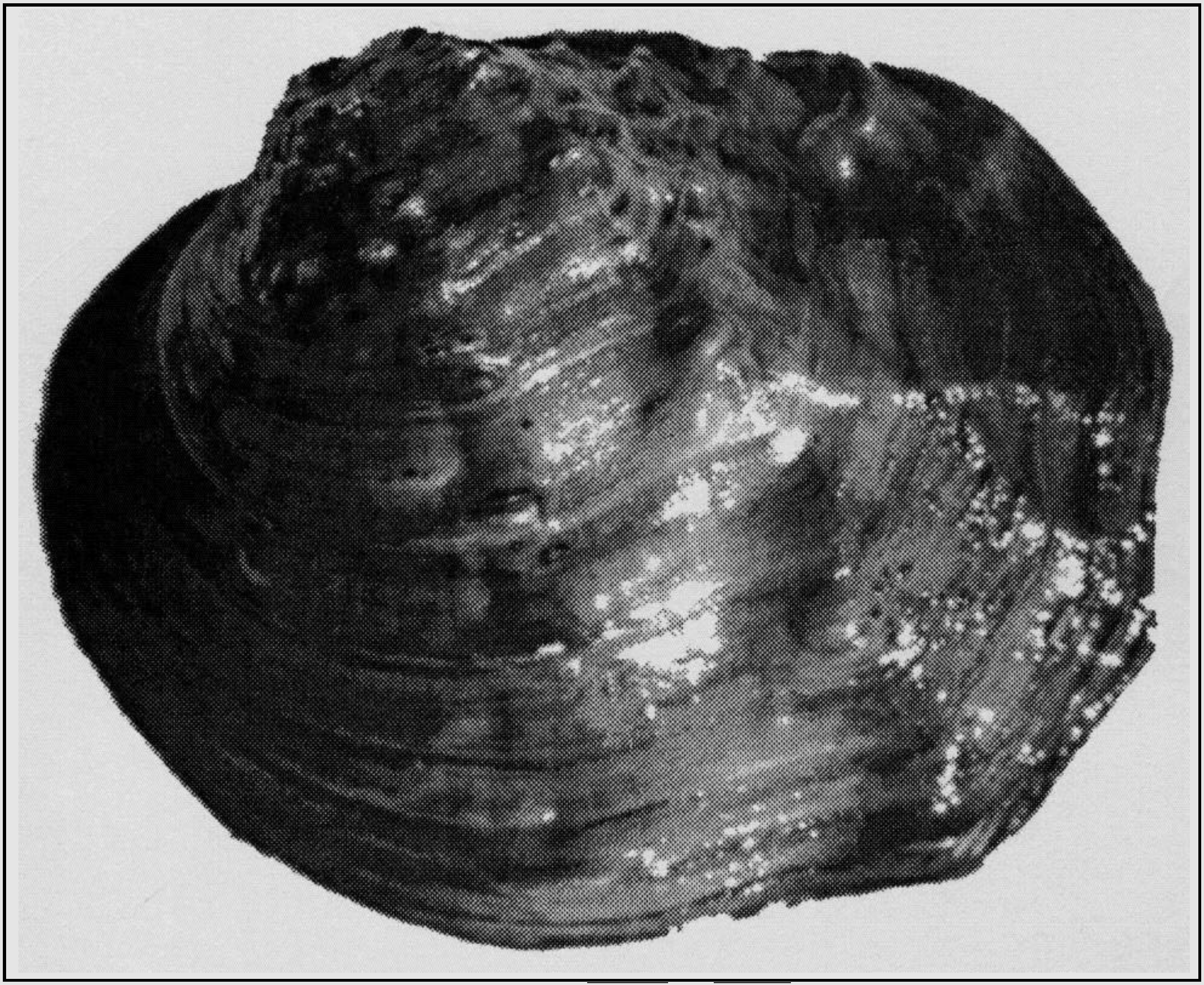
Winged Mapleleaf Mussel Recovery Plan

(*Quadrula fragosa*)



Department of the Interior
United States Fish & Wildlife Service

Photo by David Heath, Wisconsin Department of Natural Resources

WINGED MAPLELEAF MUSSEL (*Quadrula fragosa*)
RECOVERY PLAN

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Date

Disclaimer

This is the winged mapleleaf mussel (*Quadrula fragosa*) recovery plan. Recovery plans delineate reasonable actions believed required to recover and/or protect listed species. Plans are published by the U.S. Fish and Wildlife Service (Service), sometimes prepared with the assistance of recovery teams, contractors, state agencies, and others. Objectives will be attained and any necessary funds made available subject to budgetary and other constraints affecting the parties involved, as well as the need to address other priorities. Recovery plans do not necessarily represent the views nor official positions or approval of any individuals or agencies involved in plan formulation, other than the Service. They represent the official position of the Service **only** after being signed by the Regional Director or Director as **approved**. Approved recovery plans are subject to modifications as dictated by new findings, changes in species status, and the completion of recovery tasks.

Acknowledgements

The Winged Mapleleaf Mussel Recovery team acknowledges the following individuals as technical advisors or other contributors to the development of this plan. Dr. Caryn Vaughn, Oklahoma Biological Survey, provided specimens of the Kiamichi River population of *Quadrula* sp.; David Stansbery, Ohio State University, and Charles Mather, University of Science and Arts of Oklahoma, provided systematics information on the *Quadrula* complex; Ian Chisholm and Shawn Johnson, Minnesota Department of Natural Resources, and David Hanson, of EA West, and Paul Leonard, of EDAW, Inc., provided instream flow study results and critique. The following individuals served as technical advisors to the Recovery Team: Ken Mueller, Northern States Power Co.; Mike Davis and David Leuthe, Minnesota Department of Natural Resources; Andrew Miller, Corps of Engineers Waterways Experiment Station; Jim Fossum, Dave Warburton, and Scott Yess, U.S. Fish and Wildlife Service; Mark Hove, James Perry, and Nels Troelstrup, University of Minnesota; Delwayne Nimmo, National Park Service; Alan Buchanan, Missouri Department of Conservation; Lisa Mueller, Minnesota Department of Agriculture; Ken Bovie, Greg Cope, James Layzer, Leif Marking, Teresa Naimo, Claire Stalnecker, and Diane Waller, National Biological Service (now U.S. Geological Survey, Division of Biological Resources); Kevin Cummings, Illinois Natural History Survey; Marian Havlik, Malacological Consultants; Robert Hay, Ken Johnson, and William Smith, Wisconsin Department of Natural Resources; Glenn A. Miller, Great Lakes Indian Fish and Wildlife Commission; and Edward Cawley, Loras College. Chuck Kjos, U.S. Fish and Wildlife Service, served as Service liaison to the Team and assisted development of the plan.

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Executive Summary

Current status: The winged mapleleaf mussel is a federally endangered species. The single known remnant population exists in a 20-kilometer stretch of the lower St. Croix River between Minnesota and Wisconsin. Extensive surveys of this stretch of the river between 1988 and 1992 found only 77 individuals. In recent years, recruitment to this population has been low; there has not been a large cohort recruited to the population since 1984.

Habitat requirements and population limiting factors: Specific habitat requirements of this species are not known. The St. Croix River is in a moderately to minimally disturbed watershed with generally high water quality. The river is a National Wild and Scenic River and this designation confers some protection from anthropogenic disturbance of the population. Major factors of concern for the population are: (a) low reproduction, (b) low stream flow episodes, (c) high variation in stream flow caused by hydroelectric dam peaking operation during certain seasons, (d) toxic spills, (e) potential zebra mussels colonization of the St. Croix River, (f) habitat disturbance or alteration by recreational or commercial activities, (g) human and non-human predation and disturbance, (h) water quality deterioration, (i) land-use changes in the watershed; and (j) lack of knowledge of the mussel's life history, especially its glochidial host.

Recovery objective: Recovery and delisting. The objective of this recovery plan is to improve the security of the winged mapleleaf mussel so it may be removed from the Federal list of threatened and endangered species.

Recovery criteria: Specific delisting criteria are: (a) Five discrete populations in at least three tributaries of the Mississippi River, unless Task 2D4 determines otherwise; (b) A population must be viable as defined in Task 5A of this plan's the narrative outline; (c) A population must demonstrate persistence as defined in the narrative outline under Task 5B; (d) A population must have long-term habitat protection as defined in the narrative outline under Task 5C.

Actions needed:
1) Maintain the St. Croix population of *Q. fragosa.*
2) Improve our understanding of *Q. fragosa* biology and ecology.
3) Increase the St. Croix population of *Q. fragosa.*
4) Reestablish four *Q. fragosa* populations in its historical range.
5) Reclassify and delist *Q. fragosa.*

Estimated Costs (000 omitted):

Year	Need 1	Need 2	Need 3	Need 4	Need 5	
	Total					
1	$306.5	$140.0	TBD	TBD	TBD	$446.5
2	$238.0	$140.0	TBD	TBD	TBD	$378.0
3	$203.0	$100.0	TBD	TBD	TBD	$303.0
Total	$747.5	$380.0	TBD	TBD	TBD	$1,127.5

Date of expected recovery: To be determined.

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Acronyms: Key to acronyms used in the Recovery Plan:

MDNR = Minnesota Department of Natural Resources
MDOT = Minnesota Department of Transportation
MPCA = Minnesota Pollution Control Agency
NSP = Northern States Power Company
USACOE = United States Army Corps of Engineers
USEPA = United States Environmental Protection Agency
USFWS = United States Fish and Wildlife Service
USGS = United States Geological Survey
USNPS = United States National Park Service
WDOT = Wisconsin Department of Transportation
WDNR = Wisconsin Department of Natural Resources

Introduction

<u>Description of *Quadrula fragosa*:</u>

Taxonomy and systematics:

Phylum:	Mollusca; (Linne 1758, Cuvier 1797).
Class:	Bivalvia; (Linne 1758 after Bonnani 1681).
Order:	Unionoida; (Stoliczka 1871).
Family:	Unionidae; (Fleming 1828, Ortmann 1911).
Genus:	*Quadrula*; (Rafinesque 1820).
Species:	*Quadrula fragosa*; (Conrad 1835) near sigf.

Quadrula fragosa belongs to the *Q. quadrula* complex, which includes the following species: *Q. quadrula* (Rafinesque 1820), *Q. apiculata* (Say 1829), *Q. rumphiana* (Lea 1852), and *Q. asperata* (Lea 1861).

Synonyms include: *Unio fragosus* (Conrad 1835) and *U. tragosus* (sic) (Hanley 1842-1856). Vernacular names include: maple-leaf (Danglade 1914, Coker 1921, Shimek 1921), hickory nut shell (Baker 1928), rough mapleleaf, stranger (Fuller 1980b), false mapleleaf (Fuller 1980a), winged mapleleaf (Turgeon *et al.* 1988), and winged maple leaf (Watters 1988).

The Type locality is the Scioto River, Ohio. The location of the holotype specimens is unknown.

Physical description:

Shell: (Figure 1) Adult shells grow to about 10 cm in length (Watters 1988). The shell profile is variously described as being suborbicular (Conrad 1835), roundly quadrate (Baker 1928), irregularly quadrate (Simpson 1914) to quadrate (Scammon 1906, Watters 1988). The shell is ventricose, but the degree of inflation varies from moderate (Watters 1988) to greatly inflated (Utterback 1915). Umbos are prominent, tuberculated, and incurved or turned forward over the lunule (Conrad 1835, Scammon 1906, Baker 1928, and Watters 1988). The umbonal slope is angular with a ratio of 0.2 to 0.3 (Conrad 1835, Scammon 1906). The anterior umbonal slope is smooth (Scammon 1906, Simpson 1914), while the posterior umbonal slope is excavated and covered with a series of small, irregular or transverse plications, which are gently bowed ventrally (Scammon 1906).

The shell has two prominent, heavily tuberculated, radial ridges (Conrad 1835, Utterback 1915). The posterior slope is slightly concave with a few narrow, costate tubercles, which are more prominent near the margin (Conrad 1835, Utterback 1915, Watters 1988). The lateral slope is marked posteriorly by a wide radial sulcus, bordered by a row of erect, prominent tubercles, which extend from the umbos to the margin. Minor tubercles are scattered among the major ones, particularly in the anterior series (Scammon 1906). The ligament slope is straight or slightly oblique (Conrad 1835, Utterback 1915). Growth lines are continuous and prominent (Scammon 1906).

The posterior margin is direct and slightly emarginate (Conrad 1835), forming a right angle with the posterior half of the ventral margin (Scammon 1906). The ventral margin is rounded and forms a full curve with the anterior margin (Scammon 1906, Simpson 1914). The dorsal margin is straight or only slightly curved and is oblique to both the anterior and posterior margins (Scammon 1906). The light brown ligament is short and of moderate thickness (Scammon 1906).

The epidermis of adults is dull brown, usually with two or three broad and widely interrupted green rays (Conrad 1835, Simpson 1914, Ortmann 1924). Some describe the adult color as "horn color to seal-brown" (Scammon 1906) or even dark yellowish (Utterback 1915). Juveniles are tan to greenish (Watters 1988).

Internal structures: Very little study of internal anatomy has been done on this species. The following description, except where noted, is from Scammon (1906). The pseudocardinal teeth are large, erect, serrate, and double in the left valve and single in the right valve (Scammon 1906, Simpson 1914). The interdenum is broad, short, and quite oblique. The anterior adductor scar is in front of the pseudocardinals and slightly under the anterior left pseudocardinal. The scar is small, deeply excavated, and has a level floor. The posterior scars are of moderate size, impressed, and distinct. The pallial line is impressed most of its length. Dorsal muscle scars are few, but well marked, and located on the lower surface of the pseudocardinals. The shell cavity is moderately large, but the beak cavity is deep and compressed (Scammon 1906, Simpson 1914). Wilson and Clarke (1914) studied two gravid females and demonstrated "all four gills serve as marsupia and are thick and pad-like". The nacre is white and slightly iridescent (Scammon 1906, Simpson 1914, Neel 1914, Watters 1988).

Comparison to other members of the *Q. quadrula* complex: *Quadrula fragosa* shows closest conchological affinity to *Q. quadrula* (= *Q. lachrymosa*, *Obliquaria quadrula*, *Unio rugosus*, *U. lachrymosus*, *U. quadrulus*) and is therefore most likely to be confused with this species throughout most of the Mississippi River drainage. The shell profile of *Q. fragosa* is more roundly-quadrate (Conrad 1835, Call 1900, Simpson 1914, Wilson and Clarke 1914, Utterback 1915, Coker 1921, Ortmann 1924, Baker 1928) than that of *Q. quadrula*, which is transversely quadrate. The postero-dorsal slope of *Q. fragosa* is wider and more alate (Baker 1928; Watters 1988; M.E. Gordon, Tennessee Cooperative Fishery Research Unit, Tennessee Technological University, Cookeville, *in litt.* 1992). The shell of *Q. fragosa* is more inflated (Conrad 1835, Call 1900, Wilson and Clarke 1914, Baker 1928) and more strongly tuberculated (Conrad 1835, Call 1900, Ortmann 1924, Baker 1928, Watters 1988) than *Q. quadrula*, and on the posterior slope of *Q. fragosa* the tubercles are arranged in transverse rows which form thick, relatively smooth, and well-separated costae (Scammon 1906, Wilson and Clarke 1914, and Gordon 1992). In *Q. fragosa*, the umbos are more elevated and distinctly turned forward over the lunule (Baker 1928). The medial sulcus is narrower and more centrally positioned in *Q. fragosa* (Gordon 1992). Juvenile *Q. fragosa* are greener than congeneric species (Call 1900), but they are morphologically similar (Neel 1941). Finally, there is confusion about the relative size of *Q. fragosa*. Some authors believe it the largest member of the *Quadrula* complex (Call 1885c) while others believe it does not grow as large as *Q. quadrula* (Wilson and Clarke 1914).

Only Utterback (1915) compared internal structures of *Q. fragosa* with *Q. quadrula*. He considered them "identical, as far as can be determined, with the scanty supply of material at hand -- none of which is in gravid condition," and he gives no quantitative or qualitative information by which to assess his judgement.

Quadrula apiculata (= *Unio speciosus*) has uniformly small tubercles and a completely pustulate anterior sinus (Neel 1941). The shell may be thick with distinct sinuses or flattened with indistinct anterior sinus and high, sharp ridges. The epidermis is normally gray. It is known from Louisiana to central Texas.

Quadrula rumphiana is known from the Alabama River system. The flange and ridge in *Q. rumphiana* are devoid of tubercles and are quite prominent. Pustules are smooth, somewhat flattened, and usually absent near the anterior margin. The periostracum is straw-yellow and shiny (Neel 1941).

Quadrula asperata is more widespread than *Q. apiculata* or *Q. rumphiana* and is found from the northeastern tributaries of the Alabama River to central Texas and south to the Gulf of Mexico. The shell is completely covered with small, smooth tubercles arranged in irregular rows spanning the length of the shell. Each row forms an inverted "W" shape, the rear length of which is usually continuous with the costae at the posterior margin. This pattern may not be obvious in individuals with large or very fine tubercles. The periostracum is yellow to brown, green, or black, and rays are uncommon and usually obscure (Neel 1941).

Controversy surrounding species designation: Conrad (1835) first described *Q. fragosa*. Neel (1941) reorganized the genus and reclassified *Q. fragosa* as a variant morph of *Q. quadrula*. David H. Stansbery (Museum of Zoology, Ohio State University, *in litt.* 1980) argued there are no known intergrades between *Q. fragosa* and other members of the *Quadrula* complex, and he therefore considers *Q. fragosa* a valid species. Most authorities now accept this designation (*e.g.*, Fuller 1980a and 1980b, Starnes and Bogan 1988, Gordon 1992), although some (*e.g.*, Burch 1975; Johnson 1980; R.I. Johnson, Museum of Comparative Zoology, Harvard University, *in litt.* 1990) continue to follow Neel (1941).

The U.S. Fish and Wildlife Service (Service) recognizes there is not unanimous taxonomic agreement on the validity of species designation for *Q. fragosa* (USFWS 1991). The dispute is attributable to three discrete issues. First is the lack of basic biological knowledge about the relevant organisms. For example, very little comparative anatomy has been done on the internal organs, and no molecular (protein or DNA) work has been done that might inform the discussion (Daniel J. Hornbach, Biology Department, Macalester College, pers. comm. 1995c). The second issue is the high intraspecific variability in shell morphology and coloration that naturally occurs in most populations of freshwater mollusks. This variation may reflect individual variation, environmental influences, or subspecific differentiation along riverine ecoclines or in isolated populations. Although collections of common or economically important species are quite extensive, collections of *Q. fragosa*, which is thought to always have occurred at low frequency and was not commercially important (see below), are spotty and sometimes misidentified (David H. Stansbery, *in litt.* 1991). The final issue, omnipresent in systematic discussions across taxonomic boundaries, deals with the degree of divergence required for valid species designation. Good faith assessments by acknowledged authorities may lead to divergent conclusions and should be expected in an intellectually healthy field.

The Endangered Species Act of 1973, as amended (Act), defines "species" to include subspecies and distinct populations of species. While some controversy may remain over the legitimacy of species designation, the Service believes *Q. fragosa* clearly meets the Act's definition of species.

Geographic Distribution of *Quadrula fragosa*:

Historic distribution and abundance: The historic distribution of *Q. fragosa* is summarized in Table 1 and Figure 2. There are records from 34 rivers in 12 states, all from tributaries of the upper Mississippi River or from the Mississippi River itself. The records date from 1835 to 1992, with most from 1885 to 1920. Records from the Kiamichi River, Oklahoma, are uncertain -- (Caryn Vaughn, Oklahoma Biological Survey, *in litt.*, with specimens 1992; David H. Stansbery, *in litt.* 1974) identified *Q. fragosa* in the river, but Vaughn (1992) also identified *Q. quadrula* there. *Quadrula fragosa* and *Q. quadrula* may both occur in the Kiamichi River, possibly with other underdescribed and/or described *Q. quadrula* complex taxa. The Winged Mapleleaf Mussel Recovery Team believes this issue is unresolved at this point and requires further investigation for resolution. Similarly, a 1960 report from the Tennessee River is questionable because Scruggs (1960) called one species *Q. fragosa*, but used the common name of *Q. quadrula*, mapleleaf, in describing the same organism. Extensive surveys done in the Tennessee River at the same time found *Q. quadrula*, but not *Q. fragosa* (David J. Heath, Wisconsin Department of Natural Resources, pers. comm. 1995).

Danglade (1914) found *Q. fragosa* in only 1 of 23 samples in the Illinois River, one individual of 210 individuals in that one sample. Isley (1925) found *Q. fragosa* in only 3 of 51 stations in eastern Oklahoma and described it as rare at the 3 stations. Authors who make qualitative assessments of the abundance of *Q. fragosa* support the idea that it had a sporadic distribution and was uncommon where it was found (*e.g.*, Coker 1921, Neel 1941, Frest 1987). The only exceptions to these reports are Keyes (1889), who reported *Q. fragosa* common in the Iowa and Raccoon Rivers and Shimek (1888), who also reported *Q. fragosa* abundant in the Iowa River in 1883, but rare by 1888.

Present distribution: *Quadrula fragosa* is probably extirpated from its entire historic range except for one remnant population in the St. Croix River between Minnesota and Wisconsin. Hart collected *Q. fragosa* from the St. Croix River sometime prior to 1919 (Kevin S. Cummings, Illinois State Natural History Survey, *in litt.* 1989). The Wisconsin Department of Natural Resources rediscovered this population in 1987 (WDNR unpublished data, Havlik and Frink 1989). Heath and Rasmussen (1990) found 49 live specimens in the St. Croix River at Interstate

State Park in 1988 and 1989. Glenn A. Miller (Great Lakes Indian Fish and Wildlife Commission, *in litt.* 1992) found 10 live and 24 dead *Q. fragosa* between Interstate Park and Osceola, Wisconsin, in 1990 and 1991. Hornbach (1992) found 1 *Q. fragosa* at Franconia, Minnesota, in 1991 and 26 live *Q. fragosa* at Interstate State Park and Franconia from 1992 to 1995 (Hornbach *et al.* 1996). All known specimens have been collected from about a 20-km reach of the river, but the full distribution and size of the *Q. fragosa* population in the St. Croix River are not defined.

There is a population of mussels in the Kiamichi River, Oklahoma, identified as *Q. fragosa*, but there are taxonomic questions about this particular population (see discussion above).

Biology, Ecology, and Life History:

Reproduction: Reproduction in unionid mussels occurs during a discrete breeding season. This season is not known for *Q. fragosa*, although the presumed brooding period is late May to the middle of July (Baker 1928, Heath and Rasmussen 1990). Wilson and Clark (1914) reported two gravid *Q. fragosa* from the Cumberland River on May 17 and 29, and noted they brood glochidia on all four gills. Sexes in unionid mussels are normally separate, and females produce a large number of eggs (500,000 to several million), which are brooded on specialized marsupia on the gills (Oesch 1984). Sperm are shed into the water in "volvocoid bodies" and taken into the female through the incurrent siphon (Fuller 1974). After fertilization, zygotes develop into larval glochidia, which are typically either spined or hooked, depending on the subfamily (Fuller 1974). Glochidia are released into the water through the excurrent siphon and passively infect a vertebrate host, typically a fish (Oesch 1984). Glochidia attach and then encyst on either a host fish gill or fin (Oesch 1984). Parasitism is normally obligate, but the specificity of the host-parasite relationship is highly variable and poorly known for most species (Fuller 1974). Unionids may utilize only one host species or many species across a broad range of taxonomic groups. Knowledge of host species is very limited because of problems in identifying glochidia and because of variability within individual species; a mussel may parasitize one species in one part of its distribution and a different species in a different part of its range (Heath 1991). Oesch (1984), however, believes the distribution of a host fish can limit the distribution of a mussel. After encystment, glochidia metamorphose and drop off of their host. They must settle in suitable habitat because their mobility is limited (Oesch 1984). The maximum age of *Q. fragosa* is not known, but the oldest known individual in the St. Croix population was aged at 22 years.

Feeding: Considerable gaps remain in the knowledge of the feeding ecology of mussels. Mussels are thought to be generalist filter feeders, consuming suspended particulate matter (Brönmark and Malmqvist 1982). Most of the particulate matter is thought to be phytoplankton and small zooplankton (Fuller 1974), but there is a growing consensus that detritus forms a significant fraction of the diet of most mussels and may be obtained either from suspension or deposit feeding (Way *et al.* 1990, Gordon 1992).

Habitat: Very little is known about the specific habitat requirements of *Q. fragosa*. Historical descriptions characterized *Q. fragosa* as a "large-stream" species (Wilson and Clark 1914, Baker 1928) found on mud (Baker 1928), mud-covered gravel (Ortmann 1924), and gravel (Ortmann

1925) substrates. There are three historical reports of *Q. fragosa* from impoundments (Wilson and Clark 1914, Scruggs 1960 [but note the qualification of this record in the historical distribution section]; and University of Wisconsin Zoology Museum 1985 collection from Lake St. Croix). Wilson and Clark (1914) reported *Q. fragosa* from 21 different beds in the Cumberland River system and these beds varied considerably in their habitat from impounded water to fast flowing water and from muddy to sandy to clear gravel substrates. They found mussels in 1.5 m to 6.5 m depth. Ortmann (1924) reported *Q. fragosa* from a spillway just below a dam.

There is substantial information on the habitat of the remnant population in the St. Croix River. Heath (1995) found *Q. fragosa* in riffles with clean gravel, sand, or rubble substrates and in clear water of high water quality. *Quadrula fragosa* was most abundant in shallow areas with fast current. The species was absent from recent surveys of Lake St. Croix (Heath and Rasmussen 1990, Fuller 1980a, Havlik 1985, Doolittle 1988), a natural impoundment and part of the historic distribution of *Q. fragosa* (Fuller 1980c, Malacological Consultants 1985 and 1986, Havlik 1987, Doolittle 1988). Lake St. Croix has a fine-sand or silt substrate and more turbid water than upstream reaches where *Q. fragosa* occurs.

The following is the St. Croix River habitat of *Q. fragosa*; the St. Croix River may not reflect ideal *Q. fragosa* habitat. The St. Croix River became part of the National Wild and Scenic Riverway system in 1968. Graczyk (1986) provides a thorough description of the basin and discussion of water quality of streams in the basin. The St. Croix flows south from Upper St. Croix Lake in northwestern Wisconsin to the Mississippi River at Prescott, Wisconsin/Hastings, Minnesota. The river's drainage area is 22,225 km^2 (Graczyk 1986). Forest products, agriculture, and recreation are major land uses in the basin (Graczyk 1986). The climate is continental, with long, cold winters and relatively short summers. Average annual temperature at Spooner, Wisconsin, is 5.6°C, ranging from a mean of -11.8°C in January to a mean of 21.9°C in July. Normal annual total precipitation at Spooner is 73.4 cm varying from 11.3 cm in June to 1.7 cm in January and February. Mean annual snowfall is about 115 cm (Graczyk 1986).

Physical habitat:

The U.S. Geological Survey's National Stream Quality Accounting Network (NASQAN) maintains a water sampling station at St. Croix Falls, Wisconsin, below the hydroelectric dam. The Minnesota Pollution Control Agency has also collected water quality data at St. Croix Falls in the impoundment above the dam. Physical and chemical data collected by these two agencies were retrieved through STORET and are summarized in Table 2 of this recovery plan and in Figures 4 through 13.

<u>Substrate</u>: Table 3 shows the measured physical habitat parameters for 11 *Q. fragosa* found in the St. Croix River. Hornbach *et al.* (1996) reported on a larger sample (N = 26) of *Q. fragosa*, which included these 11 individuals. The *Q. fragosa* were found at an average depth of 0.98 m (SD = 0.46), 45 percent deeper than the average depth of 268 quadrats which did not contain *Q. fragosa*. Mean ø [$-\log_2$ (particle diameter)] in quadrats with *Q. fragosa* was -1.9 (SD = 1.1),

whereas mean ø for 268 quadrats not containing *Q. fragosa* was -1.90 (SD = 1.4). Hornbach concluded there was no significant difference in ø for quadrats containing *Q. fragosa* and those that did not.

Stream flow: Stream flow in the St. Croix River is highly variable on diel, seasonal, and annual scales. Low water may expose mussel beds to predation, desiccation, extreme temperatures, physical scouring by ice, or may preclude reproduction either directly or through indirect effects on the glochidial host population. Figure 3 shows mean daily stream discharge at Interstate Park from 1902 to 1991. Stream discharge averages 122 $m^3 s^{-1}$ (4,298 cfs), but is highly variable. The highest recorded stream flow is 1,560 $m^3 s^{-1}$ (54,900 cfs) while the lowest reported stream flow is 2.1 $m^3 s^{-1}$ (75 cfs). Recent episodes of very low flow have been recorded. For example, concerning the summer drought of 1988, Heath (1995) stated "thousands, possibly tens of thousands of mussels were exposed and dying along the shore, including Higgins' eye (*Lampsilis higginsi*) and *Q. fragosa*. This appeared to have been caused by naturally low flows." Daily mean flows were as low as 31 $m^3 s^{-1}$ (1,100 cfs) in July 1988 and the July monthly mean flow was only 38 $m^3 s^{-1}$ (1,345 cfs). During the winter of 1988, the St. Croix River was termed "dewatered" at Interstate Park (Heath 1995). Winter dewatering below the hydroelectric dam at St. Croix Falls occurs because of the "peaking" mode of dam operation (Hornbach 1992, Johnson 1995, Hornbach 1995a and 1995b). Because *Q. fragosa* is a relatively heavy-shelled species, it thought incapable of significant burrowing or movement to avoid desiccation (Hornbach 1992).

Current: Table 3 shows measured current velocity at the location of six *Q. fragosa* in the St. Croix River (from Hornbach 1992). The average bottom current for 26 *Q. fragosa* was 0.19 m sec^{-1} (SD = .10), 32 percent slower than in 268 quadrats which did not contain *Q. fragosa* (Hornbach *et al.* 1996).

Temperature: Temperature influences physiological and behavioral parameters of mussels and can be lethal at either hot or cold extremes (Fuller 1974). Water temperature in the St. Croix varies seasonally from an annual high of about 25°C to an annual low of 0°C . The maximum water temperature observed between 1966 and 1990 was 28°C and the minimum was 0°C (Figure 4).

Suspended sediment: Sediment in rivers is derived from erosion of soil and scouring of stream channels. Deposition of sediment, particularly in reservoirs behind dams, is deleterious to some mussels (Chutter 1969). The mean suspended sediment level for the St. Croix River at St. Croix Falls between 1974 and 1986 was 8.8 mg l^{-1} (Figure 5). The annual peak in suspended sediment occurs between April and June in most years and correlates linearly with stream flow (Graczyk 1986). The suspended sediment concentration in the St. Croix River is well below an average figure of 110 mg l^{-1} for Wisconsin rivers used by Graczyk (1986).

Wilson and Clark (1914) reported an average of 165 mg l^{-1} suspended sediment at Kuttawa, on the Cumberland River, in 1907, which had a population of *Q. fragosa* at that time.

Chemical habitat:

Oxygen: Oxygen is required for aerobic respiration and Fuller (1974) suggests 3 mg l^{-1} is a lethal threshold for many species and 6 mg l^{-1} may be the minimum required for normal growth. The mean dissolved oxygen concentration for 161 samples between 1953 and 1990 at St. Croix Falls is 9.5 mg l^{-1}. Oxygen concentrations fell below 6 mg l^{-1} only seven times, and all episodes occurred prior to 1973 (Figure 6). The minimum oxygen concentration measured was 4.0 mg l^{-1}. Less complete data from other areas along the St. Croix River, including Osceola, and Danbury, Wisconsin, and Stillwater, Minnesota, support the indication of no significant oxygen depletion in the reach of the river inhabited by *Q. fragosa*.

Alkalinity and related parameters: Alkalinity is an important parameter for two reasons. First, it is a measure of the buffering capacity of a water body, which is important to maintain normal blood chemistry in mussels. Second, it is an indirect measure of the availability of calcium, which is required for shell growth. Total alkalinity can limit mollusks in freshwater, and Fuller (1974) suggests many mollusks require at least 15 mg l^{-1} total alkalinity. The St. Croix River at St. Croix Falls has an average total alkalinity of 74.7 mg l^{-1} and is a bicarbonate type river (Figure 7). Essentially all of the hardness is from calcium ($\approx$63 percent, see Figure 8) and magnesium ($\approx$37 percent), and the average calcium concentration is 51.2 mg l^{-1}. The water is well buffered with median pH of 7.6 -- fewer than 7 percent of the pH measurements between 1953 and 1989 were below 7.0 (Figure 9).

Wilson and Clark (1914) report an average value of 28 mg l^{-1} of calcium and about 100 mg l^{-1} of alkalinity at Kuttawa, on the Cumberland River, in 1907, which had a population of *Q. fragosa* at that time.

Nitrogen: The various inorganic forms of nitrogen are plant nutrients, but ammonia may be deleterious to unionid mussels (Fuller 1974) and is toxic to fish (Boyd 1979). Fuller suggests 0.6 mg l^{-1} ammonia may be a threshold for mussels, although he states it is not known whether the effect of ammonia on unionids is direct or is mediated through its effect on the glochidial fish host. More recent research suggests freshwater mussels are more sensitive to un-ionized ammonia than many fish species (Arthur *et al.* 1987, Hickey and Vickers 1994). Using juvenile *Anodonta imbecillis*, Wade (1992) found the LC_{50} for un-ionized ammonia was 153 g NH_3l during 9-day exposure. Ammonia levels in the St. Croix are relatively high with a mean value of 0.09 mg l^{-1}. Figure 10 indicates one sample in 1981 exceeded 0.6 mg l^{-1}, which corresponds to an episode of very low stream flow. Even with this high value excluded, however, the mean ammonia concentration is 0.07 mg l^{-1}. Graczyk (1986) reported on a trend analysis (seasonal Kendall test) done on water data collected between 1974 and 1981; the only parameter to show noticeable increase in that period was total ammonia as Nitrogen. He reported an annual increase in the mean load of 26.1 percent over that period, but the few data available do not support the continuation of that trend through the 1980s.

Phosphorus: There is no known correlation between mussel abundance and total phosphorus (TP)(Fuller 1974). Phosphorus is, however, an important plant nutrient and can stimulate phytoplankton blooms with consequent negative effects on dissolved oxygen and other water quality parameters (Wetzel 1975). In flowing rivers, nuisance algal growths are normally absent at concentrations below 0.1 mg l^{-1} TP (MacKenthum 1973). Mean TP in the St. Croix River at St. Croix Falls was 0.06 mg l^{-1}. Several individual samples greatly exceed the 0.1 mg l^{-1} threshold, but no individual measurement has exceeded about 0.2 mg l^{-1} since 1980 (Figure 11).

Conductivity: Specific conductance (Figure 12) varies seasonally, with high values over 200 μmhos cm^{-1} in winter and low values around 150 μmhos cm^{-1} in summer. The mean specific conductance of 169 μmhos cm^{-1} is well within the range typical of inland rivers. Sodium and chloride are constituents of deicing agents applied to roads and are components of conductivity that are biologically important because they can be toxic at high concentrations (Fuller 1974). Sodium and chloride do not appear to fluctuate seasonally and all measured values are within normal limits for freshwater organisms (Figure 13).

Metals: Fuller (1974) considers zinc, copper, mercury, and silver the most toxic metals to mussels. Zinc concentrations of 65 mg l^{-1} were thought to have contributed to the loss of mussel species from the Nolichucky River in Tennessee; copper concentrations of 25 μg l^{-1} are lethal to some unnamed unionids (Fuller 1974). Mercury levels in fish tissues from the St. Croix River at St. Croix Falls are shown in Table 4. In 1992, the Minnesota Department of Health (1992) posted human fish consumption advisories for eight species of fish at Marine on St. Croix because of contamination by both mercury and polychlorinated biphenols (PCBs). Cadmium has also been shown to be acutely toxic to juvenile unionids (Salanki 1979, Keller and Zam 1991, Lasee 1991, Mohan and Hameed 1991). Two trace metals (total iron and manganese) exceed USEPA (1976) standards for drinking water. The mean concentration of total iron at St. Croix Falls was 880 μg l^{-1} while the mean concentration of manganese was 80 μg l^{-1}. There is evidence of heavy metal accumulation in the shells of some species of unionids (Troelstrup and Foley 1993).

Toxics: A single chemical spill into the St. Croix upstream of the *Q. fragosa* population could prove catastrophic. Little is known about the probability of occurrence, likely nature of the chemical, or potential magnitude of this threat. However, a spill/leak of petroleum products at St. Croix Falls in the autumn of 1992 may have caused a significant fish kill in a hatchery there (Paul J. Burke, Twin Cities Field Office, U.S. Fish and Wildlife Service, pers. comm. 1995). Water from the hatchery discharges to the St. Croix River a short distance above the *Q. fragosa* population. This episode suggests the threat of toxic spills is significant.

Graczyk (1986) reported on two studies of common pesticides in the St. Croix River basin. The first study failed to detect pesticides or pesticide residue (of the 18 studied) in the water. The second study failed to detect pesticides or pesticide residue (of the 28 studied) in a mixture of water, suspended sediment, and sediment in the Namekagon River. Trace amounts of PCB and Aroclor were found in fish tissue collected in 1989 at St. Croix Falls (Table 4).

Waller (1992) demonstrated that application of *Bacillus thuringiensis israelensis* (Bti) to water to control dipteran insect pests had no impact on unionid mortality during a 1-hour exposure monitored for four days after exposure. It is not known if water treatment for dipterans, with either Bti or chemicals, occurs above or within the reach of the river containing the *Q. fragosa* population.

There are 12 municipal and industrial facilities with wastewater discharge permits between St. Croix Falls and Prescott, Wisconsin. Six of these are within the reach containing *Q. fragosa* (Table 5). These facilities are required to monitor their discharges and to remain within stated limits for specified water quality parameters. There is concern that the permits may not cover all relevant parameters, such as metals, from municipal dischargers. There is also concern that permits may not be adequately monitored or enforced (Sigford and Eleff 1990).

Biological habitat:

Mussel communities: From 1992 to 1995, Hornbach *et al.* (1996) completed a detailed mussel community survey at Franconia and Interstate Park in the St. Croix River. Twenty-six of his 294 0.25 m^2 quadrats contained *Q. fragosa*. His results from 1992 are presented in Table 6. Average mussel density in quadrats with *Q. fragosa* was 37.5 m^{-2} (SD = 18.2), while quadrats without *Q. fragosa* averaged 21.3 mussels m^{-2} (SD = 22.6) (Hornbach *et al.* 1996). *Quadrula fragosa* quadrats had average species richness of 4.9 species $quadrat^{-1}$ (SD = 1.8) compared to 2.6 species $quadrat^{-1}$ (SD = 2.0) in quadrats with no *Q. fragosa* (Hornbach *et al.* 1996). Hornbach *et al.* (1996) found three mussel species to be significantly associated with *Q. fragosa*: (1) *Truncilla truncata*, (2) *Q. metanerva*, and (3) *T. donaciformis*. Average mussel size was also larger in quadrats with *Q. fragosa* than in those without *Q. fragosa* (Hornbach *et al.* 1996). Hornbach *et al.* (1996) concluded *Q. fragosa* is found only in habitat that is generally "high quality" habitat for other mussels.

Predators and disturbance: There are many known vertebrate predators of mussels and it is likely that most predation is opportunistic rather than highly selective. Oesch (1984) suggests muskrats are particularly important mussel predators; Wilson and Clark (1914) mention muskrat predation and apparent selection of *Q. fragosa* by muskrats. Muskrat predation has been shown a serious threat to other endangered mussels (Neves and Odom 1989). Other known predators include, but are not limited to, mink, raccoons, fish, turtles, and water birds (Oesch 1984).

Archaeological research indicates native Americans used *Q. fragosa* for food (J.L. Theler, University of Wisconsin-La Crosse, *in litt.* 1987). *Quadrula fragosa* was not specifically subject to significant exploitation in the button or pearling era, possibly due to its rarity and a behavioral trait that prevents it from being susceptible to grappling hooks (Wilson and Clark 1914). Unionid mussels in general continue to be harvested for food, collection, fish bait, and other incidental purposes. Commercial harvest was closed on the St. Croix in 1986 by the State of Wisconsin (Wisconsin Administrative Code NR 24.09, 1986) and in 1991 by the State of Minnesota. Since 1987, there has been evidence that mussels, including *Q. fragosa*, have been harvested illegally, either for human consumption or for fish bait (Doolittle 1988, Hornbach 1995c, Heath 1995).

There is evidence that recreational (primarily small motor boats) and commercial (primarily paddlewheel tour boats) vessels may be causing significant local disturbance to mussel beds by physical disturbance of the substrate and by enabling boaters access to otherwise isolated mussel beds (Heath 1995). There is considerable wading and swimming activity in the immediate vicinity of one of the most important mussel beds. These disturbances are of particular concern during periods of glochidial brooding, because amblemine mussels are known to readily abort when disturbed (Heath 1991).

The entire historical distribution of *Q. fragosa* has been significantly altered by human development in the Mississippi River basin. Development included, but was not limited to, damming, dredging, and channelization of rivers; agricultural cultivation with application of fertilizers, pesticides, and herbicides; and municipal and industrial waste discharges. These developments are probably responsible for widespread and precipitous decline in mussel communities in general, and the extirpation or extinction of several species, but few studies have addressed directly the specific impact of any one of these factors (Fuller 1974).

Competitors: Little is known about interspecific competition among mussels or between mussels and species of other animal taxa. Mussels are not known to partition their food resource (Brönmark and Malmqvist 1982) and are characteristically found in communities of mixed mussel species, commonly called beds. Some sedentary organisms compete for space (Connell 1961), but there is no data on this for freshwater mussels.

Zebra mussels (*Dreissena polymorpha*) have been detected in the upper Mississippi River system as far north as Minneapolis, Minnesota, but they have not yet been detected in the St. Croix River in spite of both passive monitoring (Hornbach 1995c) and active searches (Burke 1995). Zebra mussels can interact with native mussels and cause significant negative effects on the abundance of individual mussel species and on the community parameters of species richness and species diversity (Hunter and Bailey 1992, Haag *et al.* 1993). Zebra mussel interaction may be through direct attachment to the shell of other mussels (sometimes in such numbers that the entire shell is covered), or indirectly through competition for food, calcium, or space (Hunter and Bailey 1992, Haag *et al.* 1993). Zebra mussels may degrade mussel habitat by covering the substrate with their pseudo-feces. There are similar concerns regarding the quagga mussel (*Dreissena sp.*).

Parasites and disease: Oesch (1984) lists water mites, trematodes, leeches, bacteria, and some protozoa as the principal mussel parasites, but suggests they are not normally a major limiting factor for mussels. Mussel populations in the Mississippi River system suffered serious declines in the 1980s (Neves 1987).

Population limiting factors:

Reproduction: Between 1988 and 1992, 76 live *Q. fragosa* from the St. Croix River were measured by three independent investigators (Table 7). In 1987, a single live *Q. fragosa* was found in the St. Croix River, but no measurements were taken (Havlik and Frink 1989). To date, no *Q. fragosa* has been observed brooding glochidia, including 27 individuals collected during the presumed brooding period of late May to mid-July (Heath and Rasmussen 1990, Hornbach 1992). Only one individual has been found that was recruited during the 1988 to 1992 study period (Figure 14). These two facts suggest *Q. fragosa* has failed to reproduce in significant numbers since 1987. If true, such a reproductive failure (demographic stochasticity) poses a singular concern to the viability of the St. Croix population (Gilpin and Soulé 1986). There are three possibilities to consider:

1) *Quadrula fragosa* younger than 4 years old can be difficult to identify and may be under-sampled by methods employed in these studies. Support for this hypothesis comes from surveys in 1988 and 1989 that failed to find any *Q. fragosa* recruited after 1984, even though subsequent work demonstrated reproduction in 1985, 1986, and 1987. Only one 3-year old has been found and identified in all work to date even though it is now known that there were 1, 2, and 3-year olds in the river during the 1988 and 1989 work.

2) *Quadrula fragosa* may have a highly variable recruitment rate naturally. The 1984 age class is apparently a very large class and accounts for nearly 30 percent of all *Q. fragosa* observed (Figure 14). The age histogram in Figure 14 may be typical of a healthy *Q. fragosa* population.

3) *Quadrula fragosa* may have a highly variable recruitment rate that responds to some environmental parameter and the age distribution in Figure 14 is indicative of a population at great risk of stochastic fluctuations in reproductive success.

Fish hosts for glochidia: The host fish for *Q. fragosa* glochidia is unknown. However, something is known of fish hosts for six other *Quadrula* species (Oesch 1984, Hill 1986). Historical studies of fish hosts should be treated with caution, however, because they were premised on the highly problematic assumption that glochidia could be identified to species (Hoggarth 1992). Sixteen fish species from 5 families are thought to be hosts to glochidia of the genus *Quadrula* and 11 of these are found in the St. Croix River (Table 8). Of these 11 fish species, 8 are known from recent surveys of the stretch of river where *Q. fragosa* is found. These include bluegill (*Lepomis machrochirus*), black crappie (*Pomoxis nigromaculatus*), white crappie (*P. annularis*), channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides*), and the spotfin shiner (*Notropis spilopterus*). The brown bullhead (*I. nebulosus*) has not been found in the St. Croix River since 1975 and the flathead catfish (*Pylodictis olivaris*) has demonstrated a historical decline in the St. Croix (Fago 1986). This might be significant because this catfish serves as host to three *Quadrula* species.

Only one fish host is known for *Q. quadrula* (flathead catfish), while the other *Quadrula* are thought to use between two and six fish hosts from different taxonomic families. The members of the genus also share fish hosts, *e.g.*, three *Quadrula* species use flathead catfish, while two use bluegill, channel catfish, and white crappie.

Habitat: The availability of suitable habitat is a major concern for the continued existence of *Q. fragosa*. Any species restricted to a single, small geographic population is particularly vulnerable to stochastic events (environmental stochasticity) (*e.g.*, low water levels, toxic spills, climactic events) which could kill the remaining individuals (Gilpin and Soulé 1986).

The Corps of Engineers is responsible, under the River and Harbors Act, for maintaining a navigable channel approximately 1 m deep from the mouth of the St. Croix River to St. Croix Falls. The National Park Service is responsible for development within park boundaries. Dredging and snag removal for channel maintenance, development of boat accesses, and other developments could cause significant *Q. fragosa* habitat deterioration in the river. There are no known plans for dredging or related work, and under Section 7 of the Act, the Corps of Engineers must notify the Service before such activities are initiated. The National Park Service has agreed to notify the Service of planned developments and to survey for *Q. fragosa* prior to undertaking work in the St. Croix River where *Q. fragosa* occurs.

Reasons for Listing: *Quadrula fragosa* became a Category 2 candidate for listing under the Act in 1984 (USFWS 1984). The mussel's status was changed to Category 3C in 1989 (USFWS 1989), but subsequent analysis of records of occurrence from states with known historical populations of *Q. fragosa* indicated Category 3C was inappropriate. Endangered status was first recommended in 1990 (USFWS 1990) and adopted in the final rule, effective July 22, 1991 (USFWS 1991).

The principal reasons given in the final rule (USFWS 1991) for listing *Q. fragosa* as endangered are:

1) This species has been eliminated from nearly all of its original 11-state range (Figure 2) and is now known from a single extant population along one 20-kilometer reach of the St. Croix River.

2) The remnant population is thought to be small and therefore vulnerable to stochastic disturbances, such as toxic substance spills or low water levels.

3) Reproductive success is also jeopardized by the small population size. Surveys in 1988 and 1989 (Heath and Rasmussen 1990) failed to collect any individuals brooding young or less than four years old, even though congeneric individuals collected in the same survey showed evidence of successful reproduction. Additionally, small populations are known to be vulnerable to various genetic constraints which can independently threaten a species (Allendorf and Leary 1986).

4) Changes in land use practices in the watershed are anticipated because the watershed is close to a major and growing metropolitan area. These changes will probably affect the habitat quality of *Q. fragosa*. Also, recreational boat use in the vicinity of the population is heavy and potentially damaging.

Conservation Measures: Some activities to conserve and recover *Q. fragosa* were begun before the species was listed under the Act, others were begun after listing, but before approval of this recovery plan.

Section 7(a) of the Act requires Federal agencies to evaluate their actions with respect to species proposed or listed as endangered or threatened and with respect to their critical habitat, if any is designated. Regulations implementing interagency cooperation under section 7 of the Act are codified in the Code of Federal Regulations at 50 CFR Part 402. Section 7(a)(2) requires Federal agencies to insure the activities they authorize, fund, or implement are not likely to jeopardize the continued existence of a listed species or to destroy or adversely modify its critical habitat. If a Federal action may affect a listed species or its critical habitat, the responsible Federal agency must enter into formal consultation with the Service. With listing came the protection of section 7 of the Act. Section 7(a) of the Act requires Federal agencies to consult with the Service when actions they fund, permit, approve, or conduct could adversely affect a listed species. The purpose of section 7 consultation is to allow the Service and the Federal action agency to review the proposed action to assure it will not drive a species to extinction or eliminate the possibility of its recovery.

Section 9 of the Act and implementing regulations at 50 CFR 21 address specifically prohibited activities regarding listed species involving import and export, commercial trade, possession and transportation, and take. Under the Act and regulations it is illegal to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt any of these activities.

The Act and 50 CFR 17.22 also provide for the issuance of permits to conduct the otherwise prohibited activities involving endangered species under certain circumstances. Permits can authorize take by identified individuals to enhance propagation or survival of the species. The Service anticipates few trade permits will be sought or issued for *Q. fragosa*. Requests for copies of the regulations and inquiries regarding them may be addressed to the U.S. Fish and Wildlife Service, Endangered Species Permits Coordinator, Federal Building, 1 Federal Drive, Ft. Snelling, Minnesota 55111-4056.

Protections and considerations, provided by laws and authorities other than the Act, became applicable to *Q. fragosa* with its listing under the Act. For example, a Memorandum of Understanding (MOU) was signed in 1994 by the U.S. Forest Service, Department of Defense, U.S. Army Corps of Engineers, National Marine Fisheries Service, Bureau of Land Management, Bureau of Mines, Bureau of Reclamation, Minerals Management Service, National Park Service, U.S. Coast Guard, Federal Aviation Administration, Federal Highway Administration, Environmental Protection Agency, and Fish and Wildlife Service. The MOU established a general framework for cooperation and participation among the signatory agencies in the exercise of their responsibilities under the Act. The goals of the MOU are to (1) conserve species federally listed under the Act, (2) use existing Federal authorities and programs to further the purposes of the Act, and (3) improve efficiency and effectiveness of the interagency consultations conducted pursuant to section 7(a)(2) of the Act.

In addition to the above MOU, individual Federal agencies develop their own policies for listed species. For example, rules for protection of listed species in National Parks are in the National Park Service's Management Policies (USNPS 1988) and in its Natural Resource Management Guidelines (USNPS 1991). The National Park Service must abide by the Act and the National Environmental Protection Act in managing the lands and waters it is responsible for.

Quadrula fragosa is presently listed as endangered by the States of Minnesota and Wisconsin and Minnesota's and Wisconsin's Departments of Natural Resources presently contribute to the conservation of the species. Minnesota and Wisconsin endangered species laws prohibits take or sale of protected species without State permit except under specified exemptions (State of Minnesota 1996, State of Wisconsin 1989).

In addition to legal protections, the Service has for several years contributed endangered species funding to state agencies and others for conservation measures, such as surveys, monitoring, and related studies for the conservation of *Q. fragosa*.

Examples of some of the conservation actions taken to date:

1) Wisconsin listed *Q. fragosa* as a state endangered species in 1989 (State of Wisconsin 1989) and Minnesota listed *Q. fragosa* as a state endangered species in 1996 (State of Minnesota 1996).

2) Although not intended as a winged mapleleaf mussel conservation or recovery measure, establishment of the St. Croix National Scenic Riverway in 1968 has contributed to the conservation of the species.

3) The National Park Service has posted signs at Interstate Park prohibiting the handling of mussels (U.S. Code of Federal Regulations, Title 36 CFR 2.1 (C) (1)).

4) The Wisconsin Department of Natural Resources prohibited commercial clamming on the St. Croix River in 1986 (State of Wisconsin 1986) and Minnesota Department of Natural Resources has restricted commercial clamming to the Mississippi River.

5) An important conservation measure addressing instream flow began before *Q. fragosa* was listed and continued following listing. Northern States Power Company-Wisconsin and the Minnesota and Wisconsin Departments of Natural Resources engaged in dialogue, study, and action described in some detail below.

Stream flow in the relevant stretch of the St. Croix River is influenced, in part, by a hydroelectric dam at St. Croix Falls, Wisconsin, operated by Northern States Power Company-Wisconsin. The dam and hydroplant was completed in 1906 (Smith 1980). Northern States Power is obligated under its license to release at least 45.3 $m^3 s^{-1}$ (1,600 cfs) from April 1 through October 31, which corresponds to the 80 percent excedence flow for August (Hurley 1931). Flows below 45.3 $m^3 s^{-1}$ normally occur only during drought conditions. Historically, the dam had (and currently has) no required winter minimum flow release. Until 1988, winter operation was to curtail discharge at night, except for leakage, storing water for generation the following day.

In 1988, before *Q. fragosa* was listed under the Act, several years of sub-normal precipitation caused sub-normal groundwater contribution to winter flows of the St. Croix River. As a result, the hydro dam's normal minimal winter night flow releases were not supplanted by sufficient groundwater inflow to maintain submerged habitat for mussels throughout the night. In 1988, Minnesota and Wisconsin Departments of Natural Resources requested Northern States Power to release a minimum flow of at least 22.6 $m^3 s^{-1}$ (800 cfs) and Northern States Power voluntarily agreed to maintain or exceed that flow at all times during winter months (A. G. Schuster, Northern States Power Company-Wisconsin, *in litt.* 1990) for conservation of the extraordinary mussel resource downstream of the dam, including *Q. fragosa*. This release results in about 25.5 $m^3 s^{-1}$ (900 cfs) below the dam after leakage is incorporated.

Before agreeing to increase the dam's minimum discharge beyond the 22.6 $m^3 s^{-1}$ (800 cfs) level, Northern States Power requested answers to two questions: (1) what proportion of the mussel beds are exposed at a discharge of 22.6 $m^3 s^{-1}$ (800 cfs)? (2) where are endangered mussels, including *Q. fragosa*, located within the beds? To determine the minimum flow needed for all *Q. fragosa* mussel beds to receive sufficient water, Minnesota Department of Natural Resources conducted two studies.

First, Minnesota Department of Natural conducted a single-transect wetted-perimeter study in 1990 in the east channel at Folsom Island (MDNR 1990). The "wetted perimeter" was defined as the area of stream covered by at least 0.3 m of water and "critical break points" defined as significant changes in the slope of a plot of wetted perimeter *vs.* discharge. This study indicated a well defined critical break point at 56.1 $m^3 s^{-1}$ (1,980 cfs) of total discharge (dam output, groundwater, dam leakage, bank storage) and a less well defined critical break point at 38.3 $m^3 s^{-1}$ (1,350 cfs). These critical break points are indicative of increasing slope (loss) of wetted area with small decreases in discharge. Total discharge of 22.6 $m^3 s^{-1}$ (800 cfs) resulted in a 29 percent reduction of the wetted perimeter (assumed habitat) compared to 56.1 $m^3 s^{-1}$ (1,980 cfs) (MDNR 1990). Additionally, at 22.6 $m^3 s^{-1}$ (800 cfs) the average depth of the water in the riffle was only 0.12 m (0.37 ft) and had low velocity, which "increase the possibility of ice formation and larger habitat losses" (MDNR 1990).

Second, beginning in 1992, Minnesota Department of Natural Resources conducted an instream flow incremental methodology (IFIM) study to model the relationship between discharge by the Northern States Power dam at St. Croix Falls and habitat suitability and availability in two areas, the three channels area at Folsom Island and the one channel area at Franconia. The study address suitability for *Q. fragosa*, other mussels, other aquatic macroinvertebrates, and fish (Johnson 1995, Appendix 2). Johnson used two flow regimes, 45.2 $m^3 s^{-1}$ (1,600 cfs) and 90.4 $m^3 s^{-1}$ (3,200 cfs), at the two areas to calibrate his model. Water depth, water velocity, and substrate type were measured along transects in each channel and mussel suitability criteria were developed from Hornbach's (1992, in Appendix 2) study of mussel communities at Interstate Park. Hornbach (1992) studied only 11 *Q. fragosa*, but observed they occurred in areas of both high mussel density and species richness. Therefore, Johnson (1995, Appendix 2) used these community parameters as proxies for suitable *Q. fragosa* habitat. Further mussel habitat data was later provided by Hornbach (Appendix 3, 4, and 5) which substantively supported his 1992 findings.

Johnson (1995) found the amount of suitable habitat for *Q. fragosa* was sensitive to dam discharge level in all four channels studied, with the "critical" east channel of Folsom Island the most sensitive to dam discharge levels. Significant dewatering occurs in the east channel at flows of 22.6 m^3 s^{-1} (800 cfs) and mussels are not found in areas which are periodically dewatered, even if the habitat is otherwise suitable when the area is inundated. Johnson (1995) found the majority of such low flows are associated with dam "peaking" operations, not because of natural hydrologic conditions. The study found that at flows of 56.5 m^3 s^{-1} (2,000 cfs) to 113 m^3 s^{-1} (4,000 cfs), all four channels provide good habitat for mussels, other macroinvertebrates, and fish. Peaking operations by the dam, however, frequently caused flows to fall below 56.5 m^3 s^{-1} (2,000 cfs) or to exceed 113 m^3 s^{-1} (4,000 cfs). Based on these findings, Johnson (1995) recommended a "run-of-river" flow regime to (1) minimize the occurrence of low flows, (2) minimize the amplitude of daily fluctuation in flow rate, and (3) to maximize the duration of flows at near-optimal levels for mussel habitat.

