (5 to 25% with 95% confidence). From this analysis, modify the existing (Hornbach, Heath) long term monitoring strategy such that monitoring results can be used to trigger management action. To monitor change, overall community characteristics (density, richness, dominant species, age structure) will be used as a surrogate for *Q. fragosa*. *
- Investigate other species in the population for use as surrogate for *Q. fragosa* population monitoring.
- Since fertilization of *Q. fragosa* may be dependent on the proximity of males and females and few gravid *Q. fragosa* have been located, determine the density and spatial relationship of *Q. fragosa* mussels to one another in existing populations.*

- Conduct a follow-up PHVA workshop (after some population demographics are verified or redefined) and run a suitable modeling program, such as VORTEX, to determine the density needed to maintain a stable population and for a population to grow over a period of 100 years.
- Enhance reproduction by manipulating density.

Critical Life History Stages

What life stage(s) affect the species' ability to survive? Which stage(s) are most sensitive to perturbations? On which stage should monitoring/management be focused?

Known:

a) Juvenile mussels of some species are more sensitive to some contaminants than fathead minnows and Daphnia (McKinney and Wade, 1996).
b) Adults of most species are less sensitive than juveniles, but sensitivity may be chemical and life stage dependent (Leard et al., 1980; Jacobson et al., 1993; Couillard et al., 1995; Naimo, 1995; McKinney and Wade, 1996; Metcalfe-Smith et al., 1996).
c) The life stage from glochidia to 1 year old is where the greatest mortality occurs for most species (i.e., recruitment is low).
d) Natural mortality for adult mussels of most species is relatively low.

Need:

a) Age-specific moralities.
b) Determine the major sources of mortality at each life stage.
c) Stage specific toxicity tests.

Actions:

- Continue long-term monitoring of known populations in the St. Croix River.*
- Use data from long-term mark-recapture studies to estimate age-specific mortality of *Q. fragosa* in the St. Croix River.
- After determination of age-specific mortality, identify management actions that could affect age-specific mortality.

DEMOGRAPHICS

Priority issues related to knowledge of population size, structure and dynamics were considered.

Current/historical population sizes

Known:

a) Historical range of *Q. fragosa* (presence/absence) is presumed from museum records, but no quantitative data are available on population sizes.
b) Current estimate of *Q. fragosa* density in the three areas in the St. Croix River (two closely associated beds at Interstate Park and one bed at Franconia).
c) An extant population has been identified in the Ouachita River, Arkansas (Posey et al., 1996), which extends approximately 20 to 30 river miles, however density and age structure are not known (J. Harris, per. comm.).

Need:

a) Verify identification of historical specimens.
b) Current quantitative and qualitative surveys of streams and rivers within the historical range.

c) Quantitative and qualitative survey of other populations (e.g., Ouachita River, Kiamichi (?) population).

Actions:

- An expert in the field should visit all collections with historical records of *Q. fragosa* to verify identification. Available data on other species reported from the collection sites for *Q. fragosa* should also be compiled to determine historical species associations or communities in these streams.
- Contact local unionid experts and review survey reports in each state with historical records of *Q. fragosa* to determine sites that support unionid mussels and might support *Q. fragosa*. Conduct qualitative sampling at sites with species-rich unionid communities with an emphasis on sites in the St. Croix river. Plot a species area curve for each site to determine the likelihood of additional rare species. Conduct quantitative sampling for *Q. fragosa* at sites with high species richness. Duplicate sampling methods with those currently used in the St. Croix for comparison with known populations.*

Taxonomic status

Is *Q. fragosa* a distinct species, within the *Quadrula* complex, or a subspecies?

Known:

a) Conchologically it is most similar to *Q. quadrula*.
b) Population dynamics of *Q. quadrula* are different from that of *Q. fragosa*.

Need:

a) Molecular/DNA comparison of *Q. fragosa* (adults and glochidia) with other *Quadrulas*.
b) Soft tissue comparison of *Q. fragosa* with other *Quadrulas*.
c) Comparison of glochidia of *Q. fragosa* with other *Quadrula* spp.

Actions:

- Collect tissue, using non-lethal techniques (techniques currently being developed by Berg or Naimo) from extant populations of *Q. fragosa* and from other *Quadrula* species (with highest priority on those in the *Q. quadrula* complex). Compare genetic structure of species using standard molecular genetic techniques (such as those of Mulvey et al. 1997).*
- Refine molecular genetic techniques for identification of *Quadrula* spp.
- Collect and preserve soft tissue of *Q. fragosa* and other *Quadrula* species, when available. Catalogue specimens at an appropriate museum and/or genetic bank (e.g., Leestown, WV) Compare soft tissue of individuals to determine anatomical differences among species.
- Collect glochidia of *Q. fragosa*. Characterize morphology of glochidia using standard characteristics and optical imaging analysis and compare with other *Quadrula* spp.

Demographic parameters

These are considered critical to the understanding of the species biology, and are covered in detail in the modeling work group report.

Genetic Diversity

How much variability is present in a population?

Known:

Genetic variability of some unionids has been or is being investigated (Mulvey et. al. 1997; Megalonais, Amblema), (Howell; *Quadrula*), Berg: *Q. quadrula*, *A. p. plicata, Edilatata*), (Leetown Science Center), (Hoeh; Anodonta), (Davis and Fuller 1981; Davis et al. 1981, Kat 1983).

Need:
a) How much variability is present within the St. Croix population?
b) How much variability is present within each fragment of the population?
c) How much variability is necessary to sustain a population, and prevent collapse from bottlenecking/inbreeding?
d) How much variability is present among age classes?
e) How should populations be managed to maintain genetic diversity of *Q. fragosa* in existing habitats and in newly established habitats?
f) Determine mechanisms and distance of dispersal of different life stages.

Actions:
- Develop molecular reference standard for identification of *Q. fragosa* glochidia. Collect fish in areas of existing *Q. fragosa* habitat. Examine fish for glochidial infection. Identify glochidia by use of molecular genetics methodology to identify glochidia.*
- Determine genetic variability among extant populations of *Q. fragosa*.
- Determine population levels needed to establish or maintain a diverse population.
- Develop DNA fingerprinting techniques (apparently available for fish) for glochidia within populations.

<u>Sex ratio</u>

Known:
a) Anecdotal evidence suggests that ratio is 1:1 in stable adult lampsiline mussel populations.
b) Observations of independent researchers suggest that the sex ratio is skewed towards males in declining populations of unionids.

Need:
a) How is sex determined?
b) Is the sex ratio 1:1 at birth?
c) What is the sex ratio of adult *Q. fragosa* in a stable population? Growing population? Declining population?
d) What is the incidence of hermaphroditism in *Q. fragosa*?

Actions:
- Since *Q. fragosa* is not sexually dimorphic, develop a non-lethal technique (such as fiber optics) for determining sex of adult mussels. Use methodology to determine sex and incidence of hermaphroditism of *Q. fragosa* adults in extant populations. (Use methodology to determine sex ratio of *Q. fragosa* adults in extant populations. Model effects of varying sex ratio).

DISTRIBUTION OF EXTANT POPULATIONS

<u>Taxonomic status</u>

Known:
D. H. Stansbery (Ohio State University) verified identification of Ouachita River, Arkansas, freshly dead shells (alive at the time of collection, Harris, pers. comm.,) as *Q. fragosa*.

Need:
a) Are the St. Croix and Ouachita populations the same species? Subspecies? Unrelated?
b) Are the Kiamichi River, Oklahoma and St. Croix populations the same species? Subspecies? Unrelated?

Actions:
- Confirm the identification of all extant populations.
- Use standard genetic techniques (Mulvey et al., 1997) to compare existing populations of *Q. fragosa* in Oklahoma, Arkansas, Minnesota/Wisconsin. Determine the taxonomic relationship of each population.

HABITAT

Abiotic and biotic environmental requirements of *Q. fragosa* were considered.

<u>**Abiotic**</u>
Known:
We suspect that the following factors are important:
a) substrate type and stability.
b) flow velocity and fluctuation.
c) water chemistry (hardness, alkalinity, pH, D.O.) and water temperature.
d) contaminants (toxins, metals, pesticides, nutrients).

Need:
a) What are the driving factors that determine *Q. fragosa* distribution?
b) Determine baseline water chemistry tolerance of various life stages.
c) What is the response of *Q. fragosa* to water fluctuations (dam pulsing, floods)? How is it related to time frame of occurrence (daily vs. annual).
d) Determine effects of siltation on various life stages.

Actions:
- Compile and analyze all available information on water quality, chemistry and water flow (USGS-WRD, NAWQA data; Minnesota Pollution Control Agency) for streams with existing *Q. fragosa* populations. Determine if the data are adequate for characterizing water quality and flow characteristics at those sites. Historical events of fluctuations may partially explain current distribution and community characteristics, given the long generation time of unionids. If data are inadequate, develop a monitoring program to address deficiencies in the data.*
- Compile a list of significant contaminant events that occurred in the past 100 years in stream sites with extant and historical populations of *Q. fragosa*. If significant contaminant events are identified, initiate tests of contaminant toxicity.
- Model or simulate, in a working lab model, various hydrological scenarios to test lethal and sub-lethal effects on *Q. fragosa* and its hosts or a suitable surrogate species. The surrogate should be as close to *Q. fragosa* as possible with respect to physical and behavioral characteristics (i.e. another *Quadrula* species or Ambleminae species.)
- Conduct toxicity tests with different life stages of *Q. fragosa* in effluents of immediate water quality threats as identified by the Threats/Habitat/Management group. Recommend water quality standards for the St. Croix River to protect *Q. fragosa*, based on these results.

Biotic

Known:

a) *Q. fragosa* is found in species-rich communities (about 30) in the St. Croix river.
b) Small mammals and some mollusk-eating fish (e.g., river redhorse, freshwater drum, sturgeon, channel catfish) prey on mussels.
c) Mussel parasites include mites and trematodes.

Need:

a) Determine effects of different predation pressures and parasite loads on the population.
b) Determine if *Q. fragosa* is dependent on other species, or if their occurrence in species-rich communities is a function of habitat.
c) Are there other organisms (e.g., macroinvertebrates, microflora, protozoan) in the environment that are associated with *Q. fragosa* and necessary for its survival?

Actions:

- Survey muskrat middens in areas with existing *Q. fragosa* populations to determine the number and percent composition of *Q. fragosa* to the midden.
- Collect representative mussel species from existing *Q. fragosa* habitats and survey to determine parasite fauna and load. This action could be done in conjunction with long-term monitoring at existing *Q. fragosa* sites.

Potential sites for Reintroduction

Known:

a) We potentially know locations of historical *Q. fragosa* populations.
b) Relocation methods/guidelines have been developed and successfully used to relocate other endangered unionid species (Dunn, 1994; Dunn and Sietman, 1997; Havlik, 1997)
c) Other endangered (*L. higginsi*) and common species (including *Quadrula pustulosa*) have been successfully relocated in the St. Croix River (ESI 1996, 1997, 1998; Waller et al. [on going]; Hove and Hornbach [on going])

Need:

a) Habitat evaluation of historical sites.
b) Determine all of the above habitat and life history requirements.

Actions:

- Determine the success rate of attempts to re-establish unionids in historical habitats (see Neves). Based on the results and recommendations of Neves, use similar methods to relocate *Q. fragosa* into suitable habitat within the historical range.
- Conduct comprehensive surveys of St. Croix River above Taylor Falls to determine sites that may be suitable for *Q. fragosa*.*
- Investigate feasibility of creating habitat for *Q. fragosa*.

SPECIES BIOLOGY WORKING GROUP RECOMMENDATIONS

The working group participants considered all the action statements made in their report and ranked them in order of importance. The criteria used to rank actions were: essential to the immediate and continued survival of the species and feasibility of the action. In general, this group felt that basic life history and habitat questions needed to be answered before distribution or taxonomic questions (although we believe these matters are important and should not be ignored.) These priority recommendations are marked with an * within the text above.

1. Determine quantitative and qualitative sample sizes needed to estimate changes in population density and species richness at various precision levels (5 to 25% with 95% confidence). From this analysis modify the existing (Hornbach, Heath) long term monitoring strategy such that monitoring results can be used to trigger management action. To monitor change, community characteristics (density, richness, dominant species, age structure) will be used as a surrogate for *Q. fragosa*.

2. Identify fish host and determine if the availability of fish host or its habitat is limiting, and if increasing fish abundance is prudent, manage for host fish enhancement.

2. Examine *Q. fragosa* adults every two weeks to find gravid females and determine the timing and duration of the brooding period.

4. Since fertilization of *Q. fragosa* may be dependent on the proximity of males and females and few gravid *Q. fragosa* have been located, determine the density and spatial relationship of *Q. fragosa* to one another in existing populations.

5. Develop molecular reference standard for identification of *Q. fragosa* glochidia. Collect fish in areas of existing *Q. fragosa* habitat. Examine fish for glochidial infection and identify glochidia by use of molecular genetics methodology.

6. Contact local unionid experts and review survey reports from each state with historical records of *Q. fragosa*, to determine sites that currently support unionid mussels and might support *Q. fragosa*. Conduct qualitative sampling at sites with species-rich unionid communities with an emphasis on sites in the St. Croix river.

7. Since *Q. fragosa* is not sexually dimorphic, develop a non-lethal technique (such as fiber optics) for determining sex of adult mussels. Use methodology to determine sex of *Q. fragosa* adults in extant populations.

8. Compile and analyze all available information on water quality, chemistry and water flow (USGS-WRD, NAWQA data; MPCA; other sources?) for streams with existing *Q. fragosa* populations. Unionid distribution is affected by water quality and flow. Historical events of fluctuations may partially explain current distribution and community characteristics, given the long generation time of unionids.

9. Collect tissue, using non-lethal techniques (see Berg or Naimo) from extant populations of *Q. fragosa* and from other *Quadrula* species. Compare genetic structure of species using standard molecular genetic techniques to verify species status.

10. Model or simulate, in a working lab model, various hydrological scenarios to test lethal and sub-lethal effects on *Q. fragosa* and its hosts /or a suitable surrogate species. The surrogate should be as close to *Q. fragosa* as possible with respect to physical and behavioral characteristics (i.e. another *Quadrula* species or *Ambleminae* species.)

