REPRODUCTIVE BIOLOGY, GROWTH, AND VERIFICATION OF THREE FISH HOSTS OF *MAGNONAIAS NERVOSA* (Rafinesque, 1820) (BIVALVIA: UNIONIDAE) IN THE EAST CHANNEL OF NAVIGATION POOL 10, UPPER MISSISSIPPI RIVER

A Thesis

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By
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COLLEGE OF ARTS, LETTERS, AND SCIENCES

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We recommend acceptance of this thesis to the College of Arts, Letters, and Sciences in partial fulfillment of this candidate's requirements for the degree of Master of Science in Biology. The candidate has completed her oral defense of the thesis.

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ABSTRACT

Gametogenic development of Magnonaias nervosa (Bivalvia: Unionidae) was examined monthly from April 1986 to March 1987 in Navigation Pool 10 of the Upper Mississippi River. This species attains sexual maturity at a shell height of about 68 mm and at an age of eight years. M. nervosa is a late tachytictic breeder that releases glochidia from September to November as ambient river temperature declines.

Growth in length and height of the shell were described by the following regression equations: height = 6 + 30(ln age) and length = 4 + 44(ln age). Initial growth was rapid until age 5 when growth in height slowed to an average of about 4 mm/year; growth in length slowed to an average of about 2 mm/year at age 12.

Laboratory experiments verified three fish as hosts for M. nervosa. Glochidia metamorphosed to free-living juveniles on Lepomis cyanellus (green sunfish), Ictaluras melas (black bullhead), and Ictalurus punctatus (channel catfish). In contrast, glochidia did not differentiate to free-living juveniles on Catastomus commersoni (white suckers), Cyprinus carpio (common carp), Pimephales promelas (fathead minnows), and Perca flavescens (yellow perch).

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Freshwater mussels (Mollusca: Bivalvia: Unionidae) are ecologically, scientifically, and commercially important. Their filter-feeding of suspended particulate matter permits the capture of energy sources not utilized by other biota (Wallace et al. 1977). Mussels comprise an integral part of aquatic food webs and are an important food source for otters, muskrat, mink, raccoon, fish, and waterfowl (Baker 1928, Pennak 1953).

The long life span, wide distribution, and almost sessile existence of bivalve mussels provide scientists with a means to monitor past and present environmental change and contamination through analysis of annual rings and soft body parts (Foster and Bates 1978, Rhoads and Lutz 1980). Imlay (1982) demonstrated that heavy metal concentrations in annual shell layers can be used to reconstruct past input intensities of heavy metals at a given site. Bedford et al. (1967) found increasing concentrations of DDT and its metabolites in mussel soft body parts downstream from cultivated areas.

Freshwater mussels have been important to humans as a prehistoric food and ornamental resource (Stansbery 1966, Theler 1987) and more recently as an item of commerce. Mussel shells were used to make buttons in the late 1800s to

mid 1930s and are presently harvested to make nuclei for cultured pearls. The largest commercial freshwater mussel industries in the United States have been on the Mississippi River.

Historically, the Upper Mississippi River (UMR) contained one of the richest freshwater mussel faunas in the world (van der Schalie and van der Schalie 1950). A decline in species diversity since the 1800s has been well documented (Higgins 1858, van der Schalie 1938, Coon et al. 1977, Havlik and Stansbery 1978, Fuller 1978, Theil 1981). The decline may have been caused by overharvest, siltation, impoundment, channelization, commercial boat traffic, and pollution (Ellis 1936, Bates 1962, Isom 1969, Stansbery 1971, Imlay 1972, Stein 1973, Marking and Bills 1977, Horne and McIntosh 1979, Bayne et al. 1981, Brigham et al. 1981, Miller et al. 1984, Havlik and Marking 1987). Two endemic species of mussels in the UMR have recently been placed on the Federal Endangered Species List, the Higgins, Eye (Lampsilis higginsi) and the Fat Pocketbook (Potamilus capax).

Commercial exploitation has been suggested as a primary cause of mussel decline on the UMR (van der Schalie 1938, Fuller 1978). From the late 1800s to the late 1930s, millions of tons of mussels were harvested annually from the

UMR for use in the pearl button industry (Coker et al. 1921, van der Schalie 1938, Carlander 1954, Pennak 1953). Resource depletion and invention of the plastic button essentially eliminated commercial harvest until the 1950s. The Japanese pearl culture industry then created a demand for small spheres of freshwater mussel shells as nuclei for cultured pearls.

Commercial clamming to supply the pearl industry has been a multi-million dollar business for almost two decades (Stansbery and Stein 1971, Sparks and Blodgett 1986, Fritz 1986). The demand for UMR mussels has increased. In 1985, Illinois reported a 104% increase (2 million kg to 5.5 million kg) over the 1984 UMR shell harvest (Fritz 1986). Biologists of the UMR region have expressed concern that intense exploitation is occurring in the absence of adequate knowledge of basic biology, abundance, and recruitment potential of impacted species. Consequently, over-exploitation and even extinction may occur.

Magnonaias nervosa (Rafinesque, 1820), the Washboard mussel, is found in the Mississippi River and many of its tributaries, the Tombigbee River in Alabama, and the Nuevo Leon of Mexico (Baker 1928, Fuller 1978). It is the preferred commercial species of the UMR. In 1985, M. nervosa comprised 80% (4.4 million kg at 55 cents/kg) of the

Illinois-Mississippi River shell harvest (Fritz 1986). It also accounted for 78% (by weight; 0.373 million kg) of the 1986 Mississippi River harvest in Wisconsin (Wisconsin Department of Natural Resources 1987).

Research on the basic biology of M. nervosa is lacking. Records on the reproductive pattern of this species are conflicting (Utterback 1915-1916, Howard 1914, Coker et al. 1921). Size-limits are used to regulate harvest, although the size at which individuals are sexually mature is unknown. Present harvest size-limits may not be permitting sufficient recruitment into the population to sustain intense commercial harvest. Ecological Analysts Inc. (1981) and Duncan and Thiel (1983) noted that the populations of M. nervosa were dominated by larger individuals in UMR Navigation Pools 10-24, suggesting that recruitment was minimal.

The specific objectives of this study were to:
1) describe the temporal and age specific reproductive biology of M. nervosa in selected reaches of the UMR,
2) determine the age at which sexual maturity begins and the proportion of reproducing individuals in each age-class
3) determine age-size relationships associated with reproductive potential and predict annual growth rates, and
4) verify some glochidia-host fish specificities. This

information will enhance management of this heavily exploited species. Information on the reproductive cycle and age or size at first reproduction will aid in establishing harvest size-limits, thereby ensuring adequate recruitment into the population. The identification of M. nervosa glochidial host fish could enable managers to predict reproductive success of the mussel based on knowledge of the regional ichthyofauna.

LITERATURE REVIEW

Reproductive strategies of mussels are characterized as tachytictic (short-term) or bradytictic (long-term). In early spring, tachytictic females draw sperm in through the incurrent siphon; the ova are fertilized and moved to the marsupial gills where they develop into glochidia. The females release glochidia in late spring or early summer. Glochidia attach to the gills or fins of a specific fish host as obligate parasites until they metamorphose to freeliving juveniles. Bradytictic females undergo fertilization in late summer or early fall and release glochidia the ensuing spring or summer.