Northern States Power contracted with Hanson and Leonard (1995, in Appendix 7) to critically review Johnson's (1995) study. Hanson and Leonard (1995) cited several shortcomings Johnson's report: (1) study site selection and representativeness, (2) the model's use of habitat suitability criteria, (3) calibration of the model, and (4) apparent lack of consideration of peaking flow regimes other than the 22.6 m^3 s^{-1} (800 cfs) minimum flow regime and the run-of-river flow regime. Johnson (1996, in Appendix 8) addressed these criticisms without altering his conclusion that run-of-river flow releases would provide the most suitable habitat for *Q. fragosa* and other aquatic life.

Based on the IFIM results, the majority of the Winged Mapleleaf Mussel Recovery Team believed run-of-river would be the best flow regime for the conservation of *Q. fragosa* and the entire mussel community downstream of the dam. Even though the IFIM predicts increased mussel habitat with run-of-river, a minority of the team were concerned that such a dramatic change from the present flow regime could have unforeseen detrimental effects on the mussel community. This group believed an incremental approach to changing the current discharge regime should be taken, and that 45.3 m^3 s^{-1} (1,600 cfs) would be an appropriate incremental step toward the conservation of *Q. fragosa*. No matter what changes in discharge are implemented, the whole team believes that any change in flow regime should be combined with monitoring of the abundance and diversity of the mussel community to provide a basis for adaptive management.

Strategy for Recovery: The highest priority for recovery of *Q. fragosa* is preservation of the sole known population, located in the St. Croix River. Completion of this priority requires determination and implementation of permanent suitable water flow, determination and preservation of other physical habitat requirements, management and mitigation of human disturbance, reduction of the threat of zebra mussel invasion, description of reproductive biology, and management of toxic substances.

Other items for species recovery include tasks to:

- Obtain information needed regarding *Q. fragosa* biology and its relationship to habitat and environment.

- Increase the population of *Q. fragosa* in the St. Croix River.

- Reestablish *Q. fragosa* in suitable portions of its historic range.

- Confirm the future suitability and security of the species for reclassification to "threatened" and then for delisting.

Recovery

Recovery Plan Objective and Rationale: The ultimate objective of this recovery plan is to protect the winged mapleleaf mussel from extinction. Delisting may occur only when the best scientific judgement concludes the species is not at risk of extinction in the foreseeable future, as defined below. During recovery, the species will be reclassified to threatened preliminary to its being proposed for delisting. The following reclassification and recovery criteria must, of necessity, be preliminary and subject to revision based on new information, including information resulting from performance of the recovery tasks of this plan.

Specific reclassification criteria are:

a) Three discrete populations in at least two tributaries of the Mississippi River drainage basin. For the purposes of this plan, two beds of mussels may be considered discrete populations if they are sufficiently geographically isolated from each other so both are unlikely to be affected by a single stochastic event, such as a toxic spill or a disease outbreak.

b) All three populations must be viable as defined in the narrative outline of this document under Task 5A.

c) All three populations must have demonstrated persistence as defined in the narrative outline of this document under Task 5B.

d) All three populations must have long-term habitat protection as defined in the narrative outline of this document under Task 5C.

Specific delisting criteria are:

a) Five discrete populations in at least three tributaries of the Mississippi River drainage basin unless Task 2D4 indicates more populations or tributaries are required. For purposes of this plan, two beds of mussels may be considered discrete populations if they are sufficiently geographically isolated from each other that both are unlikely to be affected by a single stochastic event, such as a toxic spill or a disease outbreak.

b) All five populations are viable as defined in the narrative outline of this document under Task 5A.

c) All five populations must have demonstrated persistence as defined in the narrative outline of this document under Task 5B.

d) All five populations must have long-term habitat protection as defined in the narrative outline of this document under Task 5C.

Narrative Outline:

The Implementation Schedule, which follows the References section of this recovery plan, contains cost estimates for the various sub-tasks presented in this Narrative Outline. Those cost estimates are of necessity uncertain because the costs of equipment and technology change unpredictably and because the scope of the sub-tasks must be estimated. The scope of some sub-tasks will depend on the research results of sub-tasks that must be performed first.

The costs presented are the estimates of the Recovery Team based on their experience with the costs of mussel work or other relevant activity; they are not based on detailed budgets prepared for individual sub-tasks. Actual costs of individual sub-tasks may be higher or lower than the cost indicated in the Implementation Schedule.

Some Task 1 and Task 2 sub-tasks have double asterisks in this Narrative Outline. Double asterisks denote priority 1 sub-tasks -- actions that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future. Task 1 is maintenance of the St. Croix River population of *Q. fragosa*, the only known population of the species. The Team considers it axiomatic that preservation of this population is essential to preservation of the species.

Task 2 is improved understanding of the biology and ecology of *Q. fragosa*. Specific identified knowledge gaps prevent effective protection and recovery actions. To give one example, preservation of a mussel species requires preservation of its glochidial host where the mussel occurs, and the host must occur in any potential relocation area, or must be moved with the mussel. It is possible the long-lived *Q. fragosa* is going extinct in its St. Croix River bed because it cannot reproduce because its host is no longer there. To save *Q. fragosa*, it may be necessary to restore the host to the St. Croix River. To do that, the host must be discovered.

The Team believes the double asterisked sub-tasks of Tasks 1 and 2 are vital to accomplishing Tasks 1 and 2 and that Tasks 1 and 2 must be accomplished to preserve the species.

Task 1: Preserve the St. Croix population of *Q. fragosa*: All known locations of *Q. fragosa* lie in the St. Croix National Scenic Riverway, administered by the National Park Service. The National Park Service is therefore responsible for developing and coordinating all aspects of Task 1.

Task 1A, Population status:

****Task 1A1, Community population monitoring:** Set up permanent monitoring plots to monitor the abundance and age structure of members of the unionid community within the known geographic range of *Q. fragosa*.

Task 1B, Stream flow: The following are recommended to address the central issue of assuring adequate stream flow for *Q. fragosa* in the St. Croix:

Task 1B1, Flow gauge: Establish and maintain a flow gauge at Folsom Island through the completion of the instream flow study.

Task 1B2, Instream flow study: Conduct an instream flow study to determine the relationship between discharge rates at the dam and water levels at critical spots downstream of the dam. The study report should include a discussion of habitat availability at each of the studied flow rates.

Task 1B3, Hourly flow records: Analyze and describe the USGS hourly flow records (mean, maximum, and minimum) for the past 20 years to describe the flow regime the mussels were exposed to in the past. The report should include discussion of any significant correlations between stream flow and reproduction.

Task 1B4, NSP: Negotiate with Northern States Power to implement a flow regime indicated by the above studies to protect *Q. fragosa* habitat.

Task 1C, Toxic spills: The following information should be gathered to assess the threat of toxic material to *Q. fragosa*:

Task 1C1, Federal/State/Local Emergency Response Plans: Prepare a review report on USEPA; MPCA; WDNR; Wisconsin Department of Agriculture (WDA); Wisconsin Department of Military Affairs, Division of Emergency Government: and Local Emergency Planning Committee (LEPC) response plans for the St. Croix River. The report should address adequacy of the plans (on site materials, time to implement) to deal effectively with potential spills identified in Tasks 1C2 and 1C3.

Task 1C2, Harmful material transport: Produce a report that inventories and quantifies the nature of harmful material transport on or across the river upstream from Stillwater by watercraft, pipeline, truck, and rail. This report should be used in developing Federal, state, and local Emergency Response Plans.

Task 1C3, Harmful material storage: Produce a report that inventories and quantifies the location and nature of harmful material storage in the St. Croix watershed upstream of Stillwater, Minnesota. The report should be used in developing or revising Federal, state, and local Emergency Response Plans.

Task 1C4, Emergency response planning: Develop a St. Croix River Emergency Response Plan, if one is not currently in place through Task 1C1. This plan should explicitly address all harmful material threats identified in Tasks 1C2 and 1C3. This plan should also include a protocol for state and Federal natural resource agencies (MDNR, MPCA, USNPS, WDNR, WDA, and USFWS) to coordinate with emergency response agencies to protect *Q. fragosa* in the event of a spill. This planning effort should be incorporated into Federal, state, and local Emergency Response Plans.

Task 1C5, NSP: Arrange with Northern States Power to manage its St. Croix Falls dam's flow release in the event of a spill above the dam. Coordinate this Task with 1C4.

Task 1C6, Hazardous waste facilities: Request that an Environmental Impact Statement (EIS) be required for any proposed hazardous waste facility, such as the proposed hazardous waste disposal facility at Osceola, and that any EIS prepared must specifically address the potential impact on *Q. fragosa*.

Task 1D, Exotic mussels: The following actions are recommended to address the issue of zebra mussels (*D. polymorpha*):

****Task 1D1, Monitoring:** Continue annual monitoring for zebra and quagga mussels, initiated in summer 1992, in the St. Croix River.

****Task 1D2, Zebra mussel loads:** As part of mussel community monitoring (Task 1A1), monitor zebra mussel loads on mussels within the known *Q. fragosa* range.

****Task 1D3, Assess impact:** Prepare a report assessing the likely effects of zebra mussels on *Q. fragosa*.

****Task 1D4, Emergency response plan:** Develop and implement a zebra mussel emergency response plan in cooperation with the Department of the Interior (USNPS and USFWS).

****Task 1D5, Protective legislation:** Develop state and Federal legislation to prevent or retard the spread of exotic species in the St. Croix River.

Task 1E, Habitat degradation: The following actions are recommended to address the issue of habitat degradation:

Task 1E1, Federal agencies: Establish formal agreements between the Service, National Park Service, and USACOE to the effect that National Park Service and USACOE notify the Service in the event of any development or maintenance work that could disturb or endanger the *Q. fragosa* population or its habitat.

Task 1E2, State agencies: Establish formal agreements with Minnesota and Wisconsin Departments of Transportation and Departments of Natural Resources to the effect that they will notify the Service prior to their development or maintenance work that could disturb or endanger the *Q. fragosa* population or its habitat.

Task 1E3, County zoning: Review county zoning rules for St. Croix and Polk Counties, Wisconsin, and Washington and Chisago Counties, Minnesota. The report should include a description of how zoning rules are likely to adversely impact or protect water quality in the drainage basin.

****Task 1E4, Critical habitat:** Prepare a proposed rule to designate appropriate areas in the St. Croix River, such as the east channel of Folsom Island, as critical habitat under the Act.

Task 1E5, Natural heritage databases: Complete entry of *Q. fragosa* distributional data into Minnesota and Wisconsin Natural Heritage databases; make the data available to USFWS, USNPS, USACOE, MDOT, MPCA, WDOT, and local county zoning boards.

Task 1F, Human disturbance and destruction of *Q. fragosa*: The following actions are recommended to address the issue of human disturbance of *Q. fragosa*:

****Task 1F1, Human disturbance:** Quantify the magnitude of these potential threats (harvesting, swimming/wading/digging, small recreational watercraft, and commercial paddlewheel watercraft) and identify specific geographic locations of greatest concern.

****Task 1F2, Educational signs:** Produce educational signs to inform the public of the presence of *Q. fragosa*, laws and penalties associated with disturbing individuals of the species, and behaviors to avoid while in critical areas. These signs should be posted at marinas, campgrounds, boat ramps and landings, and near critical mussel beds, such as at Folsom and Blast Islands.

****Task 1F3, Public education:** Contact and encourage educational institutions to conduct educational programs on *Q. fragosa*. These institutions should include the National Park Service, state parks (St. Croix, Wild River, Interstate, William O'Brien, Afton, and Kinnickinnic), the Science Museum of Minnesota, Carpenter and Wilder Nature Centers, and local conservation groups.

****Task 1F4, Paddle wheel boats:** Request owners of the commercial paddle wheel boat to review their operating procedures with the intent of minimizing their boat operation's impact on the mussel population.

Task 1G, Water quality: The following actions are recommended to address the issue of water quality:

Task 1G1, Water quality classification: Review the classification status for water quality in the St. Croix River for both Minnesota and Wisconsin and recommend changes in classification, as appropriate to protect *Q. fragosa*.

Task 1G2, Ammonia: Monitor the river for ammonia to better determine sources and concentration level trends. The report should address both chronic and acute ammonia pollution.

Task 1G3, Point discharge impacts: Perform detailed water chemistry analysis from above and below point discharge facilities and assess the effects of measurable discharges on *Q. fragosa*.

Task 1G4, Point discharge permits: Review point source discharge data on file at Minnesota

Pollution Control Agency and Wisconsin Department of Natural Resources. Cooperate with agencies to assure permits effectively protect *Q. fragosa* and that discharges are within the permitted limits.

Task 1G5, Toxins: Quantitatively sample mussels found in association with *Q. fragosa* to determine the extent of contamination with bioaccumulative, persistent toxins.

Task 1G6, Metal contamination: Review Troelstrup's data to determine history of metal contamination in the river.

Task 1G7, Water quality monitoring: Determine critical water quality parameters to monitor, and monitor them to detect changes in water quality, including toxins and metals identified in Tasks 1G5 and 1G6.

Task 1G8, Literature review: Prepare an up-to-date literature review on contaminant effects on unionid mussels.

Task 1H, Watershed: Significant changes in land use are anticipated in the St. Croix River watershed. These changes are anticipated because of a rapid increase in the human population of the watershed and because of changes in agricultural, mining, and forestry practices. The following actions are recommended to address these changes:

Task 1H1, Non-point pollution: Prepare a report which assesses the likely impact of non-point source pollution. The report should include an inventory of likely contaminants and their concentrations.

Task 1H2, Forestry: Review state and Federal forest plans for forested areas within the watershed and prepare a report which assesses the likely impact of these plans on water quality in the St. Croix River.

Task 1H3, Mining: Inventory all gravel and sand mines in the watershed and assess their likely impact on water quality in the St. Croix River.

Task 1H4, Agriculture: Prepare a report assessing the dominant agricultural practices in the watershed and their likely impact on water quality in the St. Croix River.

Task 1H5, Residential and commercial development: Prepare a report assessing residential and commercial developments in the watershed and their likely impact on water quality in the St. Croix River.

Task 1H6, Watershed remediation: Work with state and Federal agencies and non-governmental organizations to effectively mitigate *Q. fragosa* related problems identified in Tasks 1H1 to 1H5.

Task 1I, Disturbance by non-human animals: The following actions are recommended to address the issue of disturbance by non-human animals:

Task 1I1, Non-human predators: Produce a report on muskrat, raccoon, and other predator (including avian predators) population sizes along the St. Croix River between St. Croix Falls and Osceola, Wisconsin.

Task 1I2, Predation impact: Determine the importance of predation in controlling the St. Croix River population of *Q. fragosa*.

Task 1I3, Predator control: Implement predator control measures as warranted.

Task 1I4, Parasites and disease: Determine the importance of parasites and disease in controlling the St. Croix River population of *Q. fragosa*.

Task 1J) Cryopreservation: The St. Croix River population of *Q. fragosa* should be considered at very high risk of extinction because of its small size and restricted distribution. For this reason, modern technological methods of species preservation should be evaluated and applied as appropriate.

Task 1J1, Cryopreservation: Evaluate and produce a report on the efficacy of cryopreservation to preserve *Q. fragosa*.

<u>Task 2:</u> **Improve understanding of *Q. fragosa* biology and ecology.** The following sub-tasks are to provide information critical to devising actions to preserve *Q. fragosa*. Many of the sub-tasks must be completed for successful completion of sub-tasks described in Tasks 1, 3, 4, and 5.

Task 2A, Systematics: Further work is needed to determine taxonomic relationships within the *Q. quadrula* complex and to determine the appropriateness of species designation for *Q. fragosa*.

Task 2A1, Molecular systematics: Conduct molecular studies on existing *Q. fragosa* material. This study should include the population of *Quadrula* found in the Kiamichi River, Oklahoma, and all members of the *Q. quadrula* complex.

Task 2A2, Conchology: Compare shell morphology of the Kiamichi River and St. Croix River populations and all members of the *Q. quadrula* complex.

Task 2A3, Soft body morphology: Describe the soft-body morphology of *Q. fragosa* and all members of the *Q. quadrula* complex.

****Task 2A4, Glochidia:** Describe the glochidia of all members of the *Q. quadrula* complex.

Task 2B, Habitat requirements: Further work is required to identify specific habitat features usable for habitat suitability determinations for *Q. fragosa*. It is not known why *Q. fragosa* occurs where it does generally nor what limits its distribution within the St. Croix River itself.

****Task 2B1, St. Croix habitat:** Produce a report on an extensive comparison of the reach *Q. fragosa* inhabits with upstream and downstream reaches where it is not found to identify significant habitat limiting parameters. Review Wisconsin Department of Natural Resources distributional and habitat data in conjunction with this task.

Task 2B2, Historical distribution: Review the rivers comprising the historical distribution of *Q. fragosa* to assess the historical water quality parameters and other available historical trend data. Parameters to be included are: oxygen, temperature, chlorine, phosphorus, ammonia, calcium, alkalinity, total organic carbon, metals, pesticides (including herbicides), suspended solids, stream flow, pH, sodium, and potassium.

****Task 2B3, Microhabitat:** Because only 26 individual *Q. fragosa* have been studied, continue intensive microhabitat study to better identify habitat needs (substrate, depth, flow rate, etc.) of *Q. fragosa*.

Task 2B4, Scour: Evaluate and produce a report on unionid susceptibility to ice scour and exposure in winter and flood scour in spring. Evaluate ice impacts during naturally low flow and run-of-river *vs.* hydropeaking flow conditions.

Task 2B5, Sediment deposition: Evaluate and produce a report on sediment deposition patterns and unionid susceptibility to sediment deposition.

****Task 2B6, Dewatering:** Determine the effects of dewatering and of low and high temperatures on unionids. The report should include a discussion of how these parameters effect survivorship and reproduction.

Task 2C, Reproductive biology: An improved knowledge of the reproductive biology of this species is required to make sound management decisions.

****Task 2C1, Reproductive phenology:** Determine the phenology of reproduction.

****Task 2C2, Glochidial host:** Identify the glochidial host(s).

****Task 2C3, Glochidial host distribution:** Determine the distribution and abundance of glochidial host(s) population(s) in the St. Croix River.

****Task 2C4, Reproductive parameters:** Determine other factors that influence reproductive success (fecundity, sex ratio, density, spacing of adults, or external environmental factors).

Task 2D, Population biology: An improved knowledge of the population biology of this species is required to make sound management decisions.

Task 2D1, PVA and MVP: Conduct a Population Viability Analysis (PVA) to determine the Minimum Viable Population (MVP) for a discrete population of *Q. fragosa*.

Task 2D2, Demographic patterns: Determine normal growth rates and age structure from museum specimens and data from the St. Croix River.

Task 2D3, Historic distribution: Study museum specimens to better establish historic range and number of pre-settlement populations.

Task 2D4, Number of populations: Estimate the number of discrete populations needed to maintain the species and the optimal geographic distribution for those populations.

Task 2E, Population survey:

****Task 2E1, St. Croix River:** Complete a survey of the St. Croix River and its tributaries to improve our knowledge of the extent of the population and to improve estimates of population size. A survey is needed from the dam at St. Croix Falls downstream to Marine on St. Croix and upstream from the dam to the confluence of St. Croix and Namekagon Rivers. Review Wisconsin Department of Natural Resources surveys reports on substrate and mussel distribution.

Task 2E2, Historic distribution: Finish the field survey of rivers having historic distribution of *Q. fragosa*. Highest priority should be given to stretches just below dams in: 1) The Kiamichi River, Oklahoma; 2) Duck River, Tennessee, which has a recent record of a "strange looking *Q. quadrula*, which might have been *Q. fragosa*" (S. Ahlstedt, Tennessee Valley Authority, Aquatic Biology Laboratory, Norris, Tennessee, *in litt.* 1991); 3) Rivers thought to have historically had large populations of *Q. fragosa* (Iowa and Raccoon Rivers, Iowa); and 4) Rivers having relatively undisturbed watersheds or water quality characteristics similar to the St. Croix River.

Task 3: Increase the St. Croix population of *Q. fragosa*.

Translocation of mussels is problematic and has resulted in high mortality rates during transportation or shortly after transportation and there is a dearth of knowledge about the long-term viability of translocated unionids. Additionally, *ex-situ* culture techniques are poorly developed and few species have been successfully cultured. The population in the St. Croix River is so small that it is too risky to attempt either translocation or aquaculture of this species until either methodologies improve or the population in the St. Croix increases significantly.

Task 3A, Increase St. Croix population:

Task 3A1, Feasibility study: Perform a feasibility study to determine the relative merits and likely success of attempts to increase the population size of *Q. fragosa* in the St. Croix River *vis á vis* attempts to translocate individuals to initiate new populations. This feasibility study should utilize the results of tasks outlined in Tasks 2, 4A, and 4B.

Task 3A2, Plan to increase St. Croix population: If, upon completion of Task 3A1, it is deemed feasible to increase the St. Croix River population, then a plan to do so should be developed and implemented.

<u>Task 4:</u> Reestablish *Q. fragosa* populations in historical range.

Small, localized populations are very susceptible to environmental stochasticity (Gilpin and Soulé 1986). The long-term viability of *Q. fragosa* depends on establishing more than one discrete population. There are no data which suggests 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.

Task 4A, Translocation:

Task 4A1, Translocation protocol: Evaluate translocation techniques and establish a translocation protocol.

Task 4A2, Suitable habitat: Identify rivers within the historical distribution of *Q. fragosa* which have suitable physical, chemical, and biological habitat for reintroduction of *Q. fragosa*. Give priority to the following factors when selecting translocation sites:

a) Rivers close to the St. Croix so environmental and climatic factors will be similar to those to which the St. Croix River population is adapted and so new populations might function as a metapopulation.

b) Rivers having sufficient long-term protection (such as mussel sanctuaries, state or National parks) so they will qualify under the guidelines for population habitat protection in Task 5C.

c) Rivers at low risk from colonization by *Dreissena spp.*

Task 4B, Mussel culture and propagation:

Task 4B1, *in situ vs. ex situ*: Evaluate *in situ vs. ex situ* approaches to recovery and develop methods consistent with the findings.

Task 4B2, Mussel cultivation: Generally improve the knowledge of mussel cultivation.

<u>Task 5:</u> **Determination of reclassification and delisting.** Task 2D4 will establish the appropriate number and distribution of populations of *Q. fragosa*.

Task 5A, Determination of population viability: A population may be counted toward reclassification or delisting only after the following tasks are performed to demonstrate its viability:

Task 5A1, Recruitment: Conduct surveys until data demonstrate recruitment to the population in 8 of the 11 age classes aged 2 to 12 years.

Task 5A2, Population size: Conduct surveys until data demonstrate the population likely exceeds the MVP determination made in Task 2D1.

Task 5A3, Age structure: Conduct surveys until data demonstrate the population has an age structure consistent with the MVP determination made in Task 2D1.

Task 5A4, Genetic structure: Conduct surveys until data demonstrate the population has a genetic structure consistent with the MVP determination made in Task 2D1.

Task 5B, Determination of population persistence: A population may be counted toward reclassification or delisting only after the following tasks are performed to demonstrate its persistence:

Task 5B1, Longevity: The population must have been extant for 24 years following colonization or establishment.

Task 5B2, Population surveys: Three consecutive surveys taken at approximately 5-year intervals must demonstrate population levels to exceed the MVP determination made in Task 2D1.

Task 5C, Determination of habitat protection: A population may be counted toward reclassification or delisting only after the following tasks are performed to demonstrate its habitat is protected:

Task 5C1, Watershed management plan: A watershed management plan must be drafted and approved by the Service which demonstrates all potential threats to the population have been identified and either eliminated, mitigated, or otherwise provided for. The factors to be included in this plan should be similar to those outlined in this document for protection of the St. Croix Population in Task 1 and must include:

a) Physical habitat.

b) Chemical habitat.

c) Biological habitat.

d) Protection from commercial harvest.

e) Protection from toxic spills.

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Implementation Schedule

The following Implementation Schedule outlines actions and estimated costs for the recovery program. It is a guide for meeting the objective discussed in the Recovery section of this plan, and indicates task priorities, task numbers, task descriptions, duration of tasks, responsible agencies, and estimated costs. These actions, when accomplished, should bring about the recovery of the (species/group of species) and protect (its/their) habitat. As the estimated monetary needs for all parties involved in recovery are identified, this schedule reflects the total estimated financial requirements for the recovery of this (species/group of species).

Definitions of terms used in the Recovery Plan:

Priority 1: An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

Priority 2: An action that must be taken to prevent a significant decline in species population/habitat quality, or some other significant negative impact short of extinction.

Priority 3: All other actions necessary to meet the recovery objectives.

Implementation Schedule Abbreviations:

ES = USFWS, Endangered Species Prog.
NBS = National Biological Service
NPS = National Park Service
NSP = Northern States Power Co.
MDNR = Minnesota Dept. of Natural Resources
MPCA = Minnesota Pollution Control Agency
TBD = To be determined
USFWS= U.S. Fish and Wildlife Service
USGS = U.S. Geological Service
WDNR = Wisconsin Dept. of Natural Resources

Implementation Schedule for Winged Mapleleaf (*Quadrula fragosa*) Recovery Plan
(Priority 1 Tasks)

Task	Task Priority	Task Description	Years Duration	Responsible Party: USFWS Reg.	USFWS Prog.	Other	Cost Estimate (X$1000) Yr.1	2	3	Comments
1A1	1	Community population monitoring	Ongoing	USFWS	ES	NPS, contract	20	0	0	
1B1	1	Install flow gauge	Ongoing	USFWS	ES	NPS, NSP, MDNR	7.5	2.0	2.0	Installed, 1993
1B2	1	Instream flow study	2	USFWS	ES	NPS, WDNR, MDNR	60	30	0	Completed, 1995
1B4	1	NSP flow regime	Ongoing	USFWS	ES	NPS, NSP	0	1	0	
1C3	1	Document harmful material storage	1	USFWS	ES	NPS	0	3	0	
1D1	1	Monitor for zebra mussels	Ongoing	USFWS	ES	NPS				See 1D3 cost est.
1D2	1	Monitor zebra mussel loads	Ongoing	USFWS	ES	NPS				See 1D3 cost est.
1D3	1	Assess zebra mussel impact	Ongoing	USFWS	ES	NPS				See 1D3 cost est.
1D4	1	Emergency zebra mussel response plan	Ongoing	USFWS	ES	NPS	200	200	200	In progress, 1993
1D5	1	Protective legislation	2	USFWS	ES	NPS				See 1D3 cost est.
1E4	1	Propose critical habitat	2	USFWS	ES	NPS	2	2	0	
1F1	1	Assess human disturbance	1	USFWS	ES	NPS	5	0	0	
1F2	1	Educational signs	1	USFWS	ES	NPS	10	0	0	
1F3	1	Public education	Ongoing	USFWS	ES	NPS	1	1	1	
1F4	1	Tour boat operations	1	USFWS	ES	NPS	1	0	0	
2A4	1	Describe glochidia	2	USFWS	ES		10	10	0	NBS Lab, LaCrosse, WI
2B1	1	Compare St. Croix habitats	Ongoing	USFWS	ES		10	10	10	
2B3	1	Microhabitat needs	Ongoing	USFWS	ES		30	30	30	After Task 2E1
2B6	1	Assess low flow and dewatering impacts	2	USFWS	ES		30	30	0	
2C1	1	Reproductive phenology	3	USFWS	ES		20	20	20	
2C2	1	Glochidial host identification	4	USFWS	ES		20	20	20	
2C3	1	Glochidial host distribution	1	USFWS	ES		TBD	TBD	TBD	After Task 2C2
2C4	1	Reproductive success factors	TBD	USFWS	ES		TBD	TBD	TBD	
2E1	1	Population survey	Ongoing	USFWS	ES		20	20	20	

Implementation Schedule for Winged Mapleleaf (*Quadrula fragosa*) Recovery Plan
(Priority 2 Tasks)

Task	Task Priority	Task Description	Years Duration	Responsible Party: USFWS Reg.	Responsible Party: USFWS Prog.	Responsible Party: Other	Cost Estimate (X$1000) Yr.1	2	3	Comments
1B3	2	Analyze hourly flow records	1	USFWS	ES	NPS, contract	TBD	TBD	TBD	
1C1	2	Hazardous material transport	1	USFWS	ES	NPS, contract	TBD	TBD	TBD	
1C2	2	Hazardous material storage	1	USFWS	ES	NPS	TBD	TBD	TBD	
1C4	2	Spill reduction and response plan	1	USFWS	ES	NPS	TBD	TBD	TBD	
1C5	2	NSP spill assistance	1	USFWS	ES	NPS	TBD	TBD	TBD	
1C6	2	Hazardous waste facilities	1	USFWS	ES	NPS	TBD	TBD	TBD	
1E1	2	Federal agency agreements	1	USFWS	ES	NPS	TBD	TBD	TBD	
1E2	2	State agency agreements	1	USFWS	ES	NPS	TBD	TBD	TBD	
1E5	2	Natural heritage databases	Ongoing	USFWS	ES	NPS	TBD	TBD	TBD	
1G1	2	Review water quality classification	1	USFWS	ES	NPS	TBD	TBD	TBD	
1G2	2	Monitor ammonia	Ongoing	USFWS	ES	NPS	TBD	TBD	TBD	See Task 1G7
1G3	2	Point discharge impacts	Ongoing	USFWS	ES	NPS	TBD	TBD	TBD	Cost dependent on # sources
1G4	2	Point discharge permits	Continuous	USFWS	ES	NPS	TBD	TBD	TBD	Cost dependent on # sources
1G5	2	Assess toxins	2	USFWS	ES	NPS	TBD	TBD	TBD	
1G6	2	Metal contamination history	2	USFWS	ES	NPS	TBD	TBD	TBD	
1G7	2	Water quality monitoring	Ongoing	USFWS	ES	NPS	TBD	TBD	TBD	Through MPCA or USGS
1H1	2	Assess non-point pollution	1	USFWS	ES	NPS	TBD	TBD	TBD	
1H2	2	Review forestry plans	1	USFWS	ES	NPS	TBD	TBD	TBD	
1H3	2	Mining inventory and assessment	1	USFWS	ES	NPS	TBD	TBD	TBD	
1H4	2	Assess agriculture	1	USFWS	ES	NPS	TBD	TBD	TBD	
1H5	2	Assess residential and commercial development	1	USFWS	ES	NPS	TBD	TBD	TBD	
1H6	2	Watershed remediation	Continuous	USFWS	ES	NPS	TBD	TBD	TBD	
1I2	2	Assess predation	2	USFWS	ES	NPS	TBD	TBD	TBD	
1I3	2	Predator control	Continuous	USFWS	ES	NPS	TBD	TBD	TBD	
2B2	2	Historical distribution	2	USFWS	ES		TBD	TBD	TBD	After Task 2E2
2B4	2	Assess ice and flood scour	2	USFWS	ES		TBD	TBD	TBD	After Task 2E1
2B5	2	Assess sediment deposition	2	USFWS	ES		TBD	TBD	TBD	After Task 2E1
2D1	2	Conduct PVA and MVP	TBD	USFWS	ES		TBD	TBD	TBD	Good data are not available

Implementation Schedule for Winged Mapleleaf (*Quadrula fragosa*) Recovery Plan
(Priority 2 Tasks, continued, and Priority 3 Tasks)

Task	Task Priority	Task Description	Years Duration	Responsible Party: USFWS Reg.	Responsible Party: USFWS Prog.	Responsible Party: Other	Cost Estimate (X$1000) Yr.1	2	3	Comments
2D2	2	Demographic patterns	1	USFWS	ES		TBD	TBD	TBD	
2D4	2	Determine necessary number of populations	TBD	USFWS	ES		TBD	TBD	TBD	
2E2	2	Historic distribution	5	USFWS	ES		TBD	TBD	TBD	
3A1	2	Assess enhancement vs. relocation/reintroduction	TBD	USFWS	ES		TBD	TBD	TBD	
3A2	2	Develop population enhancement plan	TBD	USFWS	ES		TBD	TBD	TBD	
4A1	2	Develop translocation protocol	Ongoing	USFWS	ES		TBD	TBD	TBD	
4A2	2	Identify suitable habitat	TBD	USFWS	ES		TBD	TBD	TBD	
4B1	2	Evaluate *in situ vs. ex situ* measures	Ongoing	USFWS	ES		TBD	TBD	TBD	Work in progress elsewhere
4B2	2	Mussel cultivation	Ongoing	USFWS	ES		TBD	TBD	TBD	Work in progress elsewhere
1E3	3	Review county zoning	1	USFWS	ES	NPS	TBD	TBD	TBD	
1G8	3	Contaminants literature review	1	USFWS	ES	NPS	TBD	TBD	TBD	
1I1	3	Assess non-human predator populations	2	USFWS	ES	NPS	TBD	TBD	TBD	
1I4	3	Assess parasites and disease	2	USFWS	ES	NPS	TBD	TBD	TBD	
1J1	3	Evaluate cryopreservation	1	USFWS	ES	NPS	TBD	TBD	TBD	
2A1	3	Molecular systematics	2	USFWS	ES		TBD	TBD	TBD	Existing material
2A2	3	Conchology studies	1	USFWS	ES		TBD	TBD	TBD	Existing material
2A3	3	Describe soft body morphology	1	USFWS	ES		TBD	TBD	TBD	Existing material
2D3	3	Historic distribution	1	USFWS	ES		TBD	TBD	TBD	
5A1	3	Monitor recruitment	TBD	USFWS	ES		TBD	TBD	TBD	
5A2	3	Monitor population size	TBD	USFWS	ES		TBD	TBD	TBD	
5A3	3	Monitor age structure	TBD	USFWS	ES		TBD	TBD	TBD	
5A4	3	Monitor genetic structure	TBD	USFWS	ES		TBD	TBD	TBD	
5B1	3	Monitor longevity	TBD	USFWS	ES		TBD	TBD	TBD	
5B2	3	Population surveys	TBD	USFWS	ES		TBD	TBD	TBD	
5C1	3	Watershed Management Plan	TBD	USFWS	ES		TBD	TBD	TBD	

TABLE 1
HISTORICAL DISTRIBUTION OF
***QUADRULA FRAGOSA* WITH REFERENCES**

River	State	Citation*	Publication**	Museum***
Mississippi	WI	21,22,41		26,27,28,29,48
	IL		24	16
	MO		60	
	MN			28,29
	IA	21,22	48	16,20,23
Atchafalaya****				
Red	OK	61		
Kiamachi	OK	37,39,53		28
Boggy	OK		34	
Little	OK		34	
Arkansas				
Whitewater	KA		6	
Verdigris				
Fall	KA	55	4,8,44	23
Grand				
Neosho	KA		6,7,34	23
Ohio	OH	25,36,50,54,55	4,9,10,14,51,57	16,23,38
	IN		9,10,12,45	
Licking	KY	25		38
Tennessee	TN	50	45,46,51,56	23,43
Duck	TN	54	43,56	23,42
Cumberland*****	TN	25,36,49,50	17,45,51,56,63,38,42	
Harpeth	TN	42	56,63	
Wabash	IN	36	9,10,11,12	16,18,23,28
West White	IN		10,11,12	16,23
Raccoon Creek	OH	54	62	28
Scioto	OH	36,54	12,15,57	23,28
Kaskaskia	IL		2,24	28
Illinois	IL		2,17,24	
Spoon	IL	3,33	2,24,59	16
Sangamon	IL			16,23,28
Missouri				
Kansas				
Soldier Creek	KA		5	
Blue	NE		1	
Bow Creek	NE		1	
Osage	MO	52	60	
102	MO		60	
Fox	MO			23,28
DesMoines	IA		35	
Raccoon	IA		35	23
Iowa	IA		24,35,47	20,23,28
Cedar	IA		24	20,23
Wisconsin	WI	40,41,58		3,13,23,28,29,30
Baraboo	WI	29,41		3
St. Croix	WI	32,41	31	19,23,28,29

Many of these records have not been recently verified. Rivers are nested to show drainage basin. Rivers in bold type are rivers from which there are records of the occurrence of *Q. fragosa*.

(Table 1 continued)

* **Citation:** Records in which the author simply cites someone else's work as indicating this record exists or personal communication.

** **Publication:** Records which are published in literature or government report/document and includes at least one original report.

*** **Museum:** Records which reference a museum collection with vouchered specimens.

**** The systematics of this population are not clear. See text for discussion.

***** Gordon (1992) claims all museum vouchers for this river are misidentified *Q. quadrula*.

Key to Citations, Publications and Museum Records for Table 1

1) Aughey 1877
2) Baker 1906
3) Baker 1928
4) Call 1885a
5) Call 1885b
6) Call 1885c
7) Call 1886
8) Call 1887
9) Call 1894
10) Call 1896
11) Call 1897
12) Call 1900
13) Chadwick 1906
14) Coker 1921
15) Conrad 1835
16) Cummings 1989
17) Danglade 1914
18) Daniels 1903
19) Doolittle 1988
20) Frest 1987
21) Fuller 1980b
22) Fuller 1980c
23) Gordon 1992
24) Grier & Mueller 1922-1923
25) R.R. Hannan, Kentucky State Nature Preserves Commission, *in litt.* 1989
26) Havlik & Marking 1980
27) Havlik & Stansbery 1978
28) Heath 1981-85
29) Heath 1986a
30) Heath 1986b
31) Heath & Rasmussen 1990
32) Hornbach 1992
33) ILNHS 1986
34) Isley 1925
35) Keyes 1889
36) LaRocque 1967
37) Mather 1983
38) D.R. McCormick, Kentucky Department of Fish and Wildlife Resources, *in litt.* 1989
39) P. Mehlhop-Cifelli, Oklahoma Natural History, Inventory *in litt.* 1989
40) Morrison 1929
41) Ronald F. Nicotera, Wisconsin Department of Natural Resources, *in litt.* 1989
42) Ortmann 1924
43) Ortmann 1925
44) Popenoe 1885
45) Scammon 1906
46) Scruggs 1960
47) Shimek 1888
48) Shimek 1921
49) Sickel 1982
50) Simpson 1900
51) Simpson 1914
52) Stansbery 1972
53) Stansbery 1974
54) Stansbery *et al.* 1985
55) Stansbery 1991
56) Starnes & Bogan 1988
57) Sterki 1907
58) Stern 1983
59) Strode 1891
60) Utterback 1915
61) Valentine & Stansbery 1971
62) Watters 1988
63) Wilson & Clark 1914

TABLE 2
WATER CHEMISTRY OF
THE ST. CROIX RIVER AT ST. CROIX FALLS

Parameter	Beginning Date	Ending Date	N	Mean	Standard Error	Minimum	Maximum
Alkalinity, total (mg/l)	1/22/53	8/3/85	126	74.7	1.6	28	110
Aluminum, total (µg/l)***	11/14/74	8/7/79	19	115.8	16.7	10	250
Arsenic, total (µg/l)*	1975	1983	30	1.0	.09	<1	3
Cadmium, tot. recov. (µg/l)*	1975	1983	30	1.0	0.15	<1	3
Calcium (mg/l)	7/20/71	7/20/77	60	51.2	1.9	21	97
Carbon, tot. organic (mg/l)	12/21/74	4/10/81	47	8.41	0.59	1.6	19
Chloride (mg/l)	4/14/53	2/25/86	148	3.7	0.16	0.50	16
Chromium, tot. recov. (µg/l)*	1975	1983	30	9	1.10	<20	20
Cobalt, tot. recov. (µg/l)*	1975	1983	30	1.0	0.33	<2	4
Color (PTU)	1/22/53	4/18/74	19	68.2	10.9	10	170
Conductivity (µmhos)	7/20/71	7/31/90	202	169.2	3.0	78	295
Copper, tot. recov. (µg/l)*	1975	1983	30	4.0	0.91	<2	24
Cyanide (mg/l)	9/17/71	7/9/74	2	0.005	-	0.005	0.005
Hardness, total (mg/l)	11/7/66	2/25/86	123	80.8	1.6	31	110
Iron, tot. recoverable (µg/l)*	1975	1983	30	880	133.3	200	4,000
Lead, tot. recoverable (µg/l)*	1975	1983	30	10	2.19	<2	63
Magnesium (mg/l)	9/17/71	7/22/77	16	31.1	1.3	19	40
Manganese (µg/l)*	1975	1983	30	80	3.65	20	160
Mercury, tot. recov. (µg/l)*	1975	1983	30	0.20	0.04	<0.1	0.6
Nickel (µg/l)	7/20/71	8/19/82	69	12.6	2.7	1	190
Nitrogen, total (mg/l)	10/3/74	4/10/81	48	0.86	0.05	0.4	1.8
Nitrogen, organic (mg/l)	9/17/71	4/5/86	80	0.60	0.03	0.0	1.6
Nitrogen (NH_3&NH_4) tot. (mg/l)	7/20/71	4/5/86	33	0.092	0.02	0.0	0.69
Nitrogen (NO_2 & NO_3) (mg/l)	8/28/76	4/10/81	66	0.25	0.02	0.01	0.87
Nitrogen KJELD total (mg/l)	10/3/74	4/5/86	71	0.66	0.05	0.13	3.2
Oil, Grease, Freon (mg/l)	9/17/71	7/9/74	3	1.2	0.47	0.3	1.9
Oxygen, dissolved (mg/l)	1/22/53	10/4/90	161	9.5	0.16	4.0	14.0
pH	1/22/53	10/12/89	172	7.6**	-	6.6	8.8
Phosphorus, total (mg/l P)	7/20/71	4/5/86	146	0.063	0.005	0.01	0.67
Potassium, dissolved (mg/l)	11/7/66	2/25/86	131	1.7	0.20	0.10	21.0
Silica (mg/l)	11/7/66	2/25/86	77	11.9	0.43	4.8	27.0
Silver (µg/l)	9/17/71	8/19/82	20	0.85	0.50	0	10.0
Sodium, dissolved (mg/l)	11/7/66	2/25/86	132	3.8	0.23	1.5	29.0
Stream Flow (CFS)	1/22/53	10/4/90	168	6411	486	909	36,000
Sulfate (mg/l)	9/17/71	2/25/86	116	7.2	0.27	0.10	17.0
Sulfide (mg/l)	9/17/71	7/9/74	3	0.03	0.01	0.02	0.05
Suspended Sediment (mg/l)	12/4/74	4/5/86	69	8.8	1.2	1.0	54
Suspended Sed. (tons/day)	12/4/74	4/5/86	52	158.4	52.8	5.1	2,620
Temperature (°C)	11/7/66	10/4/90	155	9.6	0.72	0.0	28.0
Turbidity (Hach FTU)	7/21/71	2/25/86	117	4.0	0.29	0.30	20.0
Zinc, tot. recoverable (µg/l)*	1975	1983	29	30	1.28	<10	380

Unless otherwise noted, data in this table are a compilation of MPCA and USGS data retrieved from the STORET data base for samples taken at the St. Croix Falls sampling station.

* Data from Graczyk 1986.

** This is a median, rather than a mean.

*** There are no aluminum measurements recorded from the St. Croix Falls station. These values are from the USGS station at Stillwater. The five values recorded as being "less than" are treated as in Graczyk (1986).

TABLE 3

PHYSICAL HABITAT OF THE *QUADRULA FRAGOSA* POPULATION IN THE ST. CROIX RIVER

Mussel #	Depth (m)*	Bottom flow (m/sec)*	0.6 flow (m/sec)*	Mean ø
1	0.54	0.1	0.14	-2.30
2	0.62	0.14	0.23	-2.71
3	1.24	0.18	0.53	-3.23
4	1.60	0.12	0.36	-3.18
5	1.60	0.15	0.39	-2.47
6	0.60	0.04	0.16	-2.57
7	0.82	-	-	-1.58
8	0.60	-	-	-2.42
9	0.86	-	-	-2.61
10	0.82	-	-	-2.79
11	0.64	-	-	-3.13
Mean	0.90	0.12	0.30	-2.64
Standard Error	0.12	0.02	0.06	0.14

Data in this table is compiled from Hornbach (1992).

* This data is strongly dependent on Northern States Power dam operations and will be reanalyzed when dam operational data is made available and the Stream flow study is completed.

TABLE 4

FISH TISSUE CONTAMINATION AT ST. CROIX FALLS

Fish Species	PCB-1260 (µg/g wet wt)	PCB-1254 (µg/kg)	PCBS (mg/kg)	Aroclor (µg/kg)	Mercury (µg/g wet wt)
Channel catfish	<0.01	<10	<0.02	<20	0.14
Black crappie	<0.01	<10	<0.02	<20	0.07
Northern Pike	<0.01	<10	<0.02	<20	0.21
Smallmouth bass	<0.01	<10	<0.02	<20	0.31
Smallmouth bass	<0.01	<10	<0.02	<20	0.23
Smallmouth bass	<0.01	<10	<0.02	<20	0.19
Walleye	<0.01	<10	<0.02	<20	0.24
Walleye	<0.01	<10	<0.02	<20	0.61
Crappie	<0.01	<10	<0.02	<20	0.07

All data was collected by MPCA and retrieved from STORET.

TABLE 5

MAJOR MUNICIPAL AND INDUSTRIAL POINT DISCHARGERS
TO THE ST. CROIX RIVER

Minnesota Dischargers

River Mile	
53.5 (86.1 km)	Waste Water Treatment Facility, Taylor's Falls
37.8 (60.8 km)	William O'Brien State Park, Washington County
34.4 (55.4 km)	Christian Brothers' Retreat, Washington County
22.7 (36.5 km)	Waste Water Treatment Facility, Stillwater
21.6 (34.8 km)	NSP Powerplant, Stillwater
21.0 (33.8 km)	Anderson Windows, Bayport
19.8 (31.9 km)	Waste Water Treatment Facility, Bayport

Wisconsin Dischargers

53.8 (86.6 km)	Wisconsin DNR Fish Hatchery, St. Croix Falls
53.7 (86.4 km)	Waste Water Treatment Facility, St. Croix Falls
46.3 (74.5 km)	Waste Water Treatment Facility, Osceola
48.7 (78.4 km)	Wisconsin DNR Fish Hatchery, Osceola
16.7 (26.9 km)	Waste Water Treatment Facility, Hudson

TABLE 6

MUSSEL COMMUNITY FOUND IN ASSOCIATION WITH *QUADRULA FRAGOSA* IN THE ST. CROIX RIVER

Species	Total number found	Number quadrats	Mean # quadrat -1
Truncilla truncata	77	11	7.0
Quadrula fragosa	11	11	1.0
Truncilla donaciformis	10	8	1.25
Tritogonia verrucosa	5	4	*
Quadrula metanevra	4	3	*
Actinonaias carinata	4	4	*
Quadrula pustulosa	3	2	*
Ellipsaria lineolata	3	3	*
Obliquaria reflexa	2	2	*
Cyclonaias tuberculata	2	1	*
Obovaria olivaria	2	1	*
Lampsilis radiata siliquoidea	1	1	*
Epioblasma triquetra	1	1	*
Elliptio dilitata	1	1	*
Fusconaia flava	1	1	*
Alasmodonta marginata	1	1	*
Leptodea fragilis	1	1	*
Amblema plicata	1	1	*
Ligumia recta	1	1	*
Toxolasma parvus	1	1	*
Pleurobema sintoxia	1	1	*

This data is from Hornbach (1992). This is the results of a survey of 11, 0.25 m^2 quadrats that each included at least one *Q. fragosa*. Nomenclature after Turgeon *et al.* 1988.

* The sample size is too small for a meaningful calculation.

TABLE 7

SIZE AND AGE DISTRIBUTION OF 76 *QUADRULA FRAGOSA* SAMPLED IN THE ST. CROIX RIVER BETWEEN 1988 AND 1992

Year of Observation	Year of Birth	Age year of Observation	Length (mm)	Height (mm)	Investigator
1989	1967	22	83	71	Wisconsin DNR, unpub. data
1988	1968	20	91	76	Wisconsin DNR, unpub. data
1988	1968	20	78	70	Wisconsin DNR, unpub. data
1989	1968	21	74	65	Wisconsin DNR, unpub. data
1988	1968	20	82	72	Wisconsin DNR, unpub. data
1989	1969	20	79	69	Wisconsin DNR, unpub. data
1989	1971	18	73	62	Wisconsin DNR, unpub. data
1991	1973	18	96	80	Miller 1992
1991	1973	18	91	73	Miller 1992
1989	1975	14	90	72	Wisconsin DNR, unpub. data
1991	1976	15	74	68	Miller 1992
1992	1976	16	75	70	Hornbach 1992
1989	1977	12	83	71	Wisconsin DNR, unpub. data
1992	1977	15	71	68	Hornbach 1992
1988	1978	10	73	64	Wisconsin DNR, unpub. data
1988	1978	10	55	58	Wisconsin DNR, unpub. data
1989	1978	11	69	63	Wisconsin DNR, unpub. data
1989	1978	11	69	64	Wisconsin DNR, unpub. data
1989	1978	11	71	63	Wisconsin DNR, unpub. data
1991	1978	13	73	63	Miller 1992
1991	1978	13	67	58	Miller 1992
1991	1978	13	70	61	Miller 1992
1991	1978	13	68	61	Miller 1992
1988	1979	9	70	62	Wisconsin DNR, unpub. data
1988	1979	9	58	57	Wisconsin DNR, unpub. data
1989	1979	10	57	52	Wisconsin DNR, unpub. data
1989	1979	10	72	65	Wisconsin DNR, unpub. data
1989	1979	10	58	54	Wisconsin DNR, unpub. data
1989	1979	10	83	71	Wisconsin DNR, unpub. data
1989	1979	10	73	62	Wisconsin DNR, unpub. data
1989	1979	10	67	58	Wisconsin DNR, unpub. data
1989	1979	10	83	68	Wisconsin DNR, unpub. data
1991	1979	12	60	55	Miller 1992
1992	1979	13	73	68	Hornbach 1992
1988	1980	8	60	55	Wisconsin DNR, unpub. data
1989	1980	9	83	71	Wisconsin DNR, unpub. data
1992	1980	12	70	65	Hornbach 1992
1992	1980	12	72	66	Hornbach 1992
1989	1981	8	60	54	Wisconsin DNR, unpub. data
1989	1981	8	58	54	Wisconsin DNR, unpub. data
1990	1981	9	71	63	Miller 1992
1991	1981	10	54	50	Miller 1992

Continued next page.

(Table 7, continued)

Year of Observation	Year of Birth	Age year of Observation	Length (mm)	Height (mm)	Investigator
1989	1982	7	51	47	Wisconsin DNR, unpub. data
1991	1982	9	54	50	Miller 1992
1988	1983	5	44	40	Wisconsin DNR, unpub. data
1990	1983	7	54	51	Miller 1992
1992	1983	9	69	62	Hornbach 1992
1988	1984	4	29	28	Wisconsin DNR, unpub. data
1988	1984	4	35	35	Wisconsin DNR, unpub. data
1988	1984	4	36	34	Wisconsin DNR, unpub. data
1989	1984	5	39	37	Wisconsin DNR, unpub. data
1989	1984	5	46	41	Wisconsin DNR, unpub. data
1989	1984	5	48	45	Wisconsin DNR, unpub. data
1989	1984	5	45	42	Wisconsin DNR, unpub. data
1989	1984	5	46	45	Wisconsin DNR, unpub. data
1989	1984	5	44	41	Wisconsin DNR, unpub. data
1989	1984	5	46	44	Wisconsin DNR, unpub. data
1989	1984	5	44	40	Wisconsin DNR, unpub. data
1989	1984	5	40	37	Wisconsin DNR, unpub. data
1989	1984	5	83	71	Wisconsin DNR, unpub. data
1989	1984	5	83	71	Wisconsin DNR, unpub. data
1989	1984	5	83	71	Wisconsin DNR, unpub. data
1989	1984	5	31	30	Wisconsin DNR, unpub. data
1989	1984	5	40	38	Wisconsin DNR, unpub. data
1989	1984	5	38	37	Wisconsin DNR, unpub. data
1989	1984	5	37	34	Wisconsin DNR, unpub. data
1990	1984	6	51	47	Miller 1992
1990	1984	6	54	50	Miller 1992
1990	1984	6	40	38	Miller 1992
1990	1985	5	38	34	Miller 1992
1992	1986	6	45	40	Hornbach 1992
1992	1986	6	56	54	Hornbach 1992
1991	1987	4	19	14	Hornbach 1992
1992	1987	5	35	32	Hornbach 1992
1992	1987	5	37	34	Hornbach 1992
1992	1989	3	17	15	Hornbach 1992

TABLE 8

FISH DISTRIBUTION IN THE ST. CROIX RIVER

Species	Glochidia Hosts[a]	Total # 1975-83[b]	St. Croix Basin Wide 1975-83[c]	Lower River Basin River[d]	Lake St. Croix 1988[e]	Miles 23.4-44.4 1990[f]	Miles 44.4-51.0 1991[g]	Taylor's Falls 1959-63[h]
Pumpkinseed (*Lepomis gibbosus*)		2500	P	P	P			
Sauger (*Stizostedion canadense*)	3	8	P	P	P			
Mooneye (*Hiodon tergisus*)		4	P	P	P			
Flathead catfish (*Pylodictis olivaris*)	1,2,4	1	P	P	P			
American eel (*Anguilla rostrata*)		-	A	P	P			
Silver chub (*Hybopsis storeriana*)		-	A	P	P			
Shortnose gar (*Lepisosteus platostomus*)		-	A	P	P	P		
Smallmouth buffalo (*Ictiobus bubalus*)		-	A	P	P	P		
Golden redhorse (*Moxostoma erythurum*)		2700	P	P	P	P	P	
White bass (*Morone chrysops*)		74	P	P	P	P	P	
Gizzard shad (*Dorosoma cepedianum*)		-	A	P	P	P	P	
Yellow perch (*Perca flavescens*)		17000	P	P	P	P	P	P
Bluegill (*Lepomis machrochirus*)	3,4	15000	P	P	P	P	P	P
Northern pike (*Esox lucius*)		3100	P	P	P	P	P	P
Shorthead redhorse (*Moxostoma macrolepidotum*)		2400	P	P	P	P	P	P
Black crappie (*Pomoxis nigromaculatus*)	4	1800	P	P	P	P	P	P
Silver redhorse (*Moxostoma anisurum*)		1400	P	P	P	P	P	P
Smallmouth bass (*Micropterus dolomieu*)		1100	P	P	P	P	P	P
N. rock bass (*Ambloplites rupestris*)		1000	P	P	P	P	P	P
Common carp (*Cyprinus carpio*)		620	P	P	P	P	P	P
White crappie (*Pomoxis annularis*)	2,4	48	P	P	P	P	P	P
N. channel catfish (*Ictalurus punctatus*)	2,4	29	P	P	P	P	P	P
Freshwater drum (*Aplodinotus grunniens*)		9	P	P	P	P	P	P
White sucker (*Catostomus commersonnii*)		11000	P	P	P	P		P
Walleye (*Stizostedion vitreum*)		2800	P	P	P	P		P
Quillback carpsucker (*Carpoides cyprinus*)		54	P	P	P	P		P
Lake sturgeon (*Acipenser fulvescens*)		9	P	P	P			P
Bowfin (*Amia calva*)		120	P	P	P		P	
Longnose gar (*Lepisosteus osseus*)		1	P	P	P		P	
Spotted sucker (*Minytrema melanops*)		5	P	P		P		
Bigmouth buffalo (*Ictiobus cyprinellus*)		-		P		P		
N. hog sucker (*Hypentelium nigricans*)		1200	P	P		P	P	
Emerald shiner (*Notropis atherinoides*)		750	P	P		P	P	
River carpsucker (*Carpiodes carpio*)		-	A			P	P	
Largemouth bass (*Micropterus salmoides*)	4	6800	P	P		P		P
Mimic shiner (*Notropis volucellus*)		3100	P	P			P	
Johnny darter (*Etheostoma nigrum*)		6000	P	P			P	P
Spotfin shiner (*Notropis spilopterus*)	5	2200	P	P			P	P
N. log perch (*Percina caprodes*)		1300	P	P			P	P
Spottail shiner (*Notropis hudsonius*)		1100	P	P			P	P
Brook silverside (*Labidesthes sicculus*)		1000	P	P			P	P
Bluntnose minnow (*Pimephales notatus*)		17000	P	P				P
Sand shiner (*Notropis stramineus*)		1000	P	P				P
Bigmouth shiner (*Notropis dorsalis*)		370	P	A				P
Chestnut lamprey (*Ichthyomyzon castaneus*)		270	P	P				P
Trout-perch (*Percopsis omiscomaycus*)		67	P					P
Common shiner (*Notropis cornutus*)		8400	P	P				
Brown trout (*Salmo trutta*)		4300	P	P				
Golden shiner (*Notemigonus chrysoleucus*)		3300	P	P				
Fathead minnow (*Pimephales promelas*)		2800	P	P				
Brook stickleback (*Culaea inconstans*)		1700	P	P				
N. black bullhead (*Ictalurus melas*)	2	870	P	P				
Muskellunge (*Esox masquinongy*)		440	P	P				
Gilt darter (*Percina evides*)		370	P	P				
River redhorse (*Moxostoma carinatum*)		320	P	P				
Blackside darter (*Percina maculata*)		200	P	P				
Rainbow darter (*Etheostoma caeruleum*)		140	P	P				
Greater redhorse (*Moxostoma valenciennesi*)		130	P	P				
Western sand darter (*Ammocrypta clara*)		23	P	P				
Slenderhead darter (*Percina phoxocephala*)		21	P	P				
River darter (*Percina shumardi*)		17	P	P				
Pugnose minnow (*Notropis emiliae*)		13	P	P				
Silver lamprey (*Ichthyomyzon unicuspis*)		10	P	P				
Speckled chub (*Hybopsis aestivalis*)		3	P	P				
Crystal darter (*Ammocrypta asprella*)		2	P	P				
Highfin carpsucker (*Carpiodes velifer*)		2	P	P				
Blue sucker (*Cycleptus elongatus*)		1	P	P				
Green sunfish (*Lepomis cyanellus*)	3	130	P	P				
Fantail darter (*Etheostoma flabellare*)		100	P	P				

(Table 8, continued)

Species	Glochidia Hosts[a]	Total # 1975-1983[b]	St. Croix Basin Wide 1975-83[c]	Lower River Basin River[d]	Lake. St. Croix 1988[e]	Miles 23.4-44.4 1990[f]	Miles 44.4-51.0 1991[g]	Taylor's Falls 1959-63[h]
Tadpole madtom (*Noturus gyrinus*)		250	P	A				
Brown bullhead (*Ictalurus nebulosus*)	2	240	P	A				
Banded killifish (*Fundulus diaphanus*)		770	P	A				
N. yellow bullhead (*Ictalurus natalis*)		200	P	A				
Least darter (*Etheostoma microperca*)		150	P	A				
Stonecat (*Noturus flavus*)		38	P	A				
Longnose dace (*Rhinichthys cataractae*)		930	P	A				
Pugnose shiner (*Notemigonus anogenus*)		48	P					
Central mudminnow (*Umbra limi*)		1500	P					
Pearl dace (*Semotilus margarita*)		270	P					
Brassy minnow (*Hybognathus hanksinsoni*)		990	P					
Central stoneroller (*Campostoma anomalum*)		410	P					
Finescale dace (*Phoxinus neogaeus*)		140	P					
Lake herring or cisco (*Coregonus artedii*)		110	P					
Redbelly dace (*Phoxinus eos*)		930	P					
Mottled sculpin (*Cottus bairdi*)		920	P					
Hornyhead chub (*Nocomis biguttatus*)		3200	P					
Largescale stoneroller (*Campostoma oligolepsis*)		200	P					
American burbot (*Lota lota*)		180	P					
Brook trout (*Salvelinus fontinalis*)		3100	P					
Slimy sculpin (*Cottus cognatus*)		42	P					
Iowa darter (*Etheostoma exiles*)		2500	P					
Blackchin shiner (*Notropis heterodon*)		2100	P					
Blacknose dace (*Rhinichthys atratulus*)		1800	P					
Creek chub (*Semotilus atromaculatus*)		3800	P					
Blacknose shiner (*Notropis heterolepis*)		3600	P					
American brook lamprey (*Lampetra appendix*)		13	P					
Rainbow trout (*Salmo gairdneri*)		13	P					
Warmouth (*Lepomis gulosus*)		7	P					
Northern brook lamprey (*Icthyomyzon fossor*)		6	P					
Rainbow smelt (*Osmerus mordax*)		-	P					
Skipjack herring (*Alosa chrysochloris*)		-	A	A				
Goldeye (*Hiodon alosoides*)		-	A	A				
Mud darter (*Etheostoma asprigene*)		-	A	A				
Weed shiner (*Notropis texanus*)		-	A	A				
River shiner (*Notropis blennius*)		-	A	A				
Pallid shiner (*Notropis amnis*)		-	A	P				
Lake trout (*Salvelinus namaycush*)		-	A					
Southern brook lamprey (*Ichthyomyzon gagei*)*								
Shovelnose sturgeon (*Scaphirynchus platorynchus*)*					A			
Paddlefish (*Polydon spathula*)*			A					
Blue catfish (*Ictalurus furcatus*)*			P					

P = At least one individual present in survey.
A = Not found in this survey, but reported present prior to 1975.
a) Host for glochidia of mussels listed below from Oesch (1984), Hill (1986), or Watters (1994).
b) Total number of specimens taken by all methods from the entire St. Croix drainage basin. The data is from Fago (1986), Table 7.
c) The data is from Fago (1986), Table 6, for stream surveys in the entire St. Croix watershed from 1975 to 1983.
d) The data is from Fago, Hatch, and Graczyk, unpublished manuscript.
e) Data from Stewart and Gilbertson (1988).
f) Data from Minnesota DNR Stream Population Assessment, unpublished data for 1990
g) Data from Minnesota DNR Stream Population Assessment, unpublished data for 1991.
h) Data from Peterson (1964) Table 10.