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POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL (*Quadrula fragosa*)

January 1998

Final Report
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SECTION 3

THREATS, HABITAT, AND MANAGEMENT WORKING GROUP REPORT

THREATS, HABITAT, AND MANAGEMENT WORKING GROUP REPORT

Introduction

The Threats, Habitat, and Management Working Group recognized the peril posed by the fact that one of only two known occurrences of the winged mapleleaf mussel is in a segment of the lower St. Croix River (An extant population has been identified in the Ouachita River, Arkansas (Posey et al., 1996; at the same time, the group acknowledged that mussels found in Alabama, Oklahoma, and Tennessee may be *Q. fragosa*). This limited sites threat was also recognized by the Winged Mapleleaf Mussel Recovery Team and was presented by that team as the reason for major Task 4, page 28 of the Winged Mapleleaf Mussel Recovery Plan (U.S. Fish and Wildlife Service 1997):

> Small, localized populations are very susceptible to environmental stochasticity (Gilpin and Soule' 1986). The long-term viability of *Q. fragosa* depends on establishing more than one discrete population. There are not data which suggest a particular number of populations confers long-term protection from negative, stochastic environmental and genetic events. Theoretical considerations (Simberloff 1988), however, suggest a metapopulation comprised of several sub-populations confers more long-term stability on a species than fully isolated populations.

It was with the high importance of establishing separate populations in mind that the Threats, Habitat, and Management Working Group analyzed the threats identified by the entire group of PHVA participants as they applied to the St. Croix winged mapleleaf mussel.

THREAT IDENTIFICATION AND SELECTION

Of the sixty issues or topics pertinent to winged mapleleaf mussels identified by PHVA participants in plenary session, the Threats, Habitat, and Management Working Group identified 16 as issues for this Working Group to address:

A paired ranking analysis was performed to determine the most significant threats. Working group members individually considered the threat pairs; each threat was compared against the other and the ones judged to pose the greater threat to the long-term (100-year) viability of the St. Croix population received higher scores. Individual results were discussed where scoring differences were great and the average score then computed.

Using the results of this paired ranking analysis, the Threats, Habitat, and Management Working Group identified the following six threats as having the most significant impact on the long-term viability of the St. Croix winged mapleleaf mussel population: 1) zebra mussels, 2) instream flows, 3) point source pollution, 4) non-point source pollution, 5) direct human disturbance, and 6) corridor construction.

Each of these six threats was considered in depth by the working group. Definitions of the threats, actions needed to address them, and recommendations for achieving the actions are presented below.

To determine their impact on the probability of extinction of the winged mapleleaf mussel, each of these threats was assigned a percent occurrence probability and percent impact on female reproduction and adult mortality. These values were then incorporated into the Vortex model. Results of the modeling of various threat scenarios can be found in Section 4 of this report.

Zebra Mussels (ZM)

ZM could possibly cause direct mortality to the entire St. Croix winged mapleleaf mussel population by reducing their ability to reproduce, move, feed, open, close, and burrow. Additional indirect impacts on winged mapleleaf mussel health, reproduction, survivorship, and mortality include competition for food, ingestion of winged mapleleaf mussel gametes or glochidia, interfering with release of gametes and glochidia, covering of winged mapleleaf mussels under heaps of dead zebra mussels, oxygen depletion, and competition for habitat. Impacts of ZM on the winged mapleleaf mussel host fish, including spawning habitat, food availability, or any other impact on host fish life history are possible but at this time unknown.

Introduction of ZM can be via boats and boating and fishing equipment, diving equipment, deliberate human malice, and use of contaminated construction equipment. The Threats, Habitat, and Management Working Group defined a zebra mussel infestation to have occurred when a self-sustaining population of zebra mussels exists in the St. Croix River winged mapleleaf mussel area.

Generic scenario
Probability: 25%-95% annually;
Severity: Female Reproduction - 10% reduction at 5 years, 20-50% reduction at 10 years
Adult mortality - 50-100% at 100 years

Three detailed scenarios were presented to the modeling working group:
1) a high level of infestation occurring at year 5 of a given simulation. The effects last through the duration of the simulation;
2) a moderate level of infestation occurring at year 5 of a given simulation. The effects last through the duration of the simulation; and
3) a "pulsed" infestation occurring at year 5 of a given simulation. At year 15 of the simulation, female breeding success and adult mortality rebound by 50% to their original baseline levels.

Another possible scenario is a low density, but self-sustaining, population of ZM having no detectable negative impacts on winged mapleleaf mussels.

Needed Action: Prevent movement of zebra mussel into St. Croix River.

Recommendation: Continue or expand existing aggressive zebra mussel encroachment prevention and education programs of Task Force.

Needed Action: Develop management strategy to prevent winged mapleleaf mussel extinction in face of zebra mussel invasion.

Recommendations:
1. Immediately develop an Action Plan to respond to zebra mussel invasion.
2. Encourage Fish and Wildlife Service to continue to find jeopardy for the winged mapleleaf mussel under Section 7 consultations for federal activities that will likely result in the infestation by zebra mussels into the St. Croix River.
3. Consider relocation of winged mapleleaf mussels from Interstate Park site in the St. Croix River to other suitable habitats (e.g. upstream of Taylors Falls, another river, etc.).
4. Consider captive propagation.
5. Consider removing zebra mussels from winged mapleleaf mussels. Removal of encrusted zebra mussels has been shown to improve survival and permit reproduction to continue (Nichols et al., 1998). Possibly attach transmitters to winged mapleleaf mussels to facilitate recapture.
6. Determine likelihood of zebra mussel invasion in Franconia and Interstate Park (e.g. describe the size of the zebra mussel introduction needed for establishment of a viable zebra mussel population capable of exponential population growth).
7. Determine the nature of zebra mussel population dynamics likely to occur in the St. Croix River: a) sustained large population, b) sustained, widely fluctuating population, or c) initially large, subsequently small population.
8. Determine zebra mussel ability to consume (remove from water column and digest or incorporate into pseudofeces) winged mapleleaf mussel sperm, glochidia, or juveniles.
9. Determine if zebra mussel colonization of winged mapleleaf mussel hampers their ability to reproduce (i.e. detect pheromones, move to bring sexes together, exchange gametes, etc.).
10. Zebra mussels have been shown to prevent unionid valves from opening and prevent unionid valves from closing due to zebra mussel obstruction. Energy stores in unionids have been shown to be lower in zebra mussel colonized unionids vs. non-colonized unionids (Haag et al., 1993). Determine physiological impact of zebra mussel colonization on winged mapleleaf mussel congener.
11. Corbicula have been observed feeding on juvenile unionids. Determine if zebra mussel pedal feed on juvenile unionids.
12. Determine sensitive physiological requirements (e.g. nutrients, minerals, etc.) of winged mapleleaf mussel and compare with zebra mussel physiological requirements that would suggest competition. Reduced fitness due to short-term exposure to zebra mussels has been shown to be influenced by unionid species and sex (Haag et al., 1993).
13. Determine if zebra mussel colonization results in differential, sex-based winged mapleleaf mussel mortality.
14. Determine extent river flow rates have on colonized unionids ability to filter water for food collection.
15. Determine winged mapleleaf mussel ability to adapt (eg - move through, climb above, etc.) to large accumulations of zebra mussel shells over river bed.

16. Determine if sudden, large zebra mussel die-off will occur as observed in Illinois River (Whitney et al., 1997). Also, determine if winged mapleleaf mussel habitat would go anoxic due to a die-off and if this die-off would affect winged mapleleaf mussels.
17. Determine if juvenile winged mapleleaf mussel and zebra mussels compete for byssal thread attachment sites, if so, describe impact on juvenile mortality.
18. Determine if other winged mapleleaf mussel life stages and zebra mussels compete for habitat.
19. Identify impact of zebra mussels on distribution, life history (e.g. - spawning substrate, habitat, food availability, pathogen density, etc.), and behavior of host fish(s).

Note: Use other *Quadrula sp.* for research when possible.

Needed Action: Determine a threshold of zebra mussel infestation that triggers implementation of the management strategy.

Recommendations:
1. Describe the size of the zebra mussel introduction needed for establishment of a viable zebra mussel population capable of exponential population growth.
2. Until a threshold level is more accurately determined, this group recommends threshold be defined as the presence of an adult population that is reproducing upstream of Franconia.

Instream Flows

Inadequate minimum flow, in association with operation of the dam, can reduce habitat and habitat, and can cause lethal exposure to air. This is particularly threatening during freezing conditions in the winter low flow period (current minimum winter flow is 800 cfs, provided voluntarily for winged mapleleaf by Northern States Power Co. (NSP); minimum summer flow is 1,600 cubic feet per second (cfs), Federal requirement).

1,600 cfs increases available mussel winter habitat 46% over that available at 800 cfs at Interstate Park, 22% increase in available habitat at Franconia, MN. Dam failure or dam removal would present a serious sediment management problem that must be resolved to protect winged mapleleaf. Catastrophic, near-instantaneous dam failure is a possibility, but considered unlikely.

Probability of dam failure: 0.2% annually;
Severity: Female Reproduction - Interstate Park 75% reduction; Franconia 40% reduction
Adult mortality – Interstate Park 75%; Franconia 40%

Probability of inadequate minimum stream flows: 100%

Needed Action: Provide adequate minimum stream flows from the NSP dam during the winter peaking operation period (November through March) to protect mussel habitat.

c) Recommendation: Increase the minimum flow from the dam during winter peaking operations from 800 cfs to 1,600 cfs; design and fund a study to monitor the response of the mussel community to 1,600 cfs in terms of changes in mussel densities and species richness; based on the response of the mussel community to 1,600 cfs, evaluate the need to further increase the minimum flow above 1,600 cfs.

Point and Non-Point Source Pollution

Accidental spills, non-compliance or unintended discharges upstream of Interstate Park could kill most mussels within the known range of *Q. fragosa*. These events anywhere upstream in the watershed are a threat, but presumably worse the closer their occurrence to the winged mapleleaf population.

Examples could be sediment from a dam burst (an extremely low probability event), petroleum pipeline failure, fuel storage tank failure 1.0% annually, fuel handling spill 1.0% annually probability -- magnitude undetermined at this point in the exercise, sewage plant spill (especially at St. Croix Falls, WI, because of industry) probability = 20% annually. Magnitude -- reproductive depression 20%-40% in the year of occurrence; mortality at 0-1 year = 50%, adult mortality = 5-10%. Truck accident at bridge crossings, especially at Taylors Falls/St. Croix Falls, probability = 2% annually. Paddleboat fuel tank rupture probability = 0.5% annually. These factors and their associated probabilities were combined to produce composite figures representing the threat of point and non-point source pollution. The figures are given below.

Non-point source pollution of the St. Croix can increase to the point intolerable by winged mapleleaf mussels. This pollution could come from agricultural land use, increased urbanization, and land development, including upstream corridor construction, e.g., bridges, pipeline crossings. Inappropriate or excessive use of pesticides and fertilizers, highway and parking lot runoff, and sedimentation. Urban runoff also includes yard clippings of grass and leaves, potential oxygen depleters -- a progressive habitat degradation issue. Likewise manure management. Impervious ground surfaces due to houses, malls, parking lots, etc reduces filtration/percolation (and nutrient removal) of water on way to the river, particularly bad when wetlands are filled or drained. Stream channelization (usually for flood control), degrades natural communities in the streams. This was considered by some to be a high probability event. Inappropriate agricultural and construction practices contribute sediment, i.e., failure to use buffer strips by streams, farming, overgrazing. Public awareness and attitude and handling of materials are factors in non-point source pollution.

Three modeling scenarios:
(1) current conditions -- all contaminant levels below appropriate standards
Probability: 2.0% annually;
Severity: Female Reproduction – 0.05 reduction
Adult mortality – 0.05%

(2) medium pollution loading -- few pollutants exceed standards,
Probability: 2.0% annually;
Severity: Female Reproduction – 2.5% reduction over scenario1
Adult mortality – 1.25% additional over scenario 1

(3) severe pollution loading -- many pollutants exceed standards

Probability: 2.0% annually;
Severity: Female Reproduction - 5% reduction over scenario 1
Adult mortality – 2.5% additional over scenario 1

Needed Action: Establish a policy of no net increase in pollutant loading in the St. Croix watershed. The purpose of this recommendation is not to limit further development in the watershed, but to prevent additional pollution loading through implementation of programs designed to increase water quality monitoring, insure compliance with existing regulations, and adoption of voluntary Best Management Practices (BMPs).

Recommendations:

1. Insure the regulated/licensed facilities are periodically inspected and are in compliance with state and federal rules and regulations.
2. Insure that appropriate penalties are sought for non-compliance.
3. Establish baseline levels of current agricultural, forestry, and urban land use practices in the watershed.
4. Establish or modify water quality standards based on mussel research, where available, for primary contaminants in the St. Croix River.
5. Determine the maximum acceptable contaminant loads for each primary contaminant. Consider synergistic and interaction affects.
6. Adopt BMPs designed to maintain water quality levels at or beneath accepted standards. BMPs are voluntary practices designed to protect water quality.
7. Develop educational tools designed to promote BMPs.
8. Promote the water quality messages.
9. Evaluate the effectiveness and adoption rate of the educational effort, e.g., conduct water quality monitoring surveys.
10. If necessary, adopt mandatory regulations, if effective practices are not being adopted.
11. Advise St. Croix Basin county planning and zoning boards on water quality issues and suggest BMPs for water quality protection.

Direct Human Disturbance

Examples of direct human disturbance include: boating, wading, fishing (removal or displacement of host fish), musseling (including for study), relaxed or altered management plans, or poaching (for fish bait, food, or commercial purposes). Recreational and research activities could adversely impact the population by causing direct mortality of individuals, crushing by boats, canoes or footsteps, causing abortion of glochidia. To address the threats of direct human disturbances on *Quadrula fragosa*, actions are needed to restrict the impact of all users. We recommend that all stakeholders be engaged in a process to develop creative, mutually satisfactory solutions to the problems.