Records of the reproductive strategy of M. nervosa are conflicting. Observations by Utterback (1915-1916) and Coker et al. (1921) indicate a bradytictic strategy, although the primary source of Coker,s information is unclear. Howard (1914), Lefevre and Curtis (1910), and Bingham (1968) characterize M. nervosa as tachytictic. Timing of reproduction can be affected by temperature (Howard 1915, Yokley 1972). Seasonal variations in temperature may account for the conflicting characterizations of reproduction by researchers.

Early studies of unionids (Lefevre and Curtis 1910, Howard 1914, Utterback 1915-1916, Coker et al. 1921) described gravid periods for M. nervosa but did not describe gametogenic stages.

Early studies of unionids (Lefevre and Curtis 1910, Howard 1914, Utterback 1915-1916, Coker et al. 1921) described gravid periods for M. nervosa but did not describe gametogenic stages. Bingham (1968) examined gametogenesis in M. nervosa, but his sample size (n = 15) was to small to characterize seasonal reproductive stages.

The age and size at which M. nervosa begins reproducing is poorly documented. the smallest breeding individual found by Howard (1914) was 91 mm in length and eight years old.

Analysis of recruitment potential of freshwater mussels is complicated by the host-parasite relationships of the glochidia. Early host specificity studies were conducted in an attempt to propagate important commercial species (Howard 1914, Lefevre and Curtis 1912, Coker et al. 1921). Fuller (1978) summarized all glochidia-fish host relationships identified prior to 1972. A review of the literature in his bibliography revealed that few of the stated hosts of M. nervosa were observed to produce free-living juveniles. The fish host experiments by Howard (1914) defined the degree of encystment by glochidia, but it is unclear whether metamorphosed juveniles were produced from laboratory infections. Simple encystment does not guarantee metamorphosis as observed in Lampsilis higginsi by Waller

and Holland (1987). Coker et al. (1921) lists hosts of M. nervosa as determined by collections of wild fish that were infected with M. nervosa glochidia and by artificial laboratory infections. However, not all of the wild fish observations were verified in laboratory experiments. C.B. Wilson (1916) listed the species of wild fish upon which M. nervosa glochidia were found, but no mention of metamorphosed juveniles was made. The reproductive success of freshwater mussels depends on an adequate density of suitable hosts. Confirmation of host-fish listings is important to estimate the potential recruitment into a population.

METHODS

Study Area

The UMR extends from Minneapolis/St. Paul, Minnesota to the confluence of the Ohio River at Cairo, Illinois. The UMR is divided into a series of 27 navigation pools by a lock and dam system that was initiated in the 1930s (Fremling and Claflin 1984). The specific study area was the East Channel of Navigation Pool 10, between UMR Lock and Dams 9 and 10 (Fig. 1). This site was selected because of its diverse and abundant mussel populations (Havlik and Stansbery 1978, Thiel 1981), its importance as a commercial clamming site, and because *M. nervosa* is the second most abundant species in the area (Duncan and Thiel 1983).

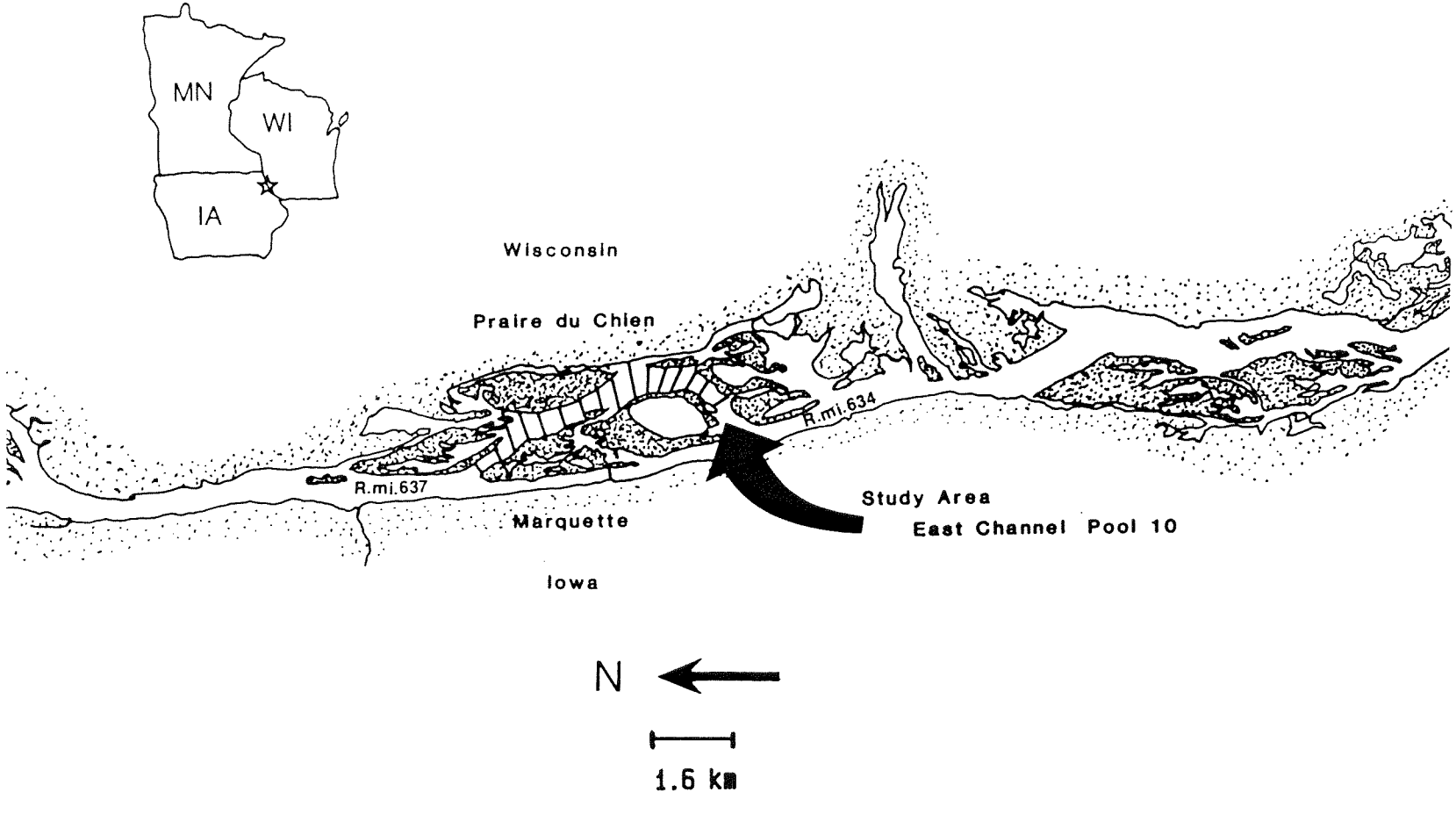
Host Specificity

Laboratory methods utilized by Zale (1980) and Waller et al. (1985) were used to identify possible host species of *M. nervosa*. Representatives of five families common to the UMR were selected. Previously identified hosts: green sunfish (*Lepomis cyanellus*), black bullhead (*Ictalurus melas*), and channel catfish (*Ictalurus punctatus*) (Howard 1914, Coker et al. 1921, Fuller 1978), and four other species were evaluated as hosts: fathead minnows (*Pimephales promelas*), common carp (*Cyprinus carpio*), white

Figure 1. Study area, East Channel, Navigation Pool 10, Upper Mississippi River.

Upper Mississippi River

Navigation Pool 10



suckers (Catostomus commersoni), and yellow perch (Perca flavescens). In the UMR green sunfish, white suckers, and fathead minnows are not sympatric with M. nervosa but were used because of their availability. However, they may be good family representatives. Glochidia for infection were collected by flushing specimens from the excised gills of a live gravid female mussel into a 15-cm dia watch glass with a water-filled hypodermic syringe. A sample of glochidia was tested for viability by addition of a few salt grains to their water. Glochidia that are suitable for use in infections snap shut when salt is introduced.