1) Mapleleaf (*Quadrula quadrula*)
2) Pimple-back (*Q. pustulosa*)
3) Monkey-face (*Q. metanerva*)
4) Warty-back (*Q. nodulata*)
5) Rabbitsfoot (*Q. cylindrica*)

* Listed in Becker (1983), Lee *et al.* (1980), or Phillips *et al.* (1982).

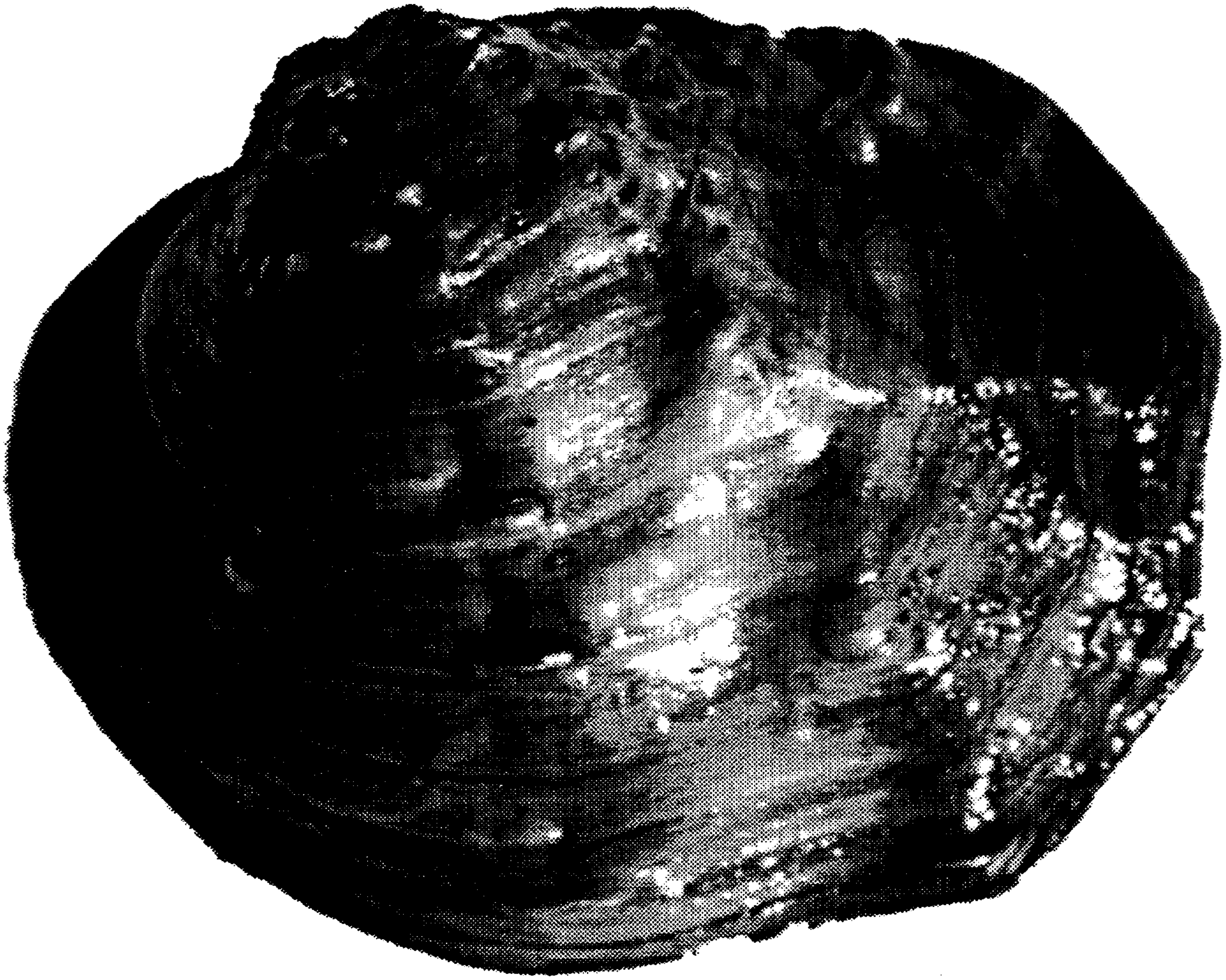
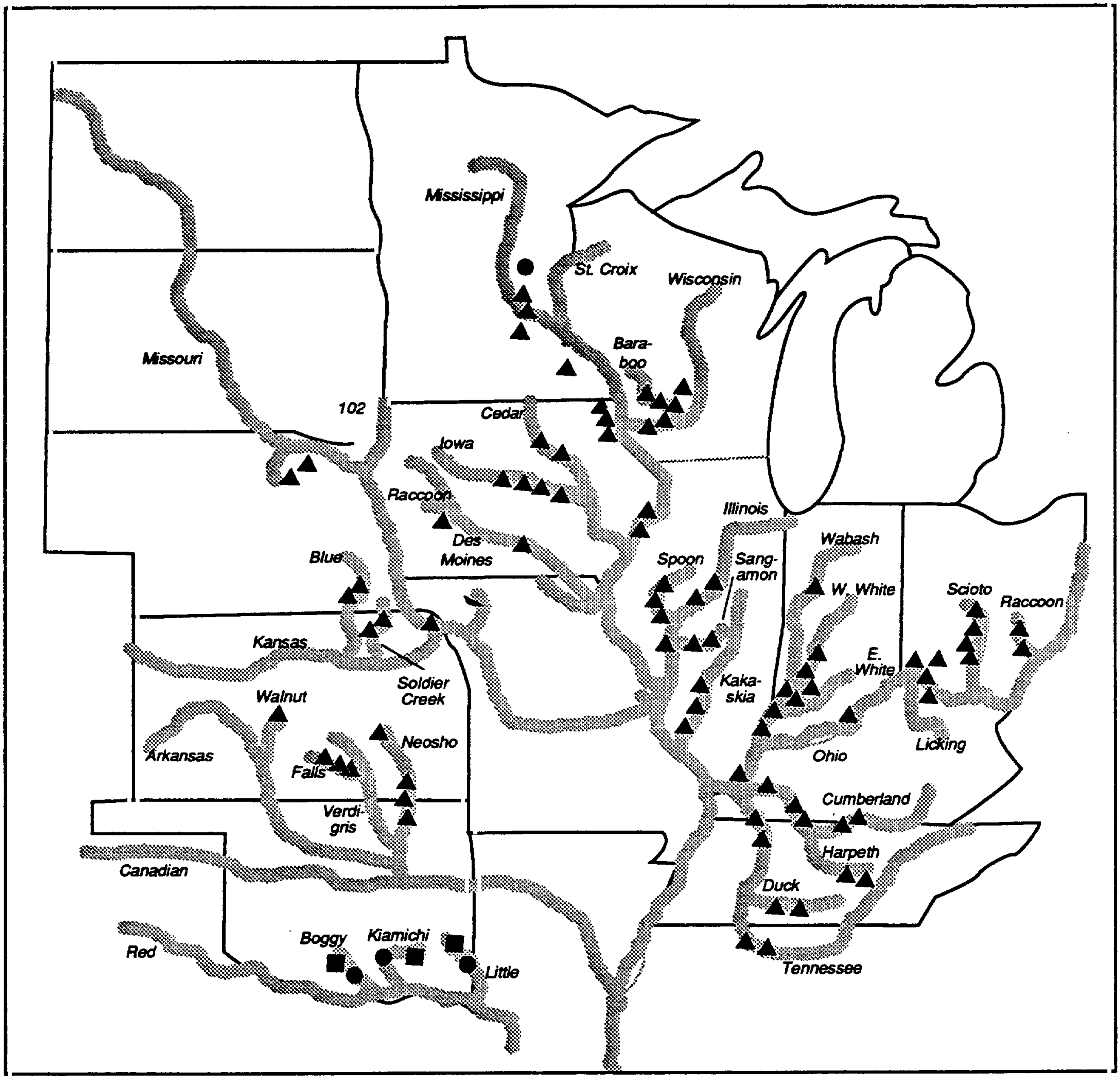


Figure 1. External shell view of winged mapleleaf freshwater mussel, *Quadrula fragosa*, St. Croix River, Interstate Park. (*Photo by David Heath*, Wisconsin Department of Natural Resources)



▲ Pre-1930 and recent subfossil

● Recent (1931-1991) *Quadrula fragosa* distribution

■ Possible sibling species

Figure 2. Historic distribtion of *Quadrula fragosa*.

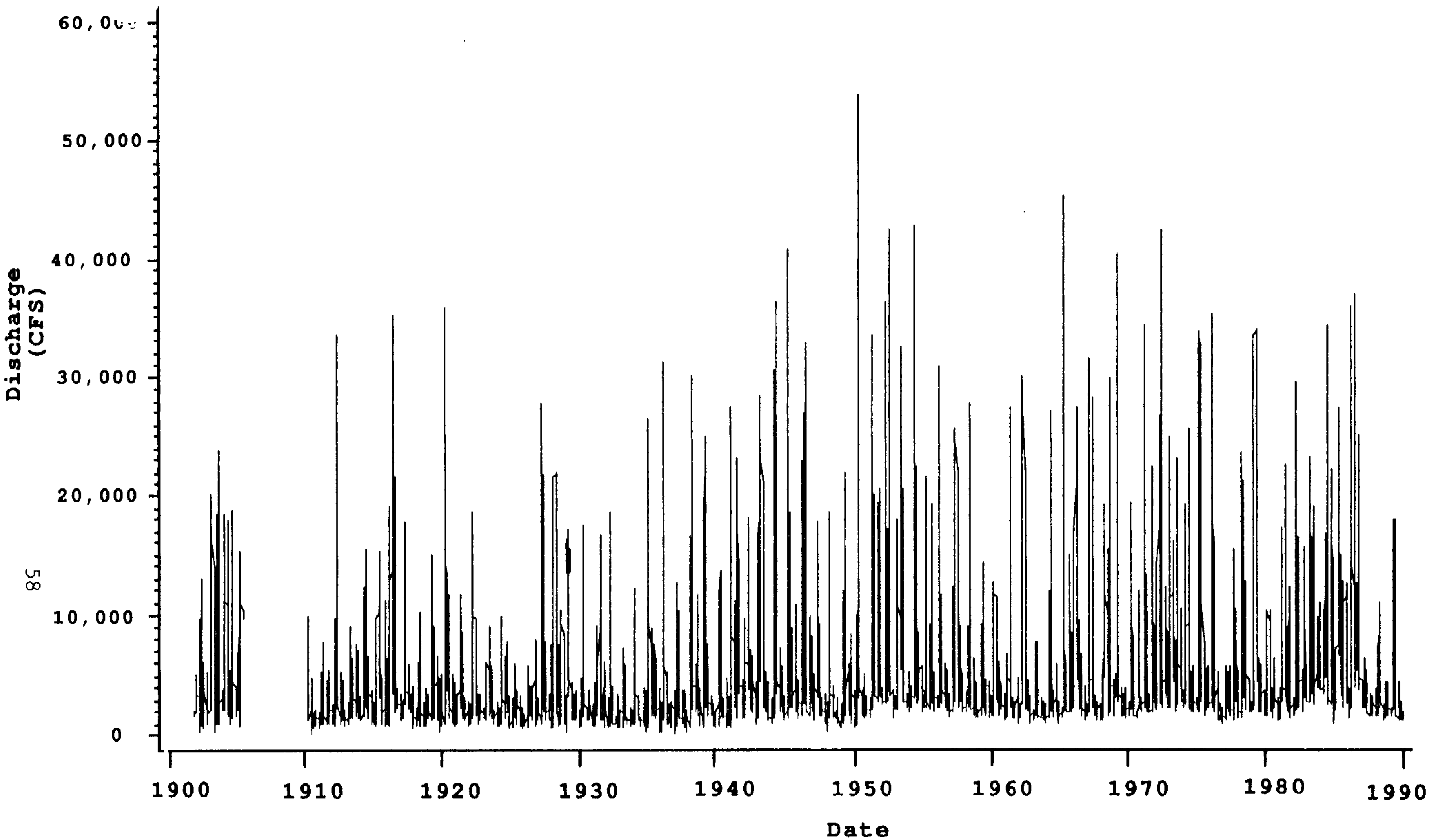


Figure 3. Mean Daily Discharge at Interstate Park, 1902 to 1991.
The data is from the USGS NASQAN station (05340500) as cited in Hornbach's Figure 20 (1992).

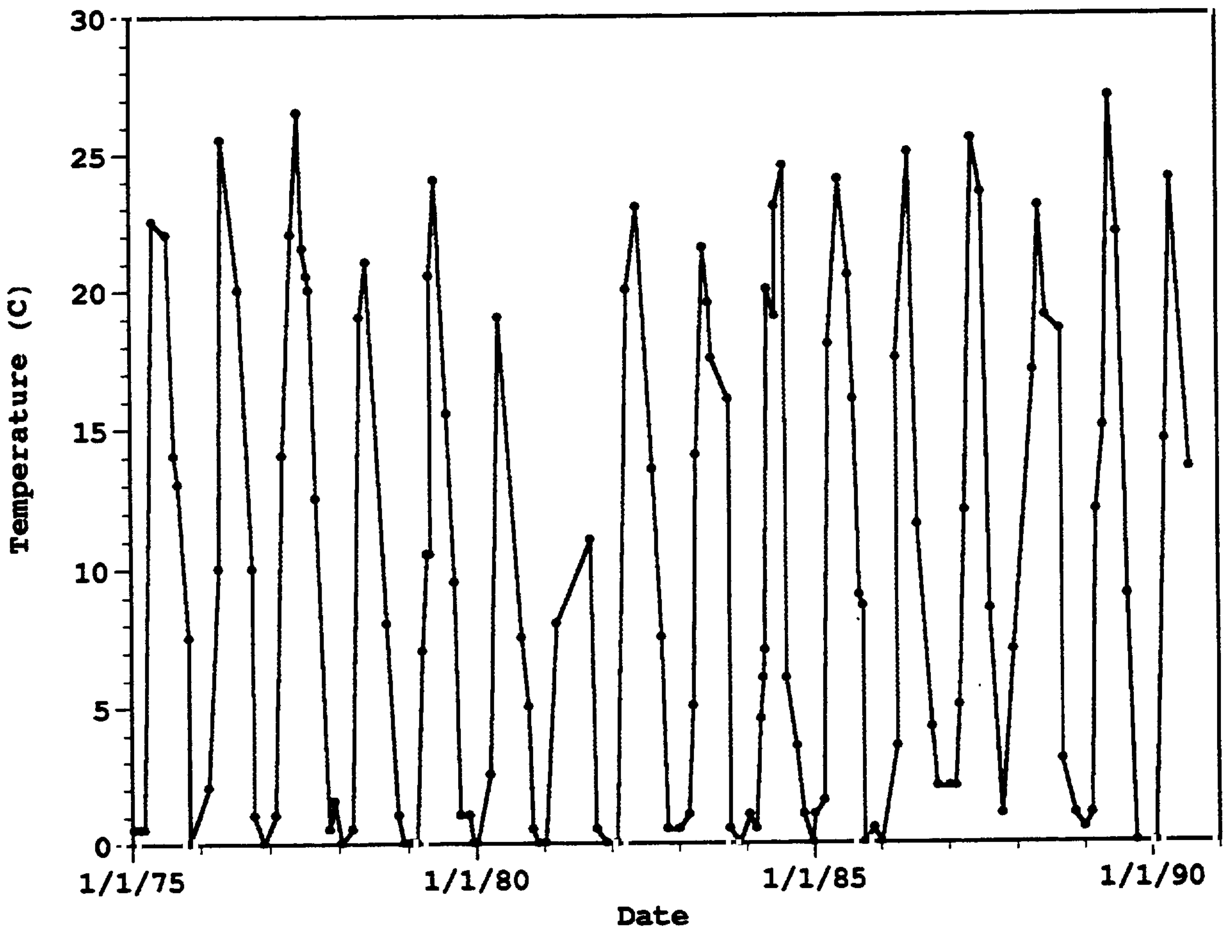


Figure 4. Water Temperature at St. Croix Falls from 1975 to 1991. The data was collected approximately monthly and is from the USGS NASQAN station (05340500) retrieved through STORET.

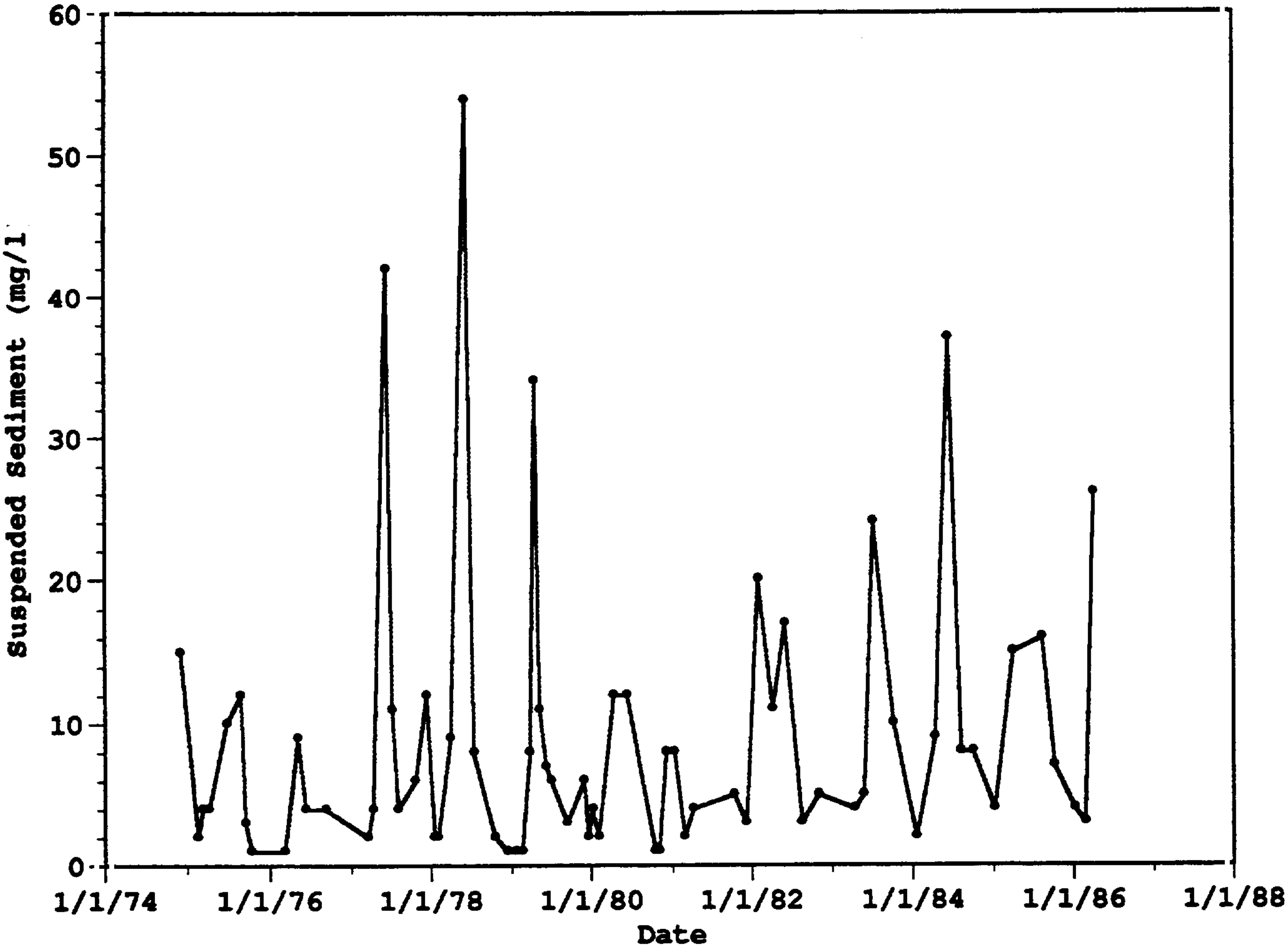


Figure 5. Suspended Sediment at St. Croix Falls from 1974 to 1986. The data was collected approximately monthly and is from the USGS NASQAN station (05340500) and the MPCA (station SCSC-52BB) retrieved through STORET.

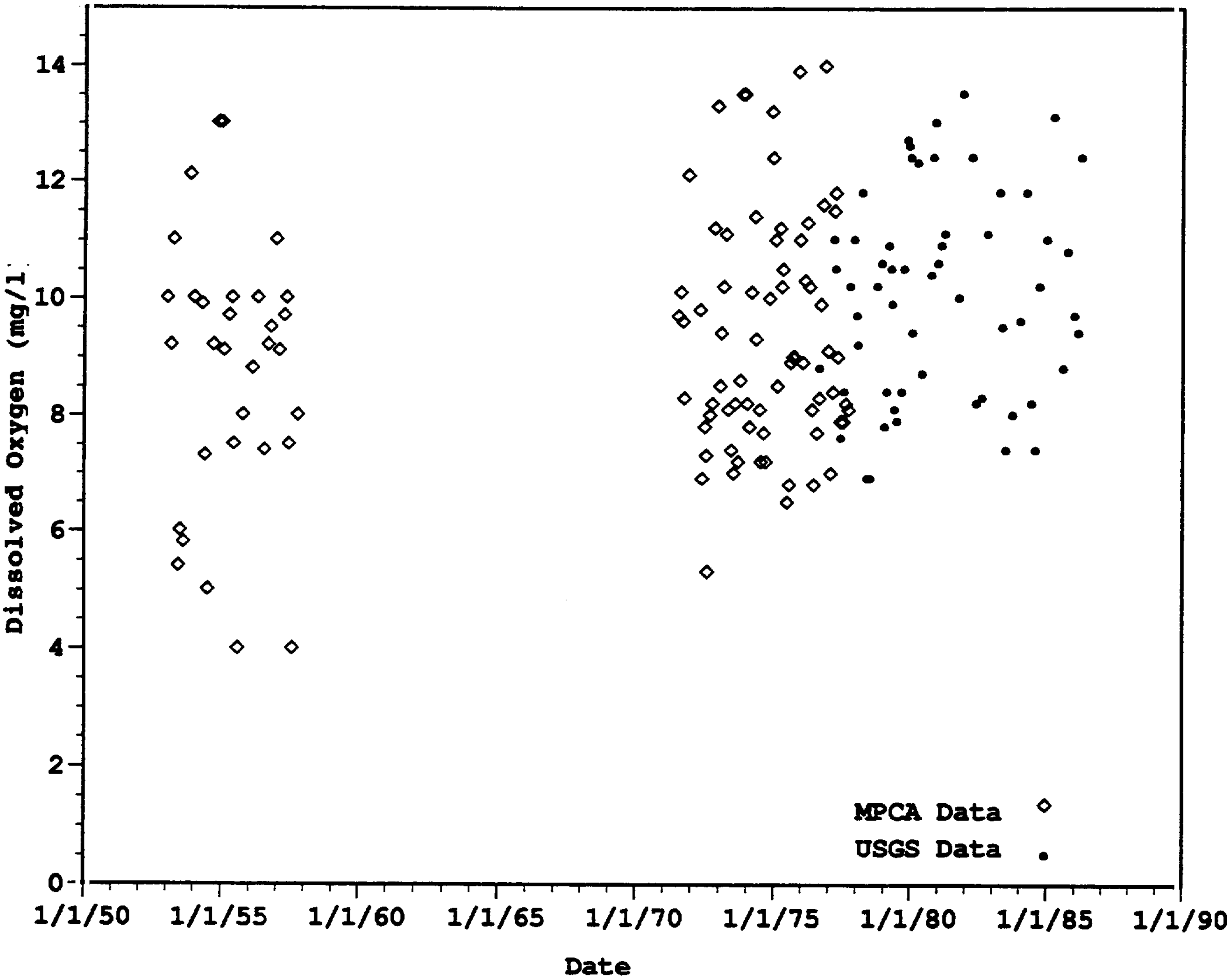


Figure 6. Dissolved Oxygen at St. Croix Falls from 1953 to 1990. The data was collected approximately monthly and is from the USGS NASQAN station (05340500) and the MPCA station (SCSC-52BB) retrieved through STORET.

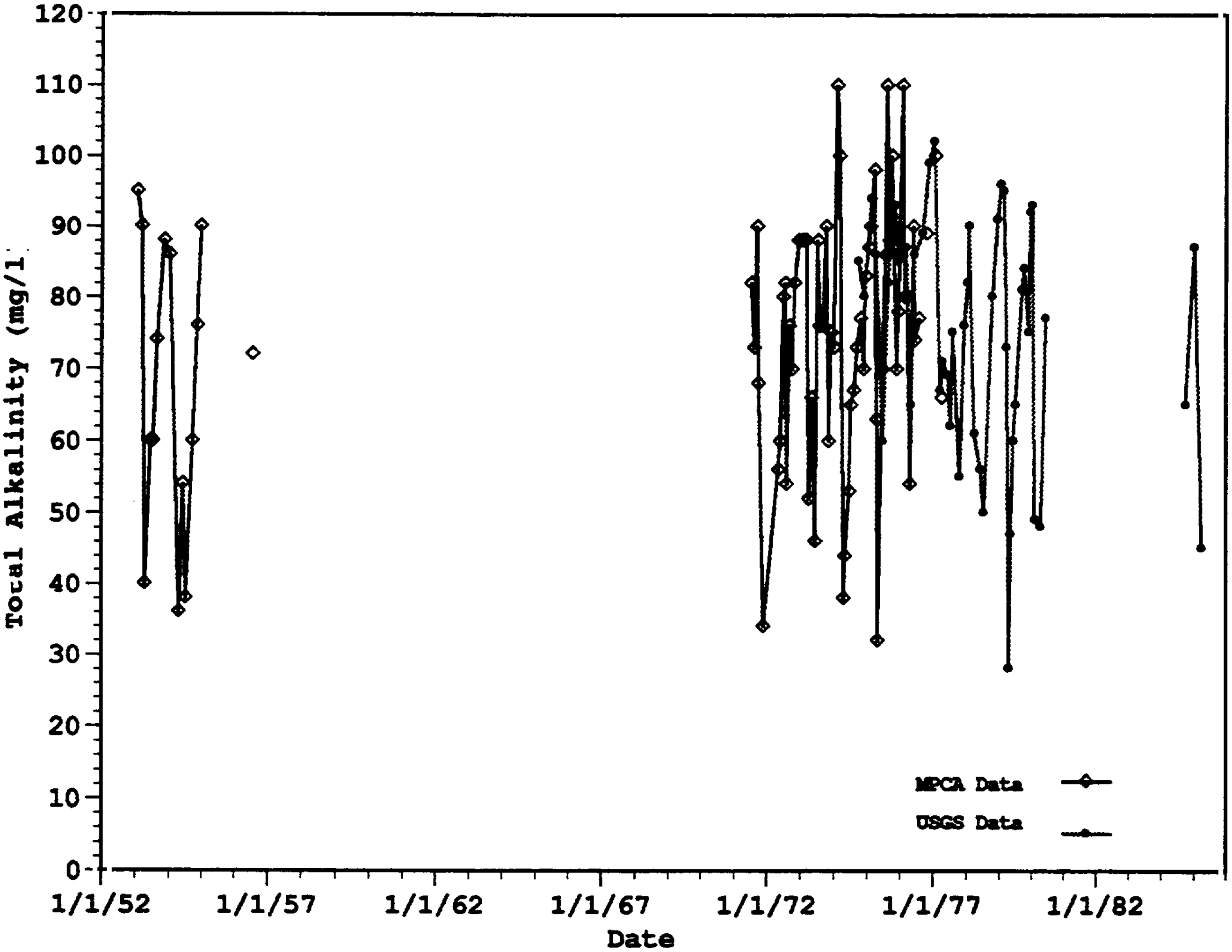


Figure 7. Total Alkalinity at St. Croix Falls from 1952 to 1986. The data was collected approximately monthly and is from the USGS, NASQAN station (05340500) and the MPCA station (SCSC-52BB) retrieved through STORET.

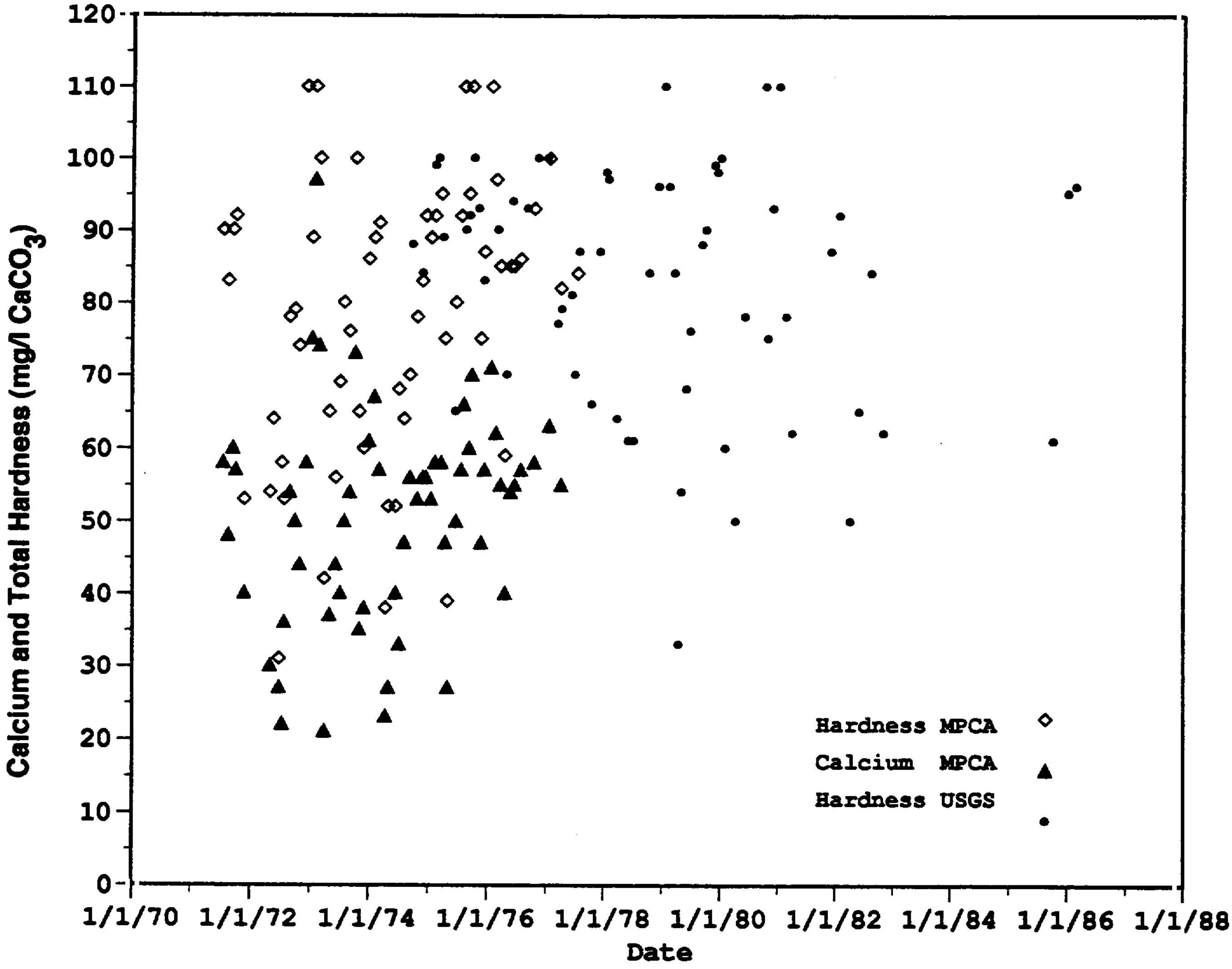


Figure 8. Calcium and Total Hardness at St. Croix Falls from 1971 to 19861. The data was collected approximately monthly and is from the USGS NASQAN station (05340500) and the MPCA station (SCSC-52BB) retrieved through STORET.

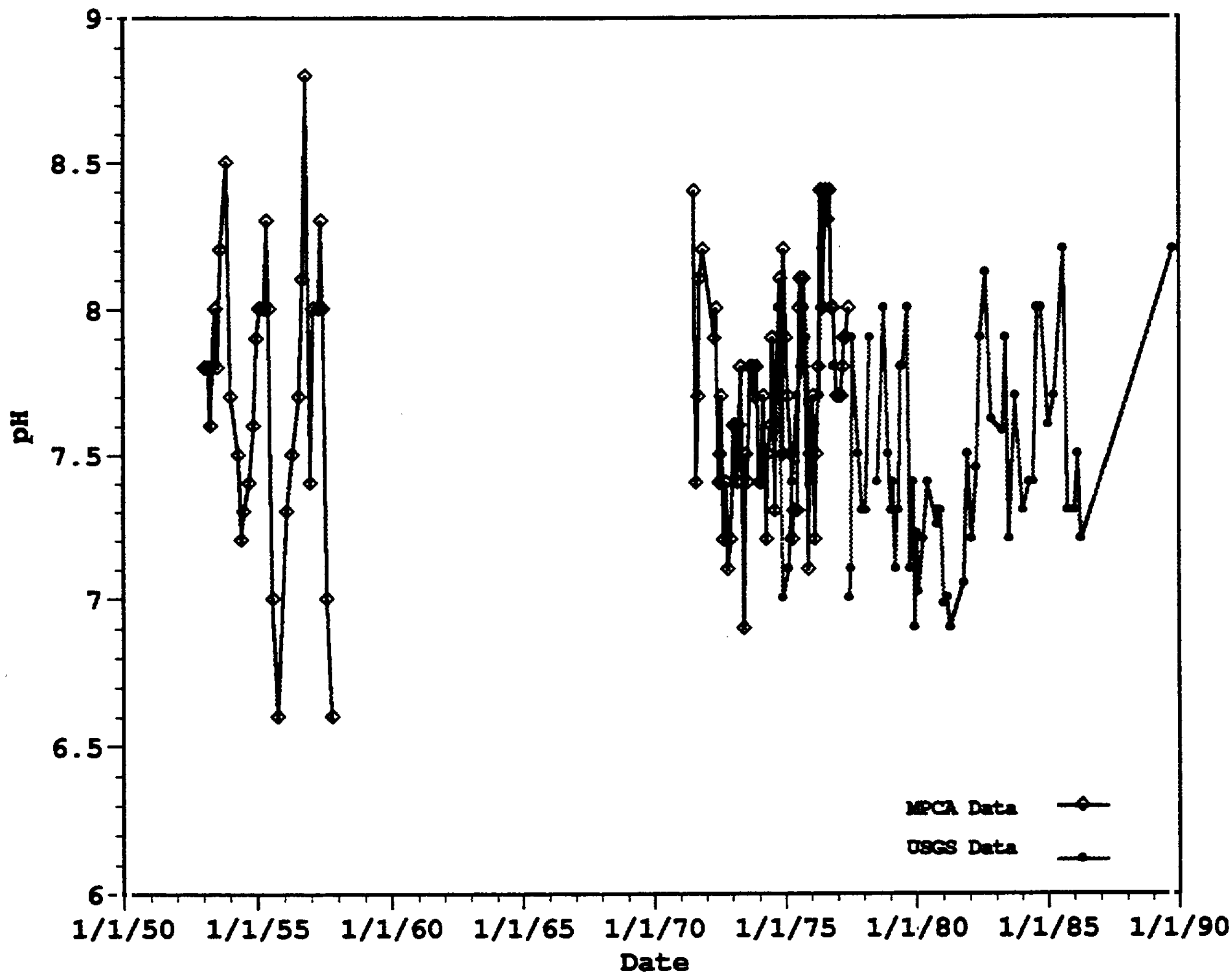


Figure 9. pH at St. Croix Falls from 1953 to 1990. The data was collected approximately monthly and is from the USGS NASQAN station (05340500) and the MPCA station (SCSC-52BB) retrieved through STORET.

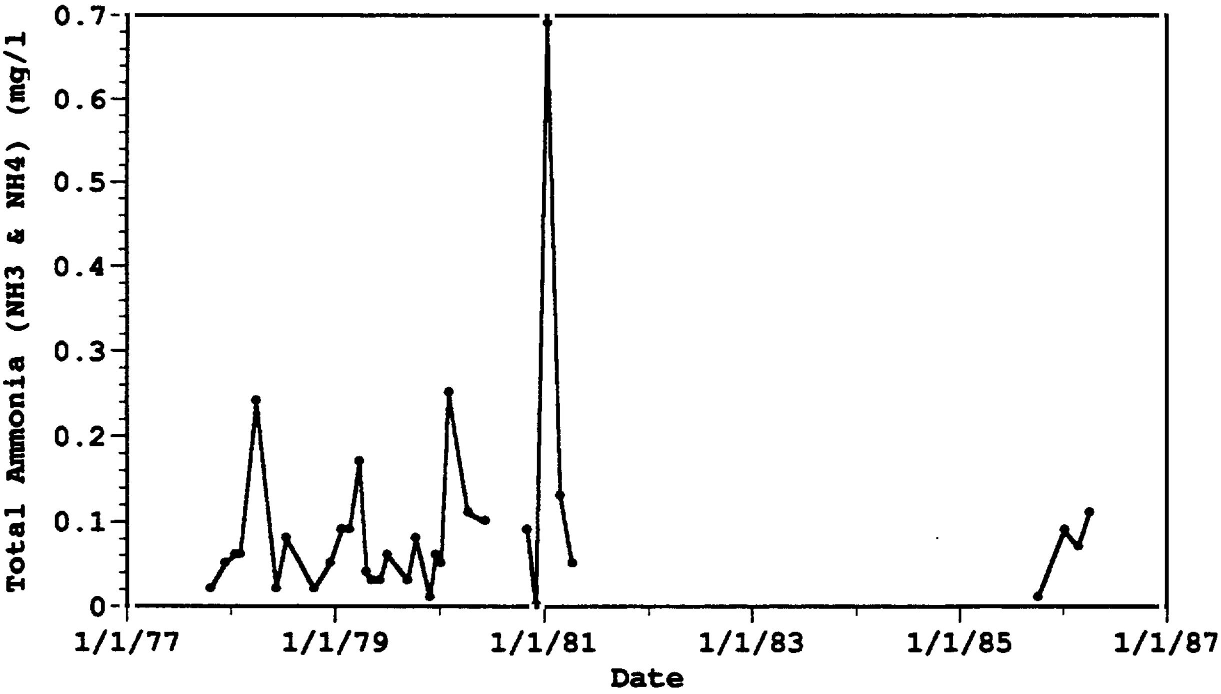


Figure 10. Total Ammonia at St. Croix Falls 1977 to 1986. The data was collected at the USGS NASQAN station (05340500).

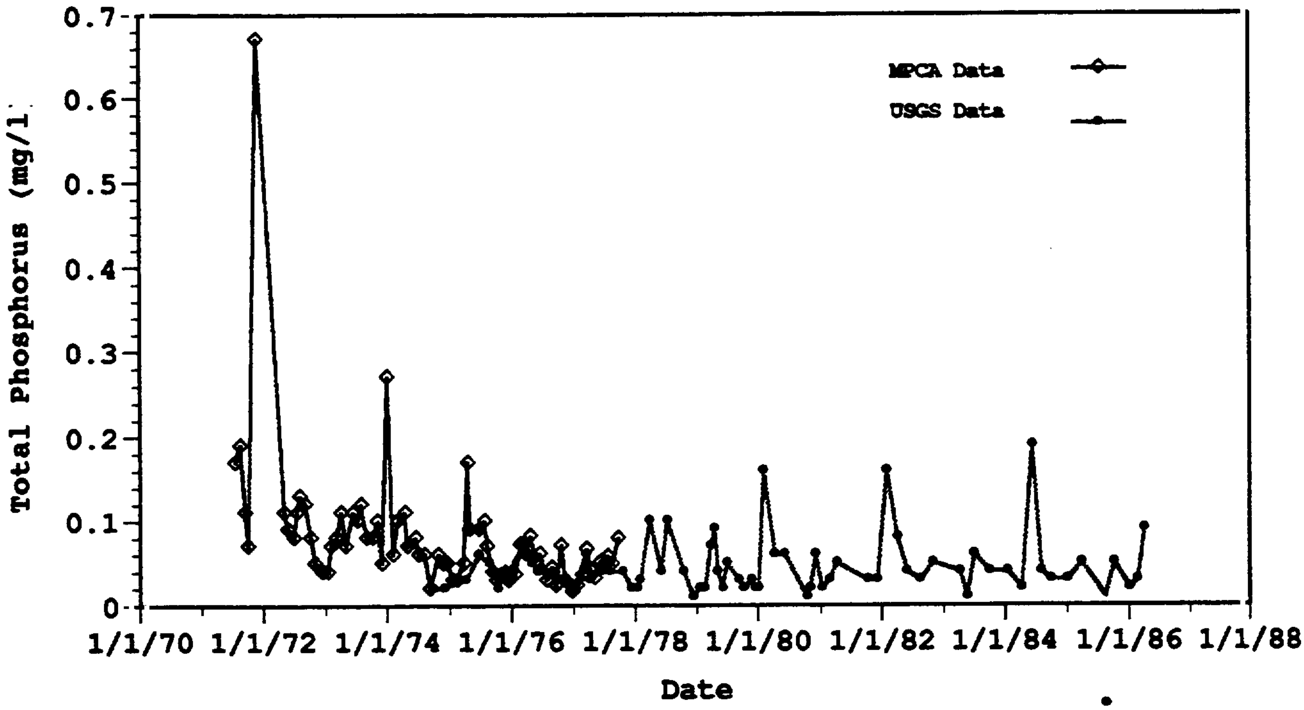


Figure 11. Total Phosphorus at St. Croix Falls 1971 to 1986. The data is from the USGS NASQAN station (05340500) and the MPCA station (SCSC-52BB) retrieved through STORET.

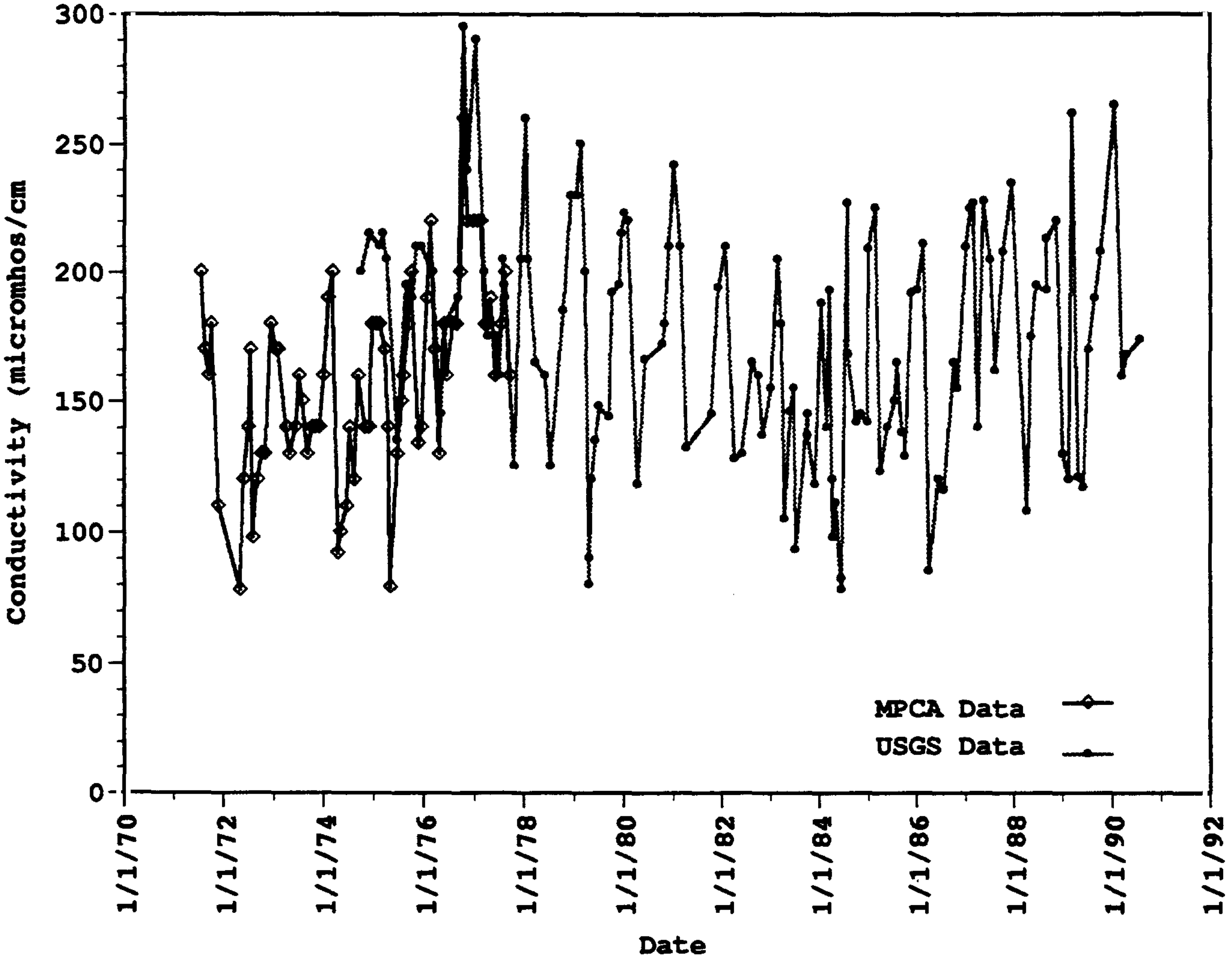


Figure 12. Specific Conductivity at St. Croix Falls from 1971 to 1991. The data is from the USGS, NASQAN station (05340500) and the MPCA station (SCSC-52BB) retrieved through STORET.

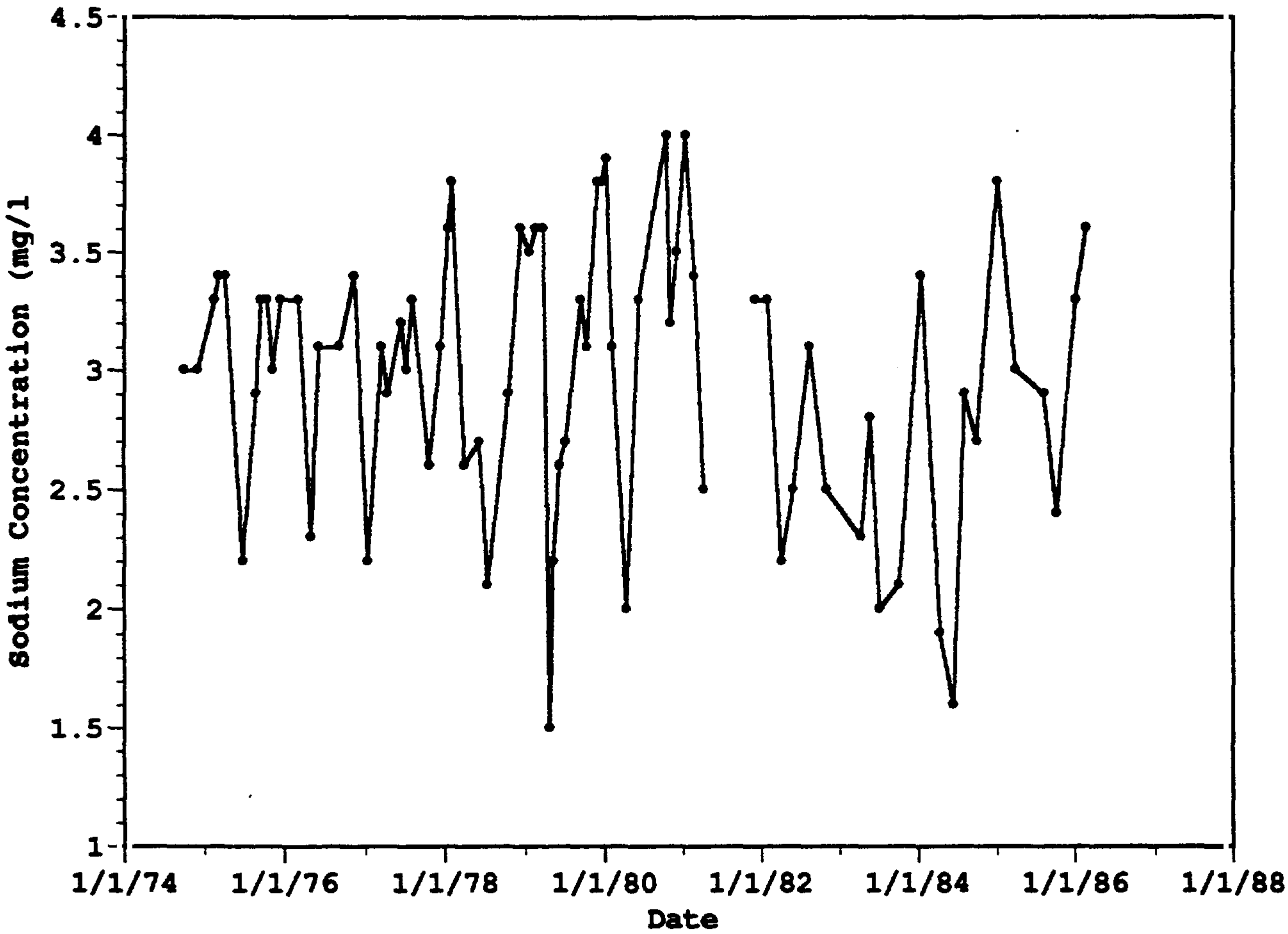


Figure 13. Sodium Concentration at St. Croix Falls from 1974 to 1986. The data was collected approximately monthly and is from the USGS NASQAN station (05340500) retrieved through STORET.

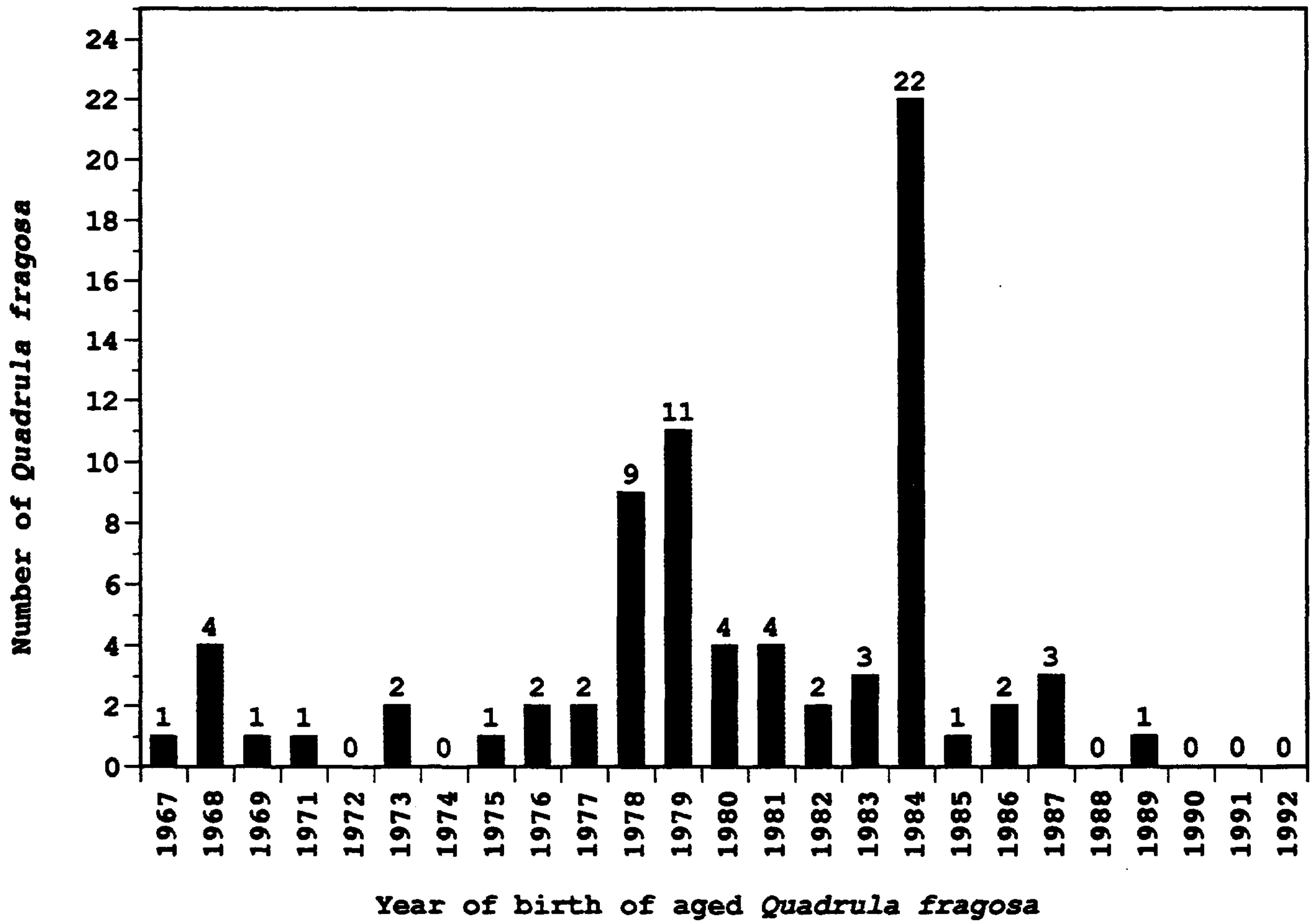


Figure 14. Age Distribution of *Quadrula fragosa* sampled in the St. Croix River from 1988 to 1992. The data is from Hornbach (1992) and Miller (1992).

APPENDIX 1

TECHNICAL ADVISORS CONTRIBUTION,

TECHNICAL/AGENCY DRAFT REVIEW,

AND PEER REVIEW AND CONTRIBUTION

APPENDIX 1

Technical Advisors to the Recovery Team

The Winged Mapleleaf Recovery Team commenced its work by meeting with 10 technical advisors on February 24, 1992, to develop an overview of information and issues relevant to the protection and recovery of the species.

Peer Review and Peer Contributors

The U.S. Fish and Wildlife Service gives special thinks to experts, in addition to the experts on the recovery team and their technical advisors, who reviewed drafts and/or provided information or expert recommendations for various parts of the *Winged Mapleleaf Mussel Recovery Plan*. On October 12, 1994, the Team met with scientists expert in the taxonomy of the *Quadrula* species complex to obtain the best and latest information and opinion regarding the status of *Q. fragosa* as a valid species. Team members continued to communicate with peer experts throughout development of the recovery plan. The input and review by peer experts was invaluable in bringing the latest expert taxonomic opinion and other current information to the final plan.