Probability: 100% annually
Severity: Female Reproduction – 0.05% reduction
Adult mortality – 0.05%

Needed Action: Public Education and Regulation Enforcement and Research Coordination are needed to ensure that no live mussels are taken or killed from the St. Croix River, either through the effects of commercial or recreational boating, the actual removal of mussels for food or bait, or by the commercial mussel industry for export to the Far East.

Recommendations:

A. Public Education

1. Create and install multi-lingual signage (southeast Asian, Hispanic, English) at various locations in the Interstate Parks, particularly near the St. Croix River to stress the importance of this unique area, and to reinforce the regulations that no mussels can be taken from the St. Croix whether dead or alive.

2. Consult with the MN DNR liaison who works with, and educates, the Southeast Asian community so that they understand that the St. Croix is a unique area of biological diversity, and there are grave consequences to disturbing this valuable natural resource.

3. Educate canoeists with signs and brochures explaining that the St Croix is a protected river, and ask for their cooperation. Mark several canoe channels in the vicinity of the parks, so that canoeists avoid wading and dragging their boats over sensitive or shallow areas. Mussels can be dislodged, and or crushed by human impacts. In addition to the channel west of Folsom Island, there is a small channel near the shoreline of the Wisconsin Park. The area downstream of Blast Island is generally deeper than the areas near the parks, so canoe channels should not be needed in that area.

4. The MN DNR should encourage the paddleboat concession to conduct customer education (paddleboat owners also run the MN canoe concessions). The WI DNR should work with the two canoe outfitters operating out of the WI Interstate Park.

B. Regulations

1. Work with stakeholders (National Park Service, Minnesota and Wisconsin State Parks, Minnesota and Wisconsin DNR's, boaters, environmentalist groups, local non-government organizations, local governments, local concessionaires, USFWS), to develop creative plans that minimize human activities that would disturb winged mapleleaf mussel.

2. Initiate discussions with the canoe concessionaires to enlist their cooperation in educating the public about sensitive mussel habitat and areas to be avoided. If these efforts to minimize impacts to the habitat are unsuccessful, consider restricting the number of canoeists and boaters leaving from the parks each day (over 400/day on weekends). It may be necessary to issue permits for only a certain number of canoeists per day, but this would require special regulations. There should be an active inspection program for zebra mussels, on all boats launching from all ramps from the Lion's Park upstream of the NSP Dam, continuing downstream to the Boom Site.

3. Improve and enforce regulations making harvesting of mussels illegal in St. Croix waters, whether for fish bait, a food source, and or for the oriental cultured pearl industry. In addition, no mussels from any source may be used for fish bait.

4. Request stakeholders discuss the possibility of moving canoe/boat launches at both state parks to sites as far downstream in the parks as possible.

5. If a fish or fishes are identified as hosts for winged mapleleaf mussels, stakeholders should develop strategies to minimize the impact of angling on the host(s).

6. Encourage the National Park Service and state departments of natural resources to make sure that the new Management Plans currently under development for the St. Croix Riverway Corridor do not have relaxed or altered recommendations compared to current conditions and that these plans are fully implemented.

<u>C. Research Coordination</u>

1. Coordinate all research efforts on the lower St. Croix River, including mussel research, fishing surveys, vertebrate and invertebrate sampling.

Corridor Construction

The acute (construction phase), long-term conversion and degradation (as from highway runoff), and piecemeal loss of winged mapleleaf mussel habitat and habitat quality due to construction of corridors (e.g., pipelines, powerlines, highway crossings) could fragment and reduce the St. Croix winged mapleleaf mussel population. Example of impending corridor construction are the proposed Viking-Voyageur gas pipeline near Franconia, MN, a proposed 230 kv powerline crossing near St. Croix Falls, and the reconstruction of the U.S. Highway 8 bridge. These three events are believed certain to occur within 100 years (resulting in a 3% annual probability). Impact on female reproduction and adult mortality was judged to be of a 1-time/1-season nature, e.g., construction impacts (turbidity, etc), relocation mortality (ca. 1-2% of the moved individuals could be lost), a lost season of reproduction for the involved individual mussels. The Threats, Habitat, and Management Working Group recognized that in some cases (e.g., substrate occupied by bridge footings or pipeline), habitat loss will be permanent, but probably of small area and of small consequence to the population. The known projects planned for the area will not cross known winged mapleleaf mussel high density areas.

Probability: 3% annually
Severity: Female Reproduction – minimal reduction
Adult mortality – minimal

Needed Actions: Continue careful river crossing site selection and use of appropriate mussel protecting construction techniques, including winged mapleleaf relocation and zebra mussel exclusion, as needed.

Recommendations:

1. Involve appropriate state and Federal agencies early in project planning prior to commencement of the environmental impact statement (EIS) process; inventory candidate corridors for winged mapleleaf mussels, evaluate the feasibility of mussel relocation, relocate all project impact area mussels if state or Federal threatened or endangered species are present and, take all necessary measures (e.g., describe and evaluate standard erosion control and construction practices, evaluate effectiveness of enforcement efforts) during construction to maintain water quality and exclusion of zebra mussels.

2. Project impact reduction should include consideration of improving the status of the species via "off site" research and management. Off site research and management could be developed in coordination with experts in the winged mapleleaf mussel and related areas; determine the amount of fragmentation related to corridor impacts that would cause the winged mapleleaf population to collapse.

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POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL (*Quadrula fragosa*)

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SECTION 4

SIMULATION MODELING WORKING GROUP REPORT

POPULATION BIOLOGY AND SIMULATION MODELING WORKING GROUP

Introduction

The need for and consequences of alternative management strategies can be modeled to suggest which practices may be the most effective in conserving the winged mapleleaf mussel in its native habitat. VORTEX, a simulation software package written for population viability analysis, was used as a tool to study the interaction of a number of life history and population parameters treated stochastically, to explore which demographic parameters may be the most sensitive to alternative management practices, and to test the effects of a suite of possible management scenarios.

The VORTEX package is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events on wild populations. VORTEX models population dynamics as discrete sequential events (e.g., births, deaths, sex ratios among offspring, catastrophes, etc.) that occur according to defined probabilities. The probabilities of events are modeled as constants or random variables that follow specified distributions. The package simulates a population by stepping through the series of events that describe the typical life cycles of sexually reproducing, diploid organisms.

VORTEX is not intended to give absolute answers, since it is projecting stochastically the interactions of the many parameters used as input to the model and because of the random processes involved in nature. Interpretation of the output depends upon our knowledge of the biology of the winged mapleleaf mussel, the environmental conditions affecting the species, and possible future changes in these conditions.

Input Parameters for Simulations

Population Definition: We decided that for the purposes of the VORTEX model, individuals of *Q. fragosa* should be considered to comprise two populations for the purposes of modeling so that we can set differential environmental effects. These two populations are located at Franconia and one at Interstate State Park. This allows us to accommodate the differences in habitat quality and environmental variables that affect these two locations. Although these populations and the beds within them may possess some degree of demographic isolation, the model has been constructed to create sufficient gene flow between these populations to function as a single genetic and demographic population. We concluded that gene flow among these beds and populations resulting from the movement of fish hosts and suspended glochidia is sufficient to create a panmictic (randomly mating) population of *Q. fragosa*.

Mating System: We assume that *Q. fragosa* is a polygynous species, and that males can reproduce without limit for the purposes of the model. This may not be true in nature, but we have no data to support this decision. (Neves (1997) suggests that Unionids may resort to hermaphroditism at low densities).

Age of First Reproduction: VORTEX precisely defines breeding as the time at which offspring are born, not simply the age of sexual maturity. In addition, the program uses the mean age rather than the earliest recorded age of offspring production.

We assume that the age at first reproduction is the same for males and females, namely 7 years based on studies of *Quadrula quadrula* by Whitney et al. (1997). For the purposes of sensitivity analysis of this uncertain parameter, additional models were developed in which this age was alternatively set at 5 years and 9 years (for both sexes).

Age of Reproductive Senescence: VORTEX assumes that animals can breed at a constant rate throughout their adult life.

The oldest *Q. fragosa* found is thought to be about 22 years old. However, it was thought that perhaps this species can live longer. Because of uncertainty in this parameter, additional models were developed in which the maximum age was set at 25 and 28 years.

Male Breeding Pool: We assumed that all males are available for breeding.

Sex Ratio at Birth: We are assuming that the population possesses a 50:50 sex ratio. We know of no data to contest this assumption.

Offspring Production: We assume that the percent of females that breed in any one year is 20%, with a standard deviation of 10, based on a educated estimate from Hove (he found about 40% of *Actinonaias ligamentina* females were gravid in a very good habitat under favorable conditions - we decided to use half this as our estimate of 20% for *Q. fragosa*.). Uncertainty in this parameter was assessed by developing alternative models in which the percent of successful female breeders was set at 25%.

Annual variation in female reproduction is modeled in VORTEX by entering a standard deviation (SD) for the proportion of females that do not reproduce in a given year (i.e., SD (Probability of brood = 20%). VORTEX then determines the proportion of females breeding each year of the simulation by sampling from a binomial distribution with a specified mean (e.g., 20%) and standard deviation (e.g., 10%).

We calculated a mean brood size of 10, with a standard deviation of 10 as follows. We used the Whitney et al. (1997) *Stella* model estimate of 171,000 glochidia produced per breeding female (independent of age), the Watters (1997) estimate of 0.2% of glochidia that successfully find and encyst onto a host, the guess from Whitney et al. (1997) that 15% of successfully encysted glochidia metamorphose and excyst, and the guess from Whitney et al. (1997) that 20% of these excysted juveniles succeed in finding and settling on suitable substrate. In other words,

Brood size = [171,000 glochidia/female]×[0.2% encyst] × [15% metamorphose / excyst]
× [20% find substrate]
= 10

Because of considerable uncertainty in this parameter, especially given the multiple processes necessary in producing juveniles, we incorporated this parameter in our sensitivity analysis by developing alternative models in which the number of juveniles produced is 7 or 13.

Density-Dependent Reproduction: Density dependence in reproduction (proportion of females breeding in a given year) is modeled in VORTEX according to the following equation:

$$P(N) = \left(P(0) - \left[(P(0) - (P(K))(\frac{N}{K})^{B} \right] \right) \frac{N}{N+A}$$

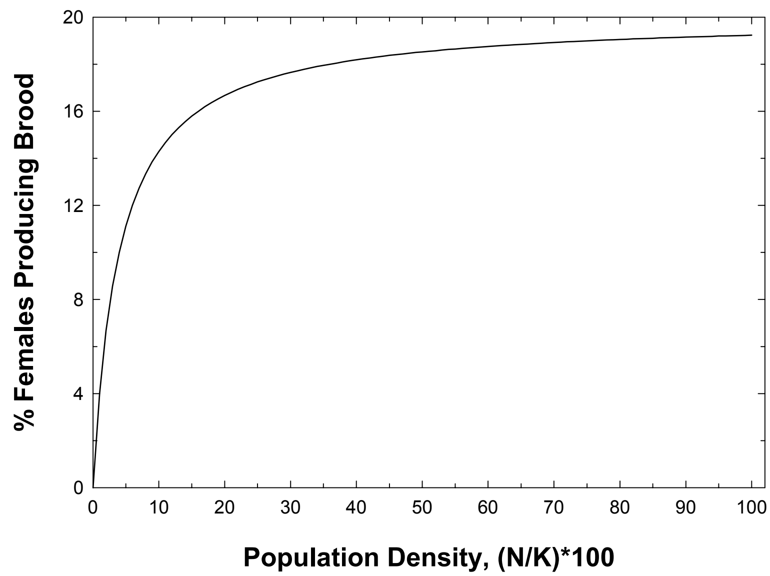
in which *P*(*N*) is the percent of females that breed when the population size is *N*, *P*(*K*) is the percent that breed when the population is at carrying capacity (*K*, to be entered later), and *P*(0) is the percent of females breeding when the population is close to 0 (in the absence of any Allee effect, i.e., a decrease in reproduction at low population densities). *B* can be any positive number. The exponent *B* determines the shape of the curve relating percent breeding to population size, as population size gets large. If *B* is 1, the percent breeding changes linearly with population size. If *B* is 2, *P*(*N*) is a quadratic function of *N*. The term *A* in the density-dependence equation defines the Allee effect. One can think of *A* as the population size at which the percent of females breeding falls to half of its value in the absence of an Allee effect (Akçakaya and Ferson 1990, p. 18).

Although we know from observations that *Quadrula sp.* tend to be clumped in their distribution, we are assuming (for the sake of model simplicity) that an estimated population of approximately 2500 individuals are evenly distributed across the 158,000 sq. m. of estimated habitat at a discharge of 1600 cfs. This produces an estimate of 11 meters between individuals. If this population is reduced to 632 (75% reduction), the distance between individuals increases to 22 meters. We are assuming that the Allee affect becomes a factor at this point. In the VORTEX model for density dependence, this translates into an Allee parameter, A, equal to 4.0. The functional form of this relationship is shown in Figure 1.

(Consider Neves' suggestion that Unionids may resort to hermaphroditism at low densities, potentially reducing any Allee effect)

Mortality Rates: We developed the following mortality schedule for *Q. fragosa* (Table 1). Based on mark-recapture data from relocation efforts, we assumed that adult mortality was quite low and that reproductive stress would result in higher mortality rates among females. Thus mortality rates of 2% and 1% were used for all adult females and males, respectively. We back-calculated mortality for 0-1 juveniles assuming that the population was stable (in other words, growth rate roughly equal to zero) and thus females would need to produce 2 individuals that would survive to age 7 to ensure population stability. Assuming that 20% of the females reproduce each year (see above) this would imply that, since a typical female would reproduce 5 times during her lifetime, about 0.4 offspring per successful breeding event would have to survive to age 7 to ensure population stability. We assumed that the majority of the mortality would occur in the first year of life (0-1), so we therefore assumed a mortality of 90% for this age class. To ramp the survivorship down to approximately 0.4 offspring from the original 10 produced, we used the

Figure 1. Density-dependence function for female reproductive success (proportion of adult females producing a brood) in simulated winged mapleleaf mussel populations.



figures in the table below. The result from this was that from 10 settling juveniles, about 0.6 survive to age 7. This may account for the slight positive growth rate in the baseline simulations.