Twenty fish of each species were slightly anesthetized with 100 ppm tricane methanosulfate (MS-222) and then exposed in groups of four to approximately 100 glochidia in a watchglass. Each species was held separately in a 40-L 17°C flow-through aquarium after infection. Examinations were made one hour after exposure to determine the percentage of fish initially infected. A subsample of five fish from each tank was examined every three days thereafter to ascertain retention of glochidia. One week after initial infection, debris from the bottom of the aquarium was collected every other day and filtered through a 130 um nylon mesh screen. The filtered material was examined with a dissecting scope for the presence of glochidia or free-

living juveniles. When juveniles were detected, aquaria bottoms were siphoned daily until one week after finding the last juvenile mussel. Fish were examined at the week,s end for continued infection. The experiment was discontinued if no further glochidial attachment was found.

An additional study was conducted to determine the effect of temperature on the duration of the parasitic period. Two aquaria, each containing 20 channel catfish were used in this host specificity study. Conditions for each group were identical except one aquarium was maintained at 12°C and one at 17°C.

The survival rate of unattached glochidia was examined. Glochidia not used to infect potential host fish were maintained in a 20-L aerated glass jar that was in a 12°C water bath. A sample was examined every two days to estimate the percentage of living glochidia.

Gametogenesis

Approximately 20 specimens of M. nervosa were randomly collected from the study area at monthly intervals from April 1986 to January 1987 and again in March 1987 by the Wisconsin Department of Natural Resources. Collections were made by SCUBA divers from April to November 1986. Winter samples (December to March) were obtained from caged

individuals that had been placed in covered wire baskets (529 mm X 381 mm X 229 mm) in July 1986. The bottom and 20 cm of each side of the baskets were lined with two layers of heavy aluminum foil. A 15-cm layer of dredge spoil sand was used as substrate. Cables were attached to the baskets) which were then placed in the river. Baskets were retrieved by breaking through the ice and retrieving the baskets by the cable. Mussels used for histological examination were pegged open and preserved in 70% ethanol denatured with methanol. Specimens were later transferred to jars containing 70% ethanol.

Each mussel was prepared for histological study of the reproductive material by removing, dehydrating, and embedding a portion of the gonadal material in paraffin. Serial sections (8 um) of the gonadal material were sectioned with a microtome, affixed to albumin-coated glass slides, stained by standard Hematoxilyn-Eosin procedures (Humason 1972), and permanently affixed to the slide with Permount (Fischer Scientific Co., Pittsburg, PA 15219). Specimens were examined with a compound microscope, and the sex and seasonal stages of gametogenesis were evaluated based on Yokely (1972). The presence of glochidia in female marsupia was also noted. Observations were numerically classified to facilitate analysis and discussion of the

gametogenic cycle (Table 1).

The age at which mussels attained sexual maturity was determined by comparing gonadal development of 74 young mussels (ages one to eight) during July, August, and September, which are months of active gametogenesis (Stages 2, 3, and 4). Gonadal sections and marsupial gills were examined, and mussels were categorized into the defined stages.

Age and Growth

The age, length, and height of 355 mussels were determined to estimate the age and size at sexual maturity and growth rates of M. nervosa. Mussels were aged by counting annular growth rings on the shells (Stansbery 1961, Rhodes and Lutz 1980). An average of three counts from each shell was used to estimate age. Validation of this technique was made by comparing results to those obtained with a thin-sectioning (internal) method (Rhodes and Lutz 1980, Moyer 1984). Internal aging is considered a more accurate estimator of age than external ring counts; however, it is time consuming, labor intensive, not practical for aging large numbers of individuals, and cannot be performed in the field. Shells were initially cut with a diamond isomet saw along the vector of maximum length beginning at the umbo. The cut edge was polished using 600-grit powder. A secondary cut was made parallel to the first with a low speed diamond isomet saw to obtain a thin-section. The section was affixed to a glass microscope slide with epoxy glue. The section was then ground to a thickness of 0.3 mm with a thin-section diamond grinder. The thin-sections were aged by counting the distinctive dark annuli under a dissecting microscope illuminated with polarized light.

External and internal aging data were compared by regression analysis to determine if a significant relationship existed between the two methods. Internal age was assumed to be the absolute indicator of age and was used as the independent variable. The data were compared to determine whether external ring counts were acceptable for this study.

Standard definitions of length and height were used when measuring shells. Length is defined as the maximum antero-posterior dimension of the shell, and height as the maximum dorso-ventral dimension of the shell measured at right angles to the length (Ortmann 1920, Ball 1922). The length and height of M. nervosa shells were measured to the nearest 0.1 mm with a caliper. A simple linear regression for length verses age and height verses age was performed and yearly growth in length and height were predicted. A 95% confidence interval for each predicted length and height measurement was also determined.

RESULTS and DISCUSSION

Host Specificity

Glochidia of M. nervosa metamorphosed to free-living juveniles on channel catfish, black bullheads, and green sunfish (Table 2), indicating that these species are suitable hosts. Juveniles were recovered from aquaria maintained at 17°C beginning 26 to 28 days after infection. In the 12°C aquarium, juveniles were recovered starting 56 days after infection, demonstrating that duration of the parasitic period of M. nervosa was negatively related to temperature. Similar observations have been made for other unionids (Lefevre and Curtis 1912). Variation in the number of juveniles recovered from host fish was attributed to differences in the number of glochidia initially attaching to fish, to predation upon the juveniles by host fish, and to intraspecific and interspecific variation in the ability of fish to retain or reject glochidia.

Howard (1914), Surber (1915), and Wilson (1916) reported several species of fish upon which M. nervosa glochidia were found; however, few of the listed hosts produced juvenile mussels. The results of my experiments verify three previously listed host fish, channel catfish, black bullheads, and green sunfish. Howard (1914) noted that laboratory-induced infections of M. nervosa glochidia

Table 2. Metamorphosis of *Magnonaias nervosa* glochidia from laboratory-induced infections on green sunfish (*Lepomis cyanellus*), black bullheads (*Ictalurus melas*), and channel catfish (*Ictalurus punctatus*).

Infected fish species	Mean temperature (°C)	Days to metamorphosis	Number of juveniles recovered
Lepomis cyanellus	17	26	6
Ictalurus melas	17	28	9
Ictalurus punctatus	17	26	152
Ictalurus punctatus	12	56	10

on channel catfish and black bullheads persisted more than four months; he concluded these species were hosts. Transformed juveniles were obtained from both of these species in my study, supporting Howard,s conclusion and Fuller,s listing. Fuller (1978) and Coker et al. (1921) listed green sunfish as a host for M. nervosa. although the primary source of their information is unclear. Six juvenile mussels were obtained from green sunfish in this study, verifying this species as a host.

The reproductive success of mussel populations depends on the abundance of host fish. Channel catfish are probably important hosts that affect the distribution and perpetuation of M. nervosa. This species occurs throughout the range of M. nervosa and occupies similar habitats (Becker 1983, Duncan and Thiel 1983, Dawley 1947, Pflieger 1973), which would increase the probability of their infection by M. nervosa glochidia thus potential recruitment. Black bullheads and green sunfish are sympatric with M. nervosa. However, these species may contribute less to potential recruitment because they prefer shallow backwaters and low gradient streams. In contrast, M. nervosa is most frequently found in large rivers with relatively higher gradients (Dawley 1947, Duncan and Thiel 1983).