The following expert peers provided review and/or scientific information to the recovery team:

Mr. Ian Chisholm, Minnesota Department of Natural Resources, St. Paul
Mr. David Hanson, EA West, Lafayette, California
Mr. Shawn Johnson, Minnesota Department of Natural Resources, Fergus Falls
Dr. James Layzer, U.S. Geological Service, Biological Resources Div., Cookeville, Tennessee
Mr. Paul Leonard, EDAW, Inc., Atlanta, Georgia
Dr. Charles Mather, University of Science and Arts, Chickasha, Oklahoma
Dr. Andrew Miller, Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi
Mr. Glenn Miller, Great Lakes Indian Fish and Wildlife Commission, Odanah, Wisconsin
Dr. Teresa J. Naimo, U.S. Geological Service, Biological Resources Div., La Crosse, Wisconsin
Dr. David Stansbery, Ohio State University, Columbus
Dr. Nels Troelstrop, University of Minnesota, St. Paul
Dr. Diane Waller, U.S. Geological Service, Biological Resources Div., La Crosse, Wisconsin

Technical/Agency Review

The Service transmitted a technical/agency review draft of the plan to 23 involved technical and agency reviewers in April 1994; notice of availability of the draft for public review was published in the April 22, 1994, *Federal Register*. The Service and members of the Winged Mapleleaf Mussel Recovery Team received 11 written responses and numerous, uncounted informal responses addressing format, content, and organization of the draft. The team welcomed and considered all comments, devoting several team meetings to appropriate disposition of written comments. Contributions of technical/agency reviewers enabled the Team to improve the final plan in its incorporation of the latest available information and in details of wording and organization.

APPENDIX 2

JOHNSON'S (1995) REPORT

ON AN

INSTREAM FLOW STUDY

IN THE

ST. CROIX RIVER

Instream Flow Requirements of *Quadrula fragosa* and the Aquatic Community in the Lower St. Croix River Downstream of the Northern States Power Hydroelectric Dam at St. Croix Falls, Wisconsin

Prepared for:

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February 1995

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1.0 BACKGROUND

The Lower St. Croix River, MN and WI, supports one of the richest freshwater unionid mussel assemblages in the Upper Mississippi River system. This diverse assemblage of 40 species is comprised of numerous rare mussels, including the winged mapleleaf (*Quadrula fragosa*) and the Higgens Eye (*Lampsilis higgensi*), both federally endangered species. The only known global population of *Q. fragosa* inhabits a 12 mile reach of the Lower St. Croix River downstream of the Northern States Power (NSP) hydroelectric dam at St. Croix Falls, WI (U.S. Fish and Wildlife Service 1991). The most important habitat for *Q. fragosa* has been identified as a riffle in the east channel at Folsum Island, Interstate State Park, about 1.5 miles downstream of the NSP dam (Heath and Miller, unpub. data; Hornbach 1992a and unpub. data). Approximately one third of the more than 30 species of mussels found in the Interstate Park area are listed as endangered, threatened, or of special concern by the states of Minnesota and Wisconsin.

The NSP hydroelectric dam operates as a peaking facility, impounding water (releasing minimal flows) during periods of off-peak demand (typically from late evening through early morning) and releasing high generation flows during periods of peak demand. During November 1989, National Park Service personnel observed that nightly shutdowns of the power plant (no water was being released downstream through the dam) were dewatering the mussel bed in the east channel at Folsum Island. Resource agencies met with NSP to express concern about *Q. fragosa* and other mussels being exposed to desiccation, freezing, predation, and ice abrasion during these nightly shutdowns. NSP stated that total plant shutdowns during winter have occurred frequently for approximately the past 80 years (Schuster, in litt., 1990). As a result of this meeting, NSP voluntarily agreed to release a minimum discharge of 800 cubic feet per second (cfs) (equivalent to keeping one turbine open at all times) from November 1 through March 31. NSP's operating license requires a minimum release of 1600 cfs for navigation from April 1 through October 31. A wetted perimeter study at Folsum Island (MnDNR 1990) and visual observations indicate that the availability of mussel habitat at a dam release of 800 cfs may be severely limited because much of the east channel is dewatered at this discharge.

The availability of stream habitat is largely a function of stream discharge (Trotzky and Gregory 1974; Milhous et al. 1981; Bovee 1982; Bain et al. 1988; Leonard and Orth 1988). Changes in discharge translate into changes in substrate, velocity, and depth conditions. These flow-dependent physical habitat features play an important role in governing the distribution and abundance of mussels (Salmon and Green 1983; Neves and Widlak 1987; Way et al. 1990; McMahon 1991; Strayer and Ralley 1993); consequently, hydroelectric peaking facilities can influence the availability of mussel habitat by creating wide fluctuations in discharge.

Similarly, the availability of habitat for many other macroinvertebrates and fishes is also tied to discharge patterns. Discharge patterns can strongly influence the structure of fish and macroinvertebrate communities (Fisher and LaVoy 1972; Ward 1976; Gorman and Karr 1978; Horwitz 1978; Schlosser 1985, 1989; Cushman 1985; Gislason 1985; Bain et al. 1988; Bain and Boltz 1989). Discharge can also influence the diversity of stream habitat (Kraft 1972; Brusven and Trihey 1978; Leonard and Orth 1988; Aadland 1993), an important factor governing the diversity of biota found within a stream (Gorman and Karr 1978; Schlosser 1982a).

2.0 STUDY OBJECTIVES

An instream flow study was initiated in 1992 to examine the relation between habitat and discharge for the aquatic community in the Lower St. Croix River downstream of the hydroelectric dam at St. Croix Falls, WI. The objectives of this study were to:

A. develop site-specific habitat criteria describing the suitability of substrate, velocity, and depth *for Q. fragosa* and the mussel community,
B. collect hydraulic and microhabitat data from two study sites below the St. Croix Falls dam,
C. use hydraulic models to examine substrate, velocity, and depth conditions at the study sites in relation to dam discharges,
D. examine habitat availability for mussels, macroinvertebrates, and fishes in relation to dam discharges, and
E. examine habitat diversity in relation to dam discharges.

3.0 METHODS

The instream flow incremental methodology (IFIM; Bovee 1982), developed by the Cooperative Instream Flow Group, U.S. Fish and Wildlife Service, was used to assess the instream flow needs of the aquatic community. The IFIM is the most commonly used instream flow method (Reiser et al. 1989) and its use is often required by the Federal Energy Regulatory Commission in the licensing and relicensing of hydroelectric dams. Hydraulic and habitat modeling was executed using the Physical Habitat Simulation System (PHABSIM), a computer-run component of IFIM which combines hydraulic simulation procedures with habitat suitability criteria to predict changes in available physical habitat with changes in discharge (Milhous et al. 1981; Milhous et al. 1989).

3.1 Study Area

The St. Croix River begins in the far northwest corner of Wisconsin and flows 154 miles south to its confluence with the Mississippi River at Prescott, WI, forming the border between Wisconsin and Minnesota over its last 130 miles (Figure 1). The NSP hydroelectric dam at St. Croix Falls, WI forms the boundary between the Upper and Lower St. Croix rivers.

3.1.1 Hydrology

The Lower St. Croix River experiences high spring flows of 5000 to 10,000 cfs from April through June, with flows ranging between 2000 and 4000 cfs the rest of the year (Figure 2a). Discharge in the Lower St. Croix River is regulated by the NSP dam at St. Croix Falls, WI. From April 1 through October 31, NSP is required to maintain a minimum dam release of 1600 cfs during peaking operations. Throughout the rest of the year, they have voluntarily maintained a minimum release of 800 cfs since 1989. Prior to this time, there was no minimum winter release. Typically, these minimum flows are maintained from late evening through early morning with high generation flows (e.g., 5000-6000 cfs) released during morning and early evening hours (Figures 2b and 2c).

Based on mean daily flows over the period of hydrologic record (1902 to the present), 1600 cfs represents an annual exceedance value of 88% (Figure 2d) and monthly exceedance values ranging from 80% to 99% for the months April through October (Table 1). A discharge of 800 cfs represents an annual exceedance value of 99% and monthly exceedance values of 98% to 99% for the months November through March.

3.1.2 Study Sites

Two PHABSIM study sites were selected: one at Interstate Park, MN and WI, (Figure 3a) and the other at Franconia, MN (Figure 3b). The Interstate Park site was selected to encompass the critical riffle located in the east channel at Folsum Island. This site begins approximately 400 feet upstream of the public boat landing at Minnesota Interstate Park and extends upstream to 100 feet downstream of the public boat landing at Wisconsin Interstate Park. Because Folsum Island divides the river into two distinct channels at

Interstate Park, this site was divided into the following three channels for modeling purposes: 1) east channel (the channel east of Folsum Island), 2) navigation channel (the channel west of Folsum Island), and 3) main channel (the channel upstream and downstream of Folsum Island). The proportion of total discharge (discharge in the main channel) that flows through the east channel increases markedly as total discharge increases: little, if any, water flows through the east channel at a total discharge of 1000 cfs (based on visual observations) compared to 20% at a total discharge of 1800 and 43% at a total discharge of 3400 cfs (based on field measurements of discharge in each of the three channels). These three flows (1000, 1800, and 3400 cfs) were used to develop a linear regression equation relating the discharge in the navigation and east channels to total discharge (Appendix A) so that habitat vs. discharge relations for the navigation and east channels could be expressed in terms of total discharge.

The Franconia site, located about 2.5 river miles downstream of Interstate Park, was selected to represent the 12 mile stretch of the Lower St. Croix River below Folsum Island where *Q. fragosa* have been found. This site contains a large mussel bed and *Q. fragosa* has been found here (Hornbach 1991, 1992b). The Franconia site begins one fourth mile downstream of the Franconia public boat landing and extends one half mile upstream.

3.2 Transect Selection

Three transects were established across each of the three channels (main, east, and navigation) at Interstate Park (Figure 3a). Transect locations were selected to characterize the hydraulic and microhabitat conditions of each channel. Five transects were established at Franconia (Figure 3b). This site has relatively uniform hydraulic and microhabitat conditions and therefore transects were uniformly spaced one stream width apart through the study reach.

3.3 Field Measurements

Hydraulic and microhabitat data for use in PHABSIM were collected following the guidelines established by Bovee (1982) and Trihey and Wegner (1981). The standard application of PHABSIM modeling involves collecting stage-discharge data (water surface elevations and corresponding discharges) at three flows (low, medium, and high flows) and a complete velocity data set at one or more of these flows. Our study design included collecting complete stage-discharge and velocity data sets at three target flows: low (800 cfs), medium (1600 cfs), and high (3200 cfs). Target flows were in multiples of 800 cfs because each of the eight turbines at the dam is capable of releasing 800 cfs at its most efficient operational setting. Complete data sets were collected at both study sites at the medium and high target flows. Flows were never low enough to obtain a dam release of 800 cfs for a long enough time period to collect field measurements. Consequently, PHABSIM modeling was based on two flows rather than three as planned. All the hydraulic models available within PHABSIM can be calibrated using two flows.

3.3.1 Transect Measurements

3.3.1.1 Water Surface Elevations and Streambed Profiles

Water surface elevations and streambed profiles were surveyed to the nearest 0.01 ft using differential leveling techniques (Bouchard and Moffitt 1965; Brinker and Taylor 1963). Water surface elevations were measured near the water's edge along each transect at each target discharge. Permanent staff gages, established at each study site, were monitored hourly to ensure that water surface elevations were surveyed during steady flow. It took 8-10 hours for flows to stabilize after the target dam releases were initiated. All elevations at each study site were referenced to a common benchmark to allow the use of the WSP hydraulic model for determining stage-discharge relations.

Permanent headstakes were established at both ends of each transect above the high water mark to serve as points of known elevations. A closed level loop was used to establish headstake elevations. Closure error was within the acceptable limits of third order accuracy as defined by the equation: maximum closure error = $0.05(M)^{0.5}$ where M = length of level loop in miles (Trihey and Wegner 1981).

3.3.1.2 Microhabitat

Microhabitat data (substrate, velocity, and depth) were collected at verticals along each transect. The number and location of verticals depended on hydraulic and channel structure characteristics. Ten to twenty measurements are recommended for determining velocity distributions and 20-30 for calculating discharge (Trihey and Wegner 1981). Because the St. Croix is a large river, measurements were taken at 50-100 verticals along each transect. To ensure that habitat measurements were taken during steady flow, a temporary staff gage established at each transect was read immediately prior to taking and upon completing measurements along each transect.

Substrate was described according to the following size categories (diameter in inches): silt (<0.0024), sand (>0.0024-0.125), gravel (>0.125-2.5), cobble (>2.5-5.0), rubble (>5.0-10.0), small boulder (>10.0-20.0), large boulder (>20.0-40.0), and bedrock (>40.0) (Aadland et. al 1991). The percent of the area covered by each substrate type was visually estimated to the nearest 10 percent at each vertical.

Mean column velocity was measured at 0.6 of the depth in water less than 2.5 ft deep and at 0.2 and 0.8 of the depth in water 2.5 ft deep and deeper (Buchanon and Somers 1969). Velocity was measured with Price AA and Pygmy current meters equipped with digitizers which keep track of revolutions and time and convert these to velocity in ft/s. Price AA meters were equipped with optic units. All meters were spin tested prior to each use. Water depth was measured to the nearest 0.1 ft with a top setting wading rod.

Each transect was assigned a station index value and a weighting factor. A station index value identified the distance from a particular transect to the downstream-most transect and was measured between adjacent transects at water's edge along both banks. Station index values were used in conjunction with streambed and water surface elevations to establish gradients. Weighting factors described how far upstream and downstream the measurements (substrate, velocity, and depth) taken along each transect were extended during computer modeling.

3.4 Habitat Suitability Criteria

3.4.1 Mussels

Hornbach (1992a) examined the habitat characteristics of *Q. fragosa* and the mussel community at Interstate Park during the summer of 1992. Mussel habitat-use data collected during his study were used to develop habitat suitability criteria. The following is a brief description of his sampling methodology. Fifteen sampling sites were established in the east and main channels (Figure 4). At each site, all mussels (>0.5 mm diameter) within ten 0.25 m^2 quadrats were collected by divers using SCUBA. Mussels were identified to species and counted. For each sample, mean column velocity was measured with a Marsh-McBirney Model 201-D meter, and depth was measured with a calibrated rod.

A total of 1174 mussels representing 29 species were collected in these 150 samples. Bovee (1986) recommends that habitat suitability criteria be developed from a minimum of 150 observations. Because only 10 *Q. fragosa* were collected, habitat suitability criteria could not be developed for this species. Criteria were developed for overall mussel density and species richness so that habitat conditions associated with dense, diverse mussel assemblages could be identified and modeled. Hornbach (1992a) reported that *Q. fragosa* was found in "high quality" mussel habitat, habitat supporting overall high mussel densities and species richness. Flows that provide usable habitat for the mussel community should therefore provide usable habitat for *Q. fragosa*.

Suitability values for dominant substrate were based on professional judgment (Dr. Dan Hornbach, Macalaster College, St. Paul, personal communication). Criteria describing the suitability of mean column velocity and depth were developed for mussel density and species richness following the guidelines of Bovee (1986). All depths were standardized to a dam release of 1600 cfs, the minimum release during the period of mussel sampling. Habitat-use and preference values for velocity and depth were calculated by 1) dividing each habitat variable into intervals (e.g. velocity intervals were 0-10 cm/s, 10.1-20 cm/s, 20.1-30 cm/s, etc.), 2) summing the number of samples taken within each habitat interval (available habitat), 3) summing the number of mussels collected within each habitat interval (habitat-use for mussel density), 4) summing the number of mussel species collected within each habitat interval (habitat-use for species richness), and 5) dividing habitat-use for each habitat interval by the available habitat for that interval (preference). Preference values were expressed on a normalized scale from 0.0 to 1.0 by dividing each preference value by the maximum preference value. A preference value of 0.0 indicates the least preferred or least suitable habitat; a value of 1.0 indicates the most preferred or most suitable habitat.

Nonlinear regression techniques in SYSTAT (Wilkinson 1988) were used to fit preference curves to the observed preference values. Preference values were plotted and examined to determine the most appropriate equation for describing the preference function. Velocity preference curves were fit using the generalized Poisson equation, and depth curves were fit using the natural growth equation.

3.4.2 Macroinvertebrates

Generalized curves were used to describe habitat suitability for macroinvertebrates (Appendix B). Velocity and depth curves were cooperatively developed by the U.S. Fish and Wildlife Service, the Wisconsin Department of Natural Resources, Wisconsin Electric Power Company, the University of Wisconsin-Stevens Point, and the University of Wisconsin-Madison. Substrate criteria were developed by the MnDNR based on the literature and professional judgment.

3.4.3 Fishes

To address the instream flow needs of the fish community, a habitat guild approach was used to select target species (Leonard and Orth 1988; Aadland 1993). This community-based approach recognizes that different fish species and species life-stages use or require a wide range of habitat types (e.g., pools versus riffles) and consequently, can have significantly different habitat-discharge relations. Furthermore, this approach recognizes that certain habitat types are more sensitive to changes in flow than others. By selecting target species and species life-stages occupying each habitat type, especially flow-sensitive habitat types, the instream flow needs of the entire fish community can be addressed. Target species appropriate to the St. Croix River were selected from habitat guilds identified for warmwater and coolwater stream fishes of Minnesota (Aadland et al. 1991; Aadland 1993) (Table 2). Habitat suitability criteria for the selected target species were developed by Aadland et al. (1991).

3.4.4 Habitat Types

Aadland (1993) identified the following six habitat types for warmwater and coolwater streams of Minnesota: slow riffle (<60 cm deep, 30-59 cm/s velocity); fast riffle (<60 cm deep, $\geq$60 cm/s velocity); raceway (60-149 cm deep, $\geq$30 cm/s velocity); shallow pool (<60 cm deep, <30 cm/s velocity); medium pool (60-149 cm deep, <30 cm/s velocity); and deep pool ($\geq$150 cm deep). The availability of these habitat types was modeled to examine the relation between habitat diversity and discharge for the Lower St. Croix River study sites.

3.5 Physical Habitat Modeling

Hydraulic modeling was executed using a number of models (and model options) available in PHABSIM (Milhous et al. 1981; Milhous et al. 1989). Field data were collected such that any model or combination of models could be used as needed. Output from various models and model combinations were compared to determine which was most appropriate for specific locations. Hydraulic models were developed separately for each of the four channels (east, navigation, and main channels at Interstate Park and the channel at Franconia).

Hydraulic models were developed from field data collected at two calibration flows: 1800 and 3400 cfs (which correspond to dam releases of 1600 and 3200 cfs). The safe range of simulated flows was determined by multiplying the lowest measured calibration flow by 0.4 and the highest measured calibration flow by 2.5 (Milhous et al. 1981). Although habitat conditions at a dam release of 800 cfs were not measured, they could be safely simulated using the hydraulic models for all channels except the east channel. At the low calibration flow (1800 cfs in the main channel), there was 357 cfs flowing through the east channel. Therefore, flows could be safely simulated down to 143 cfs (357 cfs * 0.4) in the east channel, corresponding to a discharge of about 1330 cfs in the main channel. The PHABSIM input files and range of simulated flows for each site are provided in Appendix C.

The first step in hydraulic modeling was to develop a relation between stage and discharge (i.e., predicting water surface elevations as a function of discharge). Typically, MANSQ was used to predict the starting water surface elevation at the downstream most transect and WSP was then used to predict water surface elevations at upstream transects. The final predicted water surface elevations for each transect at each simulated flow are provided in Appendix C. Once the water surface elevation models were developed and calibrated, velocity distributions were simulated using the derived stage-discharge relations and the IFG4 model. This model predicts velocities based on Manning's equation. The velocity adjustment factors used in velocity modeling are provided in Appendix D.

Results from hydraulic modeling were combined with habitat suitability criteria in the HABTAE model to calculate weighted usable area (wua), an index of available habitat, for: 1) mussel density and species richness, 2) macroinvertebrates, 3) fish, and 4) habitat types at each study site for each simulated discharge. Weighted usable area was calculated as:

$$wua = \sum_{i=1}^{n} S_i \, A_i$$

where: S_i = composite suitability weighting factor,

A_i = surface area of the cell, and

n = total number of cells within the simulated stream reach.

The composite suitability weighting factor, S_i, was calculated using the multiplicative aggregation function $S_i = S_s * S_v * S_d$ where S_s, S_v, and S_d are suitability criteria values (range 0.0-1.0) for substrate, velocity, and depth.

4.0 RESULTS

4.1 Mussel Habitat Suitability Criteria

The most suitable substrate for mussels was gravel, with the next smallest (sand) and next largest (cobble) substrates highly suitable (Figure 5). Fine (organic detritus and silt) and large (rubble to bedrock) substrates had low suitability. Substrate data collected during PHABSIM transect measurements indicate that suitable mussel substrate is abundant at Interstate Park and Franconia: sand, gravel, or cobble was the dominant substrate in 94% of the cells sampled.

Moderate velocities had the highest suitability values for mussel density, peaking between 43 and 49 cm/s (Figure 6). There was no observed velocity preference for species richness. Although areas with low and high velocities supported low mussel densities, the number of species in these areas was similar to areas with moderate velocities.

Mussels were generally absent at shallow depths (<50 cm) and abundant at greater depths. Depth suitability for mussel density steadily increased from a value of zero at zero depth to a value of one at the maximum depth sampled (215 cm) (Figure 7). Suitability for species richness rose quickly from a value of zero at zero depth up to a depth of about 75-100 cm and then leveled off, reaching a value of one at a depth of 135 cm.

Q. fragosa was found in habitat supporting dense, diverse mussel assemblages. The velocities and depths used by the 10 *Q. fragosa* located at Interstate park in 1992 (Hornbach 1992a) and the nine *Q. fragosa* found in 1993 (Hornbach, unpub. data) (Table 3) correspond to high suitability values for both mussel density and species richness.

4.2 Weighted Usable Area vs. Discharge Relations

4.2.1 Mussel Density and Species Richness

Habitat for mussel density was limited at low discharges for all four sites (Figure 8) due to low velocities, shallow depths, and loss of wetted area. As discharge increased, WUA increased as velocities and depths became more suitable. The east channel and Franconia mussel density WUAs peaked at 6500 and 4750 cfs. Above these discharges, WUAs decreased as velocities became unsuitably high. The navigation and main channel mussel density WUAs peaked at the maximum discharge modeled (7000 cfs).

The species richness WUA vs. discharge relations (Figure 9) were driven solely by the suitability of available depths since there was no observed relation between species richness and velocity. Because the east channel was relatively shallow at low discharges, WUA was also low. As discharge increased, WUA increased rapidly as depths became more suitable (> 50 cm). A similar trend was evident for the navigation channel. Most depths in the main channel at Interstate Park and Franconia were suitable (> 50 cm), even at low discharges; consequently, there was similar habitat area at all discharges.

The availability of mussel habitat at dam releases of 1600 cfs (minimum summer dam release) and 800 cfs (minimum winter dam release) is of major concern. The WUAs at 1600 cfs were based on habitat data collected at 1600 cfs so they should reflect the availability of mussel habitat at this discharge. The WUAs at 800 cfs were based on modeling simulations so it is unknown how closely they reflect the availability of mussel habitat at this discharge. It seems reasonable, however, that WUAs would decline as flows drop from 1600 cfs to 800 cfs, as the models predict, given that available depths and velocities become increasingly unsuitable as mussel habitat as flows drop. The large and rapid loss of mussel habitat that the models predict, especially in the east channel, as flows drop below 1600 cfs is strongly supported by visual observations at 800 cfs. At 1600 cfs, about 350 cfs was flowing through the east channel and a relatively small portion of the stream channel was dewatered. At 800 cfs, very little water was flowing through the east channel, large areas were dewatered, and the wetted area was almost entirely shallow, pooled water with little or no velocity. These conditions provide highly unsuitable habitat for mussels as the models suggest. As previously noted, 800 cfs was within the safe range of modeling simulations for all channels except the east channel. Although the east channel could only be safely modeled down to 1330 cfs, visual observations indicate that the availability of mussel habitat declines rapidly as flows drop below 1330 cfs with little available habitat at 800 cfs.

4.2.2 Macroinvertebrates

Macroinvertebrate habitat was much more abundant in the east channel than in the other three channels (Figures 10a and 10b) due to the availability of moderate depths (30-90 cm) associated with moderate to high velocities (>45 cm/s). At low flows, however, invertebrate habitat was extremely limited in the east channel because of shallow depths, low velocities, and loss of wetted area. As discharge increased, invertebrate WUA increased rapidly as depths and velocities became more suitable, leveling off at about 3000 cfs and peaking at 5000 cfs. The WUA vs. discharge relations for the navigation and main channels were similar to each other with invertebrate habitat most abundant at low to moderate flows (1000-3000 cfs), and most limited at high flows. Invertebrate habitat was scarce at Franconia at all flows due to high average depths.

4.2.3 Fishes

Habitat was limited at low flows for most fishes in the east channel except for sand shiner young-of-year, a shallow pool species (Figures 11a and 11b).

Habitat was abundant at high flows for raceway and deep pool species e.g., shorthead redhorse adult and channel catfish adult. Habitat for riffle species (central stoneroller adult and slenderhead darter adult) was most abundant at moderate flows. Flows between 2000 and 3500 cfs provided the best habitat conditions for the fish community in the east channel.

Similar trends were evident for the other three study channels in that habitat was typically abundant for shallow pool species at low flows and abundant for deep pool and raceway species at high flows (Figures 12a, 12b, 13a, 13b, 14a, and 14b). There was little or no habitat for riffle species in these channels at any flow. Moderate flows (1600-3000 cfs) provided the best overall habitat conditions for the fish communities in these three channels.

4.2.4 Habitat Types

The diversity of habitat types was generally limited at low and high flows, with intermediate flows providing the greatest diversity. The east channel consisted almost entirely of shallow pool habitat at low flows and raceway habitat at high flows (Figures 15a and 15b). Habitat diversity in the east channel was highest at flows between 3000 and 4000 cfs. The navigation channel had a diverse mix of habitat types at low to moderate flows and was primarily deep pool habitat at high flows (Figures 16a and 16b). The main channel was primarily shallow pool and medium pool habitat at low flows and deep pool habitat at high flows (Figures 17a and 17b). Flows between 2000 and 3000 cfs provided the highest habitat diversity in the main channel. Franconia was entirely pool habitat at low discharges (mostly medium pool although shallow and deep pool habitat were also abundant) and almost entirely deep pool habitat at high flows (Figures 18a and 18b). Flows between 2000 to 3000 cfs provided the highest habitat diversity at Franconia. Riffle habitat was absent in the main channel at Interstate Park and at Franconia.

5.0 DISCUSSION

Freshwater mussels are the most jeopardized faunal group in North America: 213 of 297 native taxa are considered endangered, threatened, or of special concern (Williams et al. 1993). The dramatic decline in mussel distribution, abundance, and diversity has been primarily attributed to degradation of stream habitat (Bates 1962; Isom 1969; Fuller 1974; Miller et al. 1984; McMahon 1991; Layzer et al. 1993; Williams et al. 1993). The regulation of streamflow has adversely impacted stream habitat and consequently, the fish and macroinvertebrate communities found within streams, by altering substrate, velocity, and depth conditions (Ward 1976; Covich et al. 1978; Williams and Winget 1979; Cushman 1985; Bain et al. 1988). These flow-dependent habitat features are important determinants of mussel distribution and abundance (Salmon and Green 1983; Neves and Widlak 1987; Way et al. 1990; McMahon 1991; Strayer and Ralley 1993).

Discharge in the Lower St. Croix River is regulated by a hydroelectric peaking dam at St. Croix Falls, WI. During peaking operations, discharge rapidly fluctuates daily between low impounding flows (e.g., 800 cfs) and high generation flows (e.g., 6400 cfs). Habitat conditions downstream of the dam are constantly changing between slow, shallow water habitat during impounding flows and fast, deep water habitat during generation flows. The availability of suitable habitat for mussels under this flow regime largely depends on their habitat preferences.

5.1 Mussel Habitat Preferences

5.1.1 Substrate

Due to their benthic mode of existence, mussels are intimately associated with the substrate. Hornbach (1991, 1992a, 1992b) reported that substrate was an important factor influencing the distribution and abundance of mussels in the Lower St. Croix River. Most mussels at Interstate Park and Franconia were found in coarse substrate, primarily gravel, with fine (e.g., silt) and large (e.g., boulder) substrates supporting few mussels. Similar substrate preferences have previously been noted for mussels in the St. Croix River (Stern 1983; Doolittle 1988). Miller (unpub. data) found 8 live and 12 dead *Q. fragosa* in sand/gravel substrate during a 1991 mussel survey at Folsum Island. Substrate preferences of mussels in the Otter Tail, Clearwater, and Kettle rivers of Minnesota (MnDNR, unpub. data) are similar to those described here for mussels in the Lower St. Croix River. Other studies have also reported that mussel densities are typically highest in coarse substrates and lowest in silt substrates (Salmon and Green 1983; Stern 1983; Cooper 1984; Way et al. 1990).

The Lower St. Croix River at Interstate Park and Franconia provides excellent substrate conditions for mussels. This observation may in part account for the high mussel densities and species richness found in this river. Although substrate conditions do not appear to limit mussel populations at Interstate Park or Franconia, mussel density and species richness varied considerably in areas with suitable substrate conditions, suggesting that other habitat features, such as velocity or depth, are influencing mussel distribution.

5.1.2 Velocity

Velocity has been identified as an important factor influencing mussel populations (Cvancara 1966; Neves and Widlak 1987). Hornbach (1992a) found a significant relation between mean column velocity and mussel density at Interstate Park: areas with low velocities (<20 cm/s) and high velocities (>65 cm/s) supported low mussel densities while areas with moderate velocities supported high mussel densities. Hornbach (1991) concluded that, in addition to substrate type and food availability, velocity was an important factor influencing the mussel assemblage at Franconia. The MnDNR (unpub. data) and other researchers (Cvancara 1966; Neves and Widlak 1987; Strayer and Ralley 1993) have documented that mussel densities are typically highest in areas with moderate to high velocities.

Low velocities may be unsuitable for mussels due to reduced food supplies and increased difficulty extracting food, soluable mineral matter, and dissolved oxygen from the water (Cvancara 1966). Low velocities may also be unsuitable due to silt deposition (Salmon and Green 1983; Stern 1983; Lewis and Riebel 1984; Way et al. 1990). Reduced velocities and subsequent silt deposition, resulting from damming and impounding free-flowing rivers, has played a major role in the extirpation of numerous species from large river systems across North America (Isom 1969; Duncan and Theil 1983; Stern 1983; McMahon 1991; Parmalee and Klippel 1984; Starnes and Bogan 1988).

5.1.3 Depth

Recent studies suggest depth plays an important role in structuring mussel assemblages. At Interstate Park, Hornbach (1992a) found strong positive relations between depth and both mussel density and species richness: shallow areas (<50 cm) supported few mussels and consequently, few species, while deeper areas supported high mussel densities and high species richness. Hornbach concluded that depth is a major factor structuring the mussel community at Interstate Park. Similarly, the MnDNR (unpub. data) found very few mussels in shallow areas of the Otter Tail, Kettle, and Clearwater rivers, even in stream reaches with dense mussel beds and suitable substrate and velocity conditions. Strayer and Ralley (1993) and Zeto et al. (1987) reported that shallow, shoreline areas supported lower mussel densities than deeper areas.

In an experimental migration study, Isley (1913) found that most *Quadrula* spp.

placed in shallow water (e.g., one foot deep) moved into water two to three feet deep while those individuals placed in water over 3 feet deep remained stationary. Isley concluded that sufficient water depth is an essential component of quality mussel habitat. We observed considerable movement of mussels in response to a rapid, human-induced drop in discharge (from about 300 cfs down to 7 cfs in a matter of hours) on the Otter Tail River in west-central Minnesota. Mussels in dewatered areas, as well as in shallow, pooled areas, showed considerable movement, mostly in the direction of deeper water. Little movement was noted for mussels in deep thalweg areas which remained relatively deep during the low flow period.

Mussels may be absent from shallow areas due to increased incidence of predation, thermal stress, ice abrasion and scouring in winter, or exposure during low flows (Strayer 1983; Libois and Hallet-Libois 1987; McMahon 1991). Mussels in shallow areas are more accessible to predators and likely suffer higher mortality from predation than mussels in deep water (McMahon 1991). Muskrats (Ondatra zibethicus) and other mammalian predators have the potential to significantly reduce densities and recruitment and effect size and age distributions of mussel populations (Fuller 1974; Convey et al. 1989; Hanson et al. 1989; McMahon 1991). Neves and Odom (1989) reported that muskrat predation was likely inhibiting the recovery of endangered mussel species in the upper Tennessee River drainage in Virginia. The shoreline at Interstate Park is replete with large midden piles, indicating high rates of predation.

Ice abrasion and scouring in winter may also prevent mussels from inhabiting shallow areas. Miller (in litt 1991) observed that the layer of ice which covered the east channel during the winter of 1991 rose and fell as flows increased and decreased. During low flows, the ice laid directly on the stream bed, scouring and abrading the substrate as it shifted. Miller also noted that substrate froze into the underside of the ice layer. It is likely that mussels in shallow areas would also be scoured, abraded by and frozen into the ice layer.

Mortality from predation, thermal stress, and ice abrasion would likely increase in shallow areas dewatered during low flows. In addition, desiccation can lead to high mortality of mussels exposed during periods of low flow (Fisher and LaVoy 1972; Fuller 1974; Strayer 1983; Miller et al. 1984).

5.2 Habitat-Discharge Relations

5.2.1 Mussels

Results from this study suggest the availability of mussel habitat in the Lower St. Croix River is strongly influenced by discharge. Mussel habitat is limited at low flows due to large areas of exposed substrate and reduced depths and velocities. Much of the east channel at Interstate Park is dewatered during the impounding stage of winter peaking operations when 800 cfs is being released from the dam. At this low discharge, little water flows through this channel and its wetted area consists of shallow, pooled water. Large areas of shoreline along the main channel are also dewatered at 800 cfs, including a large gravel bar that extends out into the main channel above the boat landing at Interstate Park, MN.

Dewatering of shallow areas during low flows may explain why these shallow areas supported low mussel densities. Of the 150 quadrat samples taken by Hornbach (1992a) at Interstate Park, only 16 contained no live mussels. Fifteen of these 16 samples were in areas that are dewatered (or nearly dewatered) at 800 cfs, based on known water surface elevations at 1600 cfs and predicted water surface elevations and visual observations at 800 cfs. During a dam release of 800 cfs, we observed no mussels in dewatered areas of the east channel. Miller (unpub. data) noted that the *Q. fragosa* found during a 1991 mussel survey at Folsum Island were in areas that remained inundated during low flows. As discussed, mussels in dewatered areas or in very shallow water during winter likely suffer high mortality from desiccation, predation, exposure to below freezing air temperatures, or ice scouring and abrasion.

Other researchers have also noted that regulation of streamflow can adversely impact mussel populations by altering habitat conditions (Tudorancea 1972; Miller et al. 1984; Libois and Hallet-Libois 1987; McMahon 1991; Williams et al. 1993). Below a hydropeaking dam on the Connecticut River, shallow areas that were dewatered daily by dam operations had dramatically lower unionid mussel densities than did deeper areas that were not dewatered (Fisher and LaVoy 1972). They concluded that unionid mussels were intolerant to exposure. Layzer et al. (1993) noted that mussels were extirpated from a 7.5 mile stretch of river below a hydropeaking dam on the Caney Fork River, a major tributary of the Cumberland River, TN. They reported that fluctuating flows affected the hydraulics (e.g., areas of streambed were dewatered and velocities and depths were reduced by impounding flows) of this 7.5 mile reach. They further reported that the stream channel recovered from these hydraulic effects about 8 miles below the dam and this coincided with the area where they first found live mussels.

Short-term, infrequent dewatering can also adversely impact mussel populations. During the summer of 1992, we observed high mortality of mussels in riffles of the Otter Tail River (west-central MN) dewatered when flows were dramatically reduced at Orwell Dam, located about 1-2 miles upstream of the riffles. Flows were reduced during daylight hours and restored at night over a several day period. Mortality of mussels resulted from desiccation, thermal stress (high temperatures), and predation. No live mussels were found in these riffles one year after this flow reduction had occurred (MnDNR, unpub. data). The only live mussels were found in deep thalweg areas which were not dewatered during the flow reduction.

5.2.2 Macroinvertebrates

Previous studies have demonstrated that the structure of macroinvertebrate communities is intimately tied to habitat conditions and flow patterns (Hynes 1970; Ward 1976; Gore 1978; Gore and Judy 1981; Orth and Maughan 1983; Ward 1992). Most of the macroinvertebrate habitat at the St. Croix River study sites was in the east channel at Interstate Park. Of the four channels examined, the east channel is most affected by peaking flows, with large areas of the stream channel dewatered and depths and velocities drastically reduced during impounding flows. Peaking flows have been associated with adverse impacts on macroinvertebrate communities, including reduced density, diversity, and productivity (Fisher and LaVoy 1972; Abbott and Morgan 1975; Ward 1976; Williams and Winget 1979; Hauer and Stanford 1982; Cushman 1985).

Weisberg et al. (1990) compared macroinvertebrate densities downstream from a hydroelectric dam on the Susquehanna River, Maryland, before, during, and after a minimum flow was implemented at the dam. They reported almost a 100-fold increase in invertebrate density when the minimum flow was maintained. After the minimum flow was no longer maintained (when shutdowns occurred at the dam), invertebrate density declined by more than three orders of magnitude. Declines were greatest in areas dewatered during shutdowns but submerged when the minimum flow was being released.

Highest macroinvertebrate densities and biomass are typically found along the margins of large streams due to the availability of preferred habitat (Hynes 1970). Dewatering of stream margins and reduced velocities and depths resulting from peaking operations have been shown to reduce macroinvertebrate density, biomass, and species richness in these areas (Radford and Hartlan-Rowe 1971; Fisher and LaVoy 1972; Brusven et al. 1974; Trotzky and Gregory 1974; Brusven and Trihey 1978; Langdon and Fiske 1987). Gislason (1985) reported that a reduction in the amplitude and duration of peaking fluctuations greatly enhanced macroinvertebrate densities along the stream margin which, under peaking flows, supported low macroinvertebrate densities.

Adverse impacts on macroinvertebrate communities from peaking flows have resulted from stranding and desiccation (Fisher and LaVoy 1972; Kroger 1973; Brusven et al. 1974; Ward 1976; Langdon and Fiske 1987; Weisberg et al. 1990), increased drift rates and decreased recolonization rates (Minshall and Winger 1968; Pearson and Franklin 1968; Brusven and MacPhee 1976; Ciborowski et al. 1977; Gore 1977; Gersich and Brusven 1981; Beckett and Miller 1982; Irvine 1985), reduced food supplies (Powell 1958; Radford and Hartland-Rowe 1971; Ward and Short 1978; Hauer and Stanford 1982; Matter et al. 1983), increased predation rates (Cushman 1985), or low dissolved oxygen (Gislason 1985). These studies and our habitat analyses suggest that peaking flows, with a minimum winter release of 800 cfs, could be adversely impacting the macroinvertebrate community in the east channel, as well as in other areas below the dam.

5.2.3 Fishes

The fishes in the Lower St. Croix River exhibited a broad range of habitat-discharge relations. Low flows favored shallow pool species, high flows favored raceway and deep pool species, and moderate flows provided the best habitat conditions for the fish community as a whole. Previous investigators have reported similar habitat-discharge relations for fishes occupying these habitat types (Schlosser 1982a, 1985; Leonard and Orth 1988; Aadland 1993).

During peaking operations, habitat conditions for the fish community in the Lower St. Croix River rapidly fluctuates between low and high flow extremes. Numerous authors have reported that fluctuating flows adversely impacts fish communities by reducing fish densities, diversity, and productivity (Powell 1958; Trotzky and Gregory 1974; Becker et al. 1981; Cushman 1985; Langdon and Fiske 1987), particularly in shallow stream margins, which typically support an abundant and diverse fish assemblage (Bain et al. 1988; Reed 1989). These adverse impacts resulted from 1) stranding and desiccation, 2) reduced recruitment from egg desiccation, loss of nursery habitat, and downstream displacement of eggs and fry, 3) increased mortality from predation, thermal stress, and low dissolved oxygen in shallow, isolated pools, 4) downstream displacement of small fish, and 5) reduced food supply. These studies and our habitat analyses suggest that peaking flows, with a minimum winter release of 800 cfs, could be adversely impacting the fish community in the Lower St. Croix River below the NSP dam. We, and others (David Heath, Wisconsin Department of Natural Resources, personal communication), have observed mortality of fishes stranded in dewatered areas and in small, isolated pools in the east channel at 800 cfs. Mortality resulted from desiccation and freezing.

Healthy fish populations are needed to maintain healthy mussel populations: mussels require fish hosts to complete their reproductive cycle. Declines in appropriate fish host populations have been implicated in the extirpation of mussel species from river systems (Davenport and Warmuth 1965; Fuller 1974; Kat 1984; Smith 1985a and 1985b; McMahon 1991). Conversely, the restoration of fish host populations has led to the restoration of endangered mussel populations (Smith 1985b; McMahon 1991). The fish host(s) of *Q. fragosa* is unknown, as are the hosts of many of the mussel species in the Lower St. Croix River. Therefore, to ensure that appropriate fish host populations exist to maintain the diverse mussel community, instream flows needed to protect the diversity of the fish community in the Lower St. Croix River need to be considered in the management of the mussel community.

5.2.4 Habitat Types

Habitat diversity is an important factor governing the number of fish species found in warmwater streams (Gorman and Karr 1978; Schlosser 1982a). Habitat diversity may also influence the diversity of invertebrate species, including mussels, inhabiting streams (Ward 1976). Habitat diversity is typically maximized at intermediate flows and minimized at low and high flows (Kraft 1972; EA Engineering, Science, and Technology 1986; Leonard and Orth 1988; Aadland 1993). These relations between discharge and habitat diversity were evident at the Lower St. Croix River study sites.

Riffles are biologically important and productive habitats: they typically support high, and often the highest, densities and diversity of fishes and invertebrates, including mussels, in warmwater streams (Hynes 1970; Ward 1976; Gore 1978; Schlosser 1982a; Orth and Maughan 1983; Neves and Widlak 1987; Leonard and Orth 1988; Lobb and Orth 1991; Aadland 1993). Riffle habitat is very sensitive to changes in flow, being scarce or absent at both low and high flows (Curtis 1959; Kraft 1972; Schlosser 1985; Leonard and Orth 1988; Aadland 1993). Widely fluctuating flows have been associated with reduced productivity of riffles (Briggs 1948; Neel 1963; Abbott and Morgan 1975; Cushman 1985) and consequently, the productivity of the stream community. Riffle habitat was limited at the Lower St. Croix River study sites with most of it found in the east channel. It is likely that peaking flows, which dewater much of the east channel during impounding flows, are limiting the productivity of this riffle and of the river as a whole.

5.3 Flow Recommendations

Based on the hydrology of the Lower St. Croix River, the relations between habitat availability and discharge, and the impacts of peaking flows, a run-of-river flow regime is recommended to protect and restore the habitat of *O. fragosa* and to protect the integrity of the aquatic community in the Lower St. Croix River downstream of the hydroelectric dam at St. Croix Falls, WI.

Flows in the Lower St. Croix typically exceed 5000 cfs during spring. Given that the turbine capacity at the dam is 6400 cfs, little or no peaking probably takes place in spring. Flows range between 2000 and 4000 cfs throughout the rest of year, during which time peaking operations can be expected. Low flows of 800 cfs, which rarely occur naturally (see 5.3.1), can occur daily during winter peaking operations.

Mussel habitat is limited in all four channels, especially the east channel, at 800 cfs due to loss of wetted area and reduced velocities and depths. Habitat for other invertebrates and fishes is also limited at 800 cfs, as is habitat diversity. Flows between 2000 and 4000 cfs provide good habitat conditions for mussels in all channels. This range of flows also provides good habitat conditions for the macroinvertebrate and fish communities, as well as providing a diversity of habitat types. During peaking operations, flows are often either below 2000 cfs (impounding flows) or above 4000 cfs (generation flows)(Figures 2b, 2c), consequently, flows between 2000 and 4000 cfs occur for only short periods of time as flows are rapidly rising or dropping.

Not only are low flows of concern, but also the rapid fluctuations between low and high flows. Stream biota have adapted to, and often require, seasonal fluctuations in flow. Daily fluctuations in flow from peaking operations typically exceed even the most extreme natural seasonal fluctuations, especially low flow extremes (see 5.3.1). These fluctuations are rapid, unpredictable, and can occur daily throughout much of the year. Stream biota are not adapted to this unnatural flow regime and may not be able to adjust to the constantly changing habitat conditions. In the east channel, large areas of the streambed are alternately dewatered and inundated on a daily basis. Even when inundated, this "intertidal zone" is unusable habitat for many aquatic organisms, especially relatively sessile animals like mussels and other macroinvertebrates which can not move with the rapidly receding and advancing water.

The distribution of mussels at Interstate Park appears to be restricted to areas that are not dewatered at 800 cfs. As previously mentioned, of the 150 quadrat samples taken by Hornbach (1992a) at Interstate Park, only 16 contained no live mussels. Fifteen of these 16 samples were in areas that are dewatered (or nearly dewatered) at 800 cfs. While some streambed and shoreline areas are dewatered at 1600 cfs, most of the dewatering occurs as flows drop below 1600 cfs. Large areas of the streambed are dewatered at 800 cfs, especially in the east channel. Given that natural flows of 1600 cfs or less occur infrequently (see 5.3.1), the magnitude and frequency of dewatering would be greatly reduced and consequently, the amount of usable mussel habitat and habitat for other aquatic organisms would be greatly enhanced, under a run-of-river flow regime as compared to the current peaking flow regime.

5.3.1 Recommended Flows in Relation to Peaking Flows

An important step in this instream flow assessment is to compare habitat conditions under the recommended flow regime (run-of-river) to habitat conditions under the existing flow regime (peaking). Results from this study support NSP's position (Lloyd D. Everhart, NSP, memo dated March 24, 1994) that habitat conditions during low flows are critical in limiting the distribution of mussels to wetted areas of the stream channel downstream of the dam. The central question is whether natural low flows restrict usable mussel habitat to the same extent as low flows resulting from peaking operations. To address this question, the magnitude and frequency of low flows under both flow conditions were compared.

The minimum flow of 800 cfs during winter peaking operations occurs part of each day (usually at night), with flows much higher (several thousand cfs) occurring the rest of the day. Since 1902, mean daily flows of 800 cfs or less have occurred 306 times over a period of 31,513 days. It appears that all but a few of these 800 cfs days were not naturally occurring, but rather, were due to dam operations: nearly all of the 800 cfs days occurred on a Sunday and flows the week prior to and the week after the 800 cfs day were almost always much higher than 800 cfs (typically > 1600 cfs) (Appendix E). This pattern also included numerous low flows on Sunday that were higher than 800 cfs (e.g., 1000-1600 cfs) but still much lower than flows the preceding and following weeks. It seems that these Sunday shutdowns ceased in 1951: only one 800 cfs day has occurred since 1951 (February 5, 1963). Here again, this low flow was probably due to dam operations in that flows the week before and the week after averaged 1423 and 1542 cfs. The only period when 800 cfs appears to have occurred naturally was during July and August of 1934.

Because most of the lowest flows on record were due to dam operations, and do not reflect natural low flow events, exceedance values based on mean daily flows need to be interpreted cautiously. For example, the annual 90% exceedance flow is 1540. This means 10% of the mean daily flows over the period of record have been less than 1540 cfs. Many of these low flows, however, would have been higher than 1540 if it weren't for dam operations, resulting in a higher annual 90% exceedance flow. Mean monthly flows may provide a better picture of the magnitude and frequency of natural low flow events by averaging the effect of dam operations. Mean monthly flows over the period of record (1039 months) have never dropped below 800 cfs and have been below 1000 cfs only twice (August of 1933 and 1934). Most months with mean flows below 1600 cfs, the minimum flow during summer peaking operations, occurred during the 1920's and 1930's (Appendix F). Since the drought of 1976-7, only one month (July 1988, also a drought period) has had a mean flow of less than 1600 cfs.

Without question, the magnitude and frequency of low flows are much greater under the current peaking flow regime (i.e., low flows are much lower and occur much more frequently) than under the recommended run-of-river flow regime. Daily low flows during winter peaking operations subject mussels and other aquatic organisms to extreme habitat conditions, conditions associated with the most severe drought that has occurred during the 90 year period of record and one of the most severe drought periods in U.S. history (the dust bowl era of the 1930's). Daily low flows during summer peaking operations also subject organisms to drought conditions, similar to conditions which occurred during the drought of 1976. It is apparent that usable mussel habitat is much more restricted under the current peaking flow regime, especially during winter, than under the recommended run-of-river flow regime.

Severe droughts may temporarily impact the aquatic community in the Lower St. Croix River but, because they occur infrequently, may have little long-term impact on the integrity of the aquatic community. It is doubtful, however, that the aquatic community can continue to endure severe drought conditions on a sustained basis without suffering irreparable damage.

6.0 NATIONAL WILD AND SCENIC RIVERS ACT AND ENDANGERED SPECIES ACT

Two federal acts need to be considered when discussing the instream flow needs of *Q. fragosa* and the aquatic community of the Lower St. Croix River: the National Wild and Scenic Rivers Act (NWSRA) of 1968 and the Endangered Species Act (ESA) of 1973. The Lower St. Croix River was designated a National Scenic Riverway in 1972. The stated purpose of the NWSRA is to protect and preserve the "free-flowing condition" of certain rivers which possess "outstandingly remarkable" values. An outstanding value of the Lower St. Croix River is the biodiversity of its aquatic communities. Indeed, the St. Croix River is the most biologically diverse National Park unit of the Midwest region (St. Croix River Zebra Mussel Joint Task Force 1993). A major component of this biodiversity is the mussel assemblage, one of most diverse assemblages in the Upper Midwest. Loss of mussel biodiversity in the Lower St. Croix River is a real threat: nearly one third of the mussel species located below the NSP dam are considered endangered, threatened, or of special concern by the states of

Wisconsin and Minnesota. Most notably, the Interstate Park area is home to the only known global population of *Q. fragosa*, classified as a federally endangered species under the ESA. The stated purpose of the ESA is to prevent anthropogenic extinction of species by protecting the habitat and ecosystem upon which endangered and threatened species depend. Results from this study suggest that eliminating the current peaking flow regime of the Lower St. Croix River and restoring a "free-flowing condition" would protect and restore the habitat of *Q. fragosa* and the ecosystem upon which this species depends.

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Table 1. Monthly exceedance values for discharges of 800 cfs and 1600 cfs for the Lower St. Croix River at St. Croix Falls, WI. Exceedance values were based on mean daily flows. Discharge data taken from USGS gage no. 5340500 for the period 1902 to 1993.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
800 cfs	98	98	99	100	100	100	100	99	100	100	99	98
1600 cfs	77	76	91	99	99	96	86	80	85	91	90	81

Table 2. Species, life stages, and habitat guilds of target fish used in modeling fish habitat in the Lower St. Croix River, MN and WI. Life stages are spawning (S), young of the year (Y), fingerling (F), juvenile (J), and adult (A). Species codes are used in Figures 11a through 14b.

Common Name	Scientific Name	Life Stage	Species Code	Habitat Guild
Hornyhead chub	*Nocomis biguttatus*	S	HHCS	shallow pool
Smallmouth bass	*Micropterus dolomieu*	F	SMBF	shallow pool
Sand shiner	*Notropis stramineus*	Y	SDSY	shallow pool
Channel catfish	*Ictalurus punctatus*	J	CCFJ	medium pool
Channel catfish	*Ictalurus punctatus*	A	CCFA	deep pool
Central stoneroller	*Campostoma anomalum*	A	CSRA	slow riffle
Slenderhead darter	*Percina phoxocephala*	A	SHDA	fast riffle
Shorthead redhorse	*Moxostoma macrolepidotum*	A	SHRA	raceway
Smallmouth bass	*Micropterus dolomieu*	J	SMBJ	raceway
Smallmouth bass	*Micropterus dolomieu*	A	SMBA	raceway

Table 3. Mean velocity and depth used by *Q. fragosa* collected in 1992 (Hornbach 1992a) and 1993 (Hornbach, unpub. data) at Interstate State Park, Lower St. Croix River, MN and WI.

	Mean	Range	Number of *Q. fragosa*
Mean column velocity (cm/s)	41	16-66	14
Depth (cm)	95	42-190	19

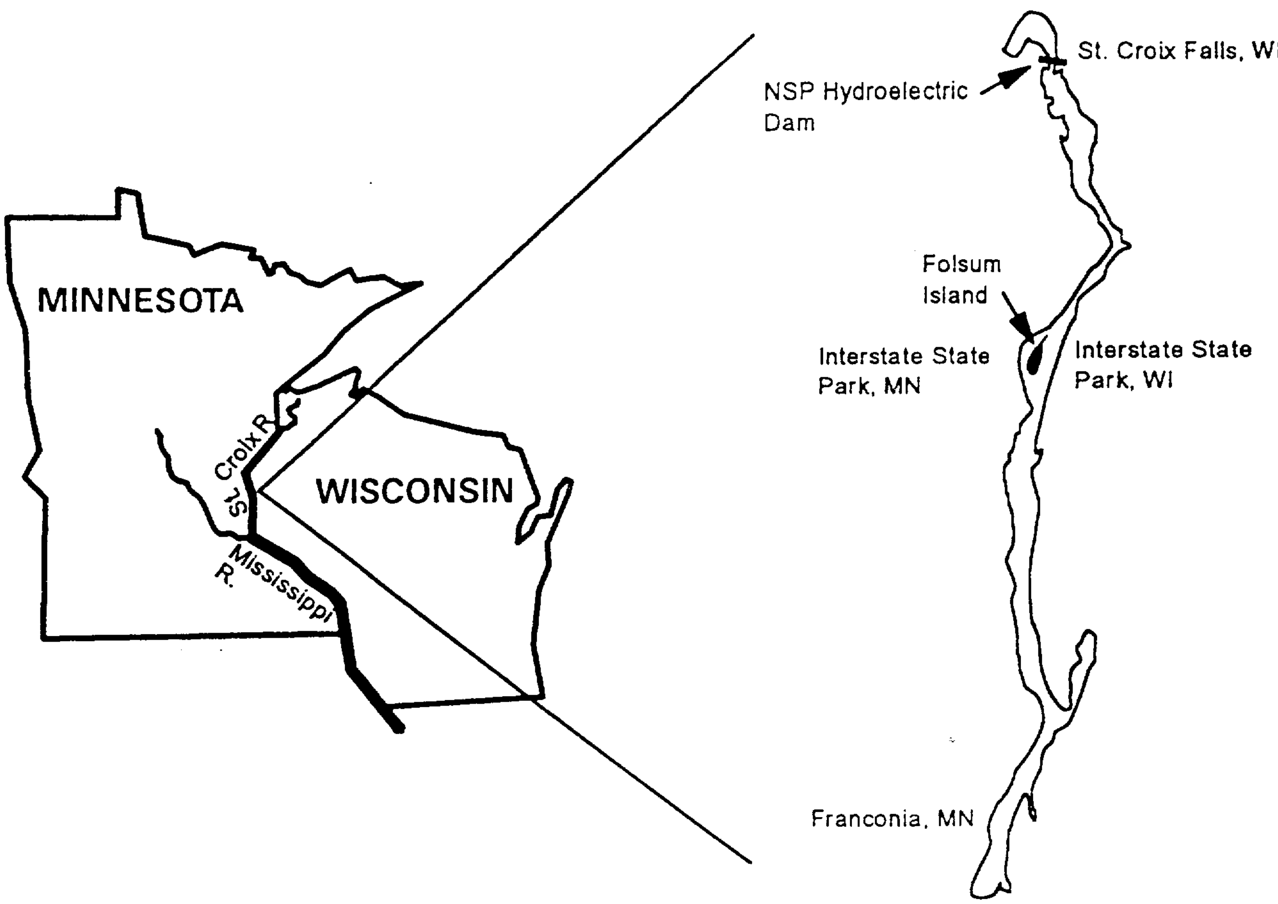

Figure 1. Lower St. Croix River study area. PHABSIM study sites were established at Interstate State Park, MN and WI (about 1.5 miles below the NSP dam) and at Franconia, MN (about 4 miles below the NSP dam).