In order to assess the impact of measurement uncertainty in mortality rates, we developed additional models in which juvenile (0-1 year) mortality was 93% instead of the baseline 90% rate. In addition, models were developed in which adult mortality was doubled for both sexes, i.e., 4% for females and 2% for males.

Table 1. Annual percent mortality rates, expressed as mean (standard deviation), for winged mapleleaf mussel models developed during the workshop.

Age	Female	Male
0-1	90 (3)	90 (3)
1-2	10 (3)	10 (3)
2-3	10 (3)	10 (3)
3-4	5 (2)	5 (2)
4-5	5 (2)	5 (2)
5-6	5 (2)	5 (2)
6-7	5 (2)	5 (2)
>7	2 (0.5)	1 (0.3)

Catastrophes: Catastrophes are singular environmental events that are outside the bounds of normal environmental variation affecting reproduction and/or survival. Natural catastrophes can be tornadoes, floods, droughts, disease, or similar events. These events are modeled in VORTEX by assigning an annual probability of occurrence and a severity factor ranging from 0.0 (maximum or absolute effect) to 1.0 (no effect).

The primary catastrophe developed at the workshop simulated a serious chemical spill upriver, such as an accident involving a vehicle carrying hazardous materials. A detailed analysis of transportation and accident data by Greg Busacker of the Minnesota Department of Transportation indicates that the probability of such an event could be quite small (see appendix at the end of this section). A very conservative estimate of this probability is 0.2%, i.e., it occurs on average once every 500 years. Moreover, in the year that such an accident occurs, the proportion of females breeding is reduced by 30% and survival (spread out across all age classes) is also reduced by 30%.

Anthropogenic Factors: In addition to acute, catastrophic events mediated by human activities, a series of more chronic conditions may impact the winged mapleleaf mussel and its habitat. For instance, generic point and non-point source pollution events will reduce reproduction and survivorship in mussel populations on an annual and non cumulative basis. Because these events were thought to occur essentially continuously, they were not included as a catastrophe but as additional mortality and reduced female breeding success. Specifically, generic point source events were thought to reduce breeding success and increase adult mortality (both sexes) by an additional 0.05%. Generic non-point source events reduced breeding success and increased adult mortality by 0.5% while direct human disturbances such as paddleboats and other watercraft reduced breeding success and increased adult mortality by a further 0.05%. Therefore, after taking all of these factors into account, the proportion of females breeding in a given year was reduced from 20% to 19.4% while adult mortality was increased from 2.0%(females) and 1.0% (males) to 2.6% (females) and 1.6% (males).

An infestation of winged mapleleaf mussel habitat by the zebra mussel was also considered to be an important anthropogenic factor to consider. Three types of infestation scenarios were considered:

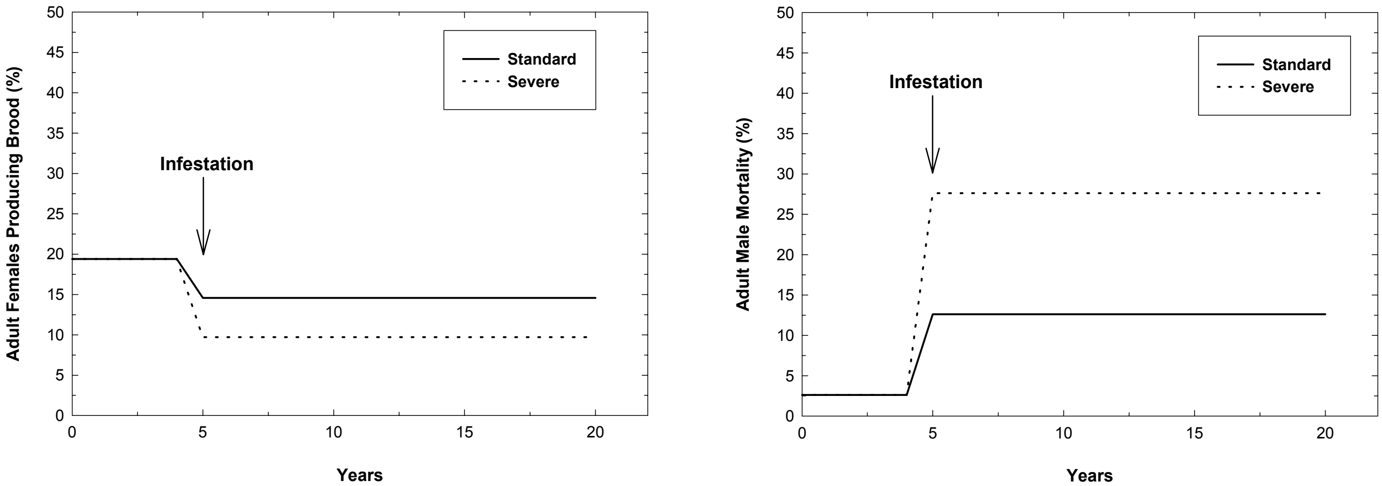
1) High level of infestation occurring at year 5 of a given simulation. Following the infestation, female breeding success is reduced by 25 to 50% of the baseline value and an additional 10 to 25% adult mortality is added to the baseline rate. These effects last through the duration of the simulation.

2) Moderate level of infestation occurring at year 5 of a given simulation. Following the infestation, female breeding success is reduced by 12 to 25% of the baseline value and an additional 5 to 12% adult mortality is added to the baseline rate. These effects last through the duration of the simulation.

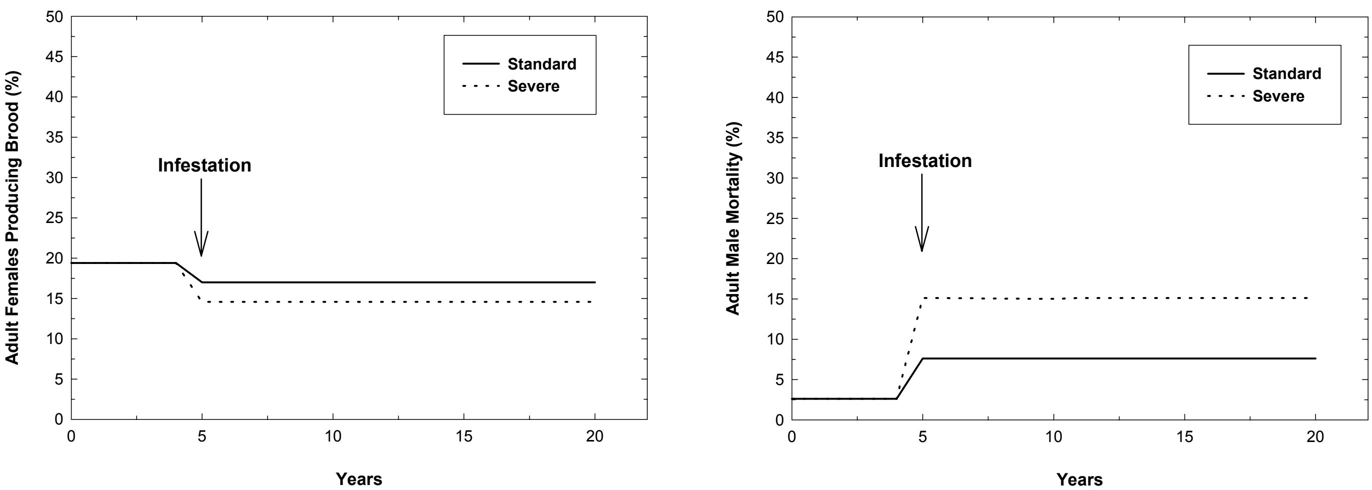
3) A Pulsed infestation occurring at year 5 of a given simulation. Following the infestation, female breeding success is reduced by 25 to 50% of the baseline value and an additional 10-25% adult mortality is added to the baseline rate. However, at year 15 of the simulation, female breeding success and adult mortality rebound by 50% to their original baseline levels.

Figure 2. Simulated effects of (A) high, (B) moderate, and (C) pulsed zebra mussel infestation events on winged mapleleaf mussel demography (% adult females breeding, left pane; adult male mortality, right pane). Solid and

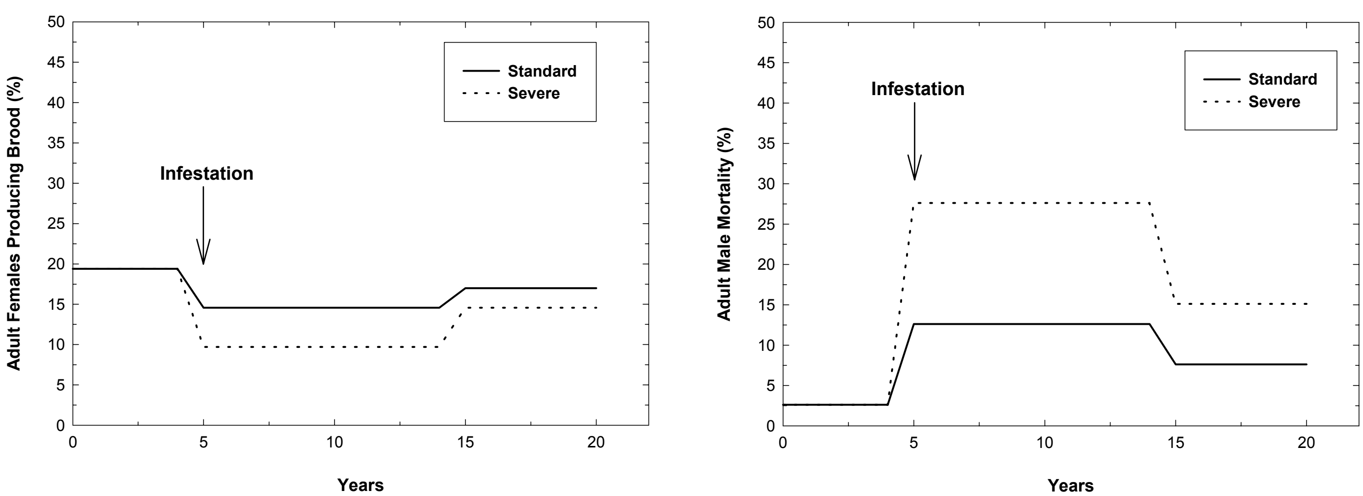
A. High



B. Moderate



C. Pulsed



Initial Population Size: We estimated the current population size several ways:

- First, we used the estimate of Heath and Rasmussen (1990) of 3,000 at Interstate Park.

- Second, we based an estimate on the estimated total area of available habitat at 1600 cfs (see Figure 3), which equals 158,000m^2 for Interstate. We subsequently reduced this areal estimate to adjust for the present minimum instream flow of 800cfs by using the data of Johnson (1995), which estimates that for the Folsom Island sites, the higher flow rate increases habitat area by 46%. Since instream flow data were not available for Blast Island, we estimated that mussel habitat at the higher flow rate is increased by 35% (midway between the 46% increase for Folsom Island and a 22% increase estimated for the Franconia site (Johnson, 1995)). Thus the total habitat area estimate at 800 cfs is 113,000m^2.

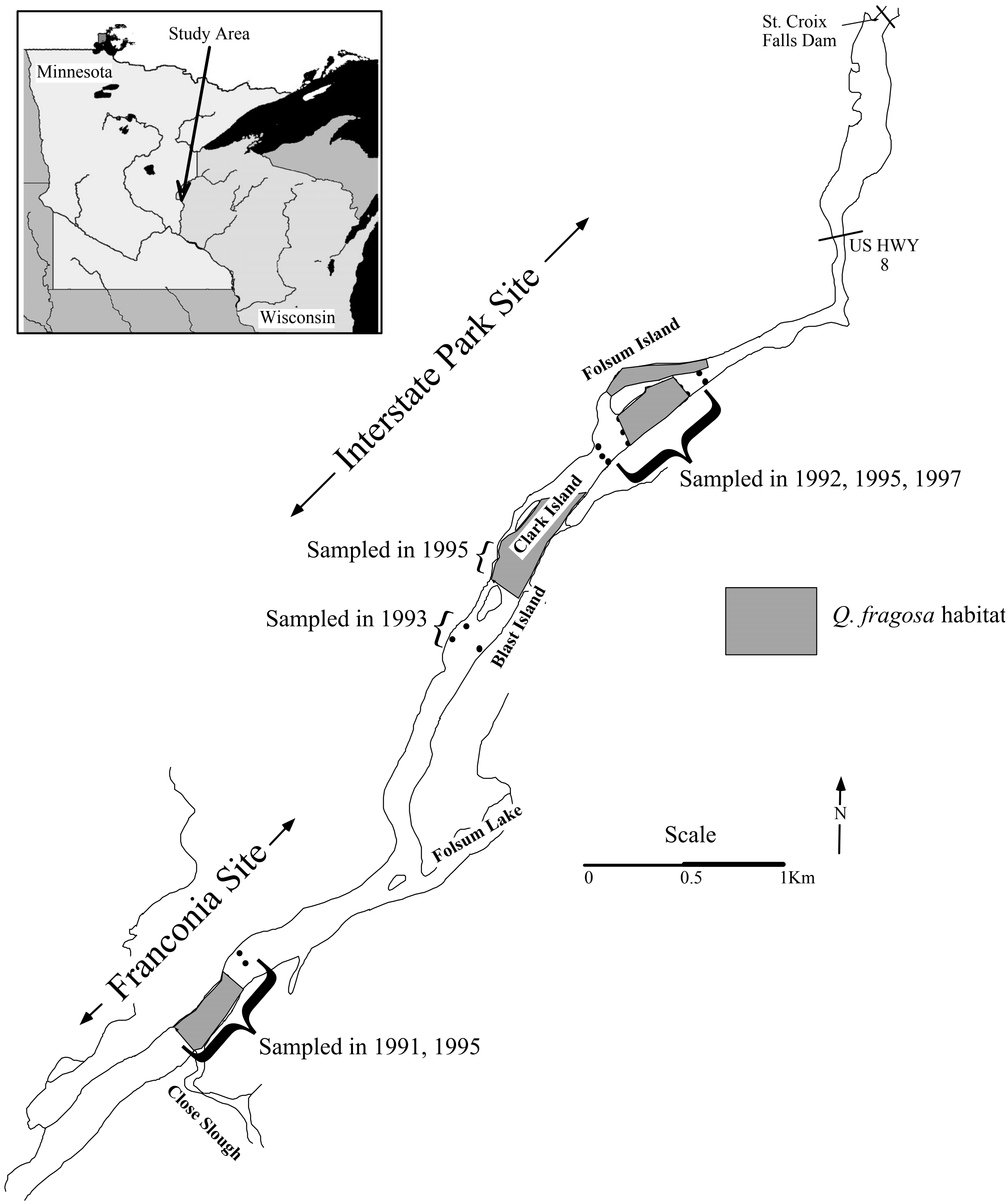
  We took this estimate of total mussel habitat, and multiplied by the observed total mussel density (30.2 mussels of any species per sq. m., based on 270 quarter-m^2 quadrats at Interstate taken by Hornbach). This product was then multiplied by the proportion of *Q. fragosa* in these quantitative samples (=0.05%), yielding an estimate of 1710 *Q. fragosa.* To examine the variability associated with this estimate, we used the standard deviation of the density (=25) and a second estimate of the proportion of *Q. fragosa* in the community (0.1%) based on qualitative transects of Hornbach. This gave us a range of 400-6200 at Interstate.