Fish behavior can influence the probability of encounter between glochidia and host fish. Zale and Neves (1982) reported release of glochidia coincident with occurrence of fish hosts. The opportunistic bottom-feeding behavior of channel catfish and black bullheads could stimulate a release response in gravid M. nervosa females, which often eject conglutinated glochidial masses when disturbed. These masses can act as a lure for fish (Coker et al. 1921, Baker 1928, Chamberlain 1934), thereby increasing the probability of glochidial attachment to a potential host.

I also observed that the hyaline threads of M. nervosa glochidia wrapped around the fins and barbels of the host fish; the glochidia trailed behind. This allowed the glochidia more opportunities to contact and infect a host.

Glochidia are not selective in their initial attachment to fish (Lefevre and Curtis 1912, Arey 1924); however, continued attachment depends on substances in fish mucous (Wood 1974). For example, no juveniles were recovered from the tanks containing fathead minnows, common carp, white suckers, or yellow perch, although the frequencies of initial infections were 95% to 100% (Table 3). Carp and fathead minnows shed all glochidia by the fourth day of the study, whereas yellow perch and white suckers retained glochidia for 23 and 26 days, respectively.

Table 3. Percent of fish initially infected and duration of Magnonaias nervosa glochidial attachment to selected fish species.

Fish species	Percent initially infected	Duration of infection (d)
Pimephales promelas	100	3
Cyprinus carpio	95	1
Catostomus commersoni	100	26
Perca flavescens	100	23

Termination of glochidial infections may be due to a natural or acquired immune response by the fish or because the fish does not provide some essential nutrient to the glochidia (Arey 1924, 1932, Barriga 1981, Meyers et al. 1980). Fathead minnows and carp were unacceptable hosts as demonstrated by the brief infection period, possibly indicating a strong natural immunity by the fish. The parasitic period for glochidia on yellow perch and white suckers endured about as long as that observed for viable hosts. These species may be marginal hosts for M. nervosa and repeated laboratory infections could verify this. Hypertrophied cysts containing glochidia were released by yellow perch and white suckers throughout the infection period, and brown scars, indicating glochidial attachment sites, were apparent on the white suckers. A similar response has been observed by Arey (1932) and Meyers et al. (1980). Acquired immunity did not contribute to the rejection of glochidia in my experiments because all fish were laboratory-reared young-of-the-year that had never been exposed to mussel glochidia.

M. nervosa glochidia can remain viable for many days without attachment to a host. Seventy-nine percent of adult females collected in October (river temperature 9°C) were gravid while <1% of females were gravid in November (3°C).

Therefore, in nature most glochidia were released at temperatures <9°C. At 12°C in the laboratory, glochidia remained capable of attaching to host fish up to 10 days after release. In the river, it is possible that glochidia may remain viable and capable of attaching to a host for perhaps two or more weeks.

The evaluation of fish as potential hosts of M. nervosa is essential to predict reproductive success of the species. Verification of all fish hosts listed by Fuller (1978) and Coker et al. (1921) and the superimposing of host-mussel distributions and habitat preferences can indicate to resource managers if recruitment into the population is likely. The importance of hosts to the perpetuation of a mussel species will vary based on the probability of their encounter with the glochidia. M. nervosa may have numerous potential fish hosts (Fuller 1978, Coker et al. 1921); however, a fish with a low probability of encountering a glochidia should not be considered a viable natural host.

Gametogenesis

Gonadal sections of 255 M. nervosa specimens collected between April 1986 and March 1987 were examined to determine reproductive life history patterns. Males appear to attain sexual maturity in their fifth or sixth year, whereas

females begin to reach maturity in their sixth or seventh year. All eight-year-olds had well differentiated active gonadal tissue, but younger specimens often did not. Therefore, I considered mussels at least eight years old as adults.

Of the 220 adult mussels examined, 72% were females and 28% were males. Oogenesis and spermatogenesis followed a seasonal pattern. Ovarian alveoli of specimens were widely separated and contained oogonia and a few small oocytes in the alveolar walls from November to May (Stage 1, Figs. 2 and 3). In June 44% of the females examined were in Stage 2, while only 16% were in Stage 2 in July. In July, 84% of the females were in Stage 3, and acinal luminas were filled with mature ova. In August and September, ova were transferred to the marsupial gills (Stage 4) where differentiation to glochidia occurred. Glochidia were released from September to November as evidenced by the change from Stage 4 to Stage 1 (Fig. 3).

Active gametogenesis in M. nervosa males was evident throughout the year except in April 1986 and November and December 1987 when all specimens were in Stage 1 of gametogenesis (Figs. 4 and 5). Stage 2 males, characterized by acini with many enlarged spermatocytes and some spermatids, were found from May through August and again in

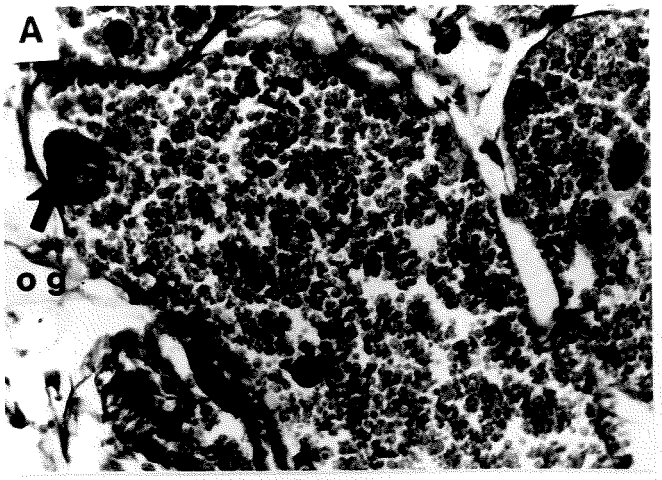
November and December. Males with spermatozoa filling the lumina became prevalent in July (Stage 3). Swollen gonado-visceral masses were common from August to October in Stage 3 males; release of gametes probably occurred during these months. These data indicate a late tachytictic breeding strategy for M. nervosa in the UMR.

Tachytictic or short-term breeders commonly complete an entire gametogenic cycle by late spring or early summer. M. nervosa completes its cycle by mid-fall and, therefore, appears to have the latest tachytictic strategy known for freshwater mussels. This observation agrees with conclusions drawn by Howard (1914), Lefevre and Curtis (1910), and Bingham (1968).

Temperature probably has a great influence on timing of the reproductive cycle of M. nervosa. It is possible that early cold temperatures could delay glochidial release until the ensuing spring. This would account for the bradytictic characterization of this species by Utterback (1915-1916) and Coker et al. (1921). Glochidia released in the fall probably remain attached to host-fish until temperatures increase in the spring as implied by my host specificity experiments.

Figure 2. Histological sections of Magnonaias nervosa ovaries. (A) Stage 1, specimen collected 8/27/86; (B) Stage 2, specimen collected 6/19/86; (C) Stage 3, specimen collected 7/29/86. Key: og=oogonia, oo=ovocytes, ov=mature ova.