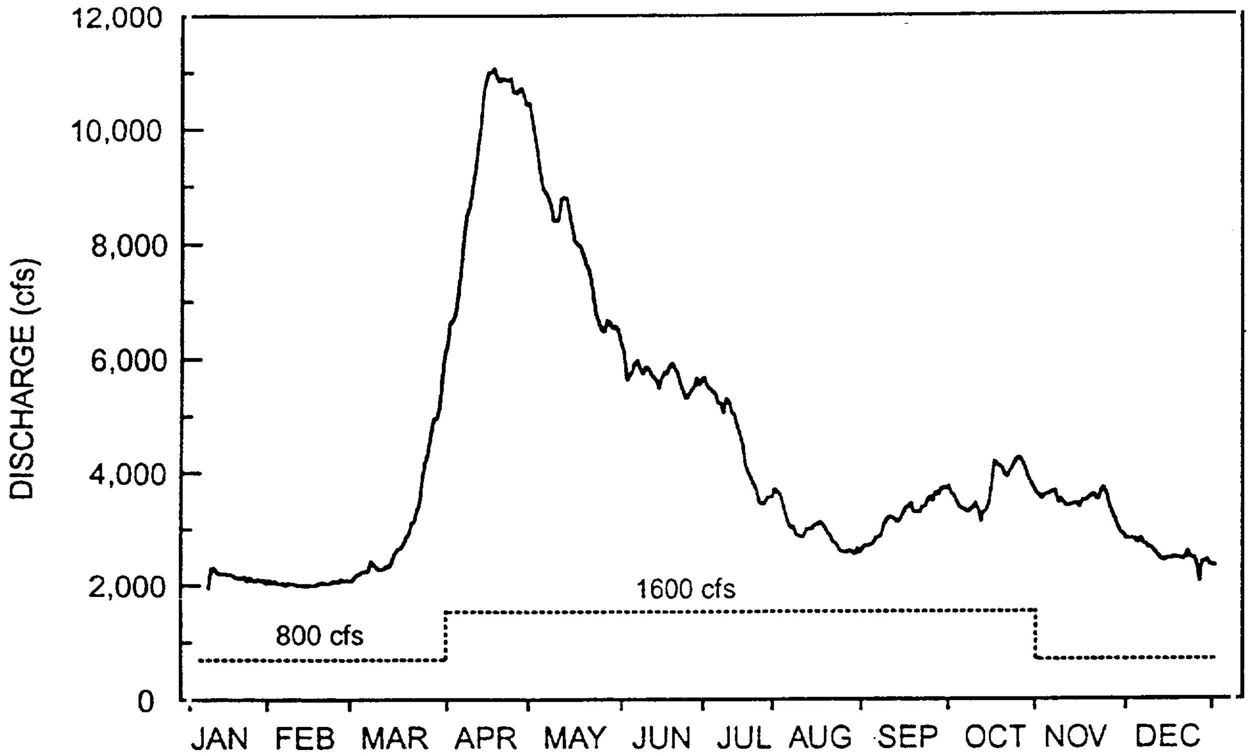

Figure 2a. Mean daily discharge for the Lower St. Croix River at St. Croix Falls, WI from 1902 to 1993. Minimum summer release from NSP dam is 1600 cfs and minimum winter release is 800 cfs. Discharge data taken from USGS gage no. 5340500.

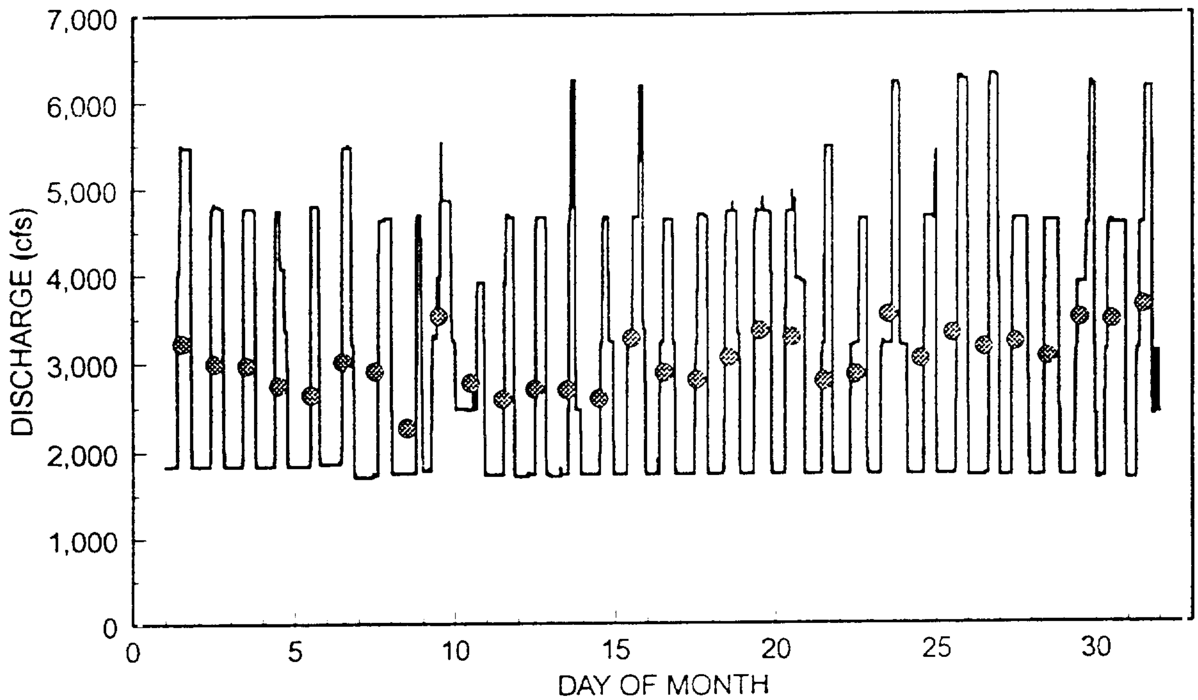

Figure 2b. Discharge at 15 minute intervals during August 1993 for the Lower St. Croix River at St. Croix Falls, WI. Circles represent mean discharge for each day. Discharge data taken from USGS gage no. 5340500.

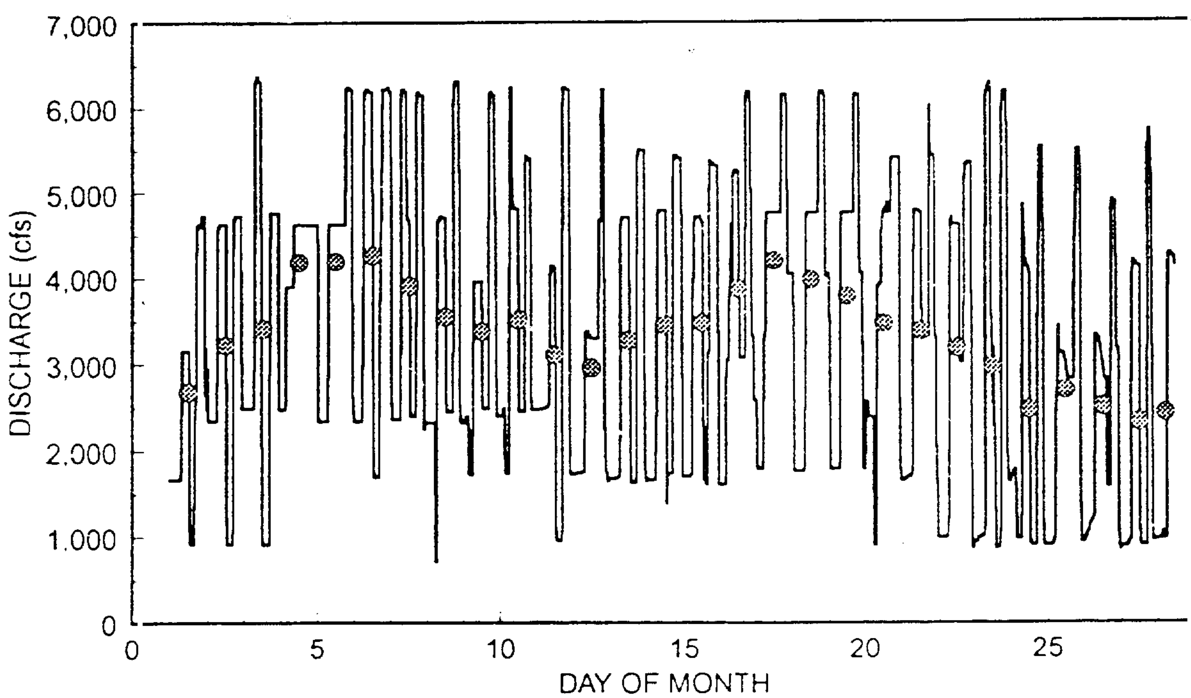

Figure 2c. Discharge at 15 minute intervals during December 1993 for the Lower St. Croix River at St. Croix Falls, WI. Circles represent mean discharge for each day. Discharge data taken from USGS gage no. 5340500.

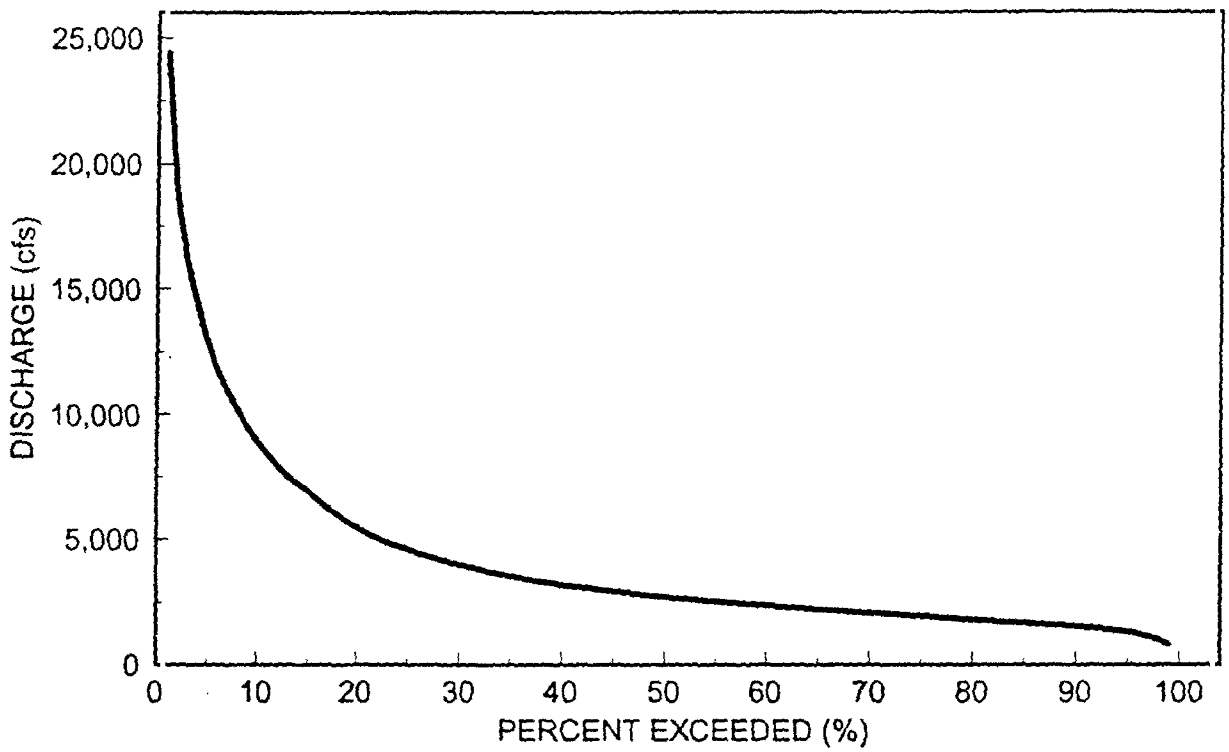

Figure 2d. Annual flow-duration curve for the Lower St. Croix River at St. Croix Falls, WI. Discharge data taken from USGS gage no. 5340500 for the period 1902 to 1993..

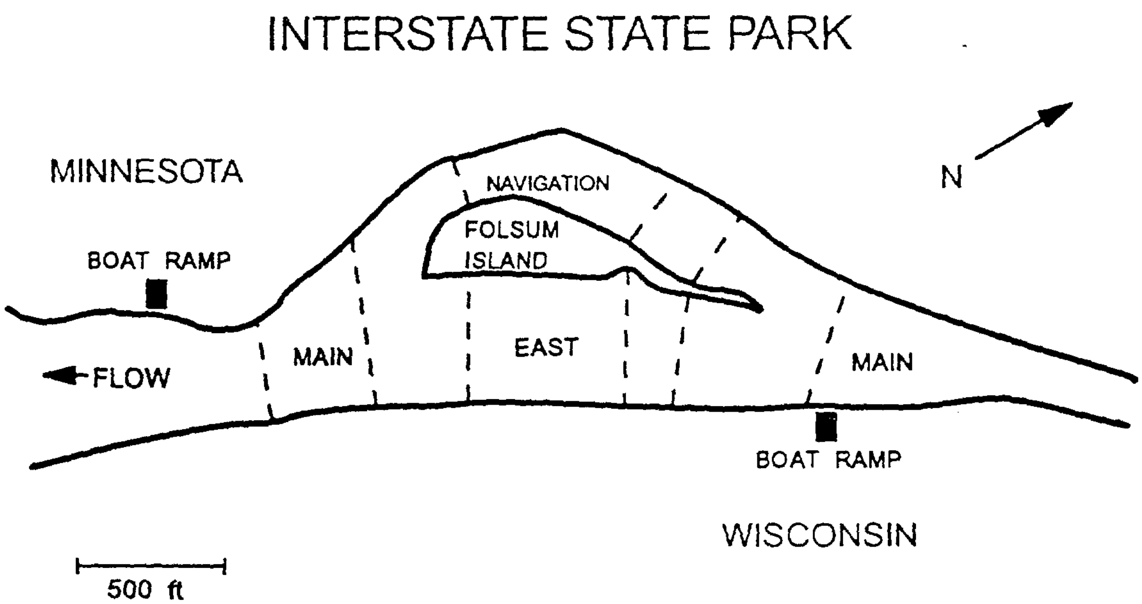

Figure 3a. Interstate State Park PHABSIM study site. Dashed lines represent transect locations. Each of the three channels (east, navigation, and main) were modeled separately.

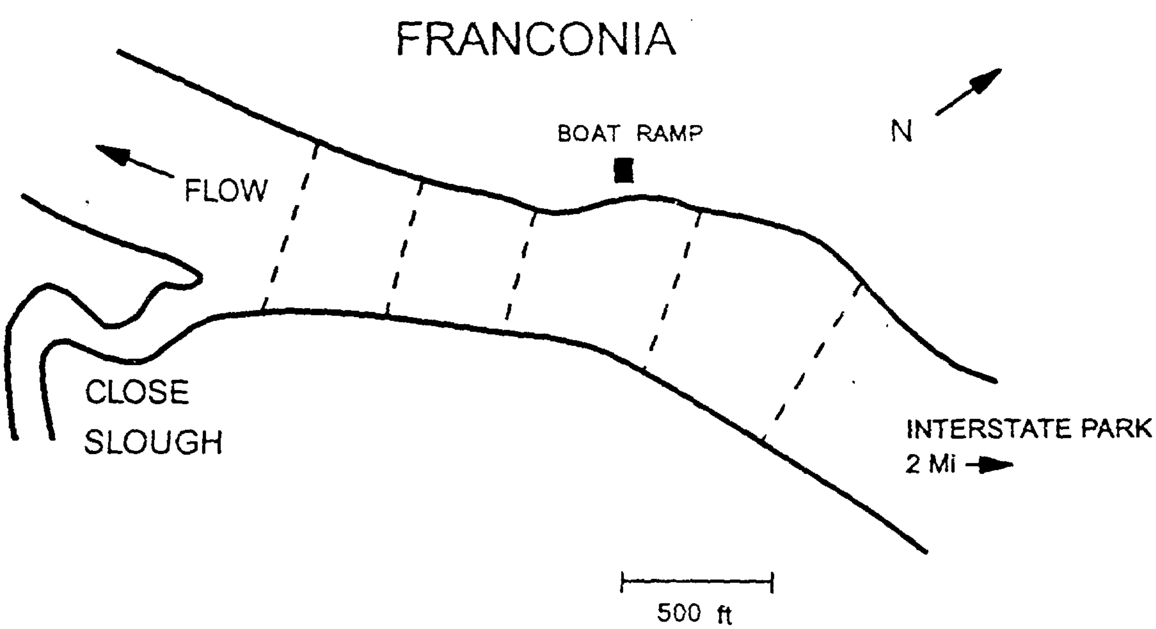

Figure 3b. Franconia PHABSIM study site. Dashed lines represent transect locations.

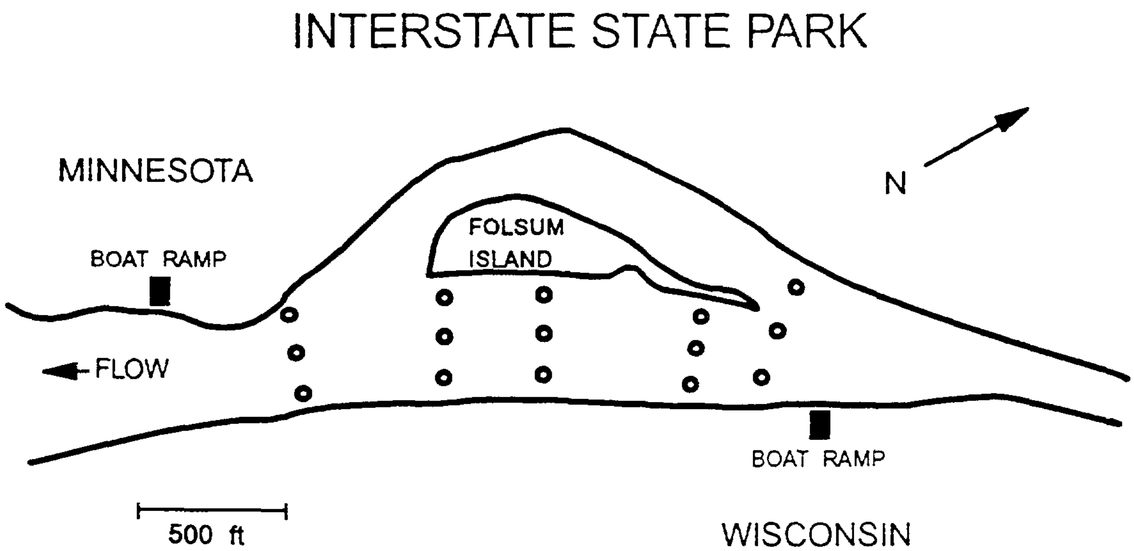

Figure 4. Mussel habitat-use sampling locations (circles) from Hornbach (1992). Ten 0.25 m^2 quadrat samples were taken at each of the 15 sampling locations.

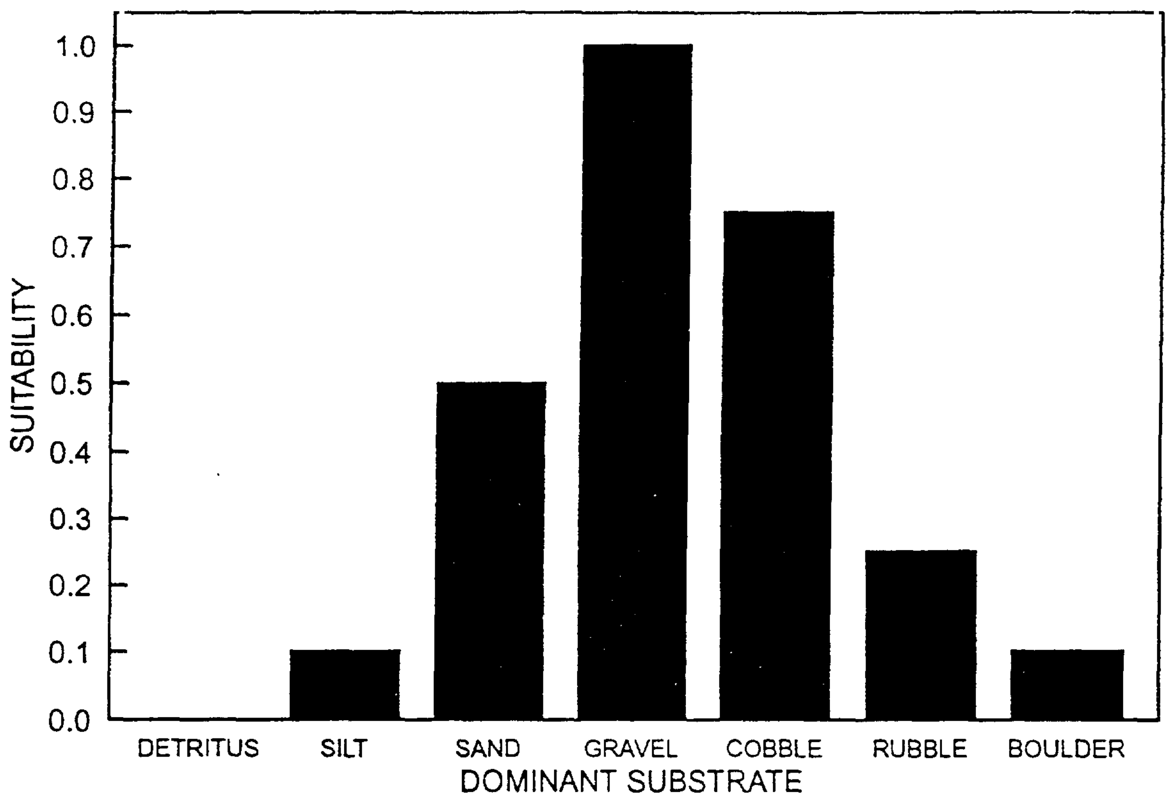

Figure 5. Dominant substrate preference of mussels at Interstate State Park, Lower St. Croix River, MN and WI.

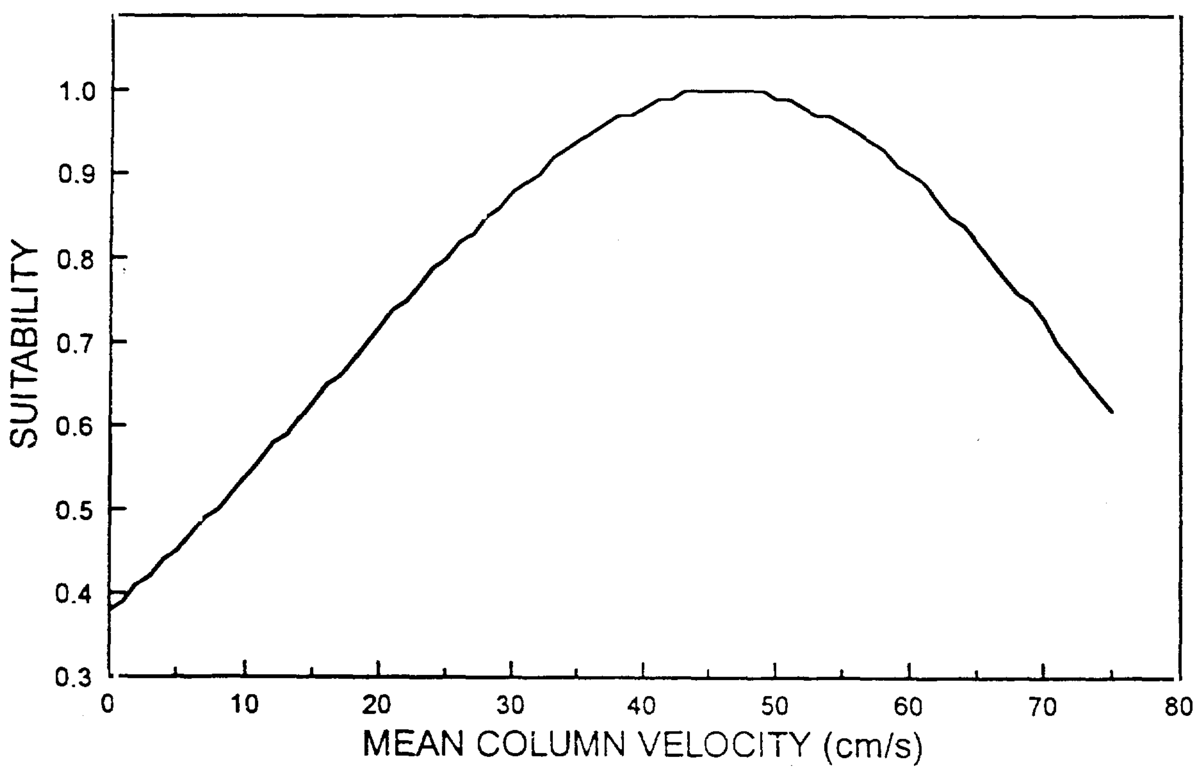

Figure 6. Velocity preference of mussels at Interstate State Park, Lower St. Croix River, MN and WI. Suitability values based on mussel density (number of samples = 150, number of individuals = 1174).

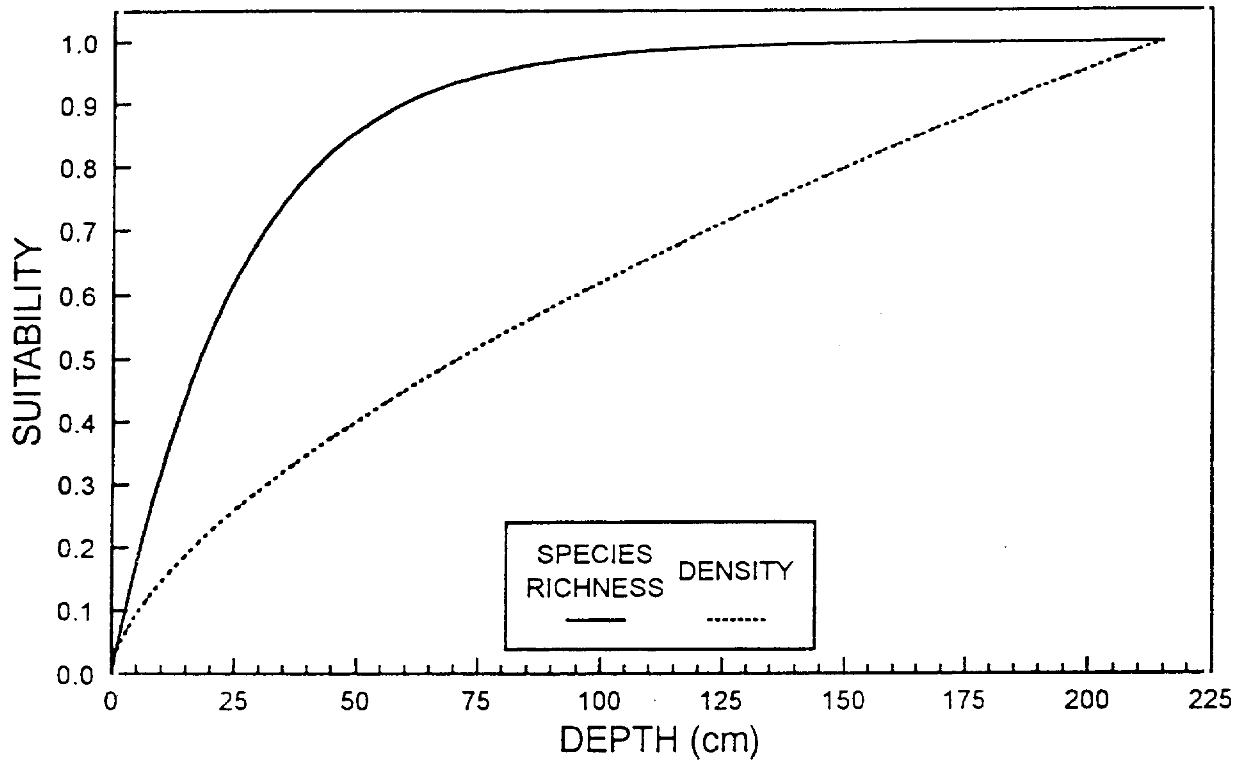

Figure 7. Depth preferences of mussels at Interstate State Park, Lower St. Croix River, MN and WI. Suitability values based on mussel density and species richness (number of samples = 150, number of individuals = 1174).

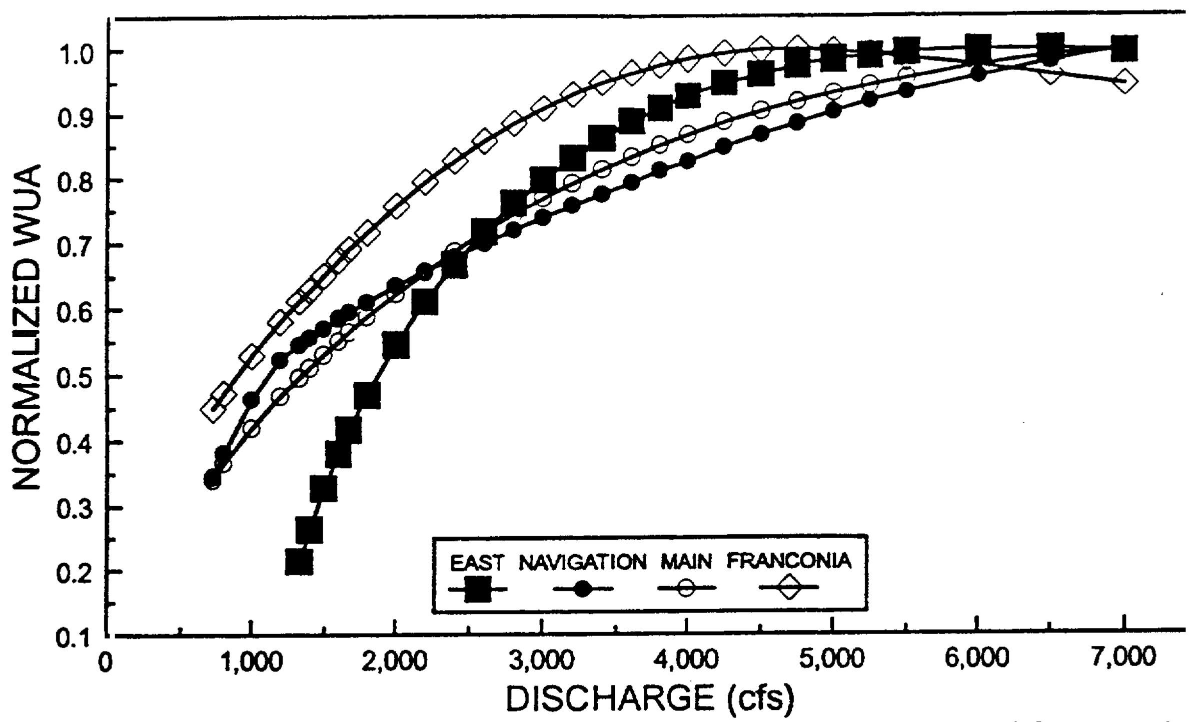

Figure 8. Relations between normalized weighted usable area (WUA) for mussel density and discharge in the east, navigation, and main channels at Interstate State Park and at Franconia, MN, Lower St. Croix River.

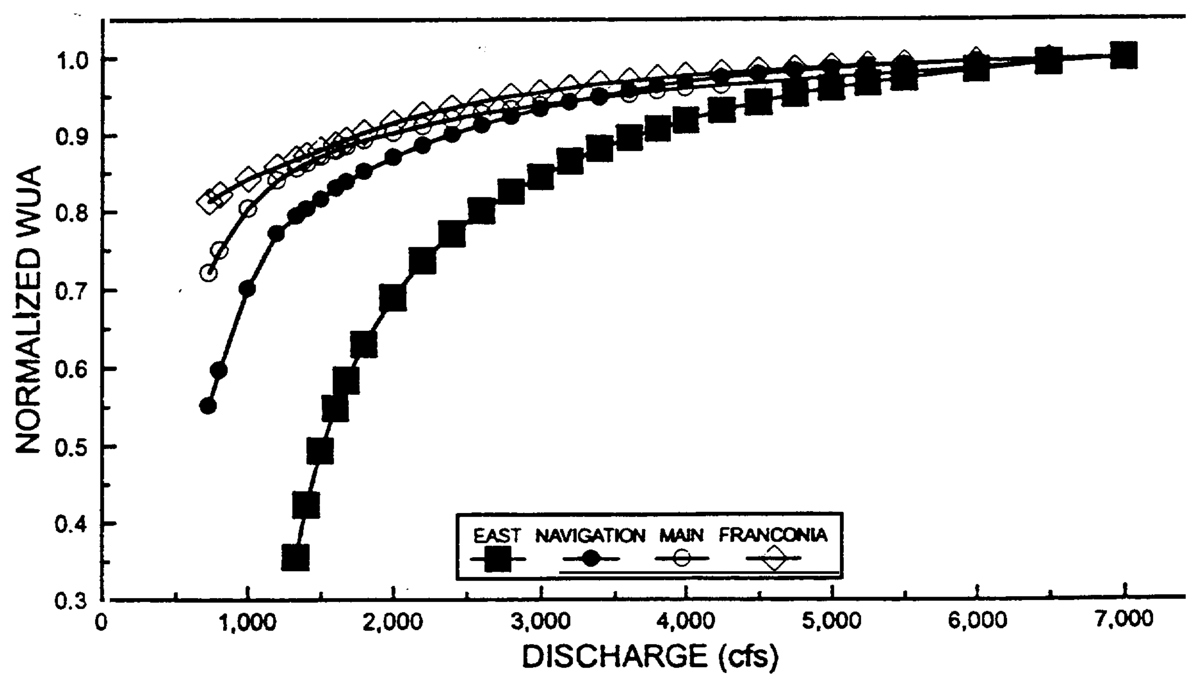

Figure 9. Relations between normalized weighted usable area (WUA) for mussel species richness and discharge in the east, navigation, and main channels at Interstate State Park and at Franconia, MN, Lower St. Croix River.

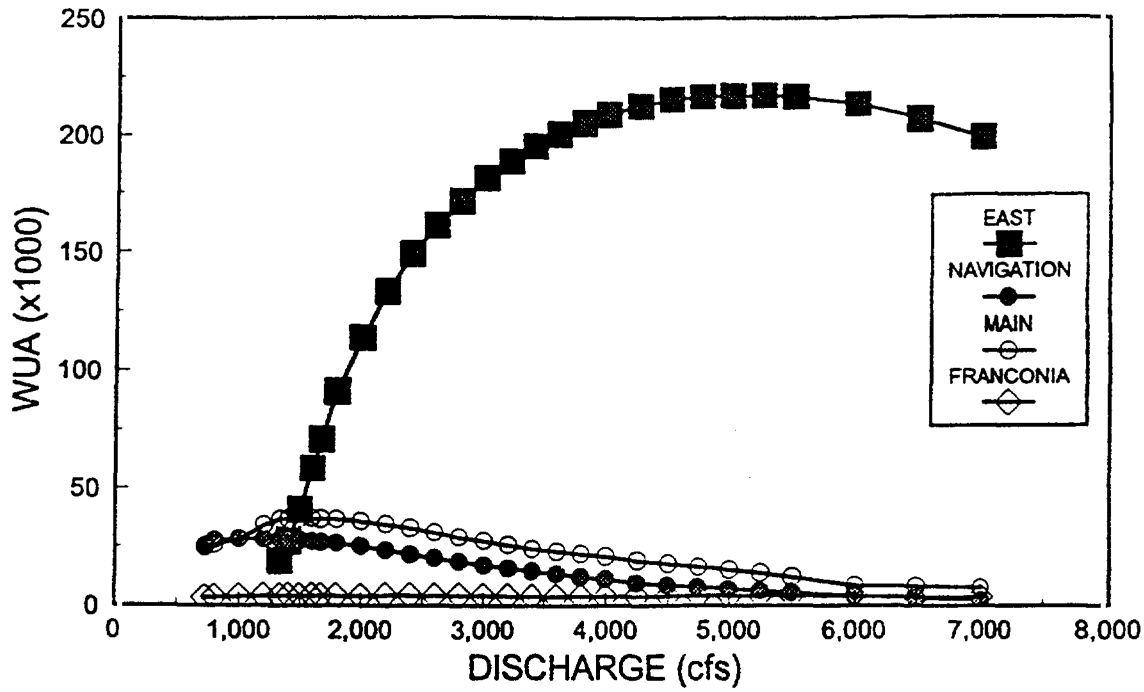

Figure 10a. Relations between weighted usable area (WUA) for macroinvertebrates and discharge in the east, navigation, and main channels at Interstate State Park and at Franconia, MN, Lower St, Croix River.

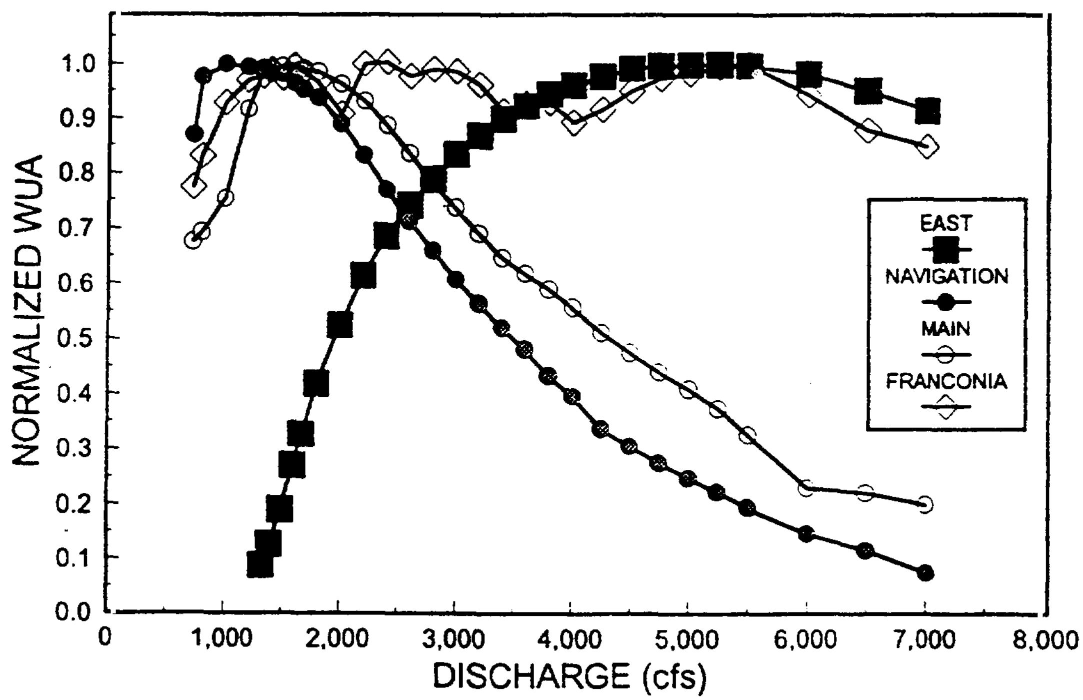

Figure 10b. Relations between normalized weighted usable area (WUA) for macroinvertebrates and discharge in the east, navigation, and main channels at Interstate State Park and at Franconia, MN, Lower St. Croix River.

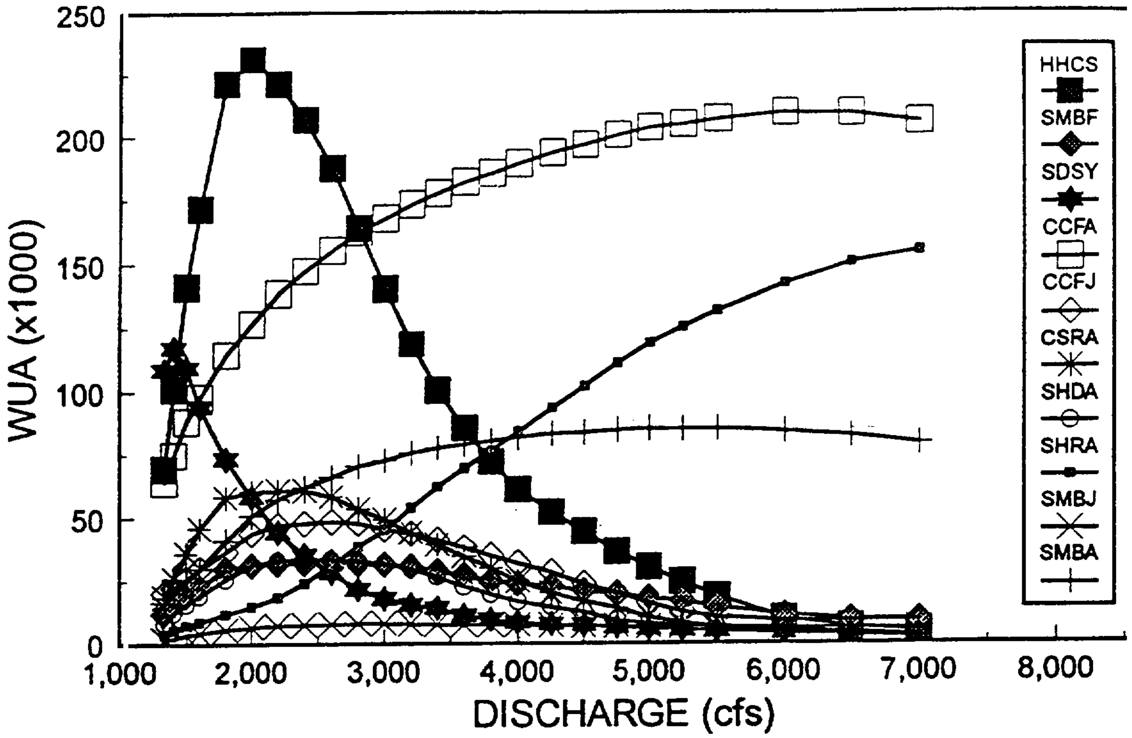

Figure 11a. Relations between weighted usable area (WUA) for fish and discharge in the east channel at Interstate State Park, Lower St. Croix River, MN and WI.

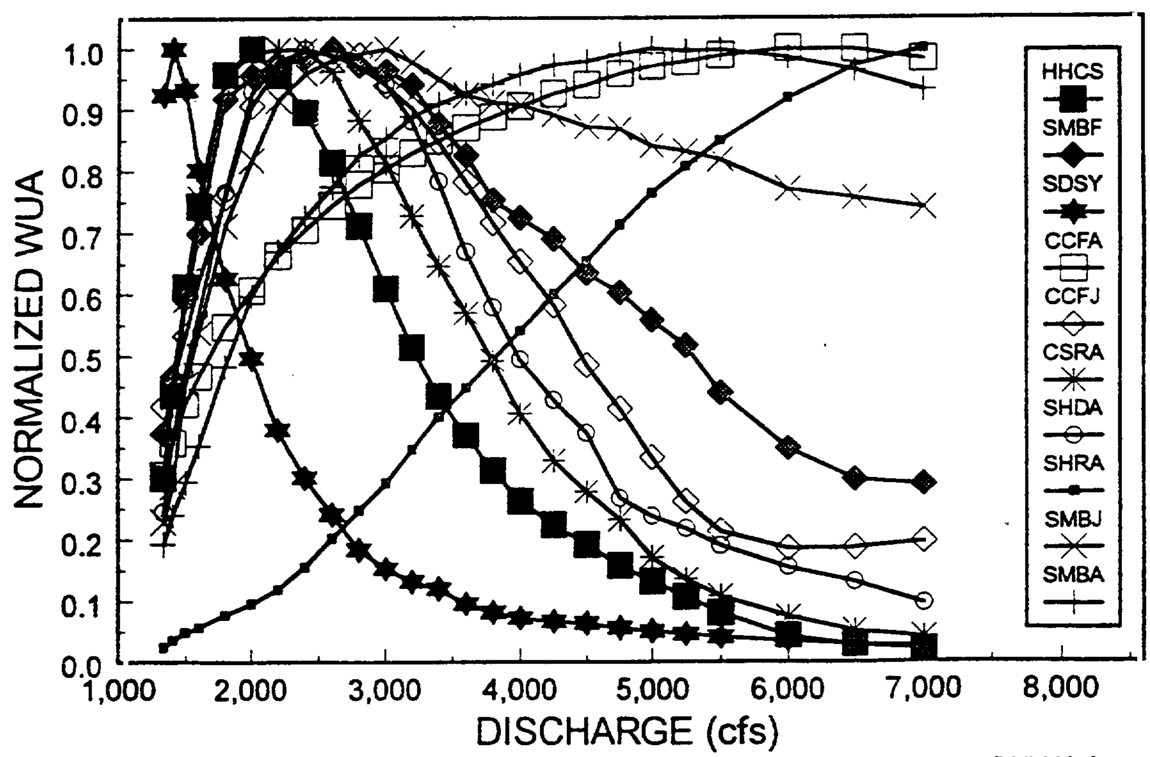

Figure 11b. Relations between normalized weighted usable area (WUA) for fish and discharge in the east channel at Interstate State Park, Lower St. Croix River, MN and WI.

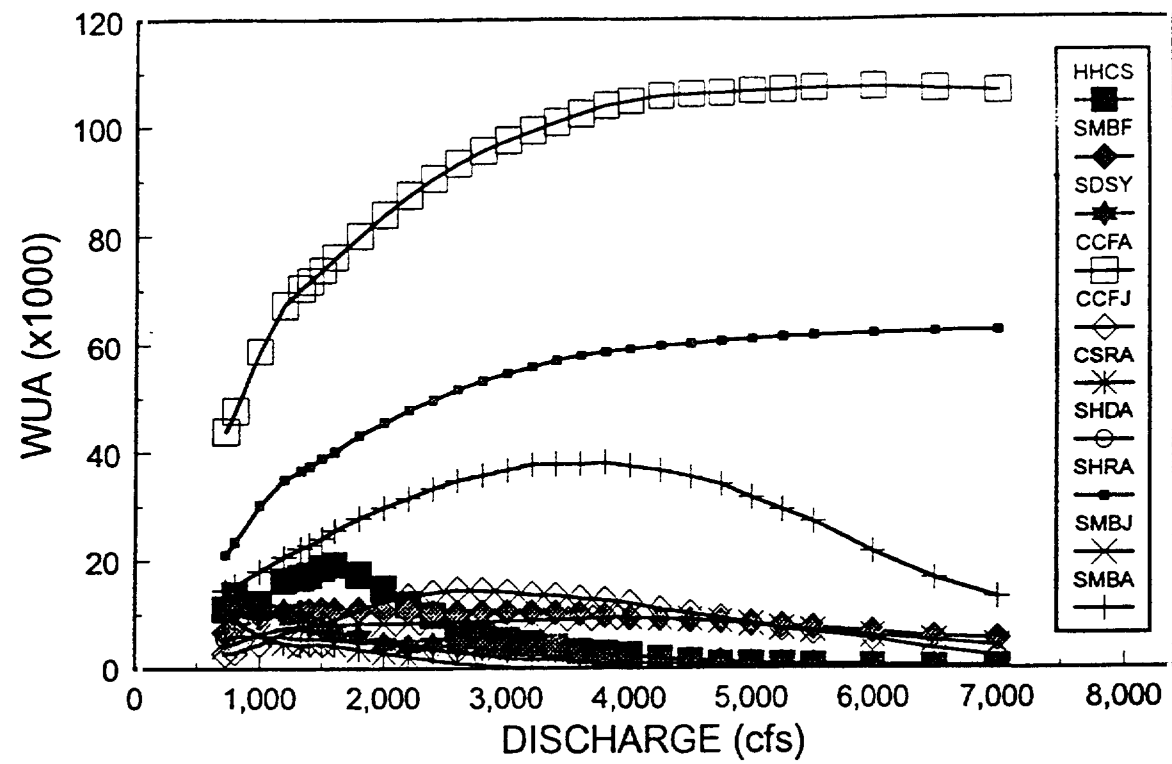

Figure 12a. Relations between weighted usable area (WUA) for fish and discharge in the navigation channel at Interstate State Park, Lower St. Croix River, MN and WI.

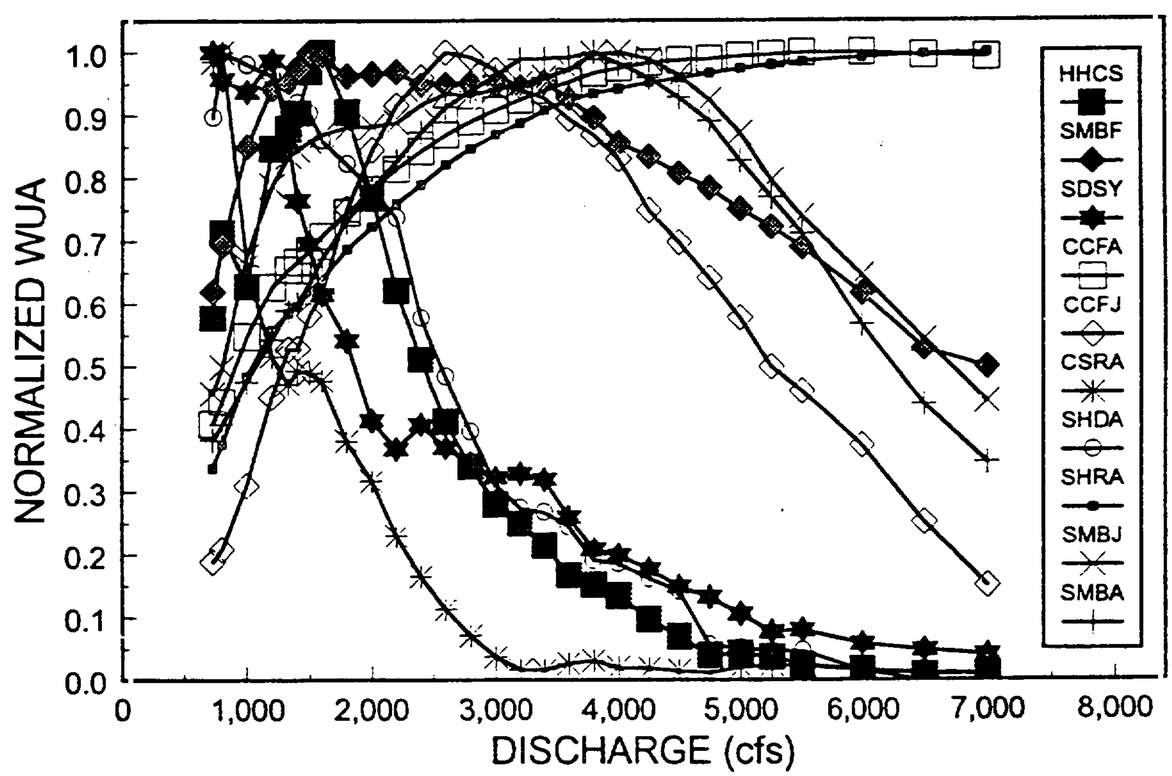

Figure 12b. Relations between normalized weighted usable area (WUA) for fish and discharge in the navigation channel at Interstate State Park, Lower St. Croix River, MN and WI.

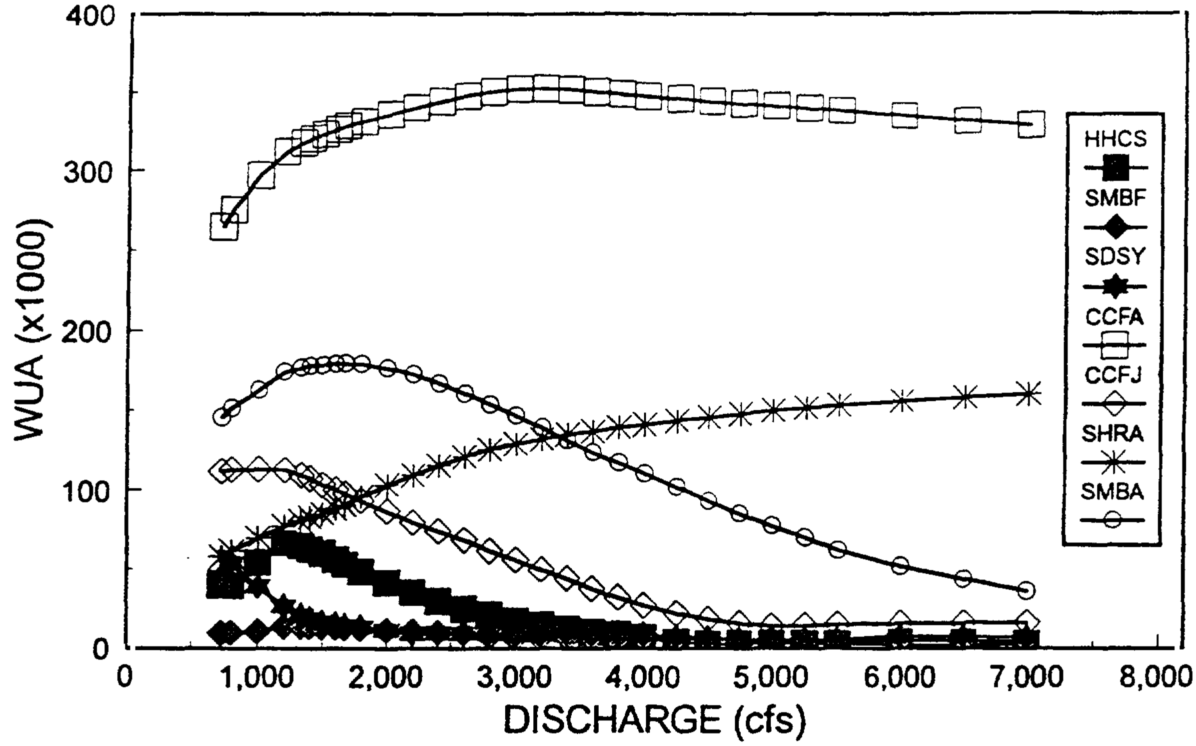

Figure 13a. Relations between weighted usable area (WUA) for fish and discharge in the main channel at Interstate State Park, Lower St. Croix River, MN and WI.

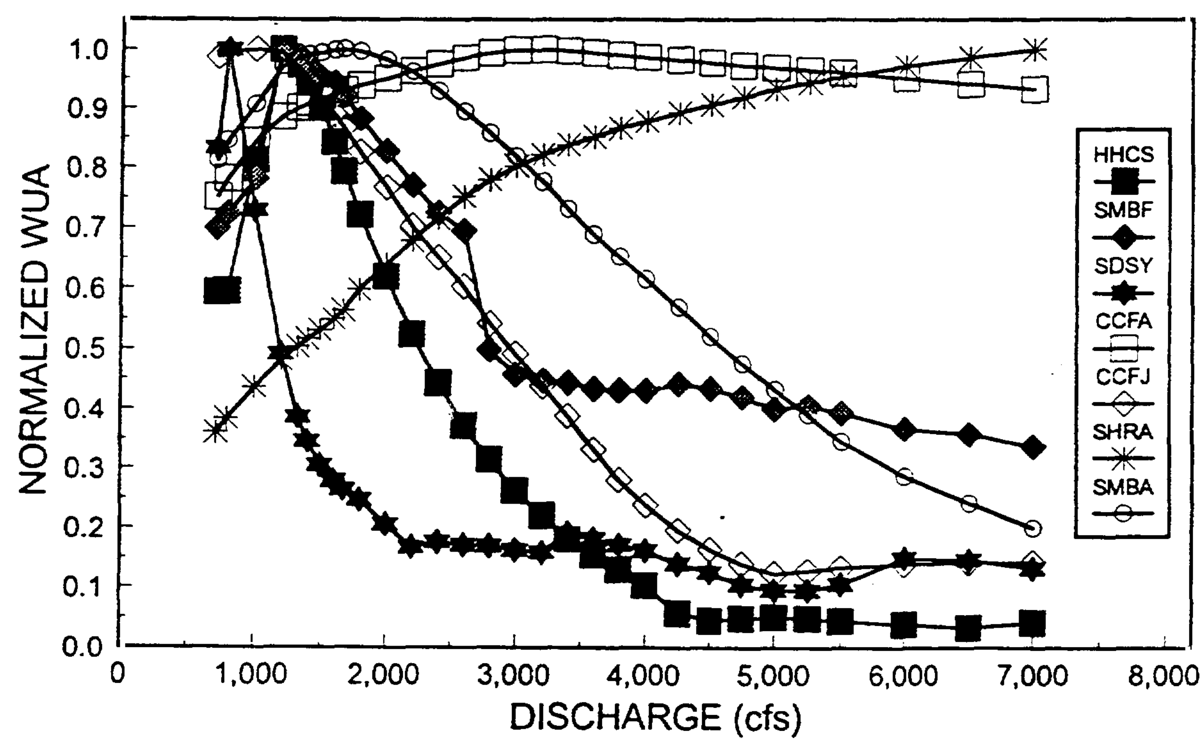

Figure 13b. Relations between normalized weighted usable area (WUA) for fish and discharge in the main channel at Interstate State Park, Lower St. Croix River, MN and WI.

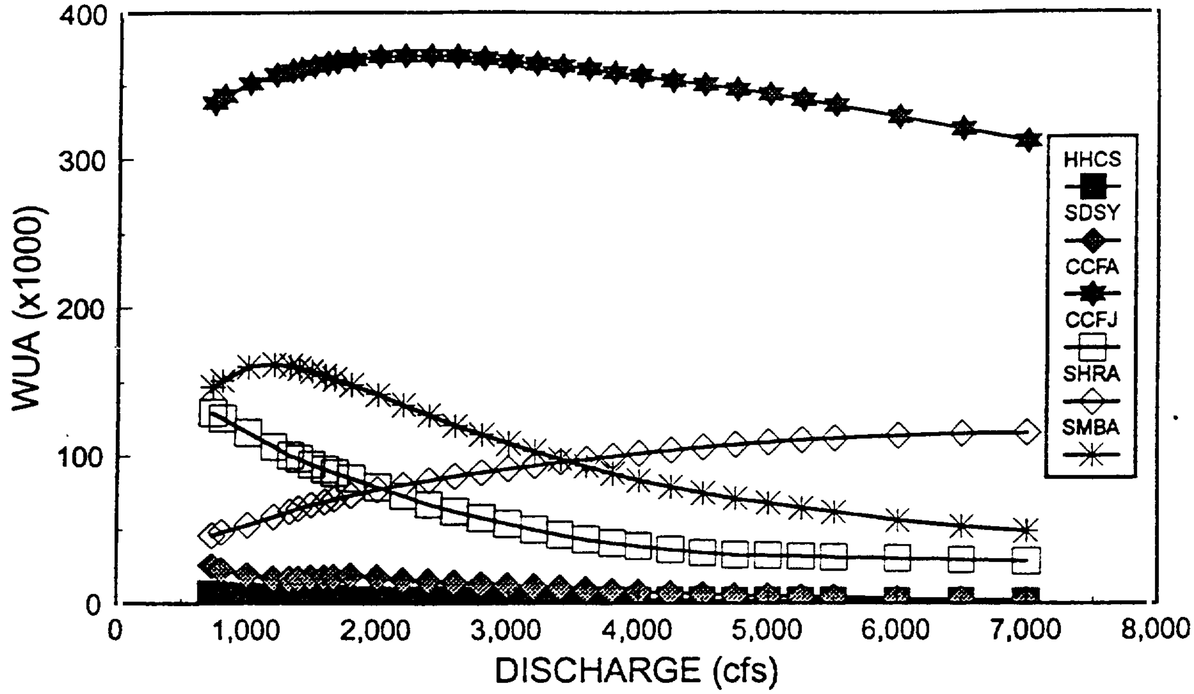

Figure 14a. Relations between weighted usable area (WUA) for fish and discharge at Franconia, MN, Lower St. Croix River.