  A comparable estimate was made for the Franconia population, (Fig. 2 - Area = 40,200m^2. based on an instream flow of 1600 cfs, which can be reduced to an area estimate = 32,970m^2 at 800 cfs by using the data of Johnson 1995 which estimated a 22% increase in habitat area at 1600 cfs, total mussel density = 11.3 mussels per m^2 (sd=11.3) and based on 240 quarter-m^2 quadrats *Q. fragosa* comprised 0.15% of the population, giving an estimate of 559 *Q. fragosa* at this location). To examine the variability associated with this estimate for Franconia, we used the standard deviation of the density (11.3) giving a range of 1-1118.

- A third estimate for the Interstate Park population was derived by back-calculating from a statistical power analysis found in Whitney et al. (1997), for a desired level of accuracy for population size estimation x, where $x = 2SD/M(n)^{1/2}$ where SD = standard deviation of mussel density, M = mean mussel density, and n = number of samples. Based on Hornbach's field data, we were able to calculate the following: M = 0.003, SD = 0.06, and n = 270. From these values, we derived a level of accuracy of 240%, yielding a possible *Q. fragosa* population size as large as 7,200 (=2.4 x 3,000). This would suggest that 0.15% of the total mussel population at Interstate State Park consists of *Q. fragosa*. Such an estimate of *Q. fragosa* occurrence tends to be consistent with our other analyses.

- A similar estimate for the Franconia population based on the power analysis gives M = 0.004, SD = 0.06, and n = 240. From these values, we derived a level of accuracy of 200%, yielding a possible *Q. fragosa* population size as large as 1,362 (=2.0 x 681). This would suggest that 0.3% of the total mussel population at Franconia consists of *Q. fragosa*. Again, this estimate of *Q. fragosa* occurrence tends to be consistent with other analyses.

Figure 3. Winged mapleleaf mussel habitat as discussed in the accompanying text.



In summary, we developed models for the entire Interstate - Franconia population in which the initial population size was estimated to be 2500 individuals, derived primarily from the second estimation method described above. Moreover, the initial age distribution was set according to observations from field estimates.

Population Stability: One of the main assumptions built into our initial VORTEX models is that the *Q. fragosa* population is stable with respect to growth, i.e., the population appears to be neither decreasing nor increasing. This assumption is based on the observation that the population size of the entire mussel community within the range of *Q. fragosa* has remained quantitatively stable during the period of 1992 - 1997. This observation is based upon the data of Hornbach, wherein analysis of variance of quadrat data for 345 quadrats (see data below) indicated that there was no significant difference among years. Based on power analysis of these data, there is a 67% chance that the population is not stable ($F = 1.5$, $p = 0.22$, 2344 df) and we are unable to detect this with an α of 0.05 and 270 samples. Therefore, our hypothesis of population stability (with respect to growth) may be incorrect.

Year	mussels/m^2	SD	n
1992	31.2	28.4	150
1995	28.8	21.6	120
1997	25.2	18.8	75

Carrying Capacity: The carrying capacity, K, for a given habitat patch defines an upper limit for the population size, above which additional mortality is imposed across all age classes in order to return the population to the value set for K. VORTEX has the capability of imposing density-dependent effects on reproduction that change as a function of K.

Population estimates (above) have been based on an instream flow of 800 cfs. Since Johnson 1995 estimated that habitat area at 1600 cfs would increase by 22-46% (see above), we concluded that an appropriate carrying capacity could be based on the increased instream flow, yielding a carrying capacity of 2385 for the Interstate sites (range: 400-8000), and 681 for the Franconia site (range: 1-1360). The aggregate value used in all models was therefore set at 3100.

Iterations and Years of Projection: All scenarios were simulated 500 times, with population projections extending for a 100 years (this is roughly equivalent to about 6 effective mussel generations). Output results were summarized at 10-year intervals for use in some of the tables and figures that follow. All simulations were conducted using VORTEX version 8.02 (December 1997).

Results from Simulation Models

Output Table Information

The tables that follow present the numerical results from the 300 models developed during this workshop. Within each table, description of the variable input centers around changes made to the age of first reproduction (AFR), the maximum age of reproduction (or "age of last reproduction", ALR), the proportion of the adult female population that produces a brood in a given year (%EE), the mean brood size, and annual mortality rates among juveniles ($Mort_J$) and adults ($Mort_A$). The results of the models are described in terms of the following:

r_s(SD) — Mean (standard deviation) stochastic growth rate, calculated directly from the observed annual population sizes across the 500 simulations. Population growth is indicated by $r_s>0$, decline by $r_s<0$, stability by $r_s=0$;

P(E) — The probability of population extinction, determined by the proportion of 500 simulated populations within a given model that become extinct during the model's 100-year time frame.

N_{100} (SD) — Mean (standard deviation) population size across those simulated population which are not extinct at 100 years;

H_{100} — Expected heterozygosity (gene diversity) in the simulated populations after 100 years;

T(E) — The mean time to extinction for those populations becoming extinct during the simulation.

Demographic Sensitivity Analysis

A series of 216 models were developed in which the demographic parameters described above were varied in a broad range of alternative combinations in an attempt to explore the relative sensitivity of winged mapleleaf mussel populations to perturbations in specific life-history variables. Moreover, the simulated populations described here are considered to be relatively free from human-mediated disturbances; these disturbances will be explored more fully in the risk assessment section that follows.

Our "baseline" winged mapleleaf mussel population model--reproductive age from 7 to 25 years, 20% of adult females breeding annually with a mean brood size of 10 juveniles, 90% juvenile mortality, and adult female/male mortality of 2%/1%--yields an expected long-term, deterministic growth rate of r = 0.003. This is in accord with our expectation of $r \approx 0.0$ based on the mortality schedule we developed. We can use this as a type of internal check on the validity of the assumptions we have made in the development of the baseline model.

The summary results of the overall sensitivity analysis are presented graphically in Figure 4. Each bar in the graph represents the mean population growth rate across all models incorporating the specific parameter value. It is important to note that the absolute values of the mean growth rates are not necessarily reflective of actual projected growth rates of winged mapleleaf mussel populations currently on the St. Croix River. Of greater importance and utility is the comparison of growth rates across life-history parameter groups.

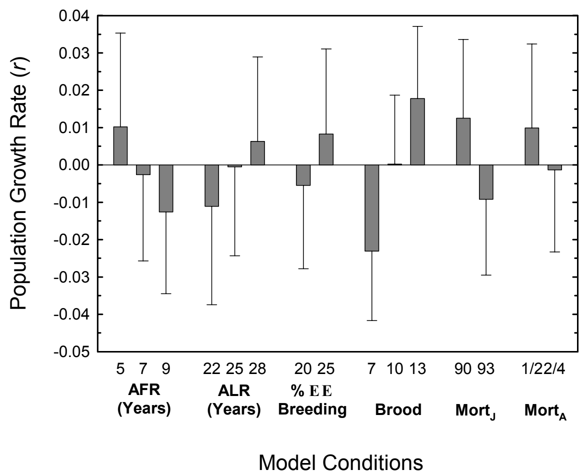


Figure 4. Demographic sensitivity analysis summary for simulated winged mapleleaf mussel (*Quadrula fragosa*) populations. Data expressed in terms of mean growth rate and associated standard deviation across all models incorporating the specified demographic parameter. AFR, age of first reproduction; ALR, age of last reproduction (equivalent here to longevity); %EE breeding, mean percent of adult females producing a brood annually; Brood, mean brood size; Mort$_J$ and Mort$_A$, annual % mortality of juveniles and adults, respectively.

As can be seen in the figure, relatively small perturbations in certain parameters lead to dramatic changes in the mean population growth rate. For example, changing the average annual brood size per female from the baseline value of 10 to 7 juveniles results in a dramatic shift from population stability (mean r = 0.0002) to strong population decline (mean r = -0.023). It is clear that this relatively small decrease in juvenile production has a tremendous impact on the dynamics of our simulated winged mapleleaf mussel population. Similarly, increasing juvenile mortality rate to 93% from the baseline value of 90% results in a shift from population growth (mean r = 0.013) to population decline (r = -0.009). With the life table we have constructed, a change in juvenile mortality from 90% to 93% is equivalent to saying that the annual total juvenile output per successful breeding female is reduced from 1.0 juvenile to 0.7 juvenile. It is interesting to note that changes made to the age of first reproduction have a greater effect on population growth dynamics compared to comparable changes in the maximum age of reproduction. This is to be expected simply by the fact that, due to the impact of continued annual mortality, there are fewer individuals aged 22-25 than those aged 7 years of age. Consequently, the total reproductive output of the older age classes is comparatively less so changes in this parameter mean correspondingly less as well. Changes in the total proportion of adult females breeding and to adult mortality have relatively less impact on population growth dynamics, although the important contributions made by these aspects of mussel life history should not be overlooked.

Based on this sensitivity analysis, we have concluded that female breeding success and juvenile mortality are the primary demographic factors to focus upon in subsequent models designed to combine both the effect of measurement error (i.e., "human ignorance") and an investigation of the effects of anthropogenic factors on winged mapleleaf mussel extinction risk.

Risk from Anthropogenic Factors

The first set of risk models was designed to investigate the impact of chronic point- and nonpoint-source pollution as well as infrequent but potentially severe chemical spills. For the sake of comparison to these and additional models to be discussed later, Table 2 is presented to show the results from initial models where these anthropogenic factors were not included (these models were actually part of the sensitivity analysis set discussed above). As discussed earlier, the growth dynamics of these simulated populations is highly dependent on the life table characteristics. The baseline model (Table 2, File#101) shows the capacity for population growth with no risk of extinction within the 100-year time frame of the simulation and the retention of very high levels of genetic variation (i.e., heterozygosity).

Table 2. Winged mapleleaf mussel risk analysis. Simulated population dynamics in the absence of anthropogenic factors.

File#	Brood	$Mort_J$	r_s (SD)	P(E)	N_{100} (SD)	H_{100}	T(E)
101	10	90	0.010 (0.062)	0.000	2693 (408)		—
119	7		-0.013 (0.057)	0.000	734 (381)		—
137	13		0.027 (0.069)	0.000	2968 (175)		—
155	10	93	-0.010 (0.061)	0.000	945 (516)		—
173	7		-0.033 (0.064)	0.000	113 (77)		—
191	13		0.055 (0.066)	0.000	2372 (620)		—

Table 3 presents the results of those models that included chronic pollution effects (modeled as annual reductions in female fecundity and adult survival) or pollution in conjunction with a chemical spill catastrophe. These results indicate that the inclusion of these anthropogenic factors (as modeled in this workshop) leads to a consistent reduction in population growth rate, although the ultimate impact on the simulated population is not especially great, particularly with respect to the inclusion of the simulated chemical spill. For example, the baseline model with chronic pollution (File #401) leads to a reduction in the stochastic growth rate from 0.010 to 0.004, but this rate is reduced to only 0.003 when the infrequent catastrophic spill is added. The added effect of these factors may be greater when, for example, juvenile mortality is increased; however, the effect of this additional juvenile mortality by itself is far more significant compared to the chronic and catastrophic anthropogenic factors as developed and modeled in this workshop (Figure 5). Of course, our estimates of the characteristics of these pollution events are quite imprecise. Results from models such as these suggest that additional effort directed towards better estimates of the frequency and severity of anthropogenic pollution events may be warranted.

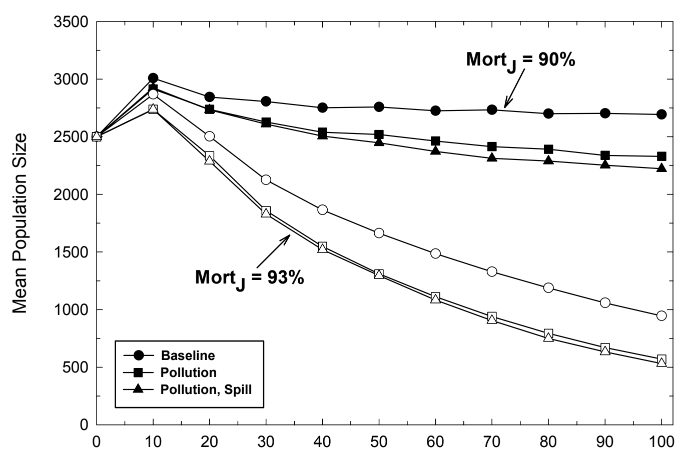


Figure 5. Simulated winged mapleleaf mussel population trajectories under the influence of chronic pollution and catastrophic chemical events. Two sets of trajectories (differentiated by symbol type) are shown for alternative possible estimates of juvenile mortality, $Mort_J$.

Table 3. Winged mapleleaf mussel risk analysis. Simulated impacts of chronic point- and nonpoint-source pollution and highway-borne chemical spills on mussel populations.