Figure 3. Seasonal gametogenic stages of Magnonaias nervosa females in the East Channel, Navigation Pool 10, Upper Mississippi River.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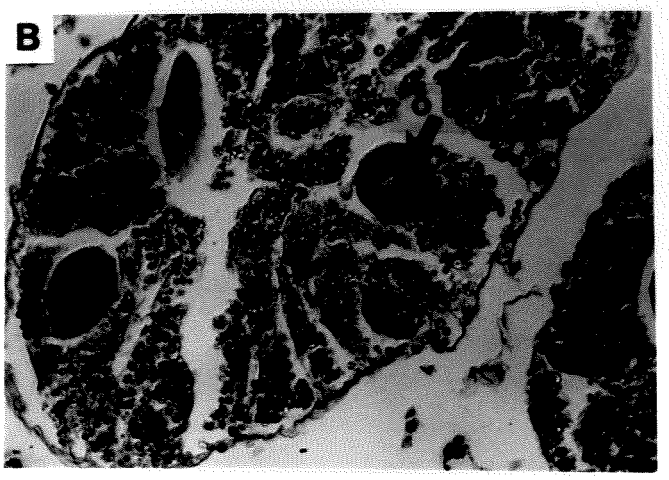
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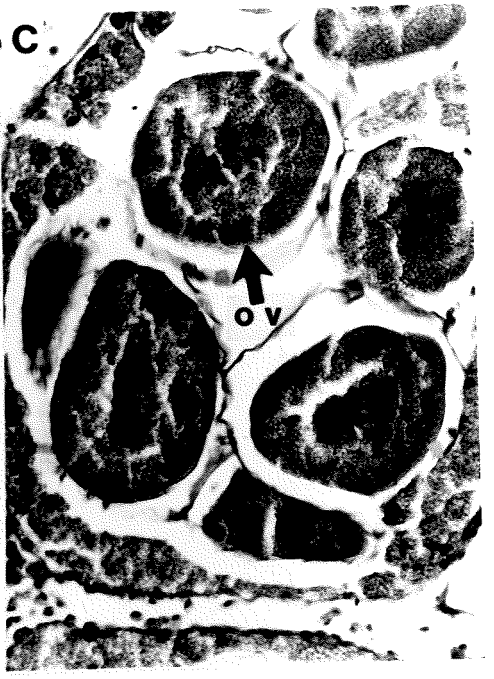
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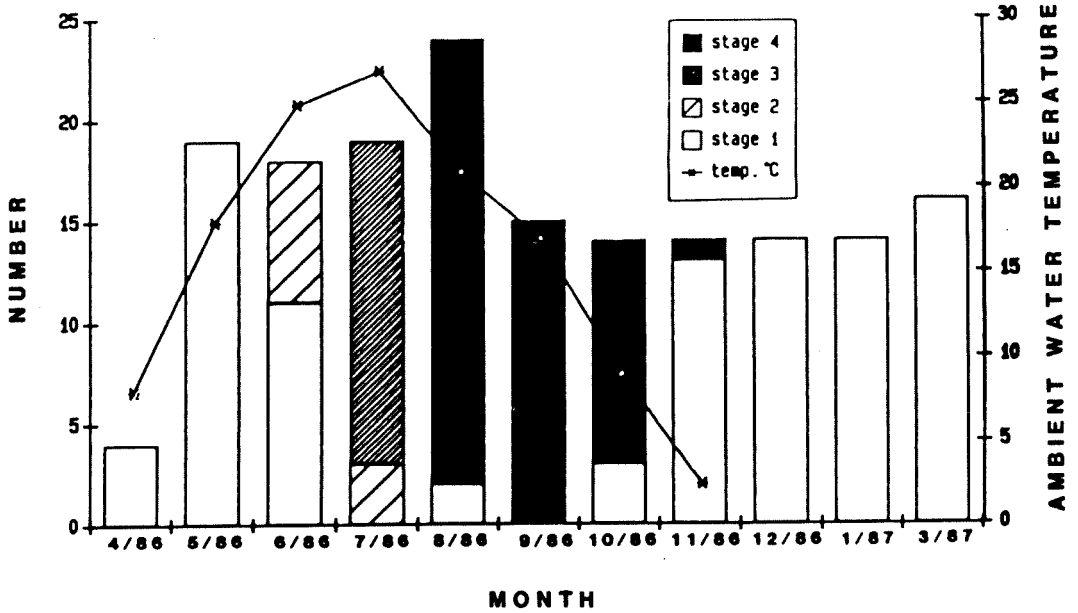
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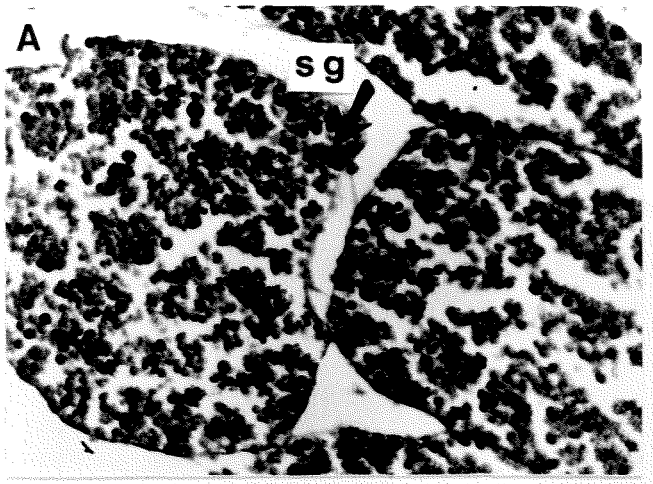
Figure 4. Histological section of Magnonaias nervosa testis. (A) Stage 1, specimen collected 6/19/86; (B) Stage 2, specimen collected 7/27/86; (C) Stage 3, specimen collected 8/27/86. Key: sg=spermatogonia, sp=spermatids, sz=spermatozoa.