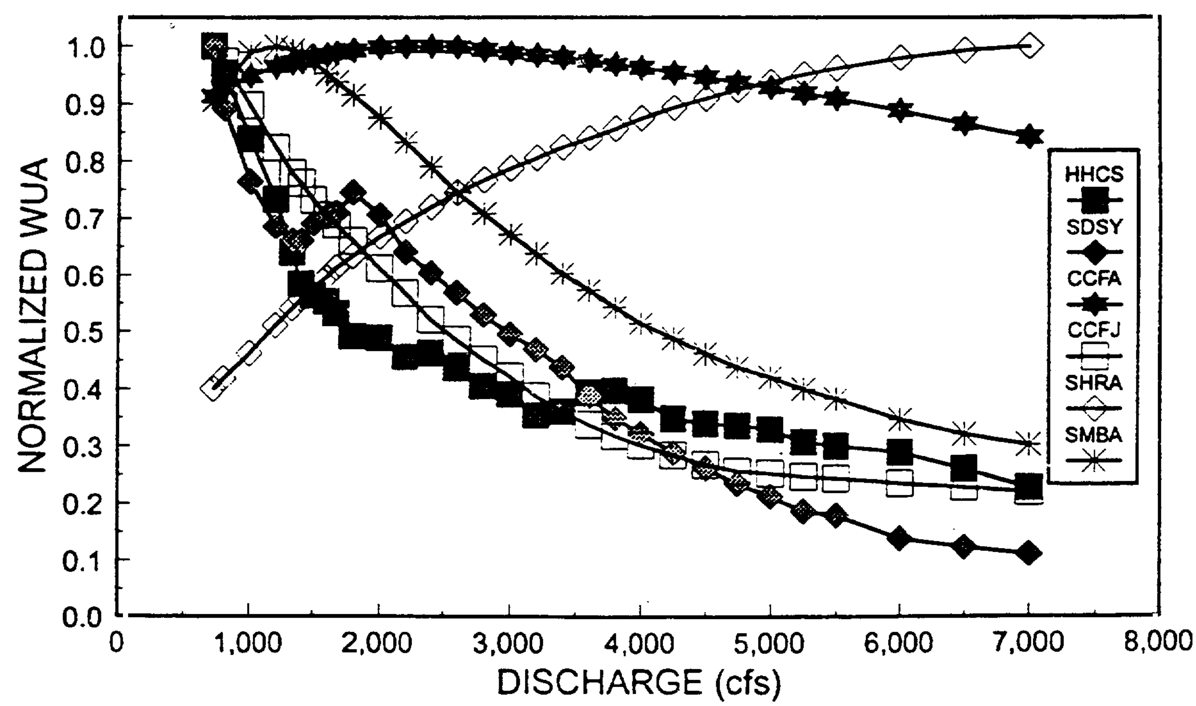

Figure 14b. Relations between normalized weighted usable area (WUA) for fish and discharge at Franconia, MN, Lower St. Croix River.

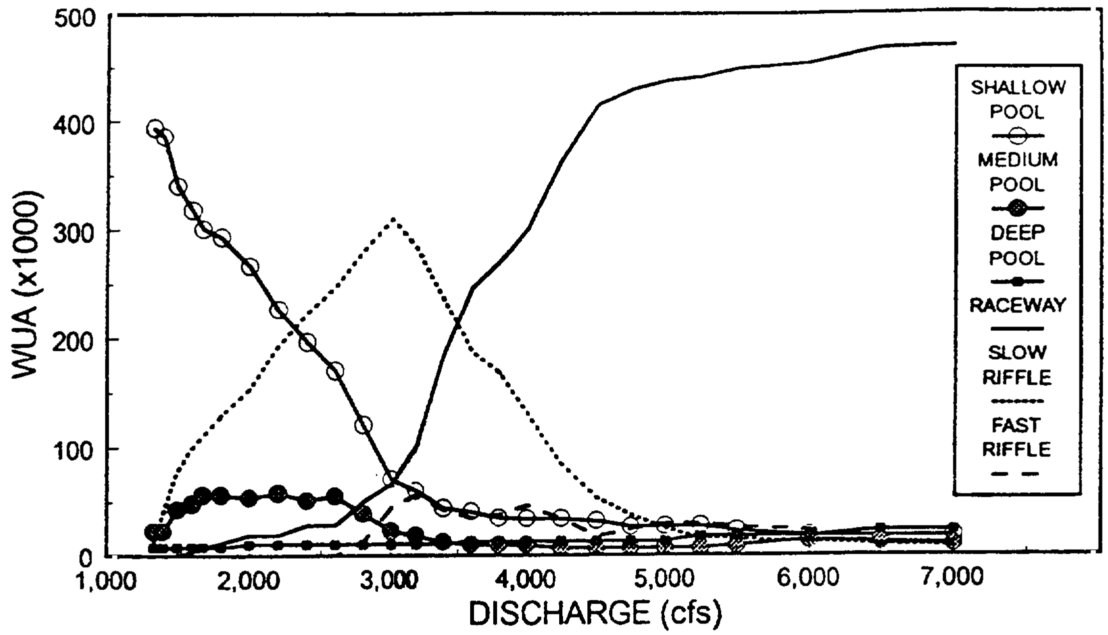

Figure 15a. Relations between weighted usable area (WUA) for habitat types and discharge in the east channel at Interstate State Park, Lower St. Croix River, MN and WI.

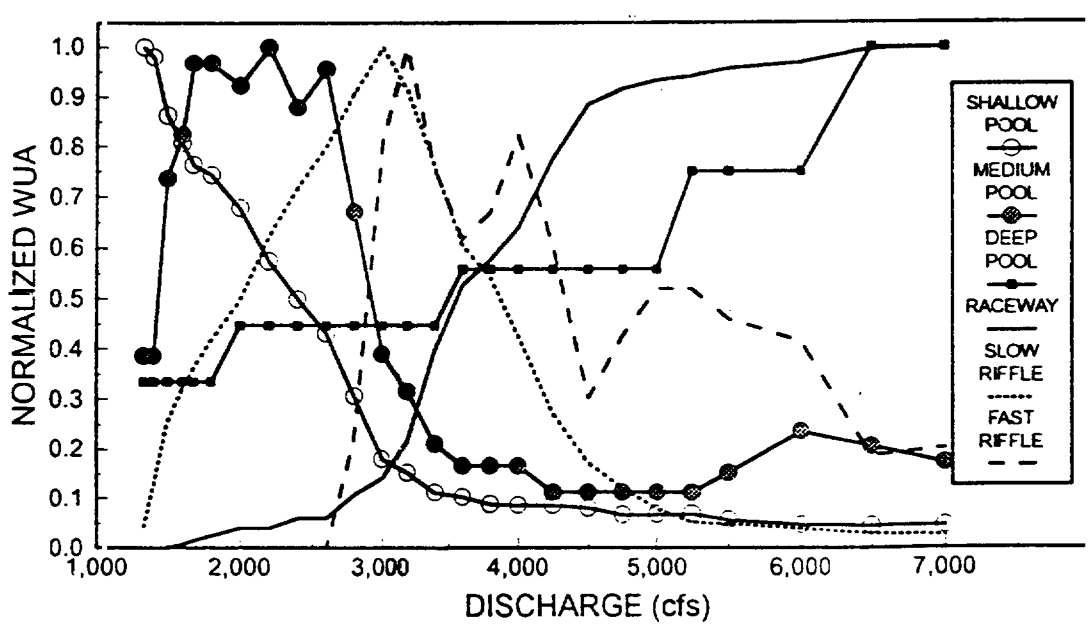

Figure 15b. Relations between normalized weighted usable area (WUA) for habitat types and discharge in the east channel at Interstate State Park, Lower St. Croix River, MN and WI.

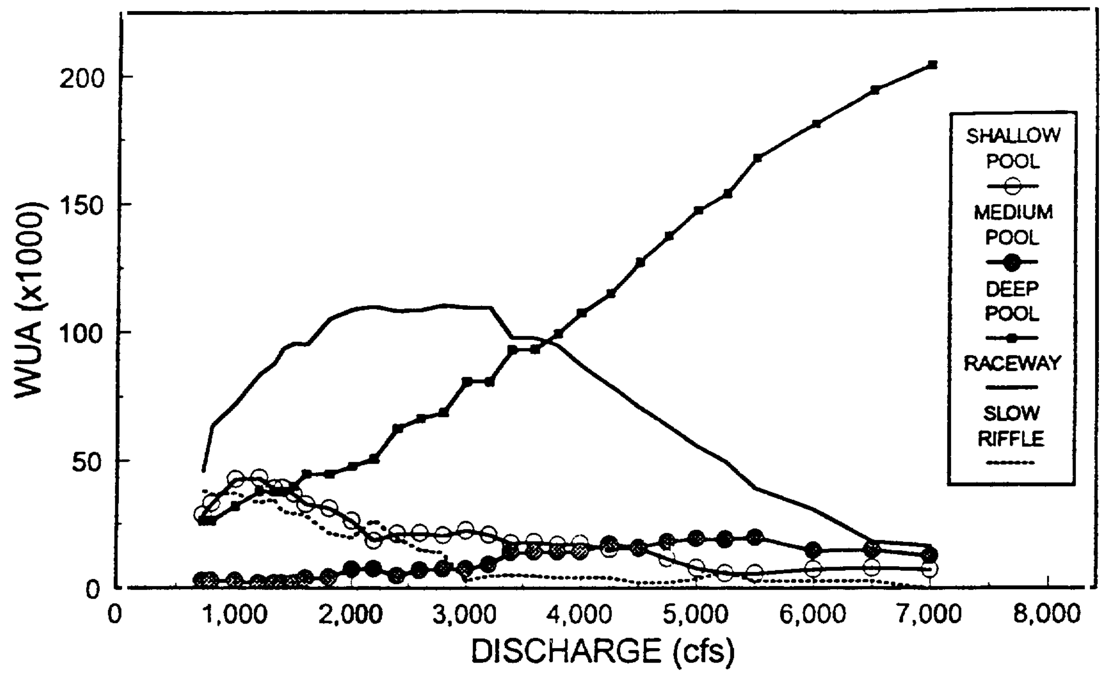

Figure 16a. Relations between weighted usable area (WUA) for habitat types and discharge in the navigation channel at Interstate State Park, Lower St. Croix River, MN and WI.

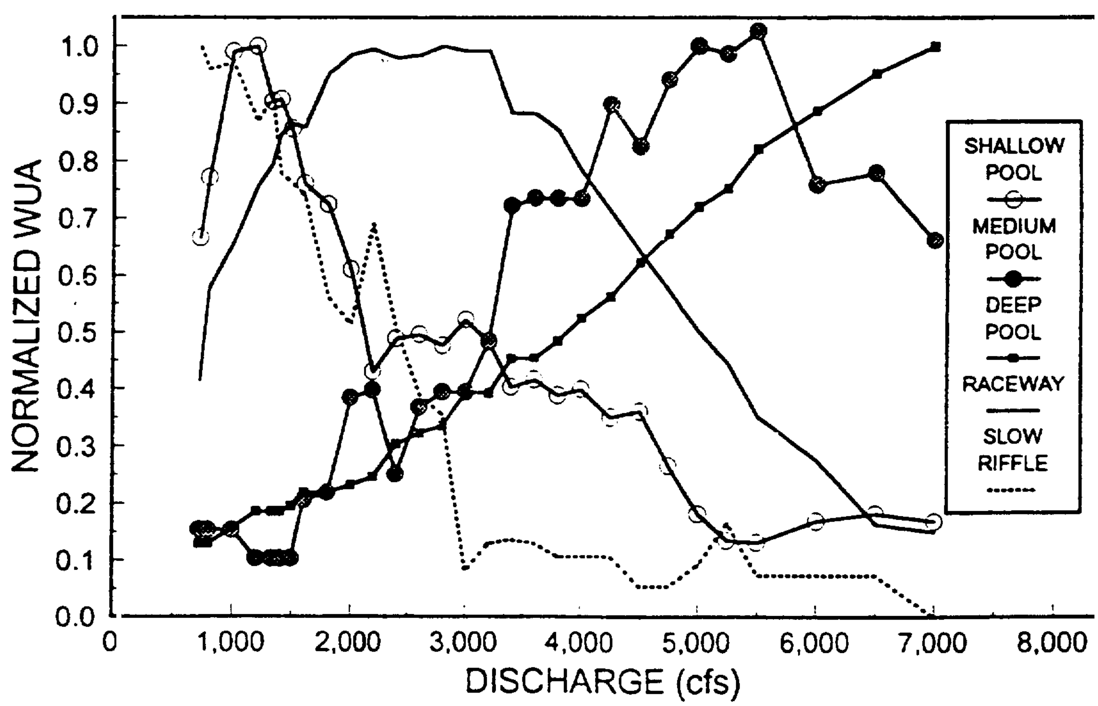

Figure 16b. Relations between normalized weighted usable area (WUA) for habitat types and discharge in the navigation channel at Interstate State Park, Lower St. Croix River, MN and WI.

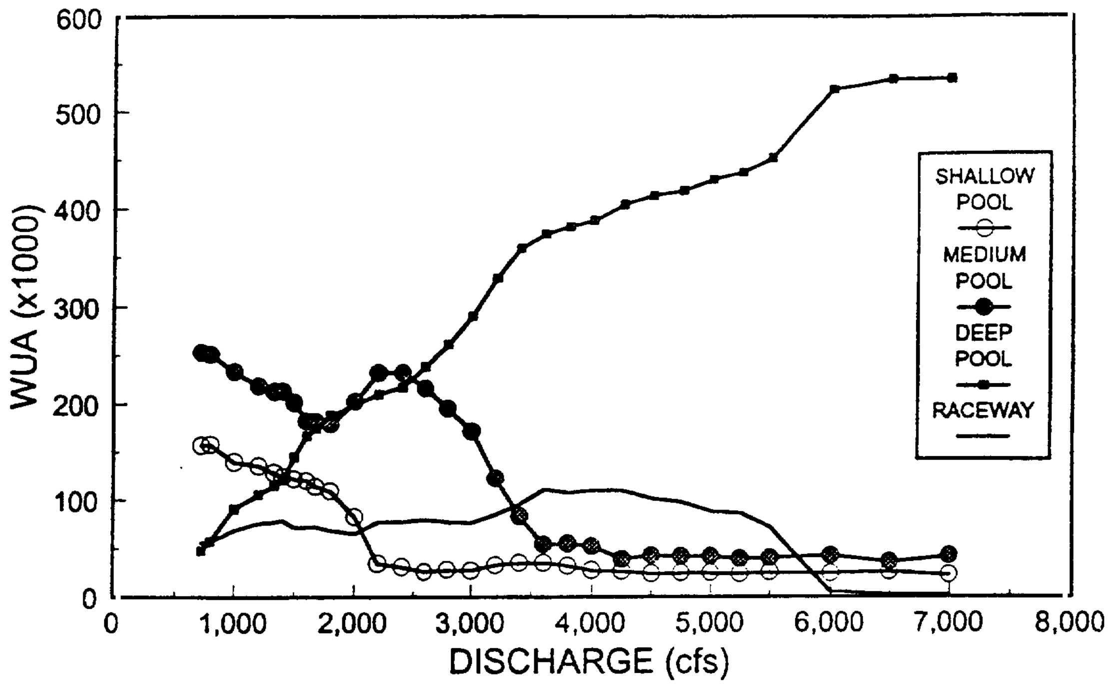

Figure 17a. Relations between weighted usable area (WUA) for habitat types and discharge in the main channel at Interstate State Park, Lower St. Croix River, MN and WI.

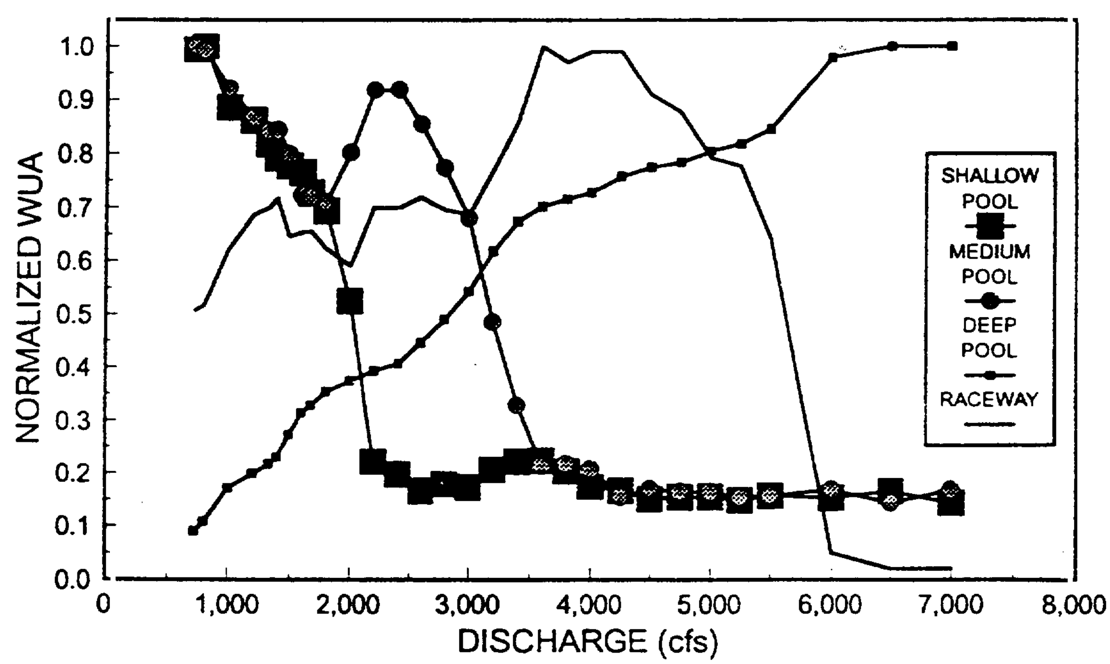

Figure 17b. Relations between normalized weighted usable area (WUA) for habitat types and discharge in the main channel at Interstate State Park, Lower St. Croix River, MN and WI.

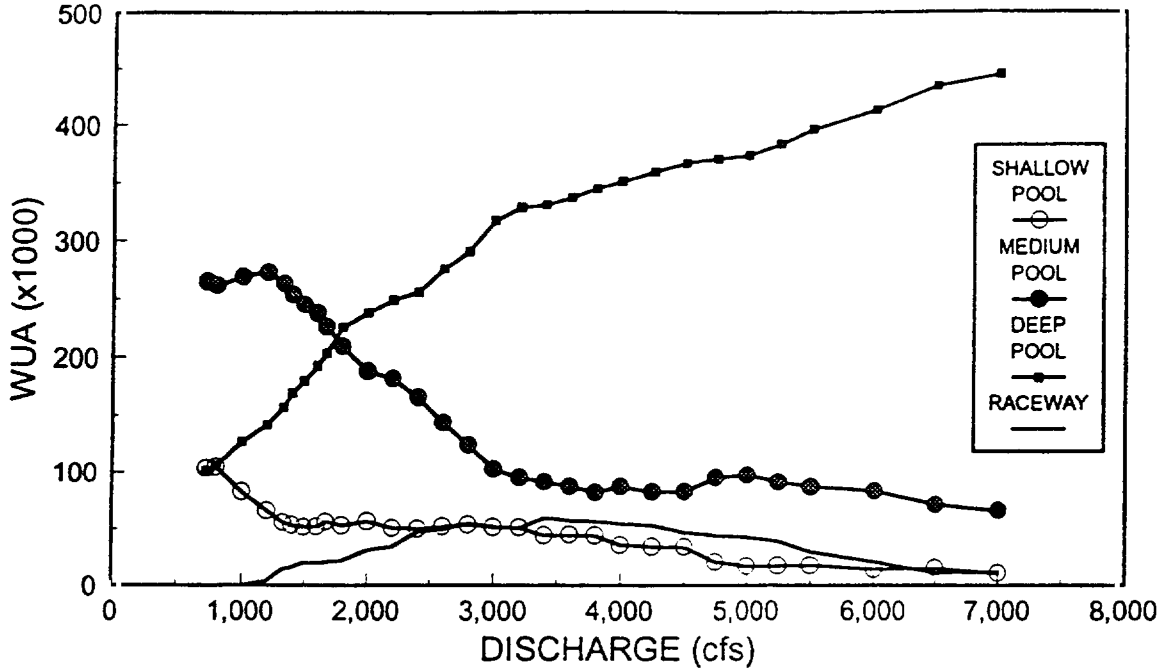

Figure 18a. Relations between weighted usable area (WUA) for habitat types and discharge at Franconia, MN, Lower St. Croix River.

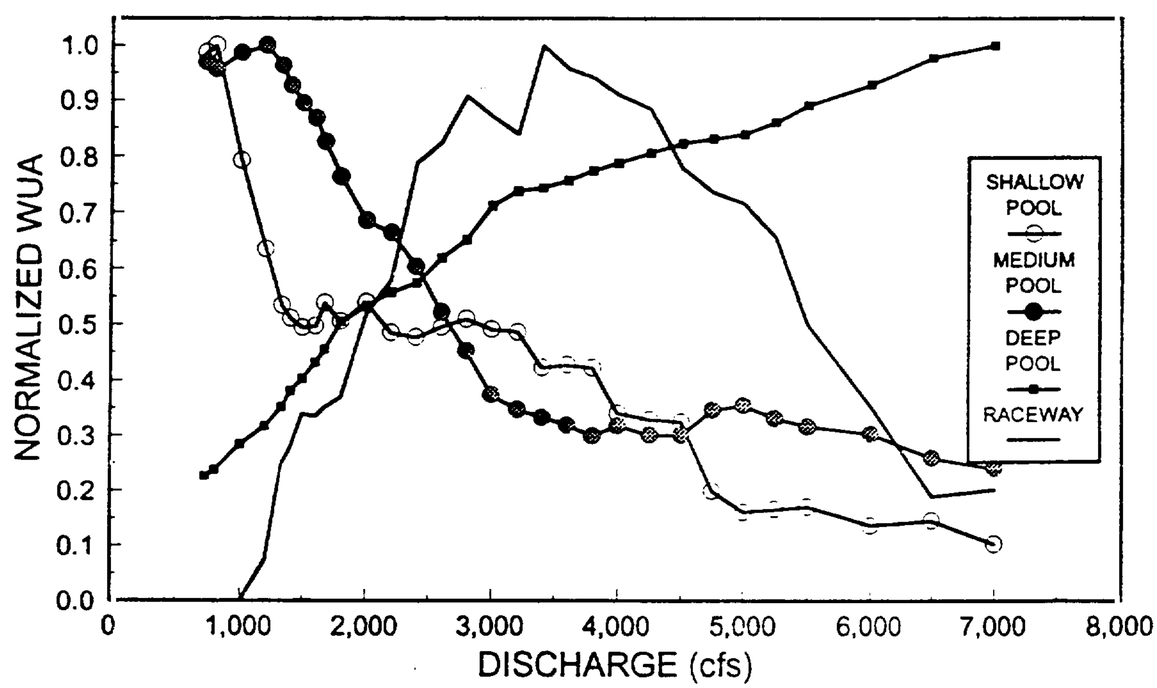

Figure 18b. Relations between normalized weighted usable area (WUA) for habitat types and discharge at Franconia, MN, Lower St. Croix River.

Appendix A. Discharge in the east and navigation channels in relation to discharge in the main channel (total discharge) at Interstate State Park, Lower St. Croix River, MN and WI. Discharges in the east and navigation channels were predicted using a regression equation developed from measured (observed values) discharges in the main and east channels.

Observed values

Total Q	East Q
1000	10
1824	357
3356	1400

Regression Output:

Constant		-650.027
Std Err of Y Est		111.9399
R Squared		0.98803
No. of Observations		3
Degrees of Freedom		1
X Coefficient(s)	0.601469	
Std Err of Coef.	0.066204	

Regression equation

East Q = Total Q(.601469)-650.027

MAIN CHANNEL Q	EAST CHANNEL Q	NAVIGATION CHANNEL Q
725	0	725
800	0	800
1000	10	990
1200	72	1128
1330	150	1180
1400	192	1208
1496	250	1246
1600	312	1288
1800	433	1367
2000	553	1447
2200	673	1527
2400	793	1607
2600	914	1686
2800	1034	1766
3000	1154	1846
3200	1275	1925
3400	1395	2005
3600	1515	2085
3800	1636	2164
4000	1756	2244
4250	1906	2344
4500	2057	2443
4750	2207	2543
5000	2357	2643
5250	2508	2742
5500	2658	2842
5750	2808	2942
6000	2959	3041
6250	3109	3141
6500	3260	3240
6750	3410	3340
7000	3560	3440

Appendix B. Macroinvertebrate habitat suitability criteria.

Substrate	Suitability
organic detritus	0
silt	0
sand	0.1
gravel	1
cobble	1
rubble	0.5
small boulder	0.1
large boulder	0.1
bedrock	0

Velocity (ft/s)	Suitability
0	0
0.2	0
2.5	1
5	0.05
10	0.02
100	0

Depth (ft)	Suitability
0	0
0.25	0
1	1
5	0.1
10	0.04
100	0

Appendix C1. PHABSIM input file for the east channel at Interstate State Park, Lower St. Croix River. File includes range of simulated discharges (QARD lines) and predicted water surface elevations (WSL lines) used in velocity simulation and habitat modeling.

```
IOC       1110100100001 0001
QARD 150.0
QARD 192.0
QARD 250.0
QARD 312.0
QARD 357.0
QARD 433.0
QARD 553.0
QARD 673.0
QARD 793.0
QARD 914.0
QARD1034.0
QARD1154.0
QARD1275.0
QARD1395.0
QARD1515.0
QARD1636.0
QARD1756.0
QARD1906.0
QARD2057.0
QARD2207.0
QARD2357.0
QARD2508.0
QARD2658.0
QARD2959.0
QARD3260.0
QARD3560.0
XSEC    1.0        0.01.00      89.80     .00029
        1.0  0.097.21  1.898.05  2.795.63  5.794.25  6.0 94.3  7.0 93.2
        1.0 10.0 92.1 20.0 89.8 30.0 90.2 40.0 90.5 50.0 91.0 60.0 91.3
        1.0 70.0 91.2 80.0 91.0 90.0 90.9100.0 91.0110.0 91.1120.0 91.3
        1.0130.0 91.4140.0 91.5150.0 91.8160.0 91.9170.0 92.2180.0 92.4
        1.0190.0 92.5200.0 92.7210.0 92.6220.0 92.6230.0 92.7240.0 92.7
        1.0250.0 92.8260.0 92.7270.0 92.7280.0 92.7290.0 92.7300.0 92.7
        1.0310.0 92.7320.0 92.6330.0 92.7340.0 92.6350.0 92.5360.0 92.5
        1.0370.0 92.5380.0 92.4390.0 92.4400.0 92.4410.0 92.5420.0 92.5
        1.0430.0 92.4440.0 92.3450.0 92.3460.0 92.4470.0 92.4480.0 92.3
        1.0490.0 92.4500.0 92.2510.0 92.3520.0 92.5530.0 92.8535.6 93.4
        1.0536.6 93.6538.3 94.3538.594.12543.795.99544.597.46545.698.74
        1.0547.297.68548.6100.3552.0102.5
NS      1.0       8.50       8.50       8.50       7.50       8.50       3.50
NS      1.0       3.50       3.10       3.10       3.40       4.10       4.40
NS      1.0       4.10       5.10       4.10       4.10       4.10       4.10
NS      1.0       5.10       5.10       4.10       5.10       5.10       4.10
NS      1.0       4.10       4.10       4.10       4.10       4.10       4.10
NS      1.0       4.10       4.10       4.10       4.10       4.10       4.10
NS      1.0       4.10       4.10       4.10       4.10       4.10       4.10
NS      1.0       4.10       4.10       4.10       4.10       4.10       4.10
NS      1.0       4.30       4.30       4.30       4.30       4.10       4.10
NS      1.0       4.10       4.10       4.10       4.10       3.10       3.10
NS      1.0       3.10       3.10       3.10       3.50       1.50       1.50
NS      1.0       1.50       1.50       1.30
WSL     1.0      92.76      92.89      93.03      93.15      93.23      93.35
WSL     1.0      93.51      93.66      93.78      93.90      94.01      94.10
WSL     1.0      94.20      94.29      94.37      94.45      94.53      94.62
WSL     1.0      94.70      94.79      94.87      94.94      95.02      95.16
WSL     1.0      95.29      95.41
CAL1    1.0      94.29    1400.00
VEL1    1.0                          0.00 .001 .3271.3121.7161.5541.2761.138
```

Appendix C1 cont.

```
VEL1    1.01.058 .966 .918 .9921.0131.1651.044  .96 1.10 1.161.1381.091
VEL1    1.01.132 1.191.152 1.171.127 .9861.1491.0861.021 .953  .98 .955
VEL1    1.0 .9281.1241.0091.091 .9531.1351.1211.1351.0561.0181.0911.091
VEL1    1.01.0831.056 1.131.2351.2791.3951.3951.6331.4721.497 .748 .126
VEL1    1.0  .12 0.00
CAL2    1.0     93.24    357.3
VEL2    1.0
VEL2    1.0
VEL2    1.0
VEL2    1.0
VEL2    1.0
VEL2    1.0
XSEC 566.4     406.38 .50      89.80     .00070
     566.4  0.0100.4  2.099.36  2.2 98.5  2.797.85  9.296.01 12.894.45
     566.4 15.093.95 19.093.35 20.093.35 30.093.25 40.092.95 50.092.85
     566.4 60.092.85 70.092.75 80.092.75 90.092.75100.092.55110.092.35
     566.4120.092.55130.092.55140.092.55150.092.55160.092.45170.092.45
     566.4180.092.35190.092.35200.092.35210.092.45220.092.45230.092.55
     566.4240.092.65250.092.95261.093.25270.093.45280.093.95285.094.25
     566.4290.094.35300.094.25310.094.25320.094.25330.094.25340.094.15
     566.4350.093.85360.093.55372.093.45375.093.45380.093.35390.093.45
     566.4400.093.45410.093.45420.093.35430.093.15440.092.95450.092.95
     566.4460.092.85470.092.55480.092.15490.091.75500.091.45510.091.25
     566.4520.091.05530.090.65540.088.45550.087.25560.087.05570.087.95
     566.4580.089.45585.091.65590.092.55594.093.85597.294.45601.595.26
     566.4606.196.74606.997.39609.8 98.4
NS   566.4       3.30      3.30      3.30      3.30      3.30      3.10
NS   566.4       3.50      3.50      4.50      4.10      4.10      4.10
NS   566.4       4.10      4.10      4.10      4.10      4.10      4.10
NS   566.4       4.10      4.10      4.10      4.10      4.10      4.10
NS   566.4       4.10      4.10      4.10      4.10      4.10      4.10
NS   566.4       4.10      4.10      4.10      3.10      4.10      4.10
NS   566.4       4.10      4.10      4.10      4.10      4.10      4.10
NS   566.4       4.10      4.10      4.10      4.10      4.10      4.10
NS   566.4       4.10      4.10      4.10      4.10      4.10      4.10
NS   566.4       4.10      4.10      4.10      4.10      4.10      4.10
NS   566.4       3.10      3.10      3.10      3.10      3.10      3.10
NS   566.4       3.10      5.40      6.10      6.10      6.10      3.30
NS   566.4       3.50      3.30      3.30
WSL  566.4      92.84     92.98     93.13     93.26     93.36     93.48
WSL  566.4      93.65     93.80     93.93     94.05     94.16     94.26
WSL  566.4      94.36     94.45     94.53     94.61     94.69     94.79
WSL  566.4      94.87     94.96     95.04     95.11     95.19     95.33
WSL  566.4      95.47     95.59
CAL1 566.4      94.45   1400.00
VEL1 566.4                          0.00 .8711.2761.351 1.701.7372.025
VEL1 566.42.3652.0542.1352.0842.3382.2032.359 2.232.1432.1212.108 2.20
VEL1 566.42.1082.2432.1252.1512.0221.837 1.86 1.76 .946 .294 .081 0.00
VEL1 566.4  .10 .556 .291 .628 .946 .6171.6282.1032.5012.6622.689 2.50
VEL1 566.41.719 1.34 .914 .889 .7371.1271.162 1.461.6371.7691.8061.499
VEL1 566.4 .735 .145 .125 .151 .064 .196 .196 .279 .163 .132 0.00
VEL1 566.4
CAL2 566.4      93.36    357.3
VEL2 566.4
VEL2 566.4
VEL2 566.4
VEL2 566.4
VEL2 566.4
VEL2 566.4
VEL2 566.4
XSEC 763.0      196.6 .25      92.50     .00154
     763.0  0.0100.2  1.399.51  1.598.28  3.597.33  8.595.96 10.495.39
```

Appendix C1 cont.

```
     763.0 12.8 94.7 15.593.66 20.0 93.3 30.093.06 40.092.76 50.092.66
     763.0 60.0 92.6 70.0 92.7 80.0 92.6 90.0 92.7100.0 92.6110.0 92.5
     763.0120.0 92.6130.0 92.7140.0 92.5150.0 92.6160.0 92.7170.0 92.7
     763.0180.0 92.6190.0 92.5200.0 92.6210.0 92.7220.0 92.8225.0 92.9
     763.0230.0 93.1235.0 93.5240.0 93.4245.0 93.4250.0 93.5260.0 93.5
     763.0265.0 93.4270.0 93.3280.0 93.2290.0 93.0300.0 93.1310.0 93.0
     763.0320.0 92.8330.0 92.7340.0 92.7350.0 92.7360.0 92.7370.0 92.7
     763.0380.0 92.7390.0 92.7400.0 92.7410.0 92.8420.0 93.0430.0 93.1
     763.0440.0 93.1450.0 93.1460.0 93.2470.0 93.0480.0 93.1485.0 93.2
     763.0487.5 93.3492.0 94.3496.3 94.7504.3 95.0
NS   763.0       3.30      3.30      3.30      3.30      3.30      3.50
NS   763.0       8.50      3.50      3.10      3.10      4.10      4.10
NS   763.0       4.10      4.10      4.10      4.10      4.10      4.10
NS   763.0       4.10      4.10      4.10      4.10      4.10      4.10
NS   763.0       4.10      4.10      4.10      4.10      4.10      4.10
NS   763.0       4.10      4.10      4.10      4.10      4.10      4.10
NS   763.0       4.10      4.10      4.10      4.50      4.10      3.10
NS   763.0       3.10      4.10      4.10      4.10      4.10      3.10
NS   763.0       4.10      4.10      4.10      4.10      4.30      4.10
NS   763.0       4.10      4.10      4.10      4.10      4.50      4.80
NS   763.0       6.80      8.50      8.50      3.50
WSL  763.0      93.31     93.39     93.50     93.59     93.66     93.76
WSL  763.0      93.90     94.03     94.15     94.26     94.37     94.47
WSL  763.0      94.57     94.66     94.75     94.83     94.91     95.01
WSL  763.0      95.11     95.20     95.29     95.38     95.46     95.63
WSL  763.0      95.79     95.94
CAL1 763.0      94.66   1400.00
VEL1 763.0                                  0.00 .069 .5261.3441.6181.559
VEL1 763.01.6471.6641.6591.9631.7151.6511.8281.8921.8462.0572.0441.954
VEL1 763.01.8241.9411.928 1.761.6471.7741.6731.4361.5181.3441.4461.483
VEL1 763.01.1431.3341.2171.1791.3571.3571.2691.2691.4221.2861.4671.385
VEL1 763.0 1.161.217 1.471.4091.5921.7641.7371.865 2.172.121 2.001.443
VEL1 763.0 1.01 .144 0.00
CAL2 763.0      93.66     357.3
VEL2 763.0
VEL2 763.0
VEL2 763.0
VEL2 763.0
VEL2 763.0
VEL2 763.0
ENDJ
```

Appendix C2. PHABSIM input file for the navigation channel at Interstate State Park, Lower St. Croix River. File includes range of simulated discharges (QARD lines) and predicted water surface elevations (WSL lines) used in velocity simulation and habitat modeling.

```
IOC       1110100100001000100000000000000
QARD 725.0
QARD 800.0
QARD 990.0
QARD  1128
QARD  1180
QARD  1208
QARD  1246
QARD  1288
QARD  1317
QARD  1367
QARD  1447
QARD  1527
QARD  1607
QARD  1686
QARD  1766
QARD  1846
QARD  1925
QARD  2005
QARD  2085
QARD  2164
QARD  2244
QARD  2344
QARD  2443
QARD  2543
QARD  2643
QARD  2742
QARD  2842
QARD  3041
QARD  3240
QARD  3440
XSEC   1.0       0.0 .78      87.70     .00003
       1.0  0.0106.0  2.3105.5  7.0 98.5 13.2 95.8 18.0 94.5 21.5 93.9
       1.0 25.0 93.1 30.0 92.5 35.0 91.9 40.0 91.4 50.0 91.0 60.0 91.0
       1.0 70.0 90.2 80.0 89.5 90.0 89.0100.0 88.4105.0 88.2110.0 87.5
       1.0115.0 87.4120.0 87.1125.0 86.8130.0 86.4135.0 85.7140.0 86.0
       1.0145.0 86.0150.0 85.4155.0 86.1160.0 86.0165.0 85.4170.0 85.4
       1.0175.0 86.3180.0 90.5185.0 91.9190.0 93.0194.0 93.4195.0 93.5
       1.0200.0 94.0202.5 94.5206.0 96.1209.0 97.1216.0 98.0
NS     1.0       1.3       1.3       3.3       3.1       3.1      3.10
NS     1.0      3.10      3.10      3.10      3.10      3.10      3.10
NS     1.0      3.10      3.10      3.10      3.10      3.10      3.10
NS     1.0      3.10      3.10      3.50      3.10      3.10      3.10
NS     1.0      3.10      3.10      3.50      4.10      4.10      4.10
NS     1.0      6.50      6.10      7.50      8.50      9.50       9.1
NS     1.0       9.5       9.5       9.1       9.1       1.3
WSL    1.0     91.19     91.42     91.99     92.38     92.53     92.60
WSL    1.0     92.70     92.82     92.89     93.02     93.23     93.43
WSL    1.0     93.63     93.82     94.01     94.20     94.39     94.57
WSL    1.0     94.75     94.92     95.09     95.30     95.50     95.70
WSL    1.0     95.90     96.09     96.29     96.66     97.02     97.38
CAL1   1.0    94.460   1956.00   1709.00
VEL1   1.0                      0.00 0.75 1.05 1.17 1.41 1.38 1.45 1.59
VEL1   1.0 1.58 1.99 2.11 2.07 2.14 1.82 2.04 2.09 2.18 2.00 1.78 2.02
VEL1   1.0 2.01 1.87 1.73 1.52 1.34 1.87 1.13 0.95 1.04 0.32 0.30 0.33
VEL1   1.0 0.39 0.00
CAL2   1.0    93.280   1467.00   1315.00
VEL2   1.0
VEL2   1.0
```

Appendix C2 cont.

```
VEL2   1.0
VEL2   1.0
XSEC   2.0     811.0 .90     87.27    .00050
       2.0   0.0100.4   1.0100.2   1.7 98.7   4.4 96.7   6.5 94.5 15.5 93.1
       2.0 20.0 92.1 25.0 91.4 30.0 90.5 35.0 90.5 45.0 90.3 55.0 90.5
       2.0 65.0 91.3 75.0 91.7 85.0 92.0 95.0 92.2105.0 92.3115.0 92.0
       2.0125.0 91.3135.0 90.7145.0 90.4155.0 89.8165.0 91.2175.0 90.4
       2.0185.0 88.7195.0 88.7205.0 90.4215.0 89.8225.0 89.3235.0 89.2
       2.0240.0 89.2245.0 89.0250.0 88.9255.0 88.5260.0 87.3265.0 88.3
       2.0270.0 89.5275.0 91.5279.0 93.4281.0 93.4285.0 94.1287.5 94.5
       2.0290.1 96.0300.1100.9
NS     2.0       1.3       1.3       1.3       1.5       2.5       3.50
NS     2.0      3.50      3.40      4.40      4.10      4.10       4.10
NS     2.0      4.40      4.10      4.10      4.10      4.10       3.10
NS     2.0      4.10      3.10      3.10      4.40      4.10       4.10
NS     2.0      3.10      4.10      4.10      4.10      4.10       4.10
NS     2.0      4.10      4.10      4.10      4.10      4.10       7.50
NS     2.0      6.50      6.50      4.50      4.10       4.1        4.1
NS     2.0       9.4       9.4
WSL    2.0     91.30     91.54     92.11     92.49     92.63     92.70
WSL    2.0     92.80     92.91     92.99     93.11     93.31     93.50
WSL    2.0     93.69     93.88     94.06     94.24     94.41     94.58
WSL    2.0     94.76     94.96     95.12     95.36     95.57     95.78
WSL    2.0     96.02     96.25     96.46     96.89     97.33     97.80
CAL1   2.0    94.480    1956.00   2069.00
VEL1   2.0                       0.00 0.32 0.27 0.31 1.01 1.57 1.53 1.59
VEL1   2.0 1.62 1.45 1.23 1.23 1.34 1.34 1.39 1.30 1.46 1.83 2.07 2.03
VEL1   2.0 1.65 1.71 2.22 2.66 2.91 3.21 3.20 3.19 3.42 3.10 2.49 1.32
VEL1   2.0 0.94 0.27 0.25 0.43 0.18 0.00
CAL2   2.0    93.360    1467.00   1384.00
VEL2   2.0
VEL2   2.0
VEL2   2.0
VEL2   2.0
XSEC   3.0     275.0 .50     89.08    .00098
       3.0  0.0 96.1  9.1 95.6 13.5 94.8 21.0 93.6 22.0 93.4 25.0 93.1
       3.0 35.0 93.0 45.0 92.9 55.0 91.8 65.0 91.5 75.0 91.2 85.0 90.9
       3.0 88.0 91.2 95.0 91.6105.0 91.4115.0 91.8120.0 92.1130.0 92.3
       3.0140.0 92.4150.0 92.3160.0 92.1170.0 91.4180.0 91.4190.0 91.9
       3.0196.0 93.3203.0 91.9208.0 92.0215.0 92.0225.0 92.3235.0 91.0
       3.0245.0 90.8255.0 90.0265.0 89.6275.0 89.1285.0 89.6295.0 90.0
       3.0305.0 90.1315.0 90.3325.0 91.0330.0 92.0340.3 94.6340.7 94.9
       3.0341.6 94.0342.7 95.4344.2 95.3345.8 95.8347.1 98.2348.3 97.2
       3.0350.1 97.5
NS     3.0       6.5       6.5      6.50      3.10      3.10       3.10
NS     3.0      3.10      3.10      4.10      4.10      4.10       4.10
NS     3.0      4.50      4.40      4.10      4.10      4.10       4.10
NS     3.0      3.10      3.10      3.50      3.10      3.10       3.10
NS     3.0      6.50      6.50      6.50      7.50      4.50       6.50
NS     3.0      6.50      7.50      7.50      7.50      7.50       7.50
NS     3.0      7.50      7.50      8.50      8.50      8.50       8.50
NS     3.0      8.50      8.50      8.50      8.50      8.50       8.50
NS     3.0      8.50
WSL    3.0     91.92     92.12     92.61     92.94     93.07     93.13
WSL    3.0     93.22     93.32     93.38     93.50     93.68     93.85
WSL    3.0     94.02     94.19     94.36     94.53     94.69     94.85
WSL    3.0     95.01     95.19     95.34     95.55     95.76     95.99
WSL    3.0     96.18     96.39     96.60     97.06     97.46     97.89
CAL1   3.0    94.750    1956.00   2091.00
VEL1   3.0            0.00 0.14 0.17 0.44 0.97 1.09 1.37 1.68 1.76 1.77
VEL1   3.0 1.80 1.76 1.59 1.67 1.37 0.97 0.63 0.56 0.57 0.86 0.96 0.95
VEL1   3.0 1.11 1.06 0.96 1.56 2.06 2.70 2.82 2.98 3.30 3.04 3.18 3.08
```

Appendix C2 cont.

```
VEL1    3.0 3.00 2.66 2.00 1.50 0.00
VEL1    3.0
CAL2    3.0    93.720    1467.00    1701.00
VEL2    3.0
VEL2    3.0
VEL2    3.0
VEL2    3.0
VEL2    3.0
ENDJ
```

Appendix C3. PHABSIM input file for the main channel at Interstate State Park, Lower St. Croix River. File includes range of simulated discharges (QARD lines) and predicted water surface elevations (WSL lines) used in velocity simulation and habitat modeling.

```
IOC       1111100100001000100000000000000
QARD 725.0
QARD 800.0
QARD  1000
QARD  1200
QARD  1330
QARD  1400
QARD  1496
QARD  1600
QARD  1674
QARD  1800
QARD  2000
QARD  2200
QARD  2400
QARD  2600
QARD  2800
QARD  3000
QARD  3200
QARD  3400
QARD  3600
QARD  3800
QARD  4000
QARD  4250
QARD  4500
QARD  4750
QARD  5000
QARD  5250
QARD  5500
QARD  6000
QARD  6500
QARD  7000
XSEC  1.0       0.0 .50      87.70     .00025
      1.0  0.0 97.2  2.0 96.5  2.7 94.9  4.7 94.5  5.0 93.9  7.5 93.3
      1.0 10.0 92.0 15.0 90.6 25.0 90.4 35.0 89.5 45.0 89.6 55.0 89.1
      1.0 65.0 88.3 75.0 88.0 85.0 88.0 95.0 88.0105.0 88.3115.0 88.7
      1.0125.0 89.5135.0 89.8145.0 89.7155.0 89.5165.0 89.7175.0 89.3
      1.0185.0 90.0195.0 90.2205.0 89.9210.0 89.7215.0 89.6220.0 90.2
      1.0225.0 89.9230.0 89.2235.0 89.2240.0 89.3245.0 89.3250.0 89.4
      1.0255.0 89.3260.0 89.3265.0 89.4270.0 89.4275.0 89.2280.0 89.3
      1.0285.0 89.2290.0 89.1295.0 88.9300.0 88.9305.0 88.7310.0 88.6
      1.0315.0 88.5320.0 88.4325.0 88.3330.0 88.1340.0 87.7350.0 87.8
      1.0360.0 87.9370.0 88.0380.0 88.2390.0 88.3400.0 88.4410.0 89.0
      1.0420.0 92.2430.0 93.6435.0 94.0437.0 94.2441.8 94.4451.8 94.5
      1.0461.8 94.5471.8 95.1481.8 96.2491.8 96.3501.8 96.3511.8 96.3
      1.0521.8 95.9531.8 96.5541.8 96.8551.8 97.1561.8 97.6571.8 98.1
      1.0581.8 99.2
NS    1.0      3.3       3.3       3.3       3.1       2.1       2.10
NS    1.0     3.40      3.40      3.10      3.40      3.10       3.10
NS    1.0     4.10      4.40      4.40      4.40      4.40       4.40
NS    1.0     4.40      4.10      4.10      4.10      4.10       4.10
NS    1.0     4.40      4.10      4.10      4.10      4.10       4.10
NS    1.0     4.10      4.40      4.10      4.10      4.10       4.10
NS    1.0     4.10      4.10      4.10      4.10      4.10       4.10
NS    1.0     3.10      4.10      4.10      4.10      4.10       4.10
NS    1.0     4.10      4.10      4.40      4.10      4.10       4.10
NS    1.0     4.10      4.10      4.10      4.10      4.10       4.10
NS    1.0     4.10      4.10      4.10      4.10       4.1        4.1
NS    1.0      4.1       4.1       4.1       4.1       4.1        4.1
NS    1.0      4.1       4.1       3.4       3.1       4.3        1.3
```

Appendix C3 cont.

```
NS     1.0       1.3
WSL    1.0      91.60       91.74       92.07       92.37       92.55       92.65
WSL    1.0      92.77       92.90       92.99       93.14       93.36       93.58
WSL    1.0      93.78       93.97       94.16       94.34       94.51       94.68
WSL    1.0      94.84       94.99       95.14       95.33       95.50       95.67
WSL    1.0      95.84       96.00       96.16       96.46       96.74       97.01
CAL1   1.0     94.200     2845.00     2719.00
VEL1   1.0                            0.00 0.15 0.61 0.97 1.03 0.97 1.09 0.55
VEL1   1.0 1.32 0.75 0.68 0.48 0.74 0.90 1.15 1.14 1.10 0.88 1.00 0.76
VEL1   1.0 0.99 1.08 1.16 1.25 1.16 1.20 1.01 1.13 1.02 1.19 1.29 1.45
VEL1   1.0 1.40 1.51 1.54 1.57 1.71 1.85 1.73 1.85 1.85 1.93 2.05 1.92
VEL1   1.0 1.80 1.91 2.09 2.01 1.83 2.16 2.14 1.84 1.74 1.78 1.20 0.14
VEL1   1.0 0.00 0.00 0.00 0.00
VEL1   1.0
CAL2   1.0     93.150     1811.00     1880.00
VEL2   1.0
VEL2   1.0
VEL2   1.0
VEL2   1.0
VEL2   1.0
VEL2   1.0
VEL2   1.0
XSEC   2.0      321.0 .32       87.70      .00028
       2.0  0.0 98.4  0.7 98.0  1.7 96.9  9.1 94.3 11.3 93.7 15.0 92.2
       2.0 25.0 89.8 35.0 89.5 45.0 89.2 55.0 89.1 65.0 89.3 75.0 88.8
       2.0 85.0 89.2 95.0 89.6105.0 90.4115.0 90.6125.0 90.8135.0 91.2
       2.0145.0 91.3155.0 91.3165.0 91.4175.0 91.5185.0 91.5195.0 91.5
       2.0205.0 91.5215.0 91.6225.0 91.7235.0 91.7245.0 91.6255.0 91.5
       2.0265.0 91.5275.0 91.4285.0 91.5295.0 91.5305.0 91.5315.0 91.6
       2.0325.0 91.5335.0 91.5345.0 91.5355.0 91.3365.0 91.3375.0 91.0
       2.0385.0 90.8395.0 90.8405.0 90.6415.0 90.2425.0 90.0435.0 89.7
       2.0445.0 89.4455.0 89.2465.0 88.7475.0 88.0485.0 87.8490.0 87.7
       2.0495.0 88.1500.0 88.2505.0 88.3510.0 88.3515.0 88.6520.0 88.8
       2.0525.0 88.8530.0 89.0535.0 89.2540.0 89.3545.0 89.2550.0 89.1
       2.0555.0 89.3560.0 89.4565.0 89.5570.0 88.9575.0 89.3580.0 89.4
       2.0585.0 89.4595.0 90.0605.0 90.8615.0 91.6625.0 92.1635.0 92.8
       2.0645.0 93.2648.2 93.3655.0 93.5665.0 93.8671.8 94.3679.4 94.7
       2.0689.4 95.7699.4 97.2709.4 99.3709.6101.1710.6102.1
NS     2.0        1.3         1.3         1.1         3.1        3.10        3.10
NS     2.0       3.10        3.10        3.10        3.10        3.40        3.10
NS     2.0       3.40        3.10        3.40        4.10        4.10        4.10
NS     2.0       4.10        4.40        4.10        4.10        4.10        4.10
NS     2.0       4.10        4.10        4.10        4.10        4.10        4.10
NS     2.0       4.10        3.10        4.10        4.10        4.10        4.10
NS     2.0       4.40        4.10        4.10        4.10        4.10        4.10
NS     2.0       4.10        4.10        4.10        4.10        4.10        4.10
NS     2.0       4.10        4.10        4.10        4.10        4.10        4.10
NS     2.0       4.10        4.10        4.10        4.10        4.10        4.10
NS     2.0       4.10        4.10        4.10        4.10        4.10        4.10
NS     2.0       4.40        4.40        4.40        4.10        4.10        4.10
NS     2.0       3.10        4.10        4.10        4.10        5.10        6.10
NS     2.0       4.10        4.10         4.5         4.5         4.5         4.1
NS     2.0        4.1         4.1         8.5         8.5         8.5
WSL    2.0      91.64       91.78       92.11       92.42       92.60       92.70
WSL    2.0      92.82       92.95       93.05       93.20       93.42       93.64
WSL    2.0      93.85       94.05       94.24       94.42       94.60       94.78
WSL    2.0      94.94       95.10       95.26       95.45       95.63       95.80
WSL    2.0      95.97       96.14       96.31       96.62       96.91       97.20
CAL1   2.0     94.280     2845.00     2669.00
VEL1   2.0                       0.00 0.35 0.48 1.22 0.84 0.72 0.73 0.70 0.67
VEL1   2.0 0.73 0.76 0.98 0.95 1.13 1.02 0.88 0.92 0.91 0.93 0.54 0.80
VEL1   2.0 0.68 0.84 0.79 0.81 0.88 0.83 0.84 0.86 0.79 0.80 0.82 0.86
```

Appendix C3 cont.

```
VEL1   2.0 0.76 0.84 0.88 0.83 0.89 0.98 1.11 1.33 1.36 1.37 1.56 1.72
VEL1   2.0 1.99 1.84 1.94 1.68 1.96 1.84 1.91 1.73 1.97 2.02 1.95 1.77
VEL1   2.0 1.64 1.62 1.57 1.40 1.49 1.29 1.10 0.99 0.53 0.34 0.34 0.32
VEL1   2.0 0.33 0.54 0.40 0.39 0.32 0.28 0.24 0.22 0.07 0.15 0.00
VEL1   2.0
CAL2   2.0     93.180   1811.00    1741.00
VEL2   2.0
VEL2   2.0
VEL2   2.0
VEL2   2.0
VEL2   2.0
VEL2   2.0
VEL2   2.0
VEL2   2.0
XSEC   3.0      782.0 .50      89.02     .00029
       3.0  0.0 98.7  5.0 96.6  7.8 96.3  8.2 97.2  9.0 96.8 10.6 95.6
       3.0 10.7 95.2 13.1 94.7 15.0 94.4 25.0 93.1 35.0 91.8 45.0 90.1
       3.0 55.0 90.0 65.0 90.2 75.0 90.1 85.0 90.1 95.0 90.1105.0 90.1
       3.0115.0 90.1125.0 90.3135.0 90.5145.0 90.2155.0 90.1165.0 89.7
       3.0175.0 89.4185.0 89.0195.0 88.7205.0 88.5215.0 88.2225.0 88.0
       3.0235.0 87.7245.0 87.3255.0 87.1265.0 87.2275.0 87.4285.0 87.6
       3.0295.0 88.2305.0 88.7315.0 88.6325.0 88.7335.0 88.6345.0 88.5
       3.0355.0 88.6365.0 88.5375.0 88.2385.0 88.1395.0 87.8405.0 87.7
       3.0415.0 87.5425.0 87.6435.0 87.9445.0 88.2455.0 87.8465.0 87.7
       3.0475.0 87.6485.0 87.4495.0 87.4505.0 87.2515.0 87.8525.0 89.7
       3.0535.0 91.7540.1 93.2540.2 95.1541.5 95.3542.5 94.8543.2 94.8
       3.0544.0 95.4546.2 95.6546.5 96.3547.5 97.8
NS     3.0        3.3       3.3       3.5       8.5       8.5       8.5
NS     3.0        3.5      2.10      2.10      2.10      2.10      3.10
NS     3.0       3.40      3.10      3.10      3.10      4.10      4.10
NS     3.0       4.10      4.10      4.10      4.10      4.10      4.10
NS     3.0       4.10      4.10      4.10      4.10      4.10      4.10
NS     3.0       4.10      4.10      4.10      4.10      4.10      4.10
NS     3.0       4.10      4.10      4.10      4.10      4.10      4.10
NS     3.0       4.10      4.10      4.10      4.10      4.10      4.10
NS     3.0       4.10      4.10      4.10      3.10      4.10      4.10
NS     3.0       3.10      3.10      3.50      3.50      3.50      3.10
NS     3.0       9.50      9.50      8.50      8.50      8.50      8.50
NS     3.0       8.50      8.50      8.50      8.50
WSL    3.0      92.49     92.62     92.94     93.18     93.33     93.40
WSL    3.0      93.50     93.60     93.68     93.80     93.98     94.17
WSL    3.0      94.36     94.54     94.71     94.89     95.06     95.24
WSL    3.0      95.41     95.57     95.73     95.92     96.09     96.26
WSL    3.0      96.43     96.60     96.77     97.10     97.41     97.71
CAL1   3.0     94.750   2845.00   3148.00
VEL1   3.0                                     0.00 0.11 0.55 0.60 0.81
VEL1   3.0 0.83 0.74 0.77 0.83 0.79 0.79 0.75 0.94 0.90 0.80 0.88 0.92
VEL1   3.0 0.89 0.85 0.89 0.88 0.87 1.03 0.97 1.07 0.87 0.92 1.05 0.99
VEL1   3.0 1.09 1.06 0.95 1.12 0.97 1.09 1.29 1.21 1.13 1.29 1.29 1.13
VEL1   3.0 1.20 1.25 1.27 1.21 1.19 1.30 1.25 1.17 1.16 1.07 1.20 1.07
VEL1   3.0 0.66 0.12
CAL2   3.0     93.840   1811.00      0.00
VEL2   3.0
VEL2   3.0
VEL2   3.0
VEL2   3.0
VEL2   3.0
VEL2   3.0
ENDJ
```