File#	Brood	$Mort_J$	r_s (SD)	P(E)	N_{100} (SD)	H_{100}	T(E)
Chemical Spill Catastrophe Absent							
401	10	90	0.004 (0.062)	0.000	2330 (602)	99.7	—
402	7		-0.019 (0.057)	0.000	432 (250)	99.1	—
403	13		0.022 (0.069)	0.000	2933 (208)	99.7	—
404	10	93	-0.016 (0.062)	0.000	570 (352)	99.2	—
405	7		-0.039 (0.067)	0.002	67 (47)	96.2	—
406	13		0.000 (0.066)	0.000	1938 (740)	99.6	—
Chemical Spill Catastrophe Present							
407	10	90	0.003 (0.064)	0.000	2222 (661)	99.6	—
408	7		-0.019 (0.059)	0.000	416 (244)	99.1	—
409	13		0.021 (0.071)	0.000	2921 (228)	99.7	—
410	10	93	-0.017 (0.065)	0.000	531 (362)	99.1	—
411	7		-0.040 (0.070)	0.008	64 (51)	95.8	—
412	13		-0.001 (0.068)	0.000	1831 (719)	99.6	—

Our final component of winged mapleleaf mussel risk assessment centered around the impact of an infestation of winged mapleleaf habitat by zebra mussels. As described above, six types of infestation were simulated: high, moderate, and pulsed infestation, each with either standard or severe effects on female fecundity and adult survival. Results of models with a high level of infestation are shown in Table 4 and Figure 6. Even under standard conditions, simulated winged mapleleaf populations are in rapid decline and show a high risk of extinction within about 70-90 years. If the effects of the infestation are severe, the decline is even more rapid and extinction is certain within 50 years of the onset of the infestation (Table 5, Figure 6).

Moderate levels of zebra mussel infestation lead to relatively low risk of extinction within the 100-year time frame of the simulation (Table 6). However, this statistic does not fully describe the characteristics of affected populations as the rate of population decline is rapid and extinction soon after 100 years appears highly likely (Figure 7). This large reduction in population size also leads to a serious erosion of genetic variability, perhaps leading to an impaired ability among winged mapleleaf populations to respond to changing long-term environmental conditions. The population trajectories for the pulsed infestation models (Table 8, Figure 8) did not differ significantly from the moderate models, but the extinction risk is higher from the initial earlier increases in fecundity and mortality. As expected, the severe forms of these infestations produce very rapid population decline, high probabilities of extinction, and large losses of population heterozygosity (Tables 7 and 9, Figures 7 and 8).

Table 4. Winged mapleleaf mussel risk analysis. Simulated impacts of a high level of zebra mussel infestation in the presence of other anthropogenic factors.

File#	Brood	$Mort_J$	r_s (SD)	P(E)	N_{100} (SD)	H_{100}	T(E)
Chemical Spill Catastrophe Absent							
413	10	90	-0.075 (0.106)	0.790	7 (6)	74.0	85
414	7		-0.096 (0.108)	0.994	4 (1)	71.7	71
415	13		-0.055 (0.098)	0.230	22 (23)	86.1	91
416	10	93	-0.093 (0.109)	0.982	4 (2)	72.2	73
417	7		-0.112 (0.108)	1.000	--	--	61
418	13		-0.078 (0.109)	0.852	6 (5)	72.4	84
Chemical Spill Catastrophe Present							
419	10	90	-0.075 (0.109)	0.830	8 (6)	75.3	85
420	7		-0.095 (0.108)	1.000	--	--	72
421	13		-0.055 (0.098)	0.222	22 (19)	86.4	--
422	10	93	-0.093 (0.109)	0.986	3 (1)	61.5	72
423	7		-0.112 (0.110)	0.998	4 (0)	53.1	61
424	13		-0.079 (0.112)	0.882	6 (5)	72.4	83

Table 5. Winged mapleleaf mussel risk analysis. Simulated impacts of a severe high level of zebra mussel infestation in the presence of other anthropogenic factors

File#	Brood	$Mort_J$	r_s (SD)	P(E)	N_{100} (SD)	H_{100}	T(E)
Chemical Spill Catastrophe Absent							
449	10	90	-0.173 (0.145)	1.000	--	--	40
450	7		-0.192 (0.143)	1.000	--	--	36
451	13		-0.156 (0.148)	1.000	--	--	43
452	10	93	-0.190 (0.142)	1.000	--	--	36
453	7		-0.210 (0.144)	1.000	--	--	33
454	13		-0.176 (0.143)	1.000	--	--	39
Chemical Spill Catastrophe Present							
455	10	90	-0.172 (0.146)	1.000	--	--	40
456	7		-0.192 (0.143)	1.000	--	--	36
457	13		-0.155 (0.149)	1.000	--	--	44
458	10	93	-0.19 (0.146)	1.000	--	--	36
459	7		-0.211 (0.148)	1.000	--	--	33
460	13		-0.174 (0.145)	1.000	--	--	39

Table 6. Winged mapleleaf mussel risk analysis. Simulated impacts of a moderate level of zebra mussel infestation in the presence of other anthropogenic factors

File#	Brood	$Mort_J$	r_s (SD)	P(E)	N_{100} (SD)	H_{100}	T(E)
Chemical Spill Catastrophe Absent							
425	10	90	-0.033 (0.068)	0.002	128 (100)	96.7	--
426	7		-0.058 (0.083)	0.218	14 (11)	86.0	--
427	13		-0.014 (0.071)	0.000	699 (436)	99.0	--
428	10	93	-0.056 (0.083)	0.192	18 (14)	87.7	--
429	7		-0.077 (0.101)	0.864	5 (3)	76.0	85
430	13		-0.036 (0.073)	0.002	88 (68)	95.7	--
Chemical Spill Catastrophe Present							
431	10	90	-0.033 (0.070)	0.002	121 (92)	96.7	--
432	7		-0.059 (0.086)	0.256	14 (12)	85.1	--
433	13		-0.015 (0.073)	0.000	645 (461)	98.9	--
434	10	93	-0.057 (0.086)	0.214	17 (14)	86.9	--
435	7		-0.078 (0.101)	0.882	4 (2)	72.5	84
436	13		-0.038 (0.075)	0.022	84 (75)	95.4	--

Table 7. Winged mapleleaf mussel risk analysis. Simulated impacts of a severe moderate level of zebra mussel infestation in the presence of other anthropogenic factors.

File#	Brood	$Mort_J$	r_s (SD)	P(E)	N_{100} (SD)	H_{100}	T(E)
Chemical Spill Catastrophe Absent							
461	10	90	-0.087 (0.113)	0.962	5 (2)	70.8	76
462	7		-0.108 (0.110)	1.000	--	--	63
463	13		-0.071 (0.113)	0.704	10 (9)	76.3	87
464	10	93	-0.105 (0.113)	1.000	--	--	65
465	7		-0.125 (0.112)	1.000	--	--	55
466	13		-0.090 (0.115)	0.972	5 (3)	66.0	74
Chemical Spill Catastrophe Present							
467	10	90	-0.089 (0.115)	0.968	3 (1)	62.3	75
468	7		-0.109 (0.112)	1.000	--	--	62
469	13		-0.071 (0.117)	0.698	9 (7)	75.6	86
470	10	93	-0.107 (0.113)	1.000	--	--	64
471	7		-0.127 (0.114)	1.000	--	--	54
472	13		-0.091 (0.116)	0.984	4 (3)	65.8	74

Table 8. Winged mapleleaf mussel risk analysis. Simulated impacts of a "pulsed" zebra mussel infestation in the presence of other anthropogenic factors.

File#	Brood	$Mort_J$	r_s (SD)	P(E)	N_{100} (SD)	H_{100}	T(E)
Chemical Spill Catastrophe Absent							
437	10	90	-0.037 (0.071)	0.002	83 (63)	95.3	--
438	7		-0.063 (0.089)	0.392	11 (9)	82.6	--
439	13		-0.017 (0.073)	0.000	540 (372)	98.7	--
440	10	93	-0.061 (0.091)	0.308	13 (11)	84.1	--
441	7		-0.082 (0.102)	0.926	5 (3)	70.6	80
442	13		-0.041 (0.077)	0.014	58 (47)	93.5	--
Chemical Spill Catastrophe Present							
443	10	90	-0.037 (0.073)	0.006	84 (68)	95.1	--
444	7		-0.064 (0.091)	0.446	11 (9)	82.4	--
445	13		-0.018 (0.075)	0.000	488 (350)	98.5	--
446	10	93	-0.061 (0.093)	0.336	14 (13)	83.5	--
447	7		-0.083 (0.103)	0.926	4 (2)	64.8	80
448	13		-0.043 (0.080)	0.038	53 (48)	92.9	--

Table 9. Winged mapleleaf mussel risk analysis. Simulated impacts of a severe "pulsed" level of zebra mussel infestation in the presence of other anthropogenic factors

File#	Brood	$Mort_J$	r_s (SD)	P(E)	N_{100} (SD)	H_{100}	T(E)
Chemical Spill Catastrophe Absent							
473	10	90	-0.102 (0.125)	0.994	4 (1)	60.3	66
474	7		-0.127 (0.125)	1.000	--	--	54
475	13		-0.083 (0.128)	0.908	7 (5)	70.7	78
476	10	93	-0.124 (0.128)	1.000	--	--	55
477	7		-0.146 (0.128)	1.000	--	--	47
478	13		-0.107 (0.128)	0.998	4 (0)	68.8	63
Chemical Spill Catastrophe Present							
479	10	90	-0.103 (0.127)	0.992	4 (2)	60.4	66
480	7		-0.128 (0.128)	1.000	--	--	53
481	13		-0.085 (0.131)	0.930	7 (5)	69.3	77
482	10	93	-0.125 (0.129)	1.000	--	--	55
483	7		-0.148 (0.131)	1.000	--	--	47
484	13		-0.107 (0.129)	1.000	--	--	64

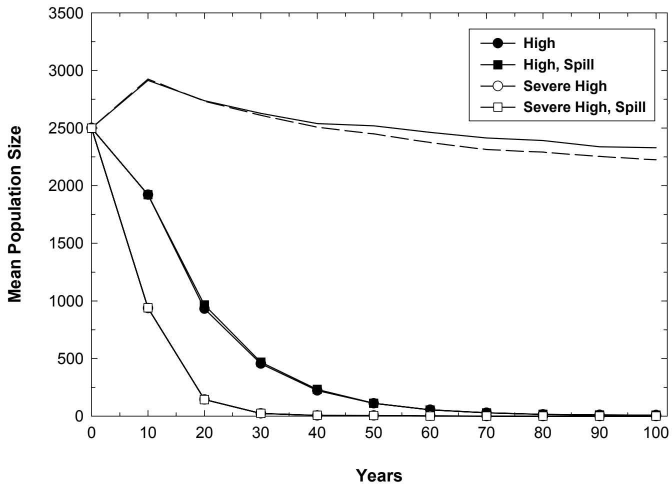
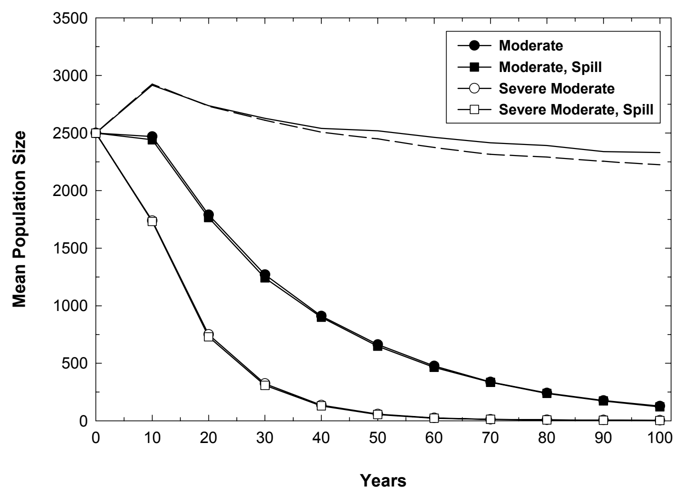


Figure 6. Mean population size of simulated winged mapleleaf mussel populations in the presence of a high level of zebra mussel infestation. "Severe" refers to the magnitude of the infestation's impact on both female fecundity and adult mortality (see text for more details). The upper solid (chronic pollution) and dashed (pollution and truck-borne chemical spill) lines indicate population trajectories in the absence of an infestation by zebra mussels. General model characteristics correspond to baseline conditions.

Figure 7. Mean population size of simulated winged mapleleaf mussel populations in the presence of a moderate level of zebra mussel infestation. "Severe" refers to the magnitude of the infestation's impact on both female fecundity and adult mortality (see text for more details). The upper solid (chronic pollution) and dashed (pollution and truck-borne chemical spill) lines indicate population trajectories in the absence of an infestation by zebra mussels. General model characteristics correspond to baseline conditions.



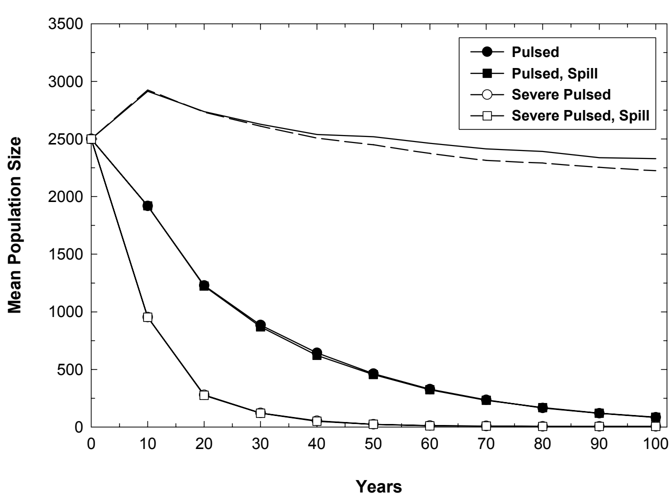


Figure 8. Mean population size of simulated winged mapleleaf mussel populations in the presence of a pulsed level of zebra mussel infestation. "Severe" refers to the magnitude of the infestation's impact on both female fecundity and adult mortality (see text for more details). The upper solid (chronic pollution) and dashed (pollution and truck-borne chemical spill) lines indicate population trajectories in the absence of an infestation by zebra mussels. General model characteristics correspond to baseline conditions.