Figure 5. Seasonal gametogenic stages of Magnonaias nervosa males in the East Channel, Navigation Pool 10, Upper Mississippi River.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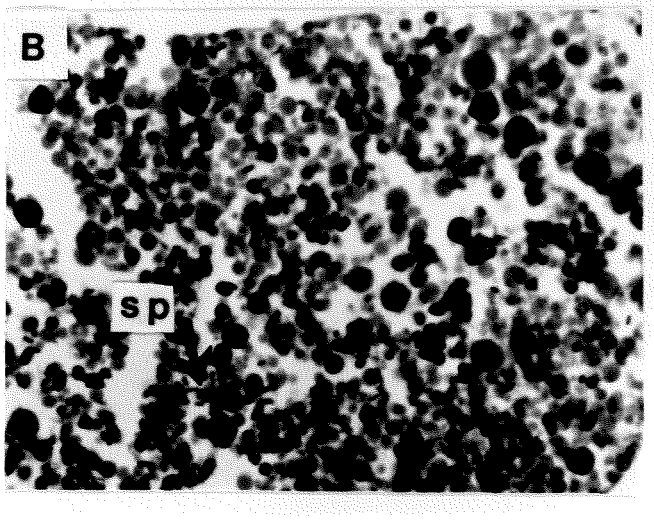
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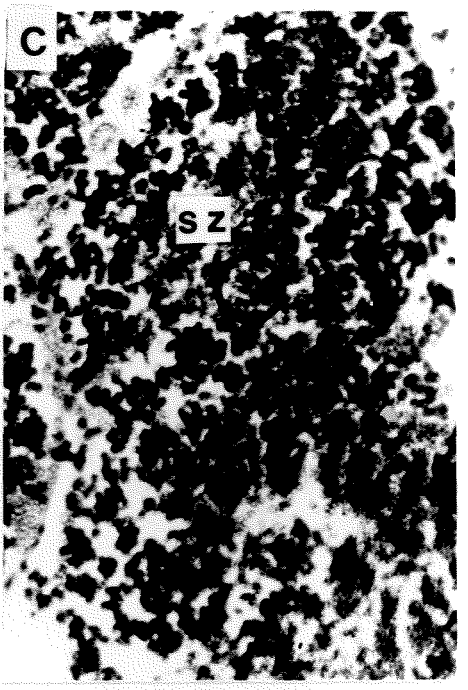
C
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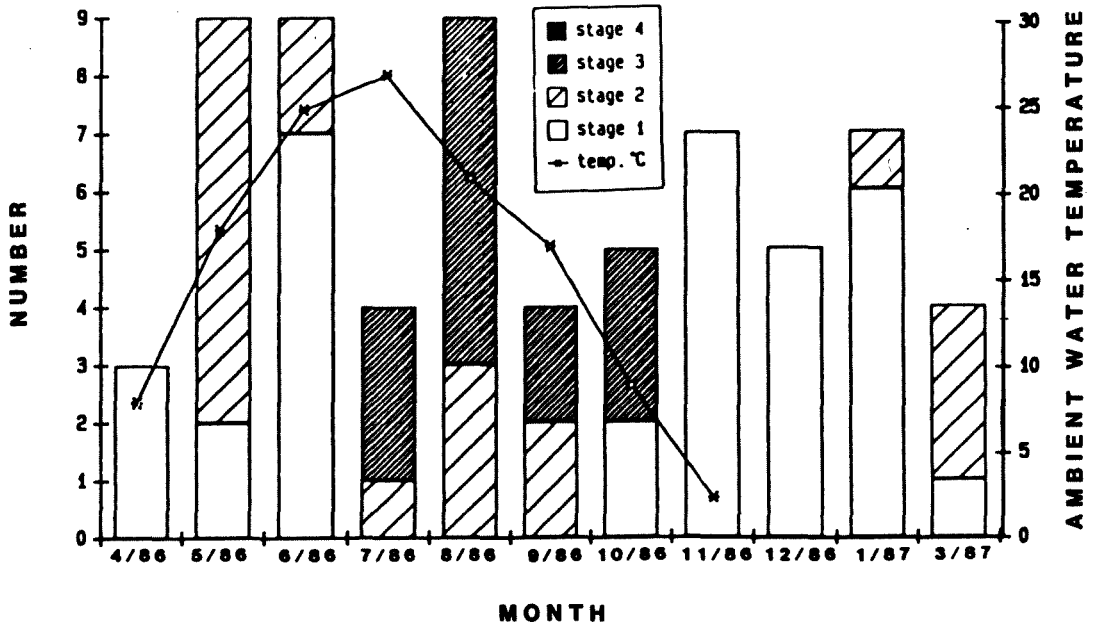
stage 4
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NUMBER
AMBIENT WATER TEMPERATURE
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4/86
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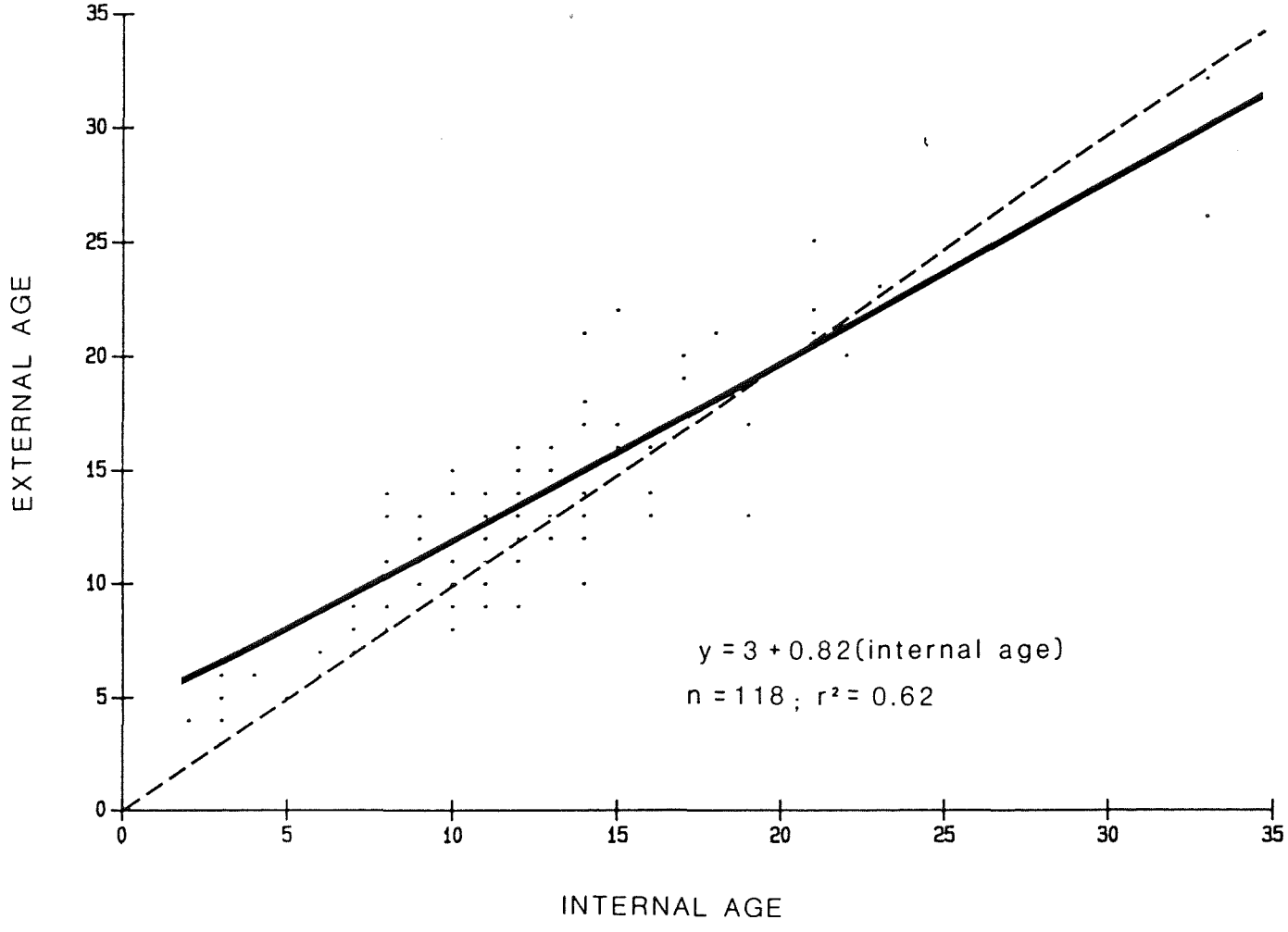
12/86
1/87
3/87

Age and Growth

The age, length, and height of 355 M. nervosa specimens were estimated to predict annual growth rates as well as age and size of organisms at sexual maturity. External and internal aging methods were compared for 118 mussels to validate the use of external rings to estimate age. The observed relationship (Fig. 6), external age = 3 + 0.82 (internal age), was significant ($p = 0.0001$; $r^2 = 0.67$); however, a high r^2 was not realized for the following reasons. The majority of specimens (94%) were between the ages of 5 and 17 and the accuracy of age estimates, external and internal, decreased for specimens age 10 and older. This was due to slower growth rates as organisms age; consequently, annuli are more crowded and difficult to count in older specimens. When the two techniques were compared for age groups 1-10, a better fit was realized ($r^2=0.80$). Variability in the independent component, internal ring count, occurred due to my inexperience with the technique, and the difficulty of distinguishing true from false annuli. False annuli can be produced in response to a stressful situation such as a flood (Rhodes and Lutz 1980). Therefore, the internal aging technique was not an absolute indicator of age.