Appendix C4. PHABSIM input file for the main channel at Franconia, Lower St. Croix River. File includes range of simulated discharges (QARD lines) and predicted water surface elevations (WSL lines) used in velocity simulation and habitat modeling.

```
IOC       0000100100001000100000000000000
QARD 725.0
QARD 800.0
QARD  1000
QARD  1200
QARD  1330
QARD  1400
QARD  1496
QARD  1600
QARD  1674
QARD  1800
QARD  2000
QARD  2200
QARD  2400
QARD  2600
QARD  2800
QARD  3000
QARD  3200
QARD  3400
QARD  3600
QARD  3800
QARD  4000
QARD  4250
QARD  4500
QARD  4750
QARD  5000
QARD  5250
QARD  5500
QARD  6000
QARD  6500
QARD  7000
XSEC   1.0       0.00.50     86.4700.00001100
       1.0  0.0 97.8  2.0 96.8  6.0 96.0 10.0 95.2 12.0 94.8 15.0 94.5
       1.0 25.0 93.5 35.0 93.2 45.0 92.9 55.0 92.6 65.0 92.4 75.0 92.0
       1.0 85.0 91.8 95.0 91.5105.0 91.3115.0 90.7125.0 90.5135.0 91.3
       1.0145.0 90.1155.0 89.8165.0 89.7175.0 89.4185.0 89.5195.0 89.5
       1.0205.0 89.0210.0 88.8215.0 88.8220.0 89.0225.0 89.4230.0 89.2
       1.0235.0 89.1240.0 88.9245.0 88.9250.0 88.7260.0 88.8270.0 88.9
       1.0280.0 88.9290.0 88.5300.0 88.3310.0 88.0320.0 88.0330.0 88.1
       1.0340.0 88.2350.0 87.8360.0 87.8370.0 87.0380.0 87.0390.0 86.8
       1.0400.0 86.7410.0 86.5420.0 87.0430.0 87.9440.0 87.8450.0 87.0
       1.0460.0 86.6470.0 87.1480.0 87.2490.0 87.1500.0 87.6510.0 88.3
       1.0520.0 88.4530.0 88.6540.0 89.2550.0 89.4560.0 89.7570.0 90.9
       1.0580.0 93.2590.0 94.8591.0 95.8593.0 98.2
NS     1.0       1.3       1.3       3.3       3.3       3.10      3.10
NS     1.0       3.10      3.10      3.10      3.10      3.10      3.10
NS     1.0       3.10      3.10      3.10      3.10      3.10      3.10
NS     1.0       3.40      3.40      3.40      3.10      3.10      3.10
NS     1.0       3.10      3.10      3.10      3.10      3.10      3.10
NS     1.0       3.10      3.10      3.10      3.10      3.10      3.10
NS     1.0       3.10      3.10      3.10      3.10      3.10      3.10
NS     1.0       3.10      3.10      3.10      3.10      3.10      3.10
NS     1.0       4.10      4.10      4.10      4.10      4.10      3.10
NS     1.0       3.10      4.10      4.10      4.10      4.10      4.10
NS     1.0       3.10      3.10      3.10      3.10      3.10      3.10
NS     1.0       2.10      2.10      2.3       1.3
WSL    1.0      92.36     92.49     92.80     93.06     93.21     93.28
WSL    1.0      93.39     93.49     93.56     93.68     93.85     94.01
WSL    1.0      94.16     94.31     94.44     94.56     94.69     94.82
```