In summary, risk assessment models incorporating anthropogenic factors indicate that the simulated chronic pollution effects, as defined by the workshop participants, do not appear to have a pronounced impact on the growth dynamics of winged mapleleaf mussel populations. In contrast, the most profound risk faced by this remnant population appears to be an infestation by zebra mussels. Direct impacts on female fecundity and adult mortality of this infestation cause affected populations to decrease rapidly toward extinction following the introduction of zebra mussels into winged mapleleaf habitat. Alternative estimates of the specific impacts of an infestation result in very different extinction risks in the short term (see, for example, Figure 9); consequently, additional effort directed towards assessing the impacts of zebra mussel introduction may be in order.

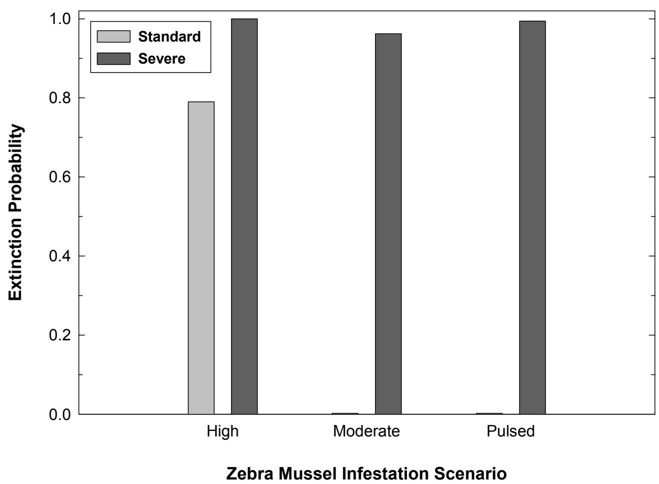


Figure 9. Summary of extinction risk over the 100-year simulation period for simulated winged mapleleaf mussel populations subjected to an infestation by zebra mussels. Simulated infestation types are separated out by their intensity and the severity of their effects on winged mapleleaf demography. General model characteristics correspond to baseline conditions.

Recommendations from Life History Analysis and Population Modeling

Ranking criterion used: Recommendation will lead to a better model.

1. Develop more precise estimates of juvenile and subadult mortality for *Q. fragosa* i.e., those in the 0-7 year age classes. Sediment traps could be employed to obtain estimates of the number of juvenile mussels settling in a given area of substrate in a given year. Furthermore, Surber and related sampling methodologies can be used to look for juvenile age classes for all mussel species in the same area repeatedly through time. Ideally, a surrogate species in this context would be another *Q. sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

2. Focus our understanding of the nature and extent of the interaction between *Q. fragosa* and the zebra mussel, particularly with respect to the following parameters: at what density/biomass of zebra mussels do measurable impact(s) on winged mapleleaf mussel demography begin to occur, how rapidly would a zebra mussel population reach this specified level on the St. Croix and grow beyond it, and which aspects of winged mapleleaf life history would be most seriously affected at these various levels of zebra mussel infestation. Ideally, a surrogate species in this context would be another *Quadrula sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

3. Improve estimates of annual rates of juvenile production per breeding female of *Q. fragosa*, primarily through more detailed analysis of literature on unionid mussels where available. Ideally, a surrogate species in this context would be another *Quadrula sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

4a. Review and improve estimates of adult winged mapleleaf (or surrogate) mussel mortality rates. This could be done through mark-recapture studies. Ideally, a surrogate species in this context would be another *Quadrula sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

4b. Improve our understanding of the nature and extent of direct and indirect anthropogenic factors on mussel habitat and by extension, winged mapleleaf mussel demographic rates, particularly those involving juveniles and breeding adults. Direct experimentation on related unionid mussels may prove useful toward this goal. Ideally, a surrogate species in this context would be another *Quadrula sp.* If this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

6. Improve estimates of environmental variance associated with adult winged mapleleaf (or surrogate) mussel mortality rates. Again, mark-recapture studies would prove useful in pursuit of this goal. Ideally, a surrogate species in this context would be another *Quadrula sp.*; if this is not possible, a genus within the subfamily Ambleminae should be chosen for study.

Note: See other groups' recommendations for specifics.

Working Group Participants: Rich Baker, Greg Busacker, Rick Hart, Dan Hornbach, Phil Miller

Sample VORTEX Input File

```
FRAG413.OUT     ***Output Filename***
Y     ***Graphing Files?***
N     ***Each Iteration?***
500     ***Simulations***
100     ***Years***
10     ***Reporting Interval***
0     ***Definition of Extinction***
1     ***Populations***
N     ***Inbreeding Depression?***
Y     ***EV concordance between repro and surv?***
1     ***Types Of Catastrophes***
P     ***Monogamous, Polygynous, or Hermaphroditic***
7     ***Female Breeding Age***
7     ***Male Breeding Age***
25     ***Maximum Age***
0.500000     ***Sex Ratio***
0     ***Maximum Litter Size (0 = normal distribution) *****
N     ***Density Dependent Breeding?***
((19.4-((4.85)*(Y>4)))*(N/(4+N)))  **breeding
10.00  **EV-breeding
10.000000     ***Population 1: Mean Litter Size***
10.000000     ***Population 1: SD in Litter Size***
90.000000  *FMort age 0
3.000000  ***EV
10.000000  *FMort age 1
3.000000  ***EV
10.000000  *FMort age 2
3.000000  ***EV
5.000000  *FMort age 3
2.000000  ***EV
5.000000  *FMort age 4
2.000000  ***EV
5.000000  *FMort age 5
2.000000  ***EV
5.000000  *FMort age 6
2.000000  ***EV
2.6+(10*(Y>4))  *Adult FMort
0.700000  ***EV
90.000000  *MMort age 0
3.000000  ***EV
10.000000  *MMort age 1
3.000000  ***EV
10.000000  *MMort age 2
3.000000  ***EV
5.000000  *MMort age 3
2.000000  ***EV
5.000000  *MMort age 4
2.000000  ***EV
5.000000  *MMort age 5
2.000000  ***EV
5.000000  *MMort age 6
2.000000  ***EV
1.6+(10*(Y>4))  *Adult MMort
0.300000  ***EV
0.200000     ***Probability Of Catastrophe 1***
1.000000     ***Severity--Reproduction***
1.000000     ***Severity--Survival***
Y     ***All Males Breeders?***
```

Sample VORTEX Input File (Contd.)

```
N     ***Start At Stable Age Distribution?***
16     ***Initial Females Age 1***
49     ***Initial Females Age 2***
33     ***Initial Females Age 3***
17     ***Initial Females Age 4***
362     ***Initial Females Age 5***
49     ***Initial Females Age 6***
33     ***Initial Females Age 7***
66     ***Initial Females Age 8***
66     ***Initial Females Age 9***
181     ***Initial Females Age 10***
148     ***Initial Females Age 11***
33     ***Initial Females Age 12***
33     ***Initial Females Age 13***
17     ***Initial Females Age 14***
0     ***Initial Females Age 15***
33     ***Initial Females Age 16***
0     ***Initial Females Age 17***
16     ***Initial Females Age 18***
0     ***Initial Females Age 19***
16     ***Initial Females Age 20***
66     ***Initial Females Age 21***
16     ***Initial Females Age 22***
0     ***Initial Females Age 23***
0     ***Initial Females Age 24***
0     ***Initial Females Age 25***
16     ***Initial Males Age 1***
49     ***Initial Males Age 2***
33     ***Initial Males Age 3***
17     ***Initial Males Age 4***
362     ***Initial Males Age 5***
49     ***Initial Males Age 6***
33     ***Initial Males Age 7***
66     ***Initial Males Age 8***
66     ***Initial Males Age 9***
181     ***Initial Males Age 10***
148     ***Initial Males Age 11***
33     ***Initial Males Age 12***
33     ***Initial Males Age 13***
17     ***Initial Males Age 14***
0     ***Initial Males Age 15***
33     ***Initial Males Age 16***
0     ***Initial Males Age 17***
16     ***Initial Males Age 18***
0     ***Initial Males Age 19***
16     ***Initial Males Age 20***
66     ***Initial Males Age 21***
16     ***Initial Males Age 22***
0     ***Initial Males Age 23***
0     ***Initial Males Age 24***
0     ***Initial Males Age 25***
3100     ***K***
0.000000     ***EV--K***
N     ***Trend In K?***
N     ***Harvest?***
N     ***Supplement?***
Y     ***AnotherSimulation?***
```

Sample VORTEX Output File

```
VORTEX -- simulation of genetic and demographic stochasticity

  1 population(s) simulated for 100 years, 500 iterations

  Extinction is defined as no animals of one or both sexes.

  No inbreeding depression

  First age of reproduction for females: 7   for males: 7
  Age of senescence (death): 25
  Sex ratio at birth (proportion males): 0.50000


Population 1:

  Polygynous mating; all adult males in the breeding pool.

  % adult females breeding = ((19.4-((4.85)*(Y>4)))*(N/(4+N)))
   EV in % adult females breeding = 10.00 SD

   Of those females producing litters, ...
   Mean litter size is 10.000000
   SD in litter size is 10.000000

   90.00 percent mortality of females between ages 0 and 1
    EV in % mortality = 3.000000 SD
   10.00 percent mortality of females between ages 1 and 2
    EV in % mortality = 3.000000 SD
   10.00 percent mortality of females between ages 2 and 3
    EV in % mortality = 3.000000 SD
   5.00 percent mortality of females between ages 3 and 4
    EV in % mortality = 2.000000 SD
   5.00 percent mortality of females between ages 4 and 5
    EV in % mortality = 2.000000 SD
   5.00 percent mortality of females between ages 5 and 6
    EV in % mortality = 2.000000 SD
   5.00 percent mortality of females between ages 6 and 7
    EV in % mortality = 2.000000 SD
   % mortality of adult females (7<=age<=8) = 2.6+(10*(Y>4))
    EV in % mortality = 0.700000 SD
   90.00 percent mortality of males between ages 0 and 1
    EV in % mortality = 3.000000 SD
   10.00 percent mortality of males between ages 1 and 2
    EV in % mortality = 3.000000 SD
   10.00 percent mortality of males between ages 2 and 3
    EV in % mortality = 3.000000 SD
   5.00 percent mortality of males between ages 3 and 4
    EV in % mortality = 2.000000 SD
   5.00 percent mortality of males between ages 4 and 5
    EV in % mortality = 2.000000 SD
   5.00 percent mortality of males between ages 5 and 6
    EV in % mortality = 2.000000 SD
   5.00 percent mortality of males between ages 6 and 7
    EV in % mortality = 2.000000 SD
   % mortality of adult males (7<=age<=8) = 1.6+(10*(Y>4))
    EV in % mortality = 0.300000 SD

    EVs may be adjusted to closest values possible for binomial distribution.
    EV in reproduction and mortality will be concordant.
```

Sample VORTEX Output File (Contd.)

```
  Frequency of type 1 catastrophes: 0.200 percent
    with 1.000 multiplicative effect on reproduction
     and 1.000 multiplicative effect on survival

  Initial size of Population 1:     2500
 Age 1     2     3     4     5     6     7     8     9    10    11    12    13    14
15    16    17    18    19    20    21    22    23    24    25    Total
    16    49    33    17   362    49    33    66    66   181   148    33    33    17
0    33     0    16     0    16    66    16     0     0     0    1250  Males
    16    49    33    17   362    49    33    66    66   181   148    33    33    17
0    33     0    16     0    16    66    16     0     0     0    1250  Females

  Carrying capacity = 3100
    EV in Carrying capacity = 0.00 SD

Deterministic population growth rate (based on females, with assumptions of
  no limitation of mates, no density dependence, and no inbreeding depression):

     r =  -0.005     lambda = 0.995     R0 =     0.932
   Generation time for:  females = 15.28    males = 15.59

Stable age distribution:  Age class    females    males
                              0        0.191      0.191
                              1        0.019      0.019
                              2        0.017      0.017
                              3        0.016      0.016
                              4        0.015      0.015
                              5        0.014      0.014
                              6        0.014      0.014
                              7        0.013      0.013
                              8        0.013      0.013
                              9        0.012      0.013
                             10        0.012      0.013
                             11        0.012      0.012
                             12        0.012      0.012
                             13        0.011      0.012
                             14        0.011      0.012
                             15        0.011      0.012
                             16        0.011      0.012
                             17        0.010      0.012
                             18        0.010      0.011
                             19        0.010      0.011
                             20        0.010      0.011
                             21        0.010      0.011
                             22        0.009      0.011
                             23        0.009      0.011
                             24        0.009      0.011
                             25        0.009      0.011

Ratio of adult (>= 7) males to adult (>= 7) females: 1.091

Population 1

Year 10
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   500, P[S] = 1.000
     Population size =          1921.00 (  13.56 SE,  303.12 SD)
     Expected heterozygosity =    0.999 (  0.000 SE,   0.000 SD)
     Observed heterozygosity =    1.000 (  0.000 SE,   0.000 SD)
     Number of extant alleles = 2454.36 (   7.90 SE,  176.60 SD)
```