Figure 6. Actual regression (——) hypothesized 1:1 relationship (— —) internal to external aging techniques.

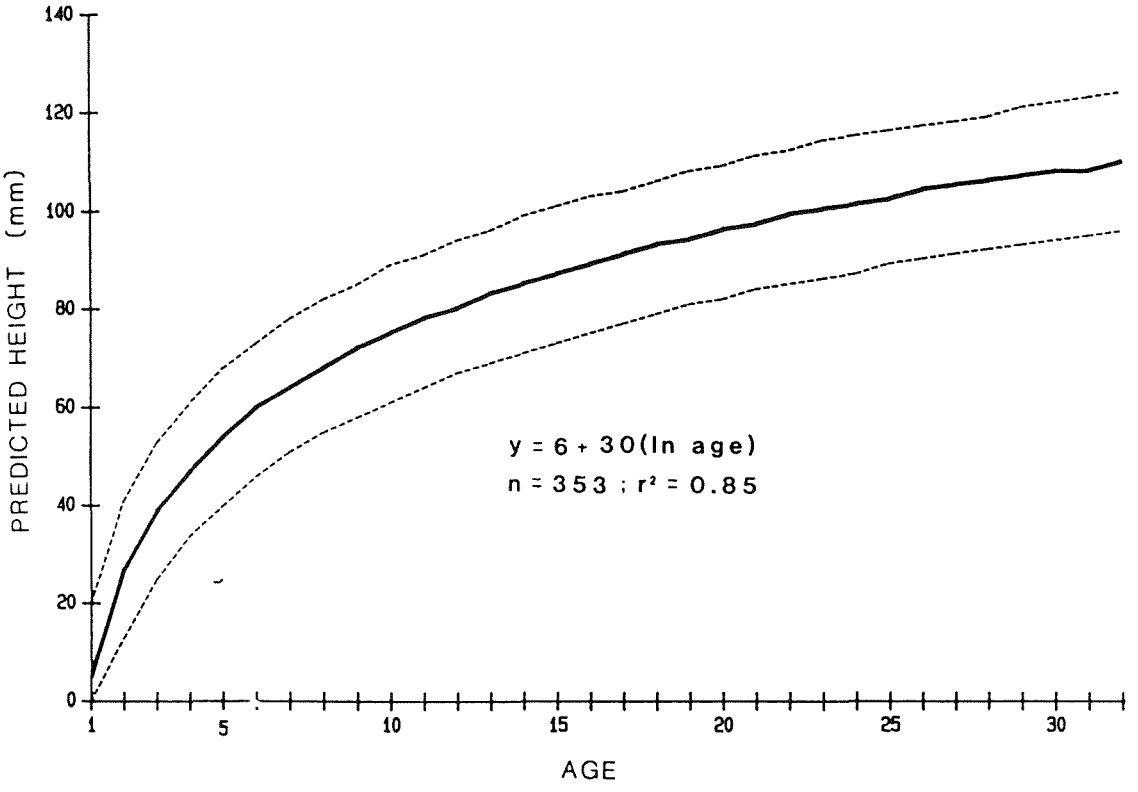

EXTERNAL AGE
INTERNAL AGE
0
5
10
15
20
25
30
35
y = 3 + 0.82(internal age)
n = 118 ; r² = 0.62

Measured components of size (height and length), exhibited characteristic growth curve functions. Annual growth in height was described by the regression equation: height = 6 + 30 (ln age), ($p=0.0001$; $r^2=0.86$). Mussels grew about 27 mm in height during the first two years but only 12 mm, 9 mm, and 7 mm in years 3-5, respectively. Growth in height slowed to an average of about 4 mm/year after age five (Fig. 7). Annual growth in length was described by the equation; length = 4 + 44 (ln age), ($p=0.0001$; $r^2=0.85$). Predicted growth in length was about 34 mm by year two. The average growth for years three through six was about 12 mm/yr. Growth in length averaged only 5 mm/yr for years seven to eleven and after age 12 about 2mm/yr (Fig. 8).

The minimum size of M. nervosa permitted to be harvested is based on the height of the individual. Prior to 1986, the legal minimum size was 1.75 in. (44.5 mm), although a minimum commercial limit of 4.0 in. (102 mm) was set by shell buyers. In 1986, Wisconsin and Minnesota established a minimum harvest size of 3.5 in. (89 mm). Superimposing this information over the predicted height at age regression (Fig. 9) indicates that individuals of 89 mm in height may be 10 to 15 years old (implied by the upper 95% confidence interval). Because the average age of attaining sexual maturity is eight years old, the 89 mm

Figure 7. Predicted annual growth (95% confidence intervals included) in height (——) of Magnonaias nervosa, Navigation Pool 10, East Channel, Upper Mississippi River.

Figure 8. Predicted annual growth (95% confidence intervals included) in length (——) of Magnonaias nervosa, Navigation Pool 10, East Channel, Upper Mississippi River.


PREDICTED HEIGHT (mm)
140
120
100
80
60
40
20
0
1
5
10
15
20
25
30
AGE
y = 6 + 30(ln age)
n = 353 ; r² = 0.85

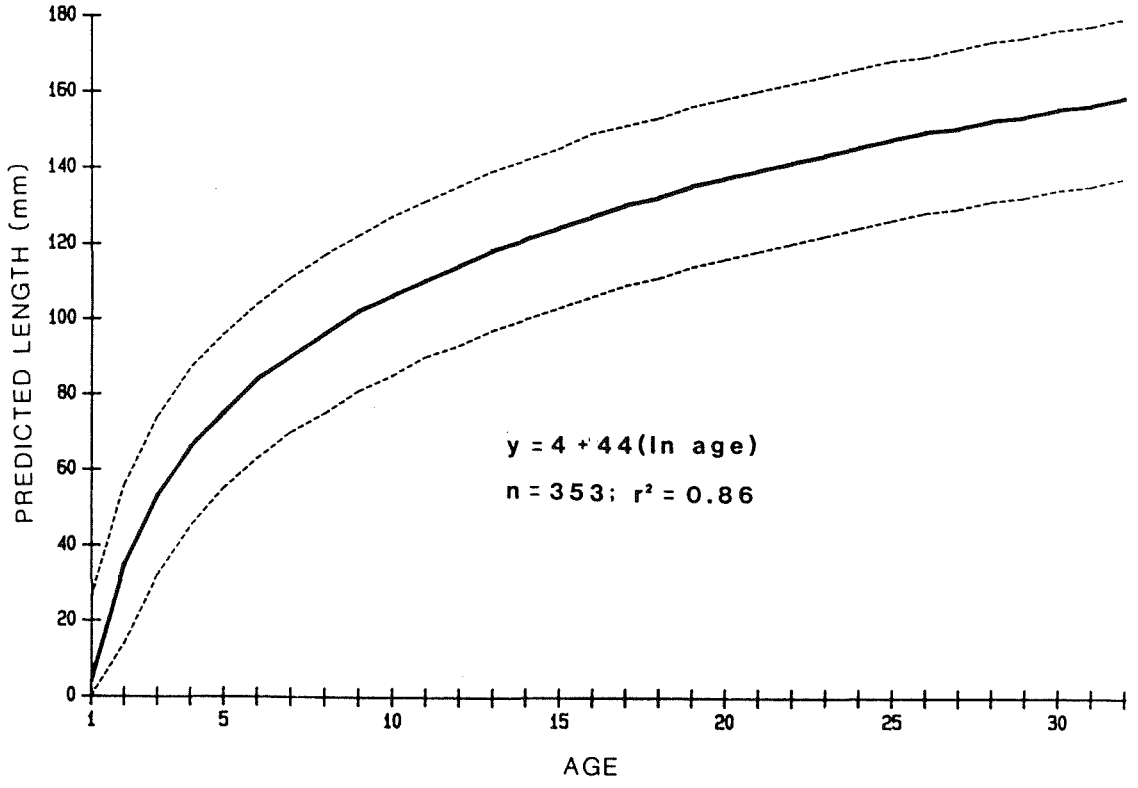
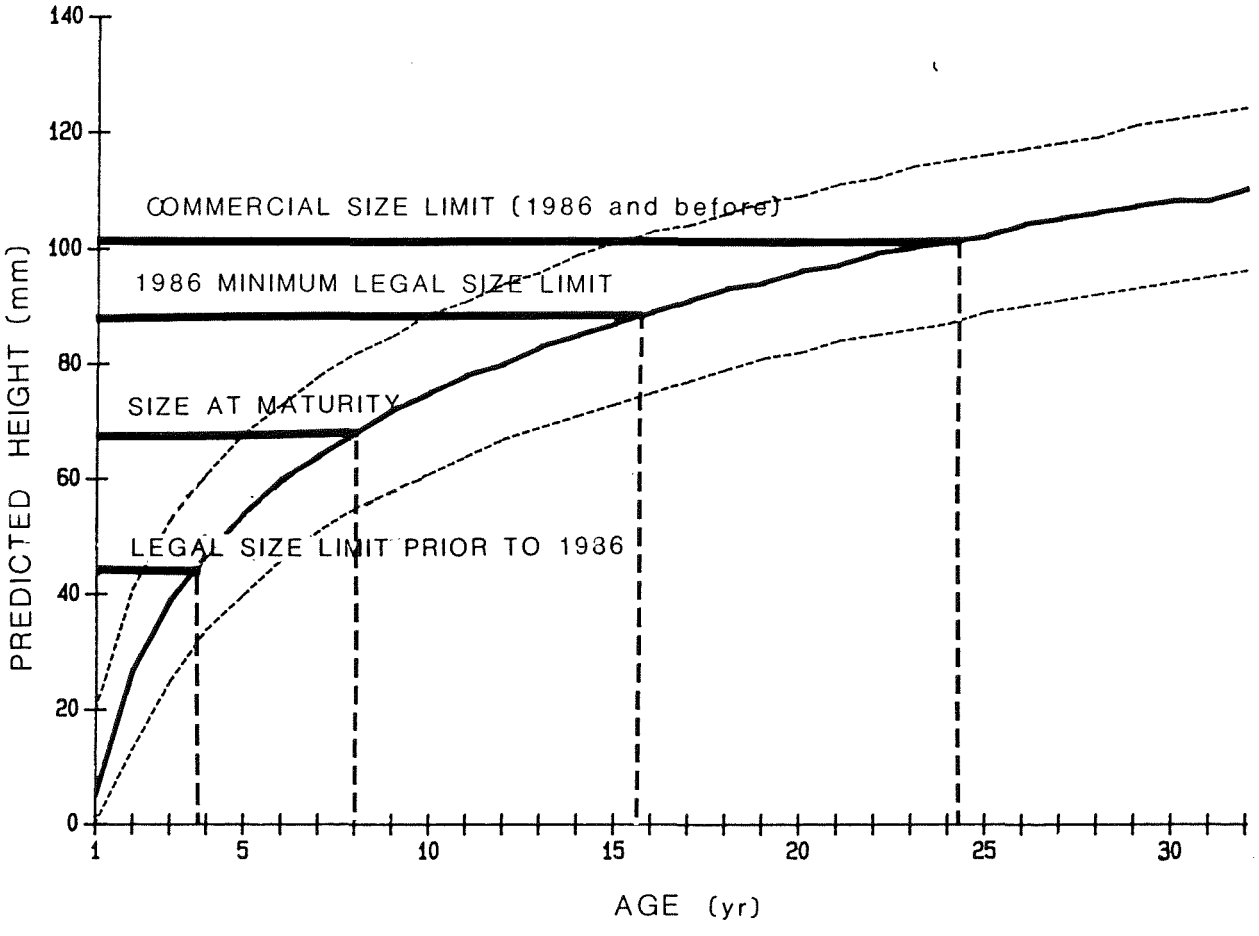

PREDICTED LENGTH (mm)
180
160
140
120
100
80
60
40
20
0
1
5
10
15
20
25
30
AGE
y = 4 + 44(ln age)
n = 353; r² = 0.86

Figure 9. Predicted annual growth in height, height at sexual maturity, and minimum harvest heights for Magnonaias nervosa in Navigation Pool 10, Upper Mississippi River. Predictions are based on the following regression equation: height = 6 + 30 (ln age).


140
120
100
80
60
40
20
0
PREDICTED HEIGHT (mm)
COMMERCIAL SIZE LIMIT (1986 and before)
1986 MINIMUM LEGAL SIZE LIMIT
SIZE AT MATURITY
LEGAL SIZE LIMIT PRIOR TO 1986
1
5
10
15
20
25
30
AGE (yr)

limit would permit two to seven years of reproduction before harvest. Referring to the 95% confidence interval for an individual of 89 mm, a minimum of one year of reproduction may be permitted by this size limit. This information could be used more effectively if an estimate of natural recruitment were also available for the species. Without this information, it is difficult to judge the net reproductive capacity of an individual.

Recruitment of M. nervosa into natural populations of the UMR is probably low. Surber (1915) examined 2,815 fish (38 species) and determined the incidence of glochidial infection by all mussel species to be 1.5%. Kammer (1986) examined 1,786 fish (33 species) in Navigation Pool 7 of the UMR and determined a 4.1% incidence of infection. These data indicate a low recruitment rate for freshwater mussel populations.

CONCLUSION

The results of my research indicate that M. nervosa in the UMR completes an entire reproductive cycle between early spring and late fall. The female gametogenic cycle follows a distinct pattern: a resting phase (December to April); the production and maturation of ova (June and July); and the differentiation of ova to glochidia, culminating in their release (August to November). A different pattern was observed for male mussels; e.g. gametogenesis occurred throughout the year with sex products maturing between July and September--sperm release probably occurred during this period. The reproductive cycle is likely affected by temperature and patterns may vary from year to year.

The study population exhibited a 3:1 female to male sex ratio. Males apparently mature between the ages of five and eight years and females between the ages of six to eight. All specimens were reproductively active by their eighth year.

The maturation size of exploited mussel species can affect recruitment because size-limits regulate harvest. M. nervosa matures at a shell height of about 89 mm. Legal harvest size limits prior to 1986 permitted the harvest of immature specimens; however, the commercial minimum size

limits set by buyers during this period (101 mm) probably determined what was actually harvested. The minimum size-limits set in 1986 allow about one to seven years of recruitment based on the predicted heights and their 95% confidence intervals (Fig. 9).

Natural recruitment into mussel populations is probably low as indicated by distributional studies (Ecological Analysts Inc. 1981, Duncan and Thiel 1983) and studies of the incidence of infection (Surber 1915, and Kammer 1986). Magnonaias nervosa is a heavily exploited species. The results of this and other recent studies (Wisconsin Department of Natural Resources 1987), combined with the unquantified impact of system alteration, suggest that management decisions regarding the intense harvest of M. nervosa be conservative.

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