Sample VORTEX Output File (Contd.)

```
Year 20
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   500, P[S] = 1.000
     Population size =           930.69 (  11.44 SE,  255.77 SD)
     Expected heterozygosity =    0.999 (  0.000 SE,   0.000 SD)
     Observed heterozygosity =    1.000 (  0.000 SE,   0.001 SD)
     Number of extant alleles = 1014.83 (   8.28 SE,  185.05 SD)

Year 30
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   500, P[S] = 1.000
     Population size =           454.47 (   7.82 SE,  174.92 SD)
     Expected heterozygosity =    0.996 (  0.000 SE,   0.001 SD)
     Observed heterozygosity =    0.999 (  0.000 SE,   0.001 SD)
     Number of extant alleles =  450.57 (   5.77 SE,  129.07 SD)

Year 40
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   500, P[S] = 1.000
     Population size =           221.23 (   4.56 SE,  101.97 SD)
     Expected heterozygosity =    0.992 (  0.000 SE,   0.003 SD)
     Observed heterozygosity =    0.998 (  0.000 SE,   0.004 SD)
     Number of extant alleles =  212.76 (   3.46 SE,   77.38 SD)

Year 50
     N[Extinct] =       0, P[E] = 0.000
     N[Surviving] =   500, P[S] = 1.000
     Population size =           110.37 (   2.81 SE,   62.81 SD)
     Expected heterozygosity =    0.982 (  0.000 SE,   0.010 SD)
     Observed heterozygosity =    0.996 (  0.000 SE,   0.008 SD)
     Number of extant alleles =  103.11 (   2.07 SE,   46.26 SD)

Year 60
     N[Extinct] =       3, P[E] = 0.006
     N[Surviving] =   497, P[S] = 0.994
     Population size =            54.06 (   1.63 SE,   36.36 SD)
     Expected heterozygosity =    0.961 (  0.001 SE,   0.028 SD)
     Observed heterozygosity =    0.991 (  0.001 SE,   0.020 SD)
     Number of extant alleles =   50.46 (   1.22 SE,   27.09 SD)

Year 70
     N[Extinct] =      26, P[E] = 0.052
     N[Surviving] =   474, P[S] = 0.948
     Population size =            26.61 (   0.98 SE,   21.36 SD)
     Expected heterozygosity =    0.919 (  0.003 SE,   0.058 SD)
     Observed heterozygosity =    0.982 (  0.002 SE,   0.044 SD)
     Number of extant alleles =   25.09 (   0.73 SE,   15.86 SD)

Year 80
     N[Extinct] =     121, P[E] = 0.242
     N[Surviving] =   379, P[S] = 0.758
     Population size =            14.70 (   0.67 SE,   13.01 SD)
     Expected heterozygosity =    0.863 (  0.004 SE,   0.082 SD)
     Observed heterozygosity =    0.976 (  0.003 SE,   0.057 SD)
     Number of extant alleles =   13.77 (   0.48 SE,    9.28 SD)
```

Sample VORTEX Output File (Contd.)

```
Year 90
     N[Extinct] =     282, P[E] = 0.564
     N[Surviving] =   218, P[S] = 0.436
     Population size =            9.98 (   0.52 SE,    7.69 SD)
     Expected heterozygosity =    0.817 (  0.006 SE,   0.089 SD)
     Observed heterozygosity =    0.950 (  0.007 SE,   0.097 SD)
     Number of extant alleles =    9.16 (   0.36 SE,    5.33 SD)

Year 100
     N[Extinct] =     395, P[E] = 0.790
     N[Surviving] =   105, P[S] = 0.210
     Population size =            7.17 (   0.56 SE,    5.70 SD)
     Expected heterozygosity =    0.740 (  0.013 SE,   0.133 SD)
     Observed heterozygosity =    0.895 (  0.017 SE,   0.177 SD)
     Number of extant alleles =    6.42 (   0.39 SE,    3.99 SD)


In 500 simulations of Population 1 for 100 years:
  395 went extinct and 105 survived.

This gives a probability of extinction of 0.7900 (0.0182 SE),
  or a probability of success of          0.2100 (0.0182 SE).

395 simulations went extinct at least once.
Median time to first extinction was 89 years.
Of those going extinct,
    mean time to first extinction was 84.77 years (0.46 SE, 9.04 SD).

Mean final population for successful cases was 7.17 (0.56 SE, 5.70 SD)

   Age 1       2       3       4       5       6   Adults    Total
    0.06    0.34    0.18    0.09    0.10    0.14    3.47      4.38  Males
    0.07    0.19    0.18    0.10    0.17    0.15    3.20      4.07  Females

Across all years, prior to carrying capacity truncation,
  mean growth rate (r) was -0.0747 (0.0005 SE, 0.1064 SD)

Final expected heterozygosity was      0.7400 ( 0.0129 SE,  0.1326 SD)
Final observed heterozygosity was      0.8952 ( 0.0172 SE,  0.1765 SD)
Final number of alleles was              6.42 (   0.39 SE,    3.99 SD)
*************************************************************************
```

Appendix I
Estimating the Probability of a Highway Chemical Spill Affecting Winged Mapleleaf Mussel Habitat

Greg Busacker, Minnesota Department of Transportation

In the following analysis, I am attempting to estimate the likelihood of a semi-trailer truck accident on a bridge in Minnesota when the truck is transporting hazardous materials. Using the disparate data available I have made several general estimates suggesting a low probability, however the data to accurately answer this question do not seem to be available.

Accidents of all types occurring on bridges in Minnesota that involved semi-trailer trucks during the time period from January 1, 1991 to December 31, 1995.

	YEAR AND NUMBER OF ACCIDENTS				
Type of Highway	1991	1992	1993	1994	1995
Interstate	55	58	66	80	98
U.S. Highway	26	20	37	28	30
State Highway	22	17	13	17	31
County State Aid Highway	16	7	12	17	13
Total	119	102	128	142	172
Total Number of Bridges in Minnesota.	9,139	9,139	9,139	9,139	9,139
Accidents divided by the total number of bridges.	0.013	0.011	0.014	0.016	0.019

In the absence of any data, the hazards group estimated the likelihood of a truck accident on the bridge over the St. Croix River at Taylor's Falls to be 0.02. I called Mr. Jon Anderson of Mn/DOT's Traffic Engineering to see what data was available. There are 9,139 bridges in Minnesota in the four major highway classifications (Interstate, U.S. Highway, State Highway, and County State Aide Highway). Of the 9, 139 bridges, 7,699 are over water. The numbers of accidents involving semi-trailer trucks for the years 1991 through 1995 is given in the table above. For the five year period, the average number of accidents on bridges was 133 ± 12 (X ± S.E.). Using this data as a prediction of future years and calculating the 95% confidence interval, the true mean for a future year lies between 100 and 166. For the five year period, the average number of accidents on bridges expressed as a fraction of the number of bridges, was 0.0145 ± 0.0013 (X ± S.E.). Using this data as a prediction of future years and calculating the 95% confidence interval, the true mean for future years lies between 0.011 and 0.018 (95% confidence interval). For the years 1991-1995 the likelihood of a truck accident on any bridge was 0.0145.

The likelihood of a spill associated with a particular accident having a catastrophic impact on nearby aquatic communities would be reduced by the proportionality of trucks carrying hazardous materials that might flow or be washed into the river following an accident. There is one source of indirect statistics that reflects on this. Nationwide data from the 1993 Commodity Flow Survey (US Census & Bureau of Transportation Statistics) show that in 1992, there were 864,897,000,000 ton miles of freight hauled by trucks and of this figure, 124,000,000 ton miles were hazardous materials (STC code 489). This suggests that the proportion of hazardous freight is 0.00014 of the total. If this proportion is multiplied by the proportion for occurrence of a truck accident on a bridge, the proportional occurrence for an accident on a bridge involving hazardous materials could be as low as 0.000002. This is an estimate and the true number may be higher or lower.

The accident data in the table above are not expressed in terms of the number of vehicles on the different highways or the design standards of the highways. For instance, the Interstate Highway system has the highest design standards and the highest number of vehicles. The Average Daily Traffic (ADT; annual traffic volume/365) on different highway classifications for the years 1992-1995 was 1836 for Interstate Highways, 339 for U.S. Highways, 124 for State Highways and 1 for County State Aid Highways. If one divides the number of accidents on bridges by annual traffic volumes, the results are 0.00011 bridge accidents per annual traffic volume for Interstate, 0.00068 for U.S Highways and 0.00044 for State Highways respectively. The proportions on the two lane highways are slightly higher even though the traffic volumes and the accident numbers are lower. Again there is a caveat; the two statistics may not be directly comparable because the ADT is for a particular segment of highway such as between two cities and an accident on a bridge is defined to some average bridge length.

In conclusion, the likelihood of a semi-trailer truck accident on a bridge is Minnesota is low. The likelihood of a semi-trailer transporting hazardous materials is much lower and could be as low as 2.0×10^{-6}.

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL (*Quadrula fragosa*)

January 1998

Final Report
June 1998

SECTION 5

WORKSHOP PRESENTATION

Reproductive Life History of *Quadrula fragosa*

Mark Hove

This morning I will briefly review what is known about the reproductive life history of *Quadrula fragosa* and some of it's congeners.

As many of you are aware, the life cycle of most freshwater mussels involves a brief encounter with a host, usually a fish, that the young mussel, or glochidium, attaches to. Malacologists believe attachment to a host increases the dispersal ability of unionids. Some mussels, including the thick-shelled quadrulas, have rather specific host requirements. The host(s) of *Q. fragosa* are unknown.

I will now review the following life history traits of *Q. fragosa*: (1) brooding period (length of time female quadrulas hold young in their brood chambers), (2) host requirements, and (3) host attraction behaviors exhibited by unionids and *Q. fragosa*.

Brooding period

Most quadrulas are short-term brooders. That is, the female mussel holds glochidia in her marsupia during the spring while they develop. Once mature, the glochidia are released later in the spring or early summer. Before 1997 I would have guessed *Q. fragosa* was a short-term brooder like it's congeners. However, a study coordinated by Dave Heath, Wisconsin Department of Natural Resources, revealed a brooding *Q. fragosa* in September 1997. This individual released conglutinates with immature glochidia in the field and in a laboratory at the University of Minnesota. This event suggests the *Q. fragosa* may be a long-term brooder (a species that brood their young over winter). Hopefully, Dave's efforts next year will shed light on the brooding behavior of this species.

Host specificity

The host requirements for *Q. fragosa* are unknown. Frequently, mussels within a genus have similar host requirements. Studies conducted in the early 1900's revealed quadrula glochidia naturally attach to sunfishes, percids, and ictalurids. However, glochidia will attach to unsuitable hosts, in which case they are sloughed off by the fish. These early studies did not show whether the attached glochidia transformed into juvenile mussels. Additional studies are needed to determine if these fishes will facilitate quadrula glochidia metamorphosis. If Dave Heath's team collects *Q. fragosa* glochidia in 1998 we will conduct laboratory host suitability studies on a wide variety of fishes including percids, sunfishes, and ictalurids.

On a positive note, successful transformation of *Q. fragosa* glochidia is taking place at Interstate State Park. David Heath and Daniel Hornbach observed year old *Q. fragosa* juveniles in 1997.

Host attraction behaviors

There are three known strategies mussels use to increase the likelihood of bringing their young in contact with suitable fish hosts. These behaviors include: (1) broadcasting individual glochidia into the water column, (2) mantle waving to attract fish to brooding mussels, and (3) conglutinate presentation. Quadrulas present conglutinates similar to those produced by this round pigtoe mussel. A conglutinate is a gelatinous matrix surrounding glochidia and unfertilized ova. These tiny dots are the glochidia. It is thought conglutinates resemble food to a fish. When a fish feeds on a conglutinate a few glochidia frequently attach themselves to the fish's gills.

Host attraction behaviors exhibited by *Q. fragosa* were observed last year. Dave Heath's team observed the gravid *Q. fragosa* was less concealed in the substrate and more exposed to the water current than nongravid individuals. This behavior is not uncommon among brooding mussels and is thought to increase the likelihood of host fish encountering glochidia.

We were fortunate enough to observe the gravid *Q. fragosa* releasing her young. Like other quadrulas, *Q. fragosa* produce long, leaf-like conglutinates filled with glochidia and unfertilized ova.

Although many details of *Q. fragosa*'s reproductive life history are unknown, we should be able to provide information for the workshop computer model. Hopefully, our efforts over the next few days will identify and prioritize research needs for this species.

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL
(*Quadrula fragosa*)

January 1998

Final Report
June 1998

SECTION 6

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POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL (*Quadrula fragosa*)

January 1998

Final Report
June 1998

SECTION 7

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POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL
(*Quadrula fragosa*)

January 1998

Final Report
June 1998

SECTION 7

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33				Muller Scenic Boat Tours	Taylors Falls	MN	55084
34			Canoe Rental	Schillberg's Brookside Canoe	Osceola	WI	54020
35			Canoe Rental	Taylors Falls Canoe Rental	Taylors Falls	MN	55084
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110	Rich	Baker		Minnesota Department of Natural Resources	St. Paul	MN	55155
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113	Frank	Pafco		Minnesota Department of Transportation	Oakdale	MN	55128-3307
114	Richard	Dickinson	Senior Resident Agent	U.S. Fish and Wildlife Service	St. Paul	MN	55106-5800
115	Nick	Rowse		U.S. Fish and Wildlife Service	Bloomington	MN	55425-1665
116	Robert	Delaney	Program Manager	Environmental Management Technical Center	Onalaska	WI	54650
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POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE WINGED MAPLELEAF MUSSEL (*Quadrula fragosa*)

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SECTION 8

GLOSSARY

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Ambleminae	Subfamily of mussels which includes Winged Maple Leaf, Wartyback, Pimpleback and Elephant Ear.
Anthropogenic	The scientific study of the origin of man.
Byssal thread	A mass of filaments by means of which certain bivalve mollusks, such as mussels, attach themselves to fixed surfaces.
Centrarchids	Subfamily of fish which includes bass, sunfish, crappies and perch.
Conchologically	The study of mollusks and shells.
Corbicula	Asian clam species which is in the same Order Veneroida than includes Zebra Mussels.
Cyprinids	Any of numerous often small freshwater fishes of the family Cyprinidae, which includes the minnows, carps, and shiners.
Dimorphic	The state of having two distinct forms in the same species when the sexes differ in secondary as well as primary sexual characteristics.
Fecundity	Capable of producing offspring, fruitful.
Glochidia	A parasitic larva of certain freshwater mussels of the family Unionidae, having hooks for attaching to a host fish.
Gravid	Pregnant.
Hermaphroditism	An organism, such as an earthworm or a monoclinous plant, having male and female reproductive organs in the same individual.
Ictalurids	Family of fish which includes catfish and bullheads.
Pedal	Of or pertaining to a foot or footlike part.
Percids	Family of fish which includes perch, darters, and walleye.
Polygynous	The state or practice of having more than one mate at a single time.
Unionid	Bivalves.

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