Appendix C4 cont.

```
WSL   1.0     94.93     95.03     95.14     95.26     95.38     95.49
WSL   1.0     95.60     95.70     95.80     96.00     96.18     96.36
CAL1  1.0    94.768   3329.00   3265.00
VEL1  1.0                        0.00 0.11 0.13 0.29 0.45 0.53 0.72 0.76
VEL1  1.0 0.80 0.81 0.75 0.67 0.76 1.00 0.46 1.13 1.00 1.14 1.02 1.29
VEL1  1.0 1.13 1.31 1.33 1.34 1.38 1.54 1.31 1.42 1.46 1.22 1.37 1.51
VEL1  1.0 1.47 1.49 1.52 1.66 1.49 1.45 1.57 1.43 1.50 1.45 1.22 1.35
VEL1  1.0 1.12 1.24 1.27 1.20 1.04 0.98 0.92 0.85 0.87 0.59 0.50 0.29
VEL1  1.0 0.34 0.24 0.15 0.22 0.11 0.16 0.07
CAL2  1.0    93.666   1780.00      0.00
VEL2  1.0
VEL2  1.0
VEL2  1.0
VEL2  1.0
VEL2  1.0
VEL2  1.0
XSEC  2.0     436.00.50    86.7700.00001500
      2.0  0.0 98.7  1.0 97.6  4.0 96.6  5.0 95.4  7.2 94.8 10.0 94.1
      2.0 20.0 92.8 30.0 92.3 40.0 91.5 50.0 90.8 60.0 90.5 70.0 90.3
      2.0 80.0 90.2 90.0 89.8100.0 89.7110.0 89.5120.0 88.8130.0 88.5
      2.0140.0 87.8150.0 87.4155.0 87.4160.0 87.4165.0 87.1170.0 86.9
      2.0175.0 86.8180.0 86.8185.0 86.8190.0 86.9195.0 87.0200.0 87.1
      2.0205.0 87.3210.0 87.5215.0 87.8220.0 88.1225.0 88.1230.0 88.3
      2.0235.0 88.4240.0 88.5245.0 88.5250.0 88.7255.0 88.7260.0 88.8
      2.0265.0 88.8270.0 88.8275.0 88.9280.0 89.0290.0 89.6300.0 90.0
      2.0310.0 90.1320.0 90.2330.0 90.4340.0 90.1350.0 90.2360.0 90.5
      2.0370.0 90.6380.0 90.9390.0 91.2400.0 91.3410.0 91.2420.0 91.3
      2.0430.0 91.3440.0 91.7450.0 92.6460.0 92.9470.0 93.3480.0 93.7
      2.0488.5 94.8490.0 96.1493.0 96.5
NS    2.0       3.3       3.3       3.4       3.3      3.30      3.10
NS    2.0      3.10      3.10      3.10      3.10      3.10      3.10
NS    2.0      3.10      3.10      3.10      3.10      3.10      3.10
NS    2.0      3.10      3.10      3.10      3.10      3.10      3.10
NS    2.0      3.10      4.10      4.10      4.10      4.10      4.10
NS    2.0      4.10      4.10      4.10      4.10      4.10      4.10
NS    2.0      4.10      4.10      4.10      4.10      4.10      4.10
NS    2.0      4.10      4.10      4.10      4.10      4.10      4.10
NS    2.0      4.10      4.10      4.10      4.10      4.10      4.10
NS    2.0      4.10      4.10      4.10      4.10      4.10      4.10
NS    2.0      4.10      4.10      4.10      4.10      4.10      4.10
NS    2.0      4.10       4.1       4.1
WSL   2.0     92.36     92.49     92.80     93.06     93.21     93.28
WSL   2.0     93.39     93.49     93.56     93.68     93.85     94.01
WSL   2.0     94.16     94.31     94.44     94.56     94.69     94.82
WSL   2.0     94.93     95.03     95.14     95.26     95.38     95.49
WSL   2.0     95.60     95.70     95.80     96.00     96.18     96.36
CAL1  2.0    94.773   3329.00   3251.00
VEL1  2.0                             0.12 0.63 1.13 1.23 1.12 1.11 1.37
VEL1  2.0 1.35 1.38 1.36 1.57 1.65 1.70 1.72 1.50 1.44 1.58 1.72 1.88
VEL1  2.0 1.80 1.89 1.85 1.69 1.82 1.70 1.72 1.66 1.67 1.66 1.70 1.70
VEL1  2.0 1.67 1.82 1.80 1.78 1.84 1.68 1.83 1.79 1.69 1.75 1.72 1.70
VEL1  2.0 1.62 1.54 1.49 1.32 1.43 1.29 1.12 1.00 0.90 0.43 0.19 0.10
VEL1  2.0 0.08 0.09 0.12 0.08 0.32 0.28
CAL2  2.0    93.671   1780.00      0.00
VEL2  2.0
VEL2  2.0
VEL2  2.0
VEL2  2.0
VEL2  2.0
VEL2  2.0
XSEC  3.0     469.00.50    86.7700.00003700
      3.0  0.0 96.2  2.0 95.5  2.5 94.8 10.0 91.4 20.0 90.3 30.0 89.8
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Appendix C4 cont.

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         3.0 40.0 89.5 50.0 88.7 60.0 88.3 70.0 87.9 80.0 87.7 90.0 87.7
         3.0100.0 87.7110.0 87.7120.0 87.6130.0 87.0140.0 86.6145.0 86.5
         3.0150.0 86.6155.0 86.8160.0 86.9165.0 87.2170.0 87.0175.0 86.8
         3.0180.0 86.7185.0 86.7190.0 86.7195.0 86.7200.0 86.2205.0 86.0
         3.0210.0 85.8215.0 85.6220.0 85.2225.0 85.2230.0 85.0235.0 84.8
         3.0240.0 84.7245.0 84.8250.0 84.7255.0 84.6260.0 84.5265.0 84.3
         3.0270.0 84.6275.0 84.8280.0 85.0290.0 85.6300.0 86.1310.0 86.7
         3.0320.0 87.3330.0 87.8340.0 89.0350.0 90.4360.0 92.2370.0 93.5
         3.0380.0 93.5390.0 93.4400.0 93.0410.0 93.3420.0 93.9429.5 94.8
         3.0433.0 95.4436.0 95.8440.0 96.7444.0 97.3
NS       3.0       1.3       1.3      3.30      3.10      3.10      3.10
NS       3.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       3.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       3.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       3.0      3.10      3.10      3.10      3.10      4.10      4.10
NS       3.0      4.10      4.10      4.10      4.10      4.10      4.10
NS       3.0      4.10      4.10      4.10      4.10      4.10      4.10
NS       3.0      4.10      4.10      4.10      4.10      4.10      4.10
NS       3.0      4.10      4.10      4.10      4.10      4.10      4.10
NS       3.0      4.10      4.10      4.10      4.10      5.10      4.10
NS       3.0       3.1       3.1       3.1       3.1
WSL      3.0     92.37     92.50     92.81     93.07     93.22     93.29
WSL      3.0     93.39     93.50     93.57     93.69     93.86     94.02
WSL      3.0     94.17     94.32     94.45     94.57     94.70     94.83
WSL      3.0     94.94     95.05     95.16     95.27     95.40     95.51
WSL      3.0     95.62     95.72     95.82     96.02     96.20     96.38
CAL1     3.0    94.782   3329.00   3329.00
VEL1     3.0                  0.74 0.96 1.05 1.21 1.28 1.31 1.33 1.25 1.28
VEL1     3.0 1.37 1.35 1.37 1.36 1.41 1.66 1.68 1.77 1.61 1.77 1.66 1.65
VEL1     3.0 1.55 1.58 1.63 1.57 1.28 0.96 1.13 1.08 1.25 1.23 1.19 1.16
VEL1     3.0 1.09 1.17 1.13 1.49 1.52 1.52 1.44 1.43 1.52 1.52 0.98 1.10
VEL1     3.0 0.91 0.92 0.52 0.21 0.10 0.10 0.10 0.20 0.05 0.14 0.08
VEL1     3.0
CAL2     3.0    93.696   1780.00      0.00
VEL2     3.0
VEL2     3.0
VEL2     3.0
VEL2     3.0
VEL2     3.0
VEL2     3.0
XSEC     4.0     495.00.50     88.0100.00002700
         4.0  0.0 98.8  4.0 97.6  5.0 96.1  6.0 94.7  8.1 94.0 15.0 92.5
         4.0 30.0 89.4 45.0 89.0 60.0 89.7 75.0 89.7 90.0 89.6100.0 89.7
         4.0110.0 89.6120.0 89.5130.0 89.6140.0 89.3150.0 88.9160.0 88.7
         4.0170.0 88.9180.0 88.8190.0 88.8200.0 88.8210.0 88.6220.0 88.6
         4.0230.0 88.6240.0 88.3250.0 88.3260.0 88.0270.0 88.1280.0 88.4
         4.0290.0 88.5300.0 88.3310.0 88.3320.0 88.5330.0 88.3340.0 88.5
         4.0350.0 88.6360.0 88.7370.0 88.7380.0 88.8390.0 89.3400.0 89.3
         4.0410.0 89.3420.0 89.5430.0 89.6440.0 89.7450.0 89.6460.0 89.7
         4.0470.0 89.6480.0 90.6490.0 91.2500.0 91.8520.0 91.6535.0 91.2
         4.0550.0 91.0565.0 91.3580.0 92.7595.0 94.3598.1 94.8600.0 96.5
         4.0602.0 97.0
NS       4.0       3.3       3.3       1.3       3.4      3.40      3.10
NS       4.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       4.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       4.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       4.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       4.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       4.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       4.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       4.0      3.10      3.10      3.10      3.10      3.10      3.10
NS       4.0      3.10      3.10      3.10      3.10      3.10       3.3
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Appendix C4 cont.

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NS    4.0      3.3
WSL   4.0     92.49      92.61      92.89      93.14      93.28      93.35
WSL   4.0     93.45      93.55      93.62      93.73      93.90      94.06
WSL   4.0     94.21      94.36      94.48      94.60      94.73      94.86
WSL   4.0     94.97      95.07      95.18      95.30      95.42      95.54
WSL   4.0     95.64      95.75      95.85      96.05      96.23      96.41
CAL1  4.0    94.809    3329.00    3331.00
VEL1  4.0                         0.00 0.50 0.77 1.04 1.09 1.21 1.26 1.04
VEL1  4.0 1.16 1.15 1.36 1.37 1.32 1.42 1.41 1.41 1.43 1.41 1.38 1.43
VEL1  4.0 1.29 1.31 1.07 1.33 1.16 1.16 1.42 1.28 1.33 1.13 1.20 1.41
VEL1  4.0 1.29 1.21 1.38 1.33 1.28 1.15 1.08 1.24 1.17 1.00 0.98 0.87
VEL1  4.0 0.71 0.58 0.52 0.52 0.31 0.27 0.19 0.08 0.06 0.13
VEL1  4.0
CAL2  4.0    93.716    1780.00       0.00
VEL2  4.0
VEL2  4.0
VEL2  4.0
VEL2  4.0
VEL2  4.0
VEL2  4.0
XSEC  5.0     539.01.00     88.0100.00000000
      5.0  0.0101.4  3.0100.4  4.0 99.6  5.0 98.6  7.0 95.6 11.0 94.8
      5.0 15.0 93.9 30.0 91.7 45.0 90.8 60.0 90.8 75.0 90.9 90.0 90.8
      5.0105.0 90.7120.0 91.0135.0 91.0150.0 91.4165.0 91.1180.0 91.2
      5.0195.0 91.0210.0 90.7220.0 90.4230.0 90.6240.0 90.4250.0 90.1
      5.0260.0 90.0270.0 89.9280.0 89.6290.0 89.4300.0 89.4310.0 89.3
      5.0320.0 88.7330.0 88.6340.0 88.0350.0 87.8360.0 87.7370.0 87.6
      5.0380.0 87.3390.0 87.1400.0 86.8415.0 86.0430.0 85.9445.0 85.6
      5.0460.0 85.1475.0 84.7490.0 85.2510.0 85.4525.0 86.2540.0 87.9
      5.0555.0 89.7570.0 91.8585.0 93.5600.0 93.8615.0 94.2622.0 94.8
      5.0627.0 96.0636.0 97.2
NS    5.0      3.3        3.3        2.3        3.4        3.4        3.10
NS    5.0      3.40       3.40       3.10       3.10       3.10       3.10
NS    5.0      3.10       3.10       3.10       3.10       3.10       3.10
NS    5.0      3.10       3.10       3.10       3.10       3.10       3.10
NS    5.0      3.10       3.10       3.10       3.10       3.10       3.10
NS    5.0      3.10       3.10       3.10       3.10       3.10       3.10
NS    5.0      3.10       3.10       3.10       3.10       3.10       3.10
NS    5.0      3.10       3.10       3.10       3.10       3.10       3.10
NS    5.0      3.10       3.10       3.10       3.10       3.10       3.10
NS    5.0      3.40       3.1
WSL   5.0     92.49      92.61      92.90      93.14      93.28      93.35
WSL   5.0     93.45      93.55      93.62      93.74      93.90      94.06
WSL   5.0     94.21      94.36      94.49      94.60      94.73      94.86
WSL   5.0     94.97      95.08      95.18      95.30      95.43      95.54
WSL   5.0     95.65      95.75      95.85      96.05      96.23      96.42
CAL1  5.0    94.809    3329.00    3452.00
VEL1  5.0                              0.00 0.15 0.45 0.75 0.95 0.89
VEL1  5.0 1.02 1.00 1.06 1.06 1.02 1.10 1.02 1.16 1.20 1.18 1.10 1.16
VEL1  5.0 1.25 1.07 1.22 1.25 1.33 1.37 1.37 1.18 1.40 1.32 1.24 1.25
VEL1  5.0 1.04 1.24 1.14 1.26 1.17 1.25 1.30 1.11 1.03 0.92 0.87 0.83
VEL1  5.0 0.51 0.28 0.25 0.19 0.09
CAL2  5.0    93.718    1780.00       0.00
VEL2  5.0
VEL2  5.0
VEL2  5.0
VEL2  5.0
VEL2  5.0
ENDJ
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Appendix D. Velocity adjustment factors used in velocity simulations.

East channel

Discharge	Transect 1	Transect 2	Transect 3
1330	0.647	1.217	0.949
1400	0.676	1.144	0.971
1496	0.714	1.093	0.963
1600	0.752	1.07	0.985
1674	0.774	1.03	0.978
1800	0.808	1.029	0.985
2000	0.857	1.013	0.998
2200	0.89	0.998	1.003
2400	0.931	0.992	1.007
2600	0.96	0.989	1.015
2800	0.986	0.987	1.014
3000	1.021	0.989	1.018
3200	1.041	0.985	1.018
3400	1.063	0.985	1.023
3600	1.088	0.99	1.024
3800	1.109	0.992	1.032
4000	1.126	0.991	1.037
4250	1.151	0.987	1.039
4500	1.179	0.997	1.04
4750	1.195	0.995	1.045
5000	1.215	0.999	1.048
5250	1.24	1.009	1.049
5500	1.255	1.009	1.055
6000	1.291	1.019	1.057
6500	1.327	1.023	1.06
7000	1.362	1.036	1.064

Navigation channel

Discharge	Transect 1	Transect 2	Transect 3
725	1.364	2.39	2.447
800	1.363	2.129	2.219
1000	1.337	1.701	1.769
1200	1.312	1.502	1.555
1330	1.299	1.439	1.48
1400	1.296	1.412	1.452
1496	1.29	1.372	1.407
1600	1.278	1.331	1.36
1674	1.275	1.302	1.336
1800	1.266	1.265	1.284
2000	1.249	1.207	1.217
2200	1.235	1.159	1.164
2400	1.22	1.115	1.115
2600	1.207	1.073	1.07
2800	1.193	1.04	1.029
3000	1.179	1.009	0.991
3200	1.164	0.983	0.96
3400	1.152	0.959	0.931
3600	1.14	0.933	0.904
3800	1.13	0.901	0.871
4000	1.12	0.885	0.852
4250	1.108	0.853	0.821
4500	1.097	0.832	0.793
4750	1.087	0.812	0.761
5000	1.076	0.786	0.742
5250	1.067	0.764	0.72
5500	1.055	0.747	0.699
6000	1.038	0.714	0.653
6500	1.023	0.683	0.624
7000	1.007	0.651	0.593

Main channel

Discharge	Transect 1	Transect 2	Transect 3
725	0.817	1.23	0.487
800	0.83	1.221	0.51
1000	0.866	1.198	0.563
1200	0.895	1.165	0.618
1330	0.912	1.153	0.65
1400	0.918	1.142	0.668
1496	0.931	1.137	0.689
1600	0.942	1.13	0.713
1674	0.95	1.119	0.727
1800	0.962	1.111	0.752
2000	0.982	1.105	0.789
2200	0.996	1.094	0.82
2400	1.013	1.085	0.846
2600	1.03	1.078	0.87
2800	1.042	1.073	0.894
3000	1.055	1.07	0.912
3200	1.069	1.066	0.93
3400	1.08	1.059	0.943
3600	1.092	1.059	0.957
3800	1.106	1.058	0.972
4000	1.117	1.056	0.984
4250	1.128	1.054	1
4500	1.143	1.055	1.019
4750	1.156	1.057	1.035
5000	1.167	1.058	1.05
5250	1.179	1.058	1.063
5500	1.189	1.056	1.075
6000	1.211	1.06	1.096
6500	1.234	1.065	1.118
7000	1.254	1.067	1.137

Franconia

Discharge	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5
725	0.505	0.561	0.392	0.519	0.449
800	0.528	0.582	0.416	0.541	0.472
1000	0.584	0.632	0.476	0.596	0.528
1200	0.636	0.679	0.532	0.643	0.58
1330	0.668	0.708	0.567	0.673	0.612
1400	0.686	0.725	0.586	0.689	0.629
1496	0.705	0.742	0.61	0.708	0.649
1600	0.729	0.764	0.634	0.729	0.672
1674	0.744	0.779	0.652	0.744	0.686
1800	0.769	0.801	0.68	0.768	0.71
2000	0.809	0.837	0.725	0.803	0.749
2200	0.846	0.871	0.768	0.836	0.784
2400	0.881	0.903	0.809	0.868	0.817
2600	0.913	0.931	0.846	0.896	0.846
2800	0.946	0.961	0.885	0.928	0.877
3000	0.979	0.992	0.923	0.959	0.91
3200	1.007	1.016	0.957	0.983	0.936
3400	1.032	1.038	0.989	1.005	0.959
3600	1.06	1.064	1.023	1.03	0.986
3800	1.09	1.091	1.055	1.057	1.01
4000	1.114	1.112	1.085	1.079	1.036
4250	1.147	1.142	1.127	1.109	1.067
4500	1.178	1.17	1.162	1.137	1.092
4750	1.21	1.199	1.2	1.162	1.122
5000	1.239	1.225	1.236	1.192	1.149
5250	1.27	1.253	1.273	1.217	1.177
5500	1.299	1.279	1.308	1.243	1.204
6000	1.351	1.326	1.373	1.29	1.253
6500	1.404	1.374	1.438	1.339	1.302
7000	1.452	1.417	1.499	1.382	1.343

Appendix E. Days with mean flows equal to or less than 800 cfs over the period of hydrologic record for the Lower St. Croix River at St. Croix Falls, WI. Mean daily flows during the week prior to and the week after each 800 cfs day are also provided. Discharge data taken from USGS gage no. 53405000.

YEAR	MONTH	DAY	CFS
1902	March	28	3120
		29	3120
		30	3040
		31	2950
	April	1	2910
		2	2840
		3	300
		4	400
		5	2750
		6	2520
		7	2280
		8	2280
		9	2190
		10	2110
		15	2020
		16	2170
		17	2070
		18	5190
		19	1510
		20	1000
		21	600
		22	5540
		23	540
		24	510
		25	1050
		26	2760
		27	3020
		28	3290
		29	3480
		30	3750
	September	14	1550
		15	1360
		16	1360
		17	1540
		18	1480
		19	1120
		20	510
		21	2800
		22	2070
		23	2540
		24	2360
		25	1060
		26	1140
	October	10	930
		11	2950
		12	1950
		13	2040
		14	2000
		15	1920
		16	800
		17	845
		18	3600
		19	1940
		20	1920
		21	2040
		22	1980
1905	April	20	3560
		21	4440
		22	3440
		23	3140
		24	2840
		25	3070
		26	580
		27	3990
		28	4310
		29	4230
		30	4670
	May	1	5130

YEAR	MONTH	DAY	CFS
1910	May	16	1830
		17	1510
		18	1180
		19	2040
		20	3320
		21	2060
		22	790
		23	2330
		24	2630
		25	3030
		26	3550
		27	4630
		28	4450
	June	13	1930
		14	1840
		15	1900
		16	1940
		17	2230
		18	1400
		19	550
		20	1820
		21	1850
		22	1740
		23	1620
		24	1670
		25	1110
		26	555
		27	1730
		28	2210
		29	1450
		30	1570
	July	1	1680
		2	1110
		3	610
		4	1120
		5	1630
		6	1420
		7	1550
		8	1680
		9	1230
		10	500
		11	1800
		12	1360
		13	1800
		14	1790
		15	1670
		16	1270
		17	75
		18	1840
		19	1800
		20	1770
		21	1810
		22	1720
		23	1300
		24	343
		25	1410
		26	1480
		27	1490
		28	1490
		29	1490
		30	1490
		31	358
	August	1	1450
		2	1450
		3	1400
		4	1400
		5	1500
		6	1260
		7	452

YEAR	MONTH	DAY	CFS
1910	August	8	1350
		9	1700
		10	1500
		11	1470
		12	1400
		13	1290
		14	393
		15	1400
		16	1550
		17	1360
		18	1410
		19	1400
		20	1320
		21	452
		22	1470
		23	1640
		24	1630
		25	1600
		26	1570
		27	1560
		28	521
		29	1530
		30	1540
		31	1690
	September	1	1700
		2	1700
		3	1820
		4	606
		5	1170
		6	1700
		7	1670
		8	1770
		9	1640
		10	1590
		11	680
		12	1740
		13	1730
		14	1410
		15	1230
		16	1380
		17	1520
		18	666
		19	1320
		20	1450
		21	1460
		22	1450
		23	1220
		24	1100
		25	759
		26	1410
		27	1640
		28	1660
		29	1670
		30	1610
	October	1	1400
		2	728
		3	1570
		4	1580
		5	1580
		6	1580
		7	1610
		8	1950
		9	602
		10	1640
		11	1770
		12	1780
		13	1770
		14	1740
		15	1730

Appendix E cont.

YEAR	MONTH	DAY	CFS
1910	December	16	629
		17	1640
		18	1510
		19	1700
		20	1720
		21	1750
		22	1780
		23	635
		24	1660
		25	1780
		26	1830
		27	1660
		28	1700
		29	1740
		30	634
		31	1580
	November	1	1380
		2	1390
		3	1400
		4	1460
		5	1670
		6	725
		7	1690
		8	1540
		9	1550
		10	1500
		11	1560
		12	1510
		13	671
		14	1290
		15	1450
		16	1500
		17	1210
		18	997
		19	1350
		20	728
		21	1610
		22	1530
		23	1730
		24	691
		25	1360
		26	1600
		27	674
		28	1470
		29	1510
		30	1520
	December	1	1950
		2	1440
		3	1050
		4	648
		5	1190
		6	1240
		7	1400
		8	1720
		9	1740
		10	1740
		11	629
		12	1420
		13	1340
		14	1140
		15	1310
		16	1470
		17	1530
		18	638
		19	1270
		20	1410
		21	1270
		22	1240
		23	1220
		24	1520
		25	842
1910	December	26	850
		27	1110
		28	1300
		29	1260
		30	1310
		31	1710
1911	January	1	653
		2	935
		3	1690
		4	1410
		5	1330
		6	807
		7	1480
		8	719
		9	1340
		10	1300
		11	1290
		12	1120
		13	1130
		14	1050
		15	557
		16	1200
		17	1110
		18	1110
		19	1080
		20	1100
		21	1100
		22	725
		23	1300
		24	1230
		25	1640
		26	1400
		27	1240
		28	1390
		29	621
		30	1360
		31	1440
	February	1	1580
		2	1430
		3	1370
		4	1620
		20	1440
		21	1580
		22	1490
		23	1590
		24	1530
		25	1510
		26	793
		27	1510
		28	1500
	March	1	1510
		2	1540
		3	1560
		4	1570
1912	March	18	1650
		19	1390
		20	1420
		21	1930
		22	1900
		23	1970
		24	710
		25	1890
		26	1490
		27	1860
		28	1950
		29	1910
		30	1830
		31	1460
	December	1	1610
		2	1540
1912	December	3	1350
		4	1940
		5	1920
		6	1740
1913	January	1	760
		2	1270
		3	1590
		4	1670
		5	1250
		6	1200
		7	1270
1915	March	1	2010
		2	2010
		3	1990
		4	2060
		5	2030
		6	2030
		7	686
		8	1970
		9	2260
		10	2100
		11	2120
		12	1950
		13	1890
	November	1	2880
		2	3210
		3	3350
		4	3160
		5	3200
		6	2910
		7	740
		8	2090
		9	3090
		10	4290
		11	10300
		12	9630
		13	10900
1916	March	20	1650
		21	1960
		22	2070
		23	2140
		24	2300
		25	3090
		26	763
		27	2240
		28	2590
		29	3040
		30	4290
		31	5030
	April	1	8740
1917	December	17	1630
		18	1800
		19	1740
		20	1880
		21	1640
		22	2120
		23	617
		24	1540
		25	467
		26	1560
		27	1430
		28	1400
		29	1770
		30	865
		31	1830
1918	February	1	1580

Appendix E cont.

YEAR	MONTH	DAY	CFS
1918	February	2	1600
		3	800
		4	1540
		5	1930
		6	1850
		7	1790
		8	1700
		9	1720
		18	1980
		19	1980
		20	1600
		21	1680
		22	1620
		23	2220
		24	700
		25	1690
		26	1830
		27	1700
		28	1860
	July	15	1440
		16	1820
		17	1800
		18	1510
		19	1690
		20	1720
		21	645
		22	1740
		23	1640
		24	1750
		25	1640
		26	1590
		27	2090
		28	603
		29	1590
		30	1930
		31	1950
	August	1	2040
		2	2550
		3	1840
		4	705
		5	1540
		6	1640
		7	1460
		8	1540
		9	1600
		10	1460
	September	9	2320
		10	1940
		11	1760
		12	1920
		13	1930
		14	1760
		15	712
		16	1650
		17	1720
		18	1580
		19	1770
		20	1570
		21	1620
		22	660
		23	1550
		24	2000
		25	1390
		26	1280
		27	1480
		28	1580
		29	1020
		30	1770
	October	1	1600
		2	1430
		3	1300

YEAR	MONTH	DAY	CFS
1918	October	4	1360
		5	1540
		6	726
		7	1380
		8	1270
		9	1180
		10	1540
		11	1190
		12	1890
		13	1350
1920	January	1	925
		2	2650
		3	2580
		4	645
		5	2760
		6	2120
		7	2180
		8	1700
		9	1800
		10	2250
		11	753
		12	2210
		13	2040
		14	2010
		15	2050
		16	1980
		17	2070
	December	13	2690
		14	3280
		15	2580
		16	2690
		17	2260
		18	1730
		19	703
		20	1760
		21	1770
		22	1980
		23	1730
		24	1470
		25	1030
1921	October	24	2640
		25	2020
		26	1530
		27	1950
		28	1860
		29	1790
		30	790
		31	2070
	November	1	1860
		2	2070
		3	2070
		4	1820
		5	1650
		6	1020
		7	2230
		8	2080
		9	1910
		10	1600
		11	870
		12	1350
		13	760
		14	1380
		15	2040
		16	1290
		17	1100
		18	1220
		19	1470
		20	1130
		21	1380

YEAR	MONTH	DAY	CFS
1921	November	22	1410
		23	1700
		24	1190
		25	1980
		26	1700
		27	780
		28	2150
		29	2330
		30	1920
	December	1	2180
		2	1810
		3	1550
1922	January	16	1750
		17	1680
		18	1710
		19	1710
		20	1870
		21	1480
		22	800
		23	1510
		24	1260
		25	1810
		26	1510
		27	1610
		28	1390
1924	January	14	1300
		15	1430
		16	1560
		17	1480
		18	1300
		19	1700
		20	695
		21	1480
		22	1320
		23	1350
		24	1340
		25	1120
		26	1520
	February	25	1580
		26	1820
		27	1640
		28	1500
		29	1420
	March	1	1900
		2	595
		3	1880
		4	1680
		5	1640
		6	1640
		7	1640
		8	1780
	November	21	2920
		22	3080
		23	1200
		24	3030
		25	2390
		26	2800
		27	635
		28	2640
		29	2500
		30	770

Appendix E cont.

YEAR	MONTH	DAY	CFS
1924	December	1	1350
		2	1190
		3	1600
		4	2060
		5	1960
		6	2570
		7	517
		8	2410
		9	2330
		10	2360
		11	1740
		12	1630
		13	2540
		14	561
		15	1990
		16	2090
		17	1970
		18	1680
		19	1580
		20	1790
1925	January	1	778
		2	1100
		3	1520
		4	613
		5	1300
		6	1170
		7	1210
		8	1420
		9	1480
		10	1400
		11	592
		12	1730
		13	1760
		14	1280
		15	1440
		16	988
		17	1570
		26	1500
		27	1630
		28	1520
		29	1620
		30	1240
		31	1540
	February	1	779
		2	1440
		3	1600
		4	1460
		5	1470
		6	1470
		7	1720
		8	472
		9	1880
		10	1650
		11	1650
		12	1740
		13	1560
		14	2000
		15	649
		16	2110
		17	2130
		18	1740
		19	1670
		20	1480
		21	1530
		22	549
		23	1600
		24	1610
		25	1420
		26	1420
		27	1520

YEAR	MONTH	DAY	CFS
1925	February	28	1700
	March	1	633
		2	1600
		3	1530
		4	1450
		5	1450
		6	1370
		7	1790
		8	616
		9	2060
		10	2610
		11	2770
		12	2500
		13	2800
		14	2980
	September	14	1600
		15	1440
		16	1490
		17	1410
		18	1440
		19	1290
		20	615
		21	1390
		22	1640
		23	1550
		24	1520
		25	1270
		26	1500
		27	776
		28	1550
		29	1780
		30	3130
	October	1	1290
		2	1170
		3	1460
	November	9	1460
		10	1420
		11	1560
		12	1560
		13	1760
		14	1970
		15	795
		16	2210
		17	1820
		18	1790
		19	1870
		20	1790
		21	1730
		22	619
		23	1690
		24	1530
		25	1270
		26	580
		27	1570
		28	1530
		29	539
		30	1470
	December	1	1250
		2	1270
		3	1600
		4	1440
		5	1580
		6	704
		7	1350
		8	1300
		9	1500
		10	1460
		11	1390
		12	1600
		13	499
		14	1860

YEAR	MONTH	DAY	CFS
1925	December	15	1660
		16	1720
		17	1600
		18	1510
		19	1280
		20	864
		21	1530
		22	1500
		23	1580
		24	1280
		25	690
		26	1440
		27	891
		28	1630
		29	1340
		30	1350
		31	1180
1926	January	1	755
		2	1090
		3	781
		4	1220
		5	1330
		6	1390
		7	1310
		8	1210
		9	1250
		10	595
		11	1380
		12	1400
		13	1130
		14	1260
		15	1290
		16	1350
		17	608
		18	1330
		19	1290
		20	1320
		21	1320
		22	1270
		23	1360
		24	641
		25	1200
		26	1390
		27	1380
		28	1160
		29	1230
		30	1200
		31	771
	February	1	1340
		2	1220
		3	1170
		4	1270
		5	1170
		6	1220
		15	1460
		16	1540
		17	1520
		18	1500
		19	1440
		20	1510
		21	786
		22	1660
		23	1570
		24	1490
		25	1410
		26	1420
		27	1500
		28	741
	March	1	1610
		2	1510

Appendix E cont.

YEAR	MONTH	DAY	CFS
1926	March	3	1430
		4	1580
		5	1380
		6	1690
		7	[illegible]
		8	[illegible]
		9	[illegible]
		10	[illegible]
		11	1470
		12	1230
		13	1510
		14	793
		15	1430
		16	1470
		17	1460
		18	1500
		19	1930
		20	1950
	November	8	3050
		9	3420
		10	3570
		11	3470
		12	3220
		13	2650
		14	668
		15	3320
		16	5670
		17	5620
		18	5940
		19	3970
		20	4530
1927	November	7	2270
		8	2260
		9	2220
		10	2420
		11	2280
		12	2270
		13	640
		14	2300
		15	1800
		16	1660
		17	569
		18	1670
		19	2040
		20	564
		21	2380
		22	2380
		23	2550
		24	1540
		25	3740
		26	2960
1928	January	9	2360
		10	2130
		11	1860
		12	1730
		13	1710
		14	2160
		15	800
		16	2410
		17	2420
		18	2080
		19	2220
		20	2020
		21	2390
	February	6	2130
		7	1840
		8	1840
		9	1800
		10	2190
		11	2060

YEAR	MONTH	DAY	CFS
1928	February	12	347
		13	2380
		14	2120
		15	2330
		16	2210
		17	1960
		18	2290
		19	478
		20	2540
		21	2630
		22	2070
		23	1880
		24	2050
		25	1920
		26	464
		27	2410
		28	2160
		29	2010
	March	1	1900
		2	1930
		3	1880
		4	520
		5	2310
		6	2290
		7	1900
		8	1760
		9	1360
		10	1940
		11	559
		12	2730
		13	2030
		14	2040
		15	1670
		16	2030
		17	2120
1929	January	1	1350
		2	3390
		3	2820
		4	2000
		5	2250
		6	588
		7	2310
		8	2170
		9	2490
		10	2250
		11	2080
		12	1990
		13	497
		14	2430
		15	2250
		16	2240
		17	2340
		18	2040
		19	2160
		20	405
		21	2640
		22	2420
		23	2320
		24	2110
		25	2300
		26	1990
		27	260
		28	2460
		29	1920
		30	2070
		31	1880
	February	1	1960
		2	2070
		3	262
		4	2360

YEAR	MONTH	DAY	CFS
1929	February	5	2450
		6	2190
		7	2040
		8	2410
		9	1860
		10	806
		11	2400
		12	2710
		13	2340
		14	2230
		15	2040
		16	2070
		17	270
		18	2380
		19	2390
		20	2540
		21	2290
		22	2130
		23	2100
		24	275
		25	2550
		26	2380
		27	2760
		28	2010
	March	1	2010
		2	2340
		3	204
		4	2560
		5	2200
		6	2280
		7	2350
		8	2370
		9	1860
		10	179
		11	3170
		12	2900
		13	2930
		14	3340
		15	3630
		16	6190
	November	18	3080
		19	2980
		20	2850
		21	2710
		22	1320
		23	1110
		24	533
		25	1960
		26	1980
		27	2040
		28	1130
		29	2470
		30	2450
	December	1	673
		2	1770
		3	2170
		4	2300
		5	1870
		6	2080
		7	2000
		8	651
		9	2190
		10	2410
		11	2160
		12	2080
		13	2030
		14	1950
		15	607
		16	2280
		17	2320
		18	2160

Appendix E cont.

YEAR	MONTH	DAY	CFS
1929	December	19	1990
		20	1930
		21	1940
		22	462
		23	2360
		24	2110
		25	552
		26	2250
		27	2310
		28	2280
		29	427
		30	2460
		31	2460
1930	January	1	741
		2	2320
		3	2220
		4	2140
		5	649
		6	2410
		7	2400
		8	2140
		9	2010
		10	1850
		11	1660
		12	404
		13	2100
		14	1890
		15	1940
		16	1720
		17	1560
		18	1430
		19	676
		20	1890
		21	1910
		22	1850
		23	1670
		24	1640
		25	1750
		26	683
		27	1840
		28	1860
		29	1780
		30	1610
		31	1670
	February	1	1640
		2	509
		3	1760
		4	1830
		5	1730
		6	1830
		7	1830
		8	1880
		9	524
		10	2000
		11	1950
		12	1870
		13	1820
		14	1860
		15	1860
		16	426
		17	1960
		18	2050
		19	1860
		20	1920
		21	2550
		22	3260
	March	17	3710
		18	4350
		19	4300
		20	4480
1930	March	21	4720
		22	3640
		23	632
		24	3880
		25	3340
		26	2900
		27	3340
		28	3080
		29	2130
	December	15	2150
		16	2130
		17	2420
		18	2080
		19	1690
		20	1640
		21	771
		22	1830
		23	2200
		24	1780
		25	851
		26	1830
		27	1830
		28	960
		29	1990
		30	2000
		31	2010
1931	January	1	849
		2	1950
		3	1820
		4	755
		5	2000
		6	1780
		7	1800
		8	1760
		9	1660
		10	1660
		11	783
		12	1770
		13	1770
		14	1700
		15	1750
		16	1830
		17	1530
		18	794
		19	1770
		20	1790
		21	1800
		22	1730
		23	1550
		24	1330
		25	738
		26	1730
		27	1730
		28	1650
		29	1660
		30	1630
		31	1360
	February	16	1720
		17	1890
		18	2290
		19	2220
		20	2080
		21	1550
		22	622
		23	1700
		24	2100
		25	2120
		26	1960
		27	2180
		28	1440
1931	December	19	2110
		20	825
		21	2540
		22	2820
		23	2920
		24	2200
		25	599
		26	2820
		27	1320
		28	2920
		29	2830
		30	2680
		31	2350
1932	January	1	947
		2	2160
		3	664
		4	2060
		5	1850
		6	1780
		7	1900
		8	1480
		9	1910
		10	419
		11	2060
		12	2090
		13	2310
		14	2120
		15	1980
		16	2400
		17	746
		18	2030
		19	2090
		20	2180
		21	2340
		22	2100
		23	2080
		24	583
		25	2080
		26	2230
		27	1930
		28	1980
		29	1800
		30	401
		31	1900
	February	1	2140
		2	1860
		3	1540
		4	1550
		5	1460
		6	1540
		7	647
		8	1580
		9	1780
		10	1650
		11	1610
		12	2150
		13	916
		14	423
		15	2120
		16	1720
		17	1580
		18	1470
		19	1500
		20	1570
		21	412
		22	1790
		23	1470
		24	1460
		25	1860
		26	1790

Appendix E cont.

YEAR	MONTH	DAY	CFS
1932	February	27	2030
		28	596
		29	2400
	March	14	2620
		15	1740
		16	1600
		17	1580
		18	1660
		19	1660
		20	693
		21	2220
		22	1560
		23	1690
		24	1570
		25	1470
		26	1780
		27	632
		28	2260
		29	2280
		30	2490
		31	2630
	April	1	2350
		2	2660
	November	14	2140
		15	1790
		16	1550
		17	1520
		18	1720
		19	1870
		20	681
		21	2030
		22	2030
		23	2030
		24	1400
		25	3280
		26	1690
		27	750
		28	2070
		29	1970
		30	1810
	December	1	1830
		2	1630
		3	1660
		4	606
		5	1810
		6	1820
		7	1920
		8	1540
		9	1370
		10	1350
		11	375
		12	1260
		13	1420
		14	1390
		15	1310
		16	1230
		17	1450
		18	590
		19	1490
		20	1380
		21	1430
		22	1510
		23	1300
		24	1550
		25	841
		26	727
		27	1860
		28	1690
		29	1500
		30	1550
		31	1860

YEAR	MONTH	DAY	CFS
1933	January	1	614
		2	990
		3	1840
		4	1640
		5	1420
		6	1210
		7	1440
		8	815
		9	1650
		10	1590
		11	1420
		12	1450
		13	1410
		14	1250
		15	584
		16	1460
		17	1570
		18	1450
		19	1330
		20	1340
		21	1520
		22	642
		23	1650
		24	1510
		25	1450
		26	1450
		27	1380
		28	1740
		29	460
		30	1740
		31	1550
	February	1	1530
		2	1460
		3	1440
		4	1650
		5	615
		6	1620
		7	1470
		8	1390
		9	1280
		10	1220
		11	1460
		12	482
		13	1460
		14	1430
		15	1240
		16	1150
		17	1210
		18	1570
		19	403
		20	1650
		21	1450
		22	1400
		23	1300
		24	1290
		25	1380
	March	6	1970
		7	2020
		8	1780
		9	1510
		10	1570
		11	1740
		12	559
		13	2060
		14	1690
		15	1780
		16	1730
		17	1870
		18	2430
		19	722
		20	2350

YEAR	MONTH	DAY	CFS
1933	March	21	1700
		22	1750
		23	1480
		24	1770
		25	1900
	November	1	1590
		2	1720
		3	1980
		4	1930
		5	790
		6	2100
		7	1970
		8	2080
		9	1750
		10	1510
		11	1190
		12	896
		13	1620
		14	1280
		15	1180
		16	1100
		17	1220
		18	1570
		19	697
		20	1810
		21	1740
		22	1850
		23	1760
		24	1660
		25	1830
1934	March	12	2200
		13	2080
		14	2020
		15	1870
		16	1880
		17	1610
		18	798
		19	2170
		20	1980
		21	2150
		22	2000
		23	2250
		24	1840
	July	22	990
		23	922
		24	878
		25	893
		26	812
		27	826
		28	726
		29	745
		30	726
		31	761
	August	1	783
		2	808
		3	743
		4	719
		5	776
		6	762
		7	735
		8	735
		9	855
		10	771
		11	759
		12	762
		13	757
		14	750
		15	755
		16	746
		17	748

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YEAR	MONTH	DAY	CFS
1934	August	18	813
		19	785
		20	771
		21	908
		22	805
		23	1130
		24	1180
		25	1120
		26	1220
	November	5	2480
		6	2290
		7	2400
		8	2410
		9	1900
		10	2130
		11	678
		12	2440
		13	2190
		14	1700
		15	1740
		16	1560
		17	1350
		18	745
		19	2580
		20	2510
		21	2570
		22	2360
		23	2690
		24	3040
		25	660
		26	2960
		27	3380
		28	3300
		29	962
		30	3490
	December	1	3340
		2	496
		3	2070
		4	1920
		5	1860
		6	2320
		7	1500
		8	1620
		9	532
		10	2360
		11	2240
		12	2580
		13	2390
		14	2320
		15	2190
		16	416
		17	2420
		18	2650
		19	2340
		20	2200
		21	2010
		22	2060
		23	354
		24	1700
		25	795
		26	3400
		27	1790
		28	1830
		29	1700
		30	669
		31	1520
1935	January	1	569
		2	2420
		3	2160
		4	1720

YEAR	MONTH	DAY	CFS
1935	January	5	2070
		6	246
		7	2090
		8	1980
		9	1740
		10	1720
		11	1630
		12	2090
		13	178
		14	2280
		15	1790
		16	1620
		17	1570
		18	1640
		19	1610
		20	223
		21	2070
		22	1810
		23	1450
		24	1490
		25	1480
		26	1730
		27	502
		28	2040
		29	1750
		30	1770
		31	1630
	February	1	1460
		2	1650
		3	549
		4	1660
		5	2120
		6	1950
		7	1760
		8	1780
		9	1880
		10	471
		11	2290
		12	2080
		13	1870
		14	2100
		15	1670
		16	1820
		17	493
		18	2280
		19	2210
		20	1880
		21	1860
		22	1530
		23	1710
		24	565
		25	2990
		26	2370
		27	2110
		28	1710
	March	1	1610
		2	1630
		3	373
		4	2690
		5	1690
		6	1940
		7	2000
		8	2100
		9	2050
		10	420
		11	2620
		12	3000
		13	2630
		14	2230
		15	2610
		16	2810

YEAR	MONTH	DAY	CFS
1935	November	25	2420
		26	2860
		27	3060
		28	1490
		29	2720
		30	1740
	December	1	778
		2	2420
		3	1630
		4	1770
		5	2060
		6	2010
		7	2710
		19	2300
		20	2180
		21	1630
		22	833
		23	1780
		24	1770
		25	398
		26	2140
		27	2350
		28	1580
		29	129
		30	2430
		31	2520
1936	January	1	720
		2	2700
		3	2450
		4	2090
		5	239
		6	2340
		7	2130
		8	1980
		9	1840
		10	2080
		11	2180
		12	674
		13	2250
		14	1610
		15	1890
		16	2240
		17	2160
		18	1570
		19	559
		20	2110
		21	2020
		22	2140
		23	1880
		24	1560
		25	1670
		26	487
		27	1970
		28	1760
		29	1810
		30	1740
		31	1530
	February	1	1460
		2	207
		3	2190
		4	1740
		5	1720
		6	1480
		7	1470
		8	1610
		9	611
		10	1860
		11	1570
		12	1420
		13	1480

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YEAR	MONTH	DAY	CFS
1936	February	14	1510
		15	1630
		16	336
		17	1780
		18	1650
		19	1510
		20	1500
		21	1410
		22	1570
		23	345
		24	2090
		25	1880
		26	1690
		27	1480
		28	1400
		29	1590
	March	1	437
		2	2010
		3	2040
		4	1760
		5	1530
		6	1810
		7	1380
		8	504
		9	2030
		10	2300
		11	1980
		12	1950
		13	1710
		14	2020
		15	230
		16	2620
		17	2110
		18	1880
		19	1900
		20	1900
		21	2980
	November	2	1090
		3	1180
		4	1330
		5	1950
		6	2320
		7	2220
		8	655
		9	1980
		10	2150
		11	1910
		12	2210
		13	2090
		14	2260
		15	418
		16	2200
		17	2130
		18	2640
		19	2560
		20	2630
		21	2210
		22	621
		23	2470
		24	2190
		25	2080
		26	545
		27	1550
		28	1300
		29	551
		30	2050
	December	1	1780
		2	1500
		3	1590
		4	1510
		5	1260
1936	December	6	457
		7	1750
		8	1780
		9	1410
		10	1160
		11	1410
		12	1400
		13	519
		14	1740
		15	1810
		16	2480
		17	1970
		18	1880
		19	1270
		20	461
		21	2720
		22	2280
		23	2080
		24	1350
		25	637
		26	2180
		27	696
		28	3130
		29	3560
		30	1830
		31	1950
1937	January	1	790
		2	2330
		3	1630
		4	1870
		5	2380
		6	2860
		7	1960
		18	2140
		19	2060
		20	2230
		21	1700
		22	1580
		23	1600
		24	665
		25	1930
		26	2080
		27	2010
		28	1830
		29	1690
		30	1620
		31	783
	February	1	1750
		2	1990
		3	1840
		4	1750
		5	1670
		6	1770
		7	943
		8	1690
		9	1750
		10	1630
		11	2170
		12	2010
		13	1490
		14	130
		15	1940
		16	2000
		17	1960
		18	1840
		19	1860
		20	1600
		21	107
		22	1910
		23	1760
1937	February	24	2550
		25	2260
		26	1730
		27	1560
		28	653
	March	1	2310
		2	2190
		3	1950
		4	1950
		5	1900
		6	3340
		7	1460
		8	1710
		9	1600
		10	2390
		11	2230
		12	2210
		13	2160
		14	677
		15	2460
		16	2560
		17	2230
		18	1930
		19	2070
		20	1880
		21	736
		22	2750
		23	2640
		24	2540
		25	2120
		26	1930
		27	2000
		28	693
		29	2980
		30	2720
		31	3210
	April	1	3350
		2	3570
		3	5110
	November	7	900
		8	2300
		9	2300
		10	2420
		11	2140
		12	2320
		13	776
		14	1460
		15	2530
		16	2640
		17	2370
		18	2360
		19	2400
		20	2190
		21	565
		22	2200
		23	2000
		24	2020
		25	366
		26	2010
		27	2720
		28	1120
		29	1970
		30	1740
	December	1	1830
		2	1540
		3	1940
		4	1970
		5	675
		6	1850
		7	2130
		8	1680

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YEAR	MONTH	DAY	CFS
1937	December	9	1590
		10	1540
		11	1740
		12	495
		13	1790
		14	1540
		15	1560
		16	1830
		17	1580
		18	1710
		19	289
		20	1690
		21	1850
		22	1670
		23	1740
		24	1450
		25	320
		26	334
		27	1850
		28	1840
		29	2100
		30	2130
		31	1830
1938	January	1	733
		2	742
		3	1840
		4	2030
		5	2020
		6	1770
		7	1500
		8	1440
		9	727
		10	1570
		11	1550
		12	1500
		13	1650
		14	1610
		15	1390
		16	743
		17	1620
		18	1470
		19	1540
		20	2060
		21	1620
		22	1470
		23	576
		24	1640
		25	1750
		26	1600
		27	1590
		28	1570
		29	1600
		30	646
		31	1610
	February	1	1690
		2	1700
		3	1690
		4	1820
		5	1480
		6	695
		7	1700
		8	1760
		9	1690
		10	1750
		11	1660
		12	1580
		13	528
		14	1890
		15	2500
		16	1630

YEAR	MONTH	DAY	CFS
1938	February	17	1650
		18	1560
		19	1450
		20	732
		21	1660
		22	1750
		23	1820
		24	1660
		25	1660
		26	1750
		27	782
		28	1680
	March	1	2180
		2	2190
		3	2240
		4	2150
		5	1930
		6	562
		7	1830
		8	1760
		9	2040
		10	2120
		11	2490
		12	1520
	December	5	3060
		6	2980
		7	3280
		8	2900
		9	2840
		10	2460
		11	766
		12	2540
		13	3000
		14	1170
		15	1680
		16	1940
		17	1940
		18	588
		19	1990
		20	2010
		21	2190
		22	2430
		23	2200
		24	2130
		25	777
		26	1520
		27	2220
		28	2750
		29	2340
		30	1990
		31	1850
1939	January	9	2980
		10	3080
		11	3030
		12	3040
		13	3080
		14	3030
		15	689
		16	2340
		17	2840
		18	2550
		19	2730
		20	2620
		21	2500
		22	1010
		23	2680
		24	2640
		25	2850
		26	2540
		27	2360
		28	1960

YEAR	MONTH	DAY	CFS
1939	January	29	720
		30	1920
		31	2870
	February	1	2790
		2	2540
		3	2280
		4	1850
		5	710
		6	2020
		7	2170
		8	2040
		9	2160
		10	2160
		11	2110
		12	534
		13	2420
		14	2150
		15	2340
		16	2300
		17	1990
		18	2190
		19	425
		20	2330
		21	2280
		22	2150
		23	2150
		24	1990
		25	2130
		26	448
		27	2260
		28	2270
	March	1	2330
		2	2290
		3	2370
		4	2540
		5	340
		6	2870
		7	2480
		8	2030
		9	2070
		10	2170
		11	2060
	November	13	2030
		14	2130
		15	2070
		16	1880
		17	1760
		18	1660
		19	696
		20	1840
		21	2140
		22	2370
		23	2220
		24	2470
		25	2220
1940	January	1	1100
		2	1500
		3	1790
		4	1640
		5	1280
		6	718
		7	1600
		8	1820
		9	1830
		10	1900
		11	1740
		12	1000
		13	403
		14	1310
		15	1550

Appendix E cont.

YEAR	MONTH	DAY	CFS
1940	January	16	1780
		17	1720
		18	1570
		19	1620
		20	671
		21	1010
		22	1510
		23	1810
		24	1410
		25	1290
		26	1270
	February	12	1360
		13	1900
		14	1660
		15	1660
		16	1880
		17	1810
		18	674
		19	1920
		20	1800
		21	1860
		22	979
		23	1770
		24	1960
	March	11	1950
		12	1760
		13	2410
		14	1750
		15	1790
		16	2320
		17	684
		18	2240
		19	1980
		20	1830
		21	1760
		22	1990
		23	1640
	November	25	3330
		26	3890
		27	2930
		28	3550
		29	2460
		30	2440
	December	1	440
		2	2190
		3	2280
		4	2580
		5	2480
		6	2560
		7	2410
		19	2450
		20	1900
		21	2430
		22	993
		23	2310
		24	2120
		25	713
		26	2800
		27	2540
		28	2570
		29	1180
		30	2890
		31	2530
1941	January	27	2360
		28	2250
		29	2100
		30	2070
		31	1900
	February	1	1940
		2	702
1941	February	3	2290
		4	2290
		5	2100
		6	1920
		7	2010
		8	2090
		9	648
		10	2270
		11	2120
		12	2160
		13	2040
		14	2060
		15	1930
		16	582
		17	2440
		18	2300
		19	1630
		20	2200
		21	2140
		22	2060
		23	616
		24	2340
		25	2200
		26	2060
		27	1940
		28	1980
	March	1	2140
		2	487
		3	2370
		4	2000
		5	1940
		6	1930
		7	1820
		8	1840
		9	671
		10	2250
		11	2410
		12	2250
		13	1850
		14	1820
		15	2100
		16	574
		17	2320
		18	2300
		19	2250
		20	2060
		21	1600
		22	1950
		23	671
		24	2450
		25	2200
		26	2480
		27	2170
		28	1970
		29	2270
1948	January	18	1080
		19	2240
		20	2150
		21	2450
		22	1640
		23	2080
		24	296
		25	1360
		26	2310
		27	2220
		28	2030
		29	1530
		30	1330
	December	6	1850
		7	1790
1948	December	8	1590
		9	1780
		10	2110
		11	1520
		12	480
		13	2080
		14	2120
		15	1940
		16	2370
		17	1920
		18	1560
		19	1380
		20	2250
		21	2390
		22	2250
		23	2240
		24	1010
		25	1260
		26	799
		27	2020
		28	2390
		29	1770
		30	1830
		31	1560
1949	November	28	2220
		29	1880
		30	2740
	December	1	3490
		2	2170
		3	1310
		4	504
		5	1720
		6	2140
		7	2230
		8	2500
		9	2620
		10	647
		11	739
		12	2260
		13	2200
		14	2230
		15	2190
		16	2380
		17	856
		18	1800
		19	2440
		20	2730
		21	2530
		22	2150
		23	2040
		24	750
		25	1000
		26	799
		27	2170
		28	1880
		29	1820
		30	2180
		31	842
1950	January	1	1240
		2	1600
		3	2010
		4	1960
		5	1780
		6	2120
		7	786
		8	1050
		9	1940
		10	1720
		11	1720

Appendix E cont.

YEAR	MONTH	DAY	CFS
1950	January	12	2030
		13	2130
	February	12	1190
		13	2060
		14	2060
		15	1900
		16	2140
		17	2270
		18	732
		19	1520
		20	2660
		21	2220
		22	1970
		23	2060
		24	2160

Appendix F. Months with mean flows less than or equal to 1600 cfs over the period of hydrologic record for the Lower St. Croix River at St. Croix Falls, WI. Discharge data taken from USGS gage no. 53405000.

YEAR	MONTH	CFS	YEAR	MONTH	CFS	YEAR	MONTH	CFS
1910	Jul	1358	1926	Feb	1307	1937	Dec	1551
1910	Aug	1344	1929	Aug	1556	1938	Jan	1457
1910	Sep	1416	1930	Aug	1233	1938	Feb	1568
1910	Oct	1515	1930	Sep	1325	1940	Jan	1433
1910	Nov	1342	1931	Jan	1562	1940	Feb	1567
1910	Dec	1287	1931	Aug	1519	1940	Jul	1592
1911	Jan	1157	1931	Sep	1384	1940	Sep	1598
1911	Feb	1417	1932	Feb	1538	1948	Sep	1409
1912	Jan	1489	1932	Jul	1307	1948	Oct	1452
1912	Feb	1447	1932	Aug	1165	1961	Aug	1561
1912	Mar	1538	1932	Sep	1344	1963	Feb	1533
1912	Nov	1553	1932	Oct	1380	1964	Jan	1563
1912	Dec	1491	1932	Dec	1395	1964	Feb	1514
1913	Jan	1328	1933	Jan	1341	1968	Feb	1586
1913	Feb	1257	1933	Feb	1311	1970	Aug	1495
1914	Feb	1530	1933	Jul	1222	1970	Sep	1554
1917	Dec	1589	1933	Aug	945	1976	Aug	1475
1918	Jan	1554	1933	Sep	1152	1976	Sep	1292
1921	Nov	1582	1933	Oct	1540	1976	Nov	1569
1922	Jan	1513	1933	Nov	1554	1976	Dec	1492
1922	Feb	1551	1933	Dec	1544	1977	Jan	1488
1924	Jan	1443	1934	Jan	1554	1977	Feb	1456
1924	Feb	1433	1934	Feb	1389	1988	Jul	1345
1925	Jan	1331	1934	Jun	1481			
1925	Feb	1501	1934	Jul	1014			
1925	Aug	1356	1934	Aug	839			
1925	Sep	1481	1934	Sep	1402			
1925	Oct	1539	1935	Jan	1583			
1925	Nov	1459	1936	Feb	1455			
1925	Dec	1350	1936	Jul	1303			
1926	Jan	1168	1936	Aug	1274			

ADDENDUM A

Addendum A is provided as a supplement to the February 1995 report Instream Flow Requirements of Quadrula fragosa and the Aquatic Community in the Lower St. Croix River Downstream of the Northern States Power Hydroelectric Dam at St. Croix Falls, Wisconsin, prepared by Shawn L. Johnson, Minnesota Department of Natural Resources. This addendum contains information generated in the original analyses but presented here as figures that were not included in the main report. These figures summarize the composite suitability weighting factors, an index of habitat suitability, of each cell along each of the three PHABSIM transects established in the east channel at Folsum Island, Interstate State Park (Figure A1) at dam releases of 800, 1600, 2400, and 3200 cfs. Flows are in multiples of 800 cfs because each of the eight turbines at the dam is capable of releasing 800 cfs at its most efficient operational setting. From April 1 through October 31, NSP is required to maintain a minimum dam release of 1600 cfs; throughout the rest of the year, they voluntarily maintain a minimum release of 800 cfs. At dam releases of 800, 1600, 2400, and 3200 cfs there was approximately 10, 350, 900, and 1400 cfs flowing through the east channel (see section 3.1.2 and Appendix A, main report). All references to discharge in this addendum refer to the discharge being released from the dam.

Based on the recommended application of PHABSIM, the lowest discharge that could be reliably modeled in the east channel was 1130 cfs. Although 800 cfs is below this recommended value, we did model the east channel at 800 cfs for comparative purposes and have included these results in the following figures. We believe that the modeling results at 800 cfs reflect actual conditions in the east channel based on 1) visual observations of the channel at 800 cfs, 2) modeling results at 1130 cfs, and 3) field measurements at 1600 cfs.

To calculate composite suitability weighting factors, each transect was divided into cells based on the location of verticals at which depth, velocity, and substrate were measured (Figure A2). These habitat variables were measured at 1600 and 3200 cfs and simulated at 800 and 2400 cfs. Depth, velocity, and substrate values were each assigned a suitability value between 0.0 and 1.0 based on the habitat suitability criteria developed for mussel density and species richness (see sections 3.4.1 and 4.1 and Figures 5, 6, and 7, main report). A suitability value of 0.0 indicates the least preferred or least suitable habitat; a value of 1.0 indicates the most preferred or most suitable habitat. The three suitability values were multiplied together to determine the composite suitability weighting factor for each cell along the three transects at the four discharges. Also, the habitat type of each cell at each discharge was determined based on the criteria described in section 3.4.4 of the main report.

Results from this analysis suggest that the availability of suitable mussel habitat in the east channel is strongly influenced by discharge. At a dam release of 800 cfs, much of the east channel is dewatered and its wetted area consists of shallow, slow moving water which provides poor habitat conditions for both mussel density and species richness (Figures A3-A8). At 1600 cfs, most of the channel is inundated but suitable mussel habitat is still limited, especially for mussel density, due to shallow depths and low velocities. Of the four flows examined, 3200 cfs provides the best habitat conditions for mussels. Because Q. fragosa was found in habitat supporting dense, diverse mussel assemblages, flows that provide suitable habitat for the mussel community should also provide suitable habitat for Q. fragosa.

Discharge also influences the diversity of available habitat types, an important factor governing the diversity of biota found within a stream. At 800 cfs, the east channel consists almost entirely of shallow pool habitat (Figures A9-A11). As flow increases, habitat diversity also increases with 3200 cfs providing the most diverse conditions. Riffle habitat, which is very biologically important and productive habitat, is absent at 800 cfs but abundant at 2400 and 3200 cfs. Other than in the east channel, riffle habitat is scarce or absent in the other three channels modeled (see section 4.2.4, main report).

The recommended run-of-river flow regime (see section 5.3, main report) would increase the availability of suitable mussel habitat in the east channel over the current peaking flow regime. Flows in the Lower St. Croix River typically exceed 5000 cfs during spring. Considering that the turbine capacity at the dam is 6400 cfs, little or no peaking probably takes place in spring. Flows range between 2000 and 4000 cfs throughout the rest of year, during which time peaking operations can be expected. During peaking operations, discharge rapidly fluctuates daily between impounding flows (e.g., 800 cfs during winter and 1600 cfs during summer) and generation flows (e.g., 6400 cfs). Consequently, flows between 2000 and 4000 cfs, which provide good habitat conditions for mussels in the east channel, occur for only short periods of time as flows are rapidly rising or dropping. These daily fluctuations in flow typically exceed even the most extreme natural seasonal fluctuations. In the east channel, large areas of the streambed are alternately dewatered and inundated on a daily basis. Even when inundated, this "intertidal zone" is unusable habitat for many aquatic organisms, especially relatively sessile animals like mussels which can not move with the rapidly receding and advancing water. Natural flows of 1600 cfs or less occur infrequently (see 5.3.1, main report). Therefore, the magnitude and frequency of dewatering would be drastically reduced and the amount of suitable mussel habitat would be greatly increased a run-of-river flow regime as compared to a peaking flow regime.

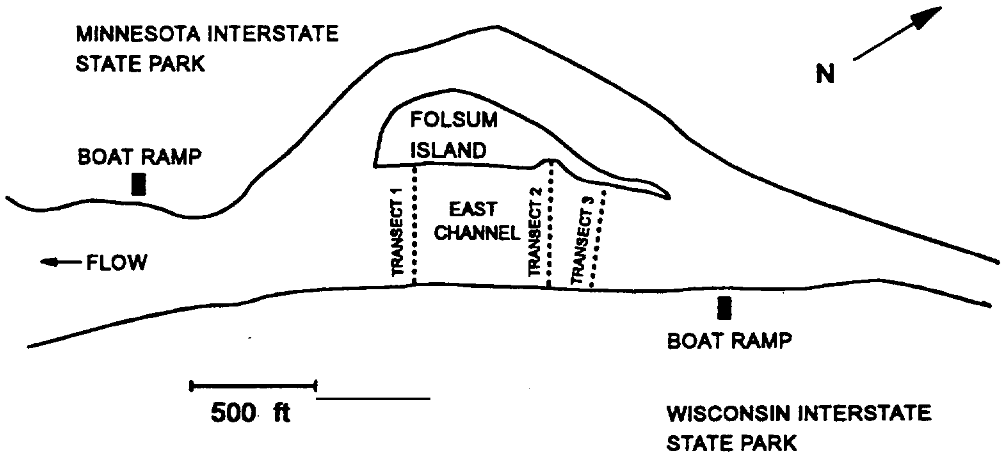

Figure A1. Location of PHABSIM transects in the east channel at Folsum Island, Interstate State Park, Lower St. Croix River, MN and WI.

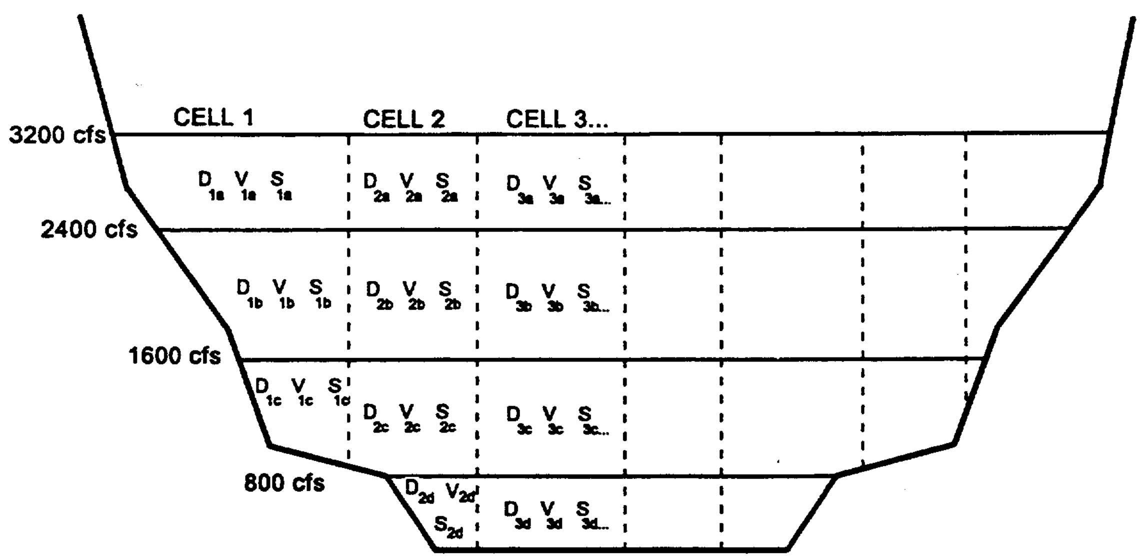

Figure A2. Generalized cross-sectional view of a PHABSIM transect at dam releases of 800, 1600, 2400, and 3200 cfs. Depth (D), velocity (V), and substrate (S) were measured in each cell at 1600 and 3200 cfs and simulated at 800 and 2400 cfs.

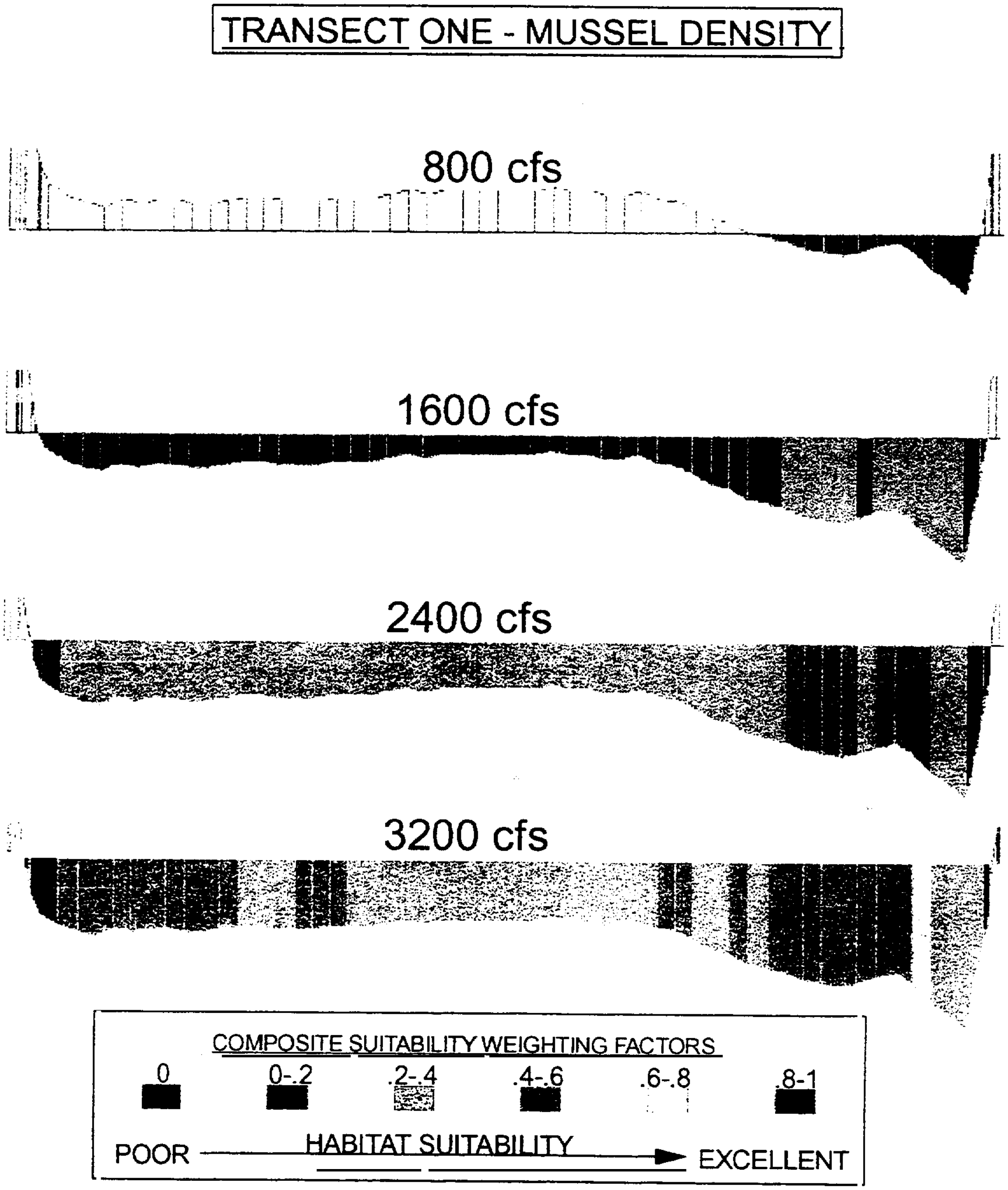

Figure A3. Cross-sectional view of composite suitability weighting factors for mussel density at dam releases of 800, 1600, 2400, and 3200 cfs along transect one in the east channel at Interstate State Park, Lower St. Croix River, MN and WI. Composite suitability weighting factors, S_i, were calculated using the multiplicative aggregation function $S_i = S_d * S_v * S_s$ where S_d, S_v, and S_s are mussel density suitability criteria values (range 0.0-1.0) for depth, velocity, and substrate (see figures 5, 6, and 7, main report).

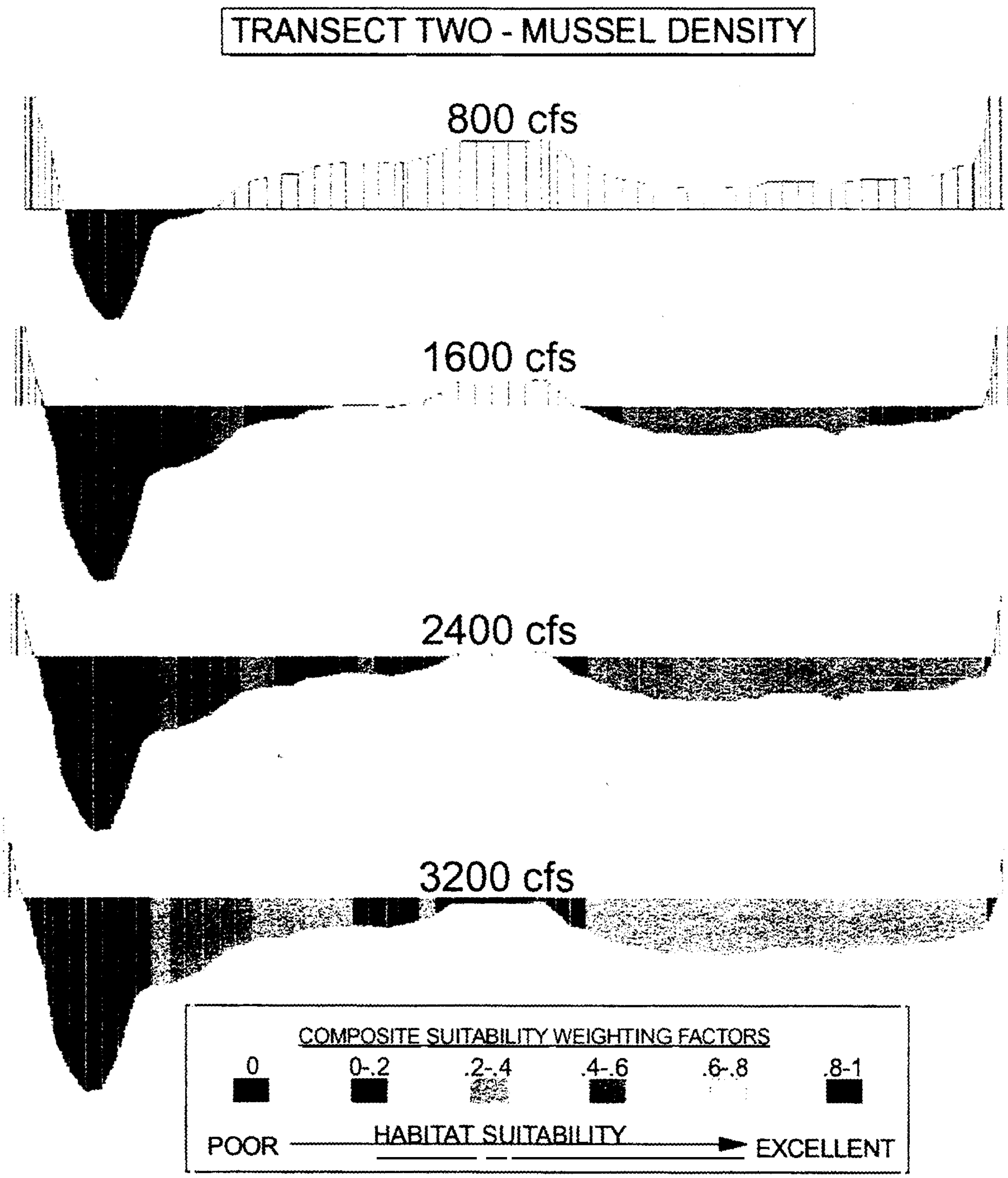

Figure A4. Cross-sectional view of composite suitability weighting factors for mussel density at dam releases of 800, 1600, 2400, and 3200 cfs along transect two in the east channel at Interstate State Park, Lower St. Croix River, MN and WI. Composite suitability weighting factors, S_i, were calculated using the multiplicative aggregation function $S_i = S_d * S_v * S_s$ where S_d, S_v, and S_s are mussel density suitability criteria values (range 0.0-1.0) for depth, velocity, and substrate (see figures 5, 6, and 7, main report).

TRANSECT THREE - MUSSEL DENSITY

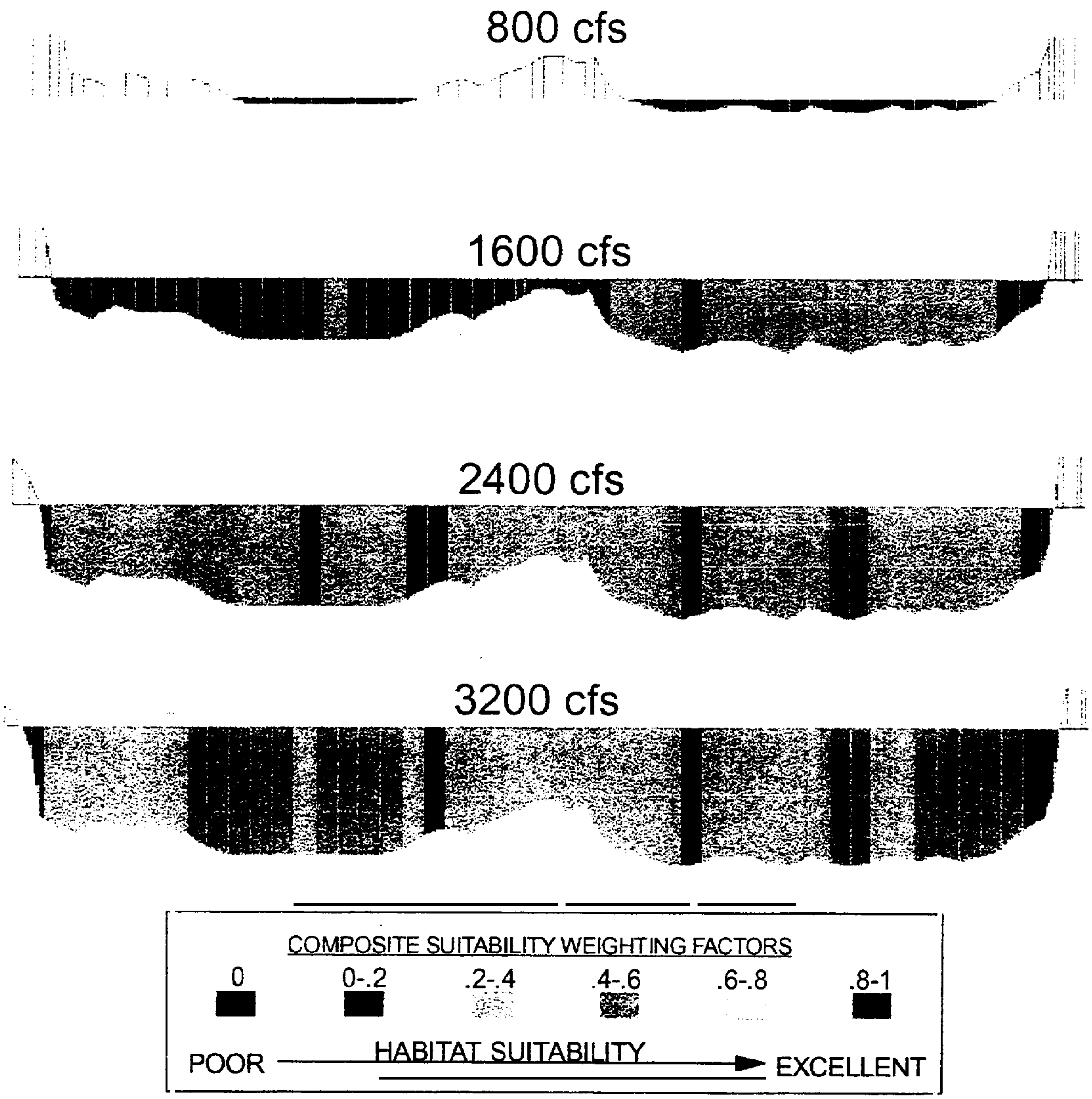

Figure A5. Cross-sectional view of composite suitability weighting factors for mussel density at dam releases of 800, 1600, 2400, and 3200 cfs along transect three in the east channel at Interstate State Park, Lower St. Croix River, MN and WI. Composite suitability weighting factors, S_i, were calculated using the multiplicative aggregation function $S_i = S_d * S_v * S_s$ where S_d, S_v, and S_s are mussel density suitability criteria values (range 0.0-1.0) for depth, velocity, and substrate (see figures 5, 6, and 7, main report).

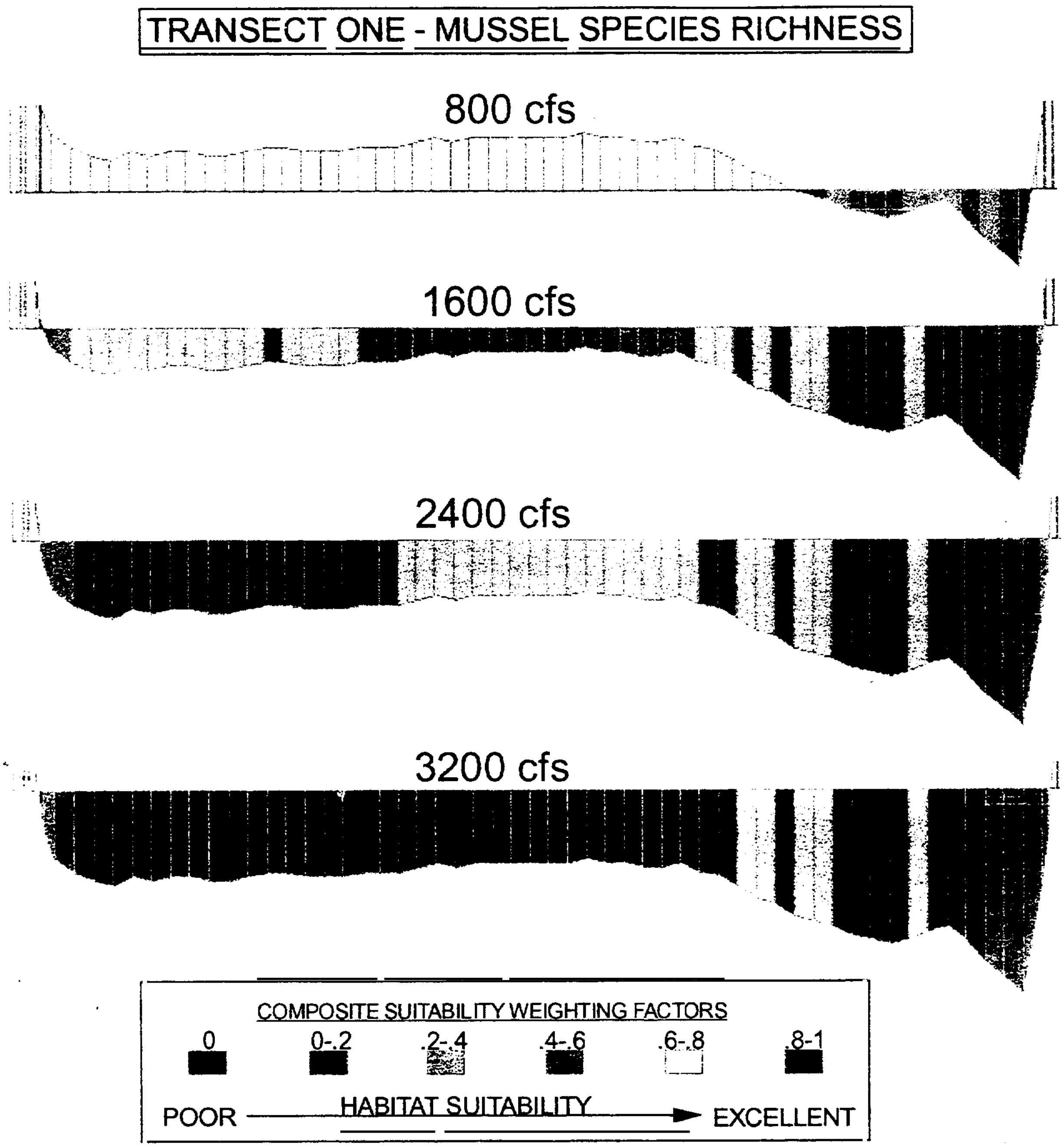

Figure A6. Cross-sectional view of composite suitability weighting factors for mussel species richness at dam releases of 800, 1600, 2400, and 3200 cfs along transect one in the east channel at Interstate State Park, Lower St. Croix River, MN and WI. Composite suitability weighting factors, S_i, were calculated using the multiplicative aggregation function $S_i = S_d * S_v * S_s$ where S_d, S_v, and S_s are mussel species richness suitability criteria values (range 0.0-1.0) for depth, velocity, and substrate (see figures 5, 6, and 7, main report).

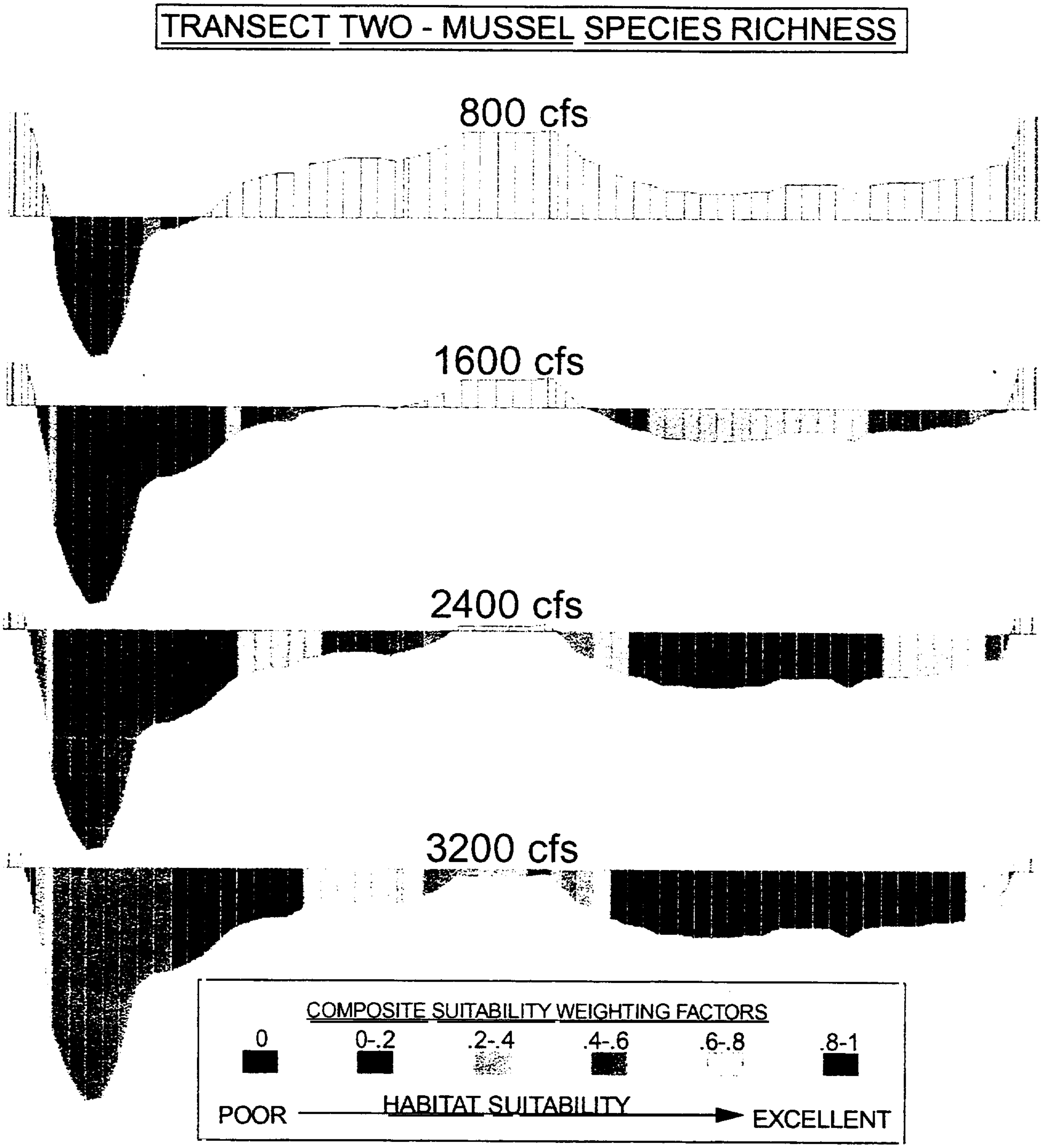

Figure A7. Cross-sectional view of composite suitability weighting factors for mussel species richness at dam releases of 800, 1600, 2400, and 3200 cfs along transect two in the east channel at Interstate State Park, Lower St. Croix River, MN and WI. Composite suitability weighting factors, S_i, were calculated using the multiplicative aggregation function $S_i = S_d * S_v * S_s$ where S_d, S_v, and S_s are mussel species richness suitability criteria values (range 0.0-1.0) for depth, velocity, and substrate (see figures 5, 6, and 7, main report).

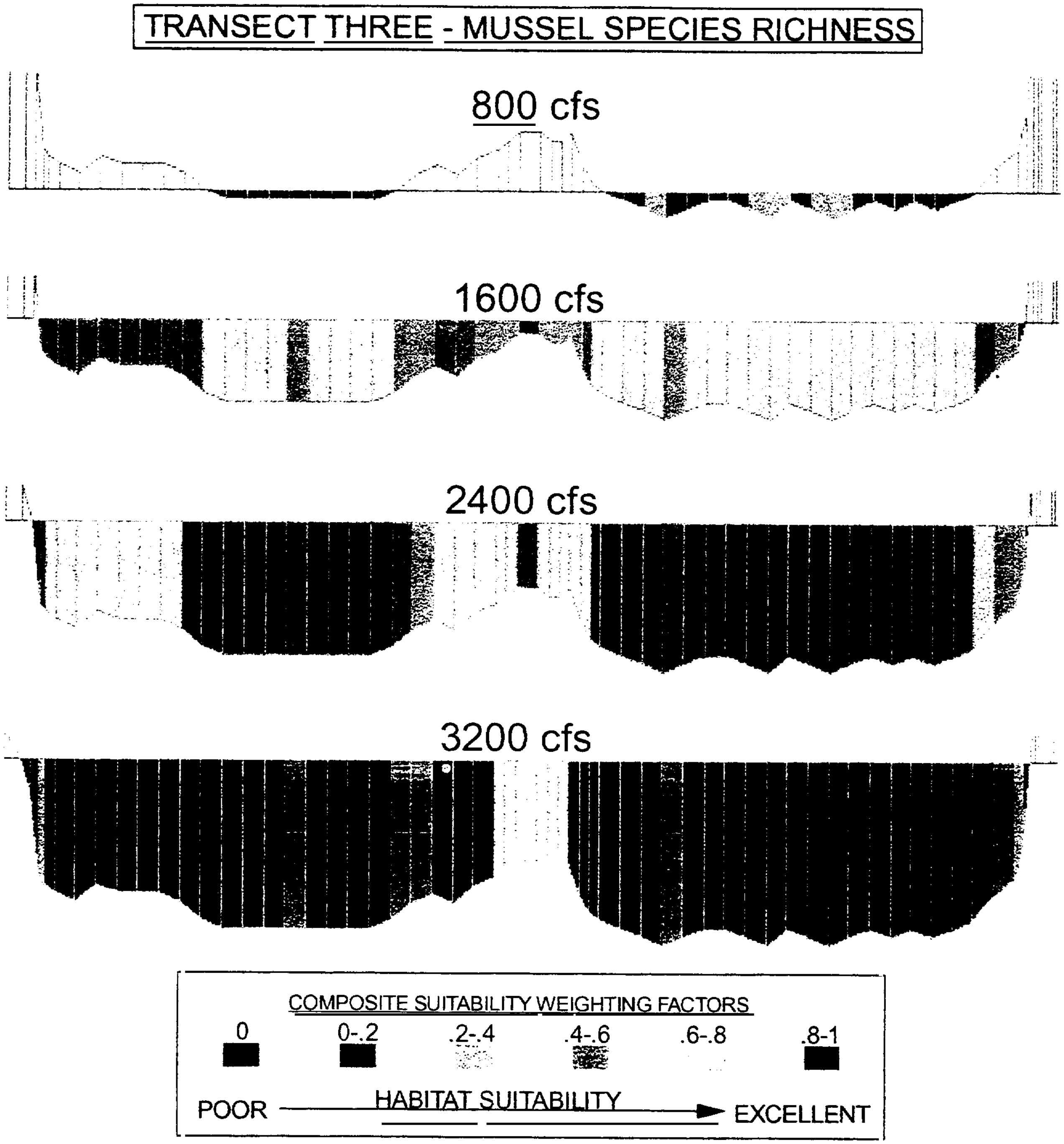

Figure A8. Cross-sectional view of composite suitability weighting factors for mussel species richness at dam releases of 800, 1600, 2400, and 3200 cfs along transect three in the east channel at Interstate State Park, Lower St. Croix River, MN and WI. Composite suitability weighting factors, S_i, were calculated using the multiplicative aggregation function $S_i = S_d * S_v * S_s$ where S_d, S_v, and S_s are mussel species richness suitability criteria values (range 0.0-1.0) for depth, velocity, and substrate (see figures 5, 6, and 7, main report).

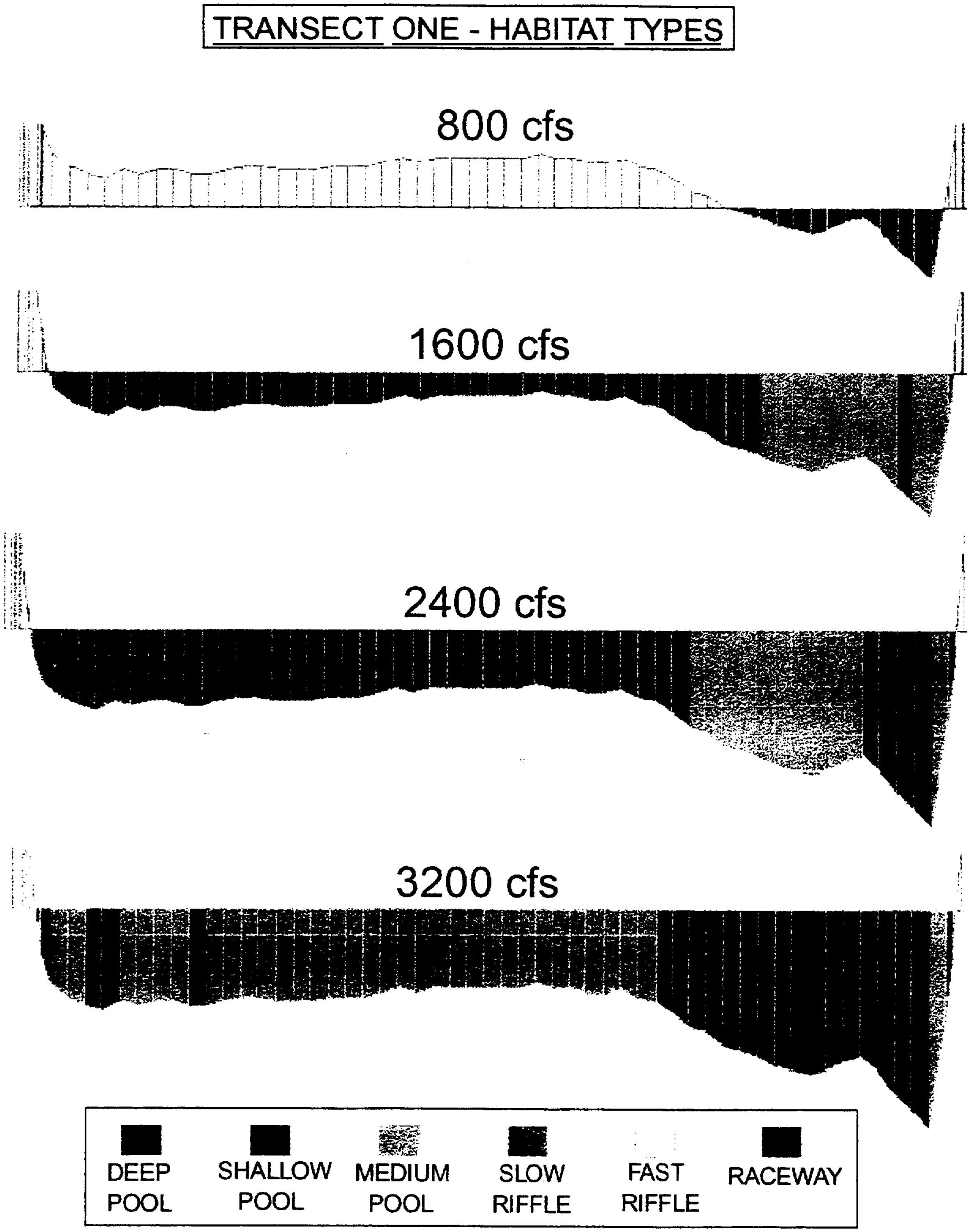

Figure A9. Habitat types present at dam releases of 800, 1600, 2400, and 3200 cfs along transect one in the east channel at Interstate State Park, Lower St. Croix River, MN and WI. Definition of habitat types is provided in section 3.4.4 of main report.

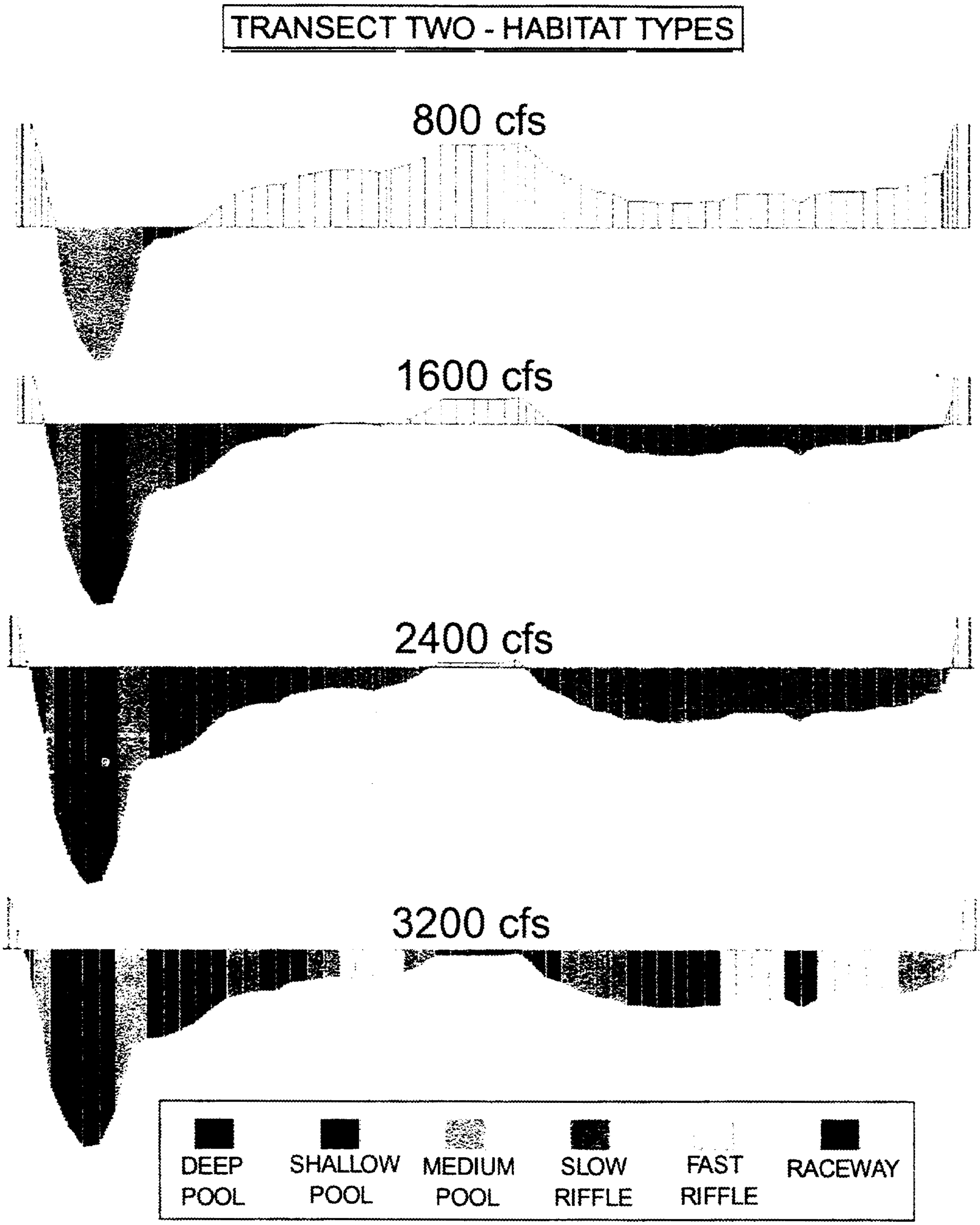

Figure A10. Habitat types present at dam releases of 800, 1600, 2400, and 3200 cfs along transect two in the east channel at Interstate State Park, Lower St. Croix River, MN and WI. Definition of habitat types is provided in section 3.4.4 of main report.

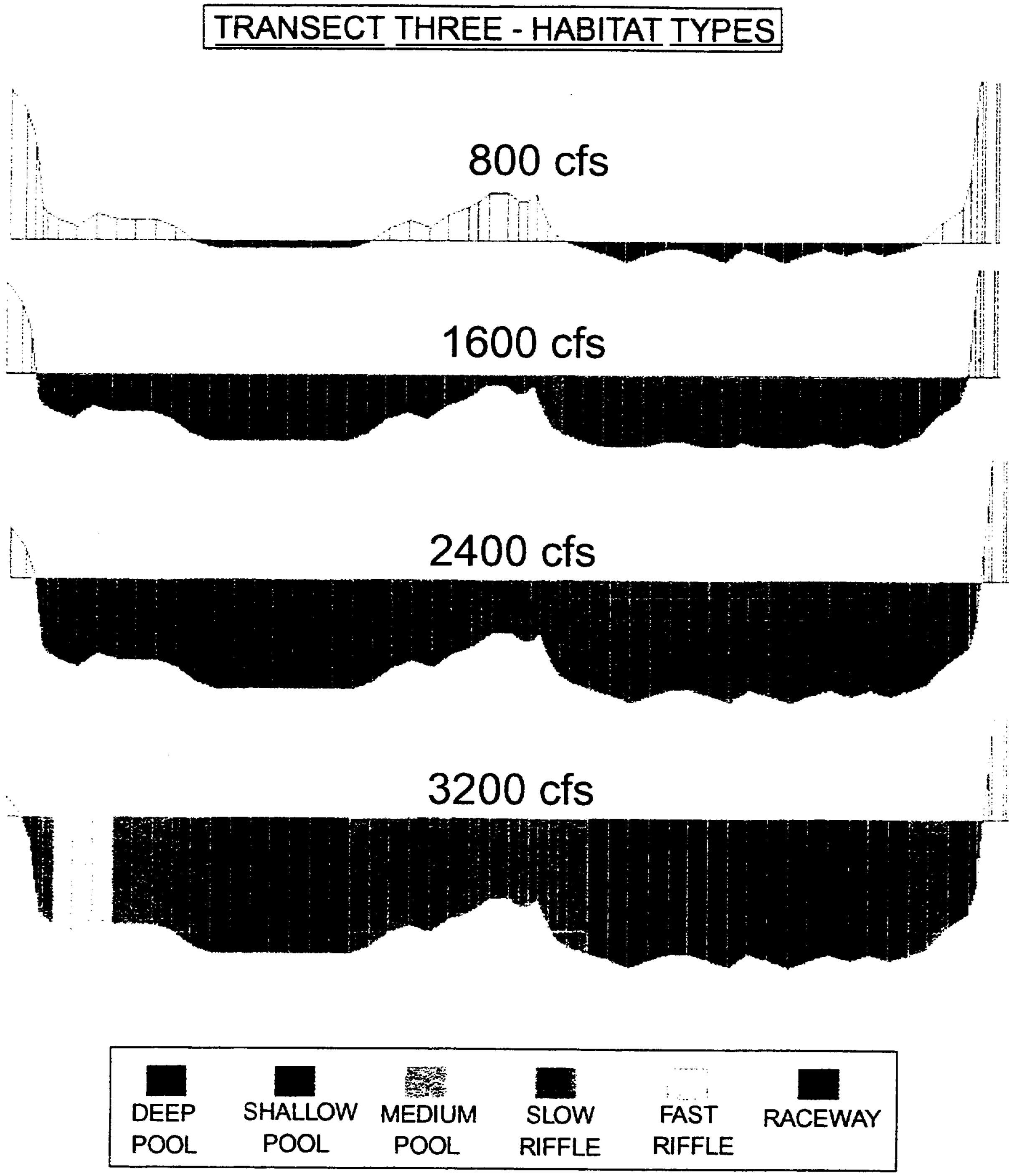

Figure A11. Habitat types present at dam releases of 800, 1600, 2400, and 3200 cfs along transect three in the east channel at Interstate State Park, Lower St. Croix River, MN and WI. Definition of habitat types provided in section 3.4.4 of main report.

APPENDIX 3

HORNBACH'S (1992) REPORT

ON HABITAT USE

BY

Q. FRAGOSA

An examination of the Population Structure, Community Relationships and Habitat Characteristics for the Winged Mapleleaf Mussel (*Quadrula fragosa*) at Interstate Park, Saint Croix River, Wisconsin and Minnesota.

by
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Submitted to Wisconsin DNR and Minnesota DNR
November 1992

Introduction

Freshwater mussels (Family Unionidae) are widely distributed throughout the United States. There are 44 species of freshwater mussels currently on the federally endangered species list (Fish and Wildlife Service, 1991). Despite this fact, there is little known concerning the factors which control the distribution of these organisms, especially in flowing water systems. Certainly factors such as surface geology, stream size, water quality, substrate type, water flow, and food availability, among others, are important in determining the community structure and population dynamics of freshwater mussels (Strayer, 1983; Holland-Bartels, 1990).

In the past there have been studies on the unionids in the St. Croix River. Baker (1928) cited 15 species from the St. Croix River although he classifies some species as statewide. Dawley (1947) reported 29 species of unionids from the St. Croix River (in addition to 4 species found in tributaries to the St. Croix but not in the river proper). Fuller (1978) recorded 23 species of unionids from the St. Croix River at Hudson, WI. Stern (1983) reported 14 species of unionids from a single site on the St. Croix. Doolittle (1988) has conducted the most extensive study to date on the distribution of unionids in the St. Croix River. Thirty-seven species of unionids (including 2 only represented by dead shells) were reported by Doolittle in the river proper. Quantitative studies by Hornbach (1992) at Franconia, MN have indicated densities of 12 mussels/m^2 at that site. Semi-quantitative estimates by Doolittle (1988) gave ranges of 0.1 to 16.3 mussels/m^2 in established beds in the St. Croix.

Of particular interest in the St. Croix River is the presence of two species of endangered mussels, *Lampsilis higginsi* and *Quadrula fragosa*. *Lampsilis higginsi*, while found in the St. Croix, is also found throughout the Upper Mississippi River, albeit at low densities (Havlik, 1981; Holland-Bartels, 1990). The winged mapleleaf, *Quadrula fragosa*, previously distributed in 11 other states, is presently restricted to the St. Croix River (Fig. 1).

Due to the highly restricted nature of *Q. fragosa*, the major thrust of this research project was to investigate the factors which may influence the distribution and abundance of this endangered species. In addition, efforts were made to characterize the mussel community associated with the presence or absence of *Q. fragosa*.

Material and Methods

Study Site

The study site was located on the St. Croix River at Taylor's Falls, MN, St. Croix Falls, WI at Interstate Park (Fig. 2). There is an extremely diverse and dense bed of mussels at this site (Doolittle, 1988). Heath and Miller (pers. comm.) have indicated that the greatest number of *Q. fragosa* in the St. Croix are found in this bed. This site is approximately 3.5 km downstream of an NSP hydroelectric dam. This is a peaking dam and thus greatly influences the daily flow regime at the sampling site. Figure 3 gives an example of the daily changes in flow that occurred just below the hydroelectric dam during January-October of 1992 (data from USGS gage 5-3405 at St. Croix Falls, WI.)

Mussel sampling

Mussels were collected by divers using SCUBA equipment. Fifteen sampling sites were established for quantitative sampling (Fig. 2). The sampling regime was set so that 5 sites (A-E) were arranged parallel to the flow of the river in the middle (M) and along the east (E) and west (W) shores of the river. The location of each site was recorded using a Magellan NAV-5000 Geographical Positioning System. At each of these sites a 2x5 m PVC grid was placed on the bottom of the river. Using this frame as a guide 10 0.25 m^2 quadrat samples were taken. All of the substrate within the 0.25 m^2 quadrat was removed and placed in a bucket. The contents were then sieved and any mussels > 0.5 mm were collected. Mussels were identified and their shell length (anterior-posterior dimension), width (lateral dimension) and height (dorsal-ventral dimension) was measured to the nearest 0.05 mm with a dial caliper. A number of studies have indicated that shell shape may vary along the length of a stream (e.g. Mackie and Topping, 1988). Therefore, since length alone is not a good indicator of age, we made the measurements of shell width and height.

To study changes in growth rate of mussels over time, we removed samples of two common species (*Truncilla truncata* and *Fusconaia flava*) from the river in order to examine both external and internal shell growth rings. Since Neves and Moyer (1988) have indicated that in some species external growth rings are not an accurate measure of age, we took a representative size-range sample of mussels for these two species and examined their internal growth rings as a check on the external ageing method. This was accomplished by cutting the shell with a diamond saw from the umbo to the ventral margin and then sectioning the shell (Neves and Moyer, 1988). The length of the shell deposited each year was determined my measuring the distance between adjacent growth rings. This was accomplished by using a digitizing pad attached to a Macintosh II cx computer, and utilizing Image software developed by Wayne Rasband (National Institute of Mental Health).

At the location of the 10 subsamples taken at each site, the water depth was measured with a calibrated rod, and water flow at the bottom and 0.6 depth was taken with a Marsh-McBirney Model 201-D flow meter. The time at which these measurements were taken was recorded so that flow and depth could be correlated with discharge measurements from the USGS gage.

When the quadrat samples were taken to ascertain the population density of mussels, the buckets containing the mussels and substrate were sieved and the wet weight of the substrate retained in each of five sieves (65, 57, 12.7, 6.35 and 0.5 mm openings) was obtained. From the weights of these fractions the average particle size was determined (Lewis, 1984).

Water sampling

To determine the availability of nutrients to mussels water samples were taken from the river. Samples were taken at the sediment water interface and at 0.5 m above the bottom. PVC standpipes (2.54 cm in diameter) were attached to a cement block so that the openings of the pipes could be oriented upstream. One pipe allowed samples to be taken at the sediment-water interface, while the other allowed sampling of the water column 0.5 m above the bottom. These pipes were connected by garden hoses to diaphragm pumps which permitted samples of water to be pumped to the surface. The time at which these samples were taken was recorded to allow for total suspended solids measurements to be adjusted for discharge.

The amount of suspended solids in the water samples was determined by APHA (1980) methods using Whatman AH934 glass fiber filters. Both the total suspended solids as dry weight and the organic fraction of the total suspended solids (assessed by loss on ignition) was determined.

Additional sampling for Quadrula fragosa

Based on the 150 0.25 m^2 quadrats sampled, only 1 *Q. fragosa* was found (see results). In order to increase the number of samples in which we found *Q. fragosa*, divers were instructed to visually search specifically for the winged mapleleaf. Once a mussel was located, a float was placed to mark the exact location of the discovery. The location was then recorded with the GPS system and a 0.25 m^2 quadrat was taken so that the nature of the substrate and the mussel community in association with *Q. fragosa* could be determined. In addition, the water depth, flow and time when these measures was taken were recorded as noted above. A total of 36 diver-hours were spent in this additional searching.

Additionally data provided by David Heath and Glen Miller for *Q. fragosa* that they have collected in the St. Croix River, were used to examine the age structure of the winged mapleleaf population at Interstate Park.

Data were also obtained from the USGS to examine the historical trends in discharge at the Interstate site.

Statistical analyses

All statistical analyses were conducted with JMP Version 2.0 (SAS Institute, 1989) using a Macintosh II ci microcomputer or on a VAX 4000-400 using SAS (SAS Institute, 1982). Levels of statistical significance were assigned at the 0.05 level.

RESULTS AND DISCUSSION

Water Depth, Flow, Substrate and Total Suspended Solids Analyses

The exact locations of the sampling sites, the dates on which these sites were visited, and various habitat characteristics for each site are given in Table 1. There were significant differences in depth of the sites examined (Table 2). The river is fairly shallow along the east side of Folsom Island, where the majority of this study was conducted (Fig. 4A). The river is deeper at the upstream end of the island (sites AE, AM and AW). There is also a somewhat deeper channel along the most eastern shore. Water velocity [whether measured at the sediment water interface (Fig. 4B) or higher in the water column at the 0.6 depth (Fig. 4C)] varied significantly among sites examined (Table 1) and was greatest at the upstream end of the sampling site and along the east shore of this channel. However, these flow data must be examined carefully since the rates were measured at different discharge levels (Table 1). For example, at site CE the water depth and flow at the bottom and 0.6 depth and was measured on June 30, 1992 at 14:29 (UT), when the discharge was 1637.449 cfs. The depth was 0.23 m, the bottom flow was 0.30 m/s and the 0.6 flow was 0.52 m/s. At 15:40 UT on the same day (about an hour later) the depth had increased to 0.68 m, the bottom flow to 0.34 m/s, the 0.6 depth flow to 0.81 m/s and the discharge to 5210.075 cfs. Obviously there are great fluctuations in river discharge (218.6% increase in discharge) but interestingly with an almost 196% increase in depth and over a 56% increase ih water velocity at the 0.6 depth, at the bottom, where mussels are found, the water velocity only increased about 13%. Once the hydrologic study that is currently being conducted by the Minnesota DNR at this site is completed, it should be possible to estimate the actual range of flows experienced by mussels at these locations.

Substrate composition was fairly similar throughout the study reach, though statistical analyses indicated there were significant differences among sites (Table 1- Fig. 5A). The most obvious variant is the somewhat finer-grained sediments found at site A. This is most likely due to the greater depth in the region resulting in a depositional area for finer sands. There was in fact a significant relationship ($F=24.17$, 1,149 df, $p<0.0001$) between water depth and the size of the sediment (Fig. 5B), with finer-grained sediments being associated with deeper water.

Figures 6A and 6B show the amount of total suspended solids and the percent organic matter of the total suspended solids of water collected at 0.5 m above the bottom of the river. Figures 6C and 6D show similar measures for water taken at the sediment-water interface. It is apparent that there is variation among sites in both the total suspended solids and the organic content of these solids (see also Table 2). It is also obvious that there is a difference in the amount of total suspended solids in water collected at the sediment-water interface or above this interface. Generally there were greater amounts of suspended solids in the water collected at the sediment-water interface (least square means for total suspended solids as dry weight at the sediment water interface was 17.3 mg/L and only 11.3 mg/L for water taken 0.5 m above the bottom). An analysis of variance indicated that the difference in total suspended solids as dry weight between water collected at the sediment-water interface or above was not quite statistically significant ($F=2.9$, 1,89 df, $p=0.09$). We believe that the greater amount of suspended solids at the sediment-water interface is due to transport of materials along the bottom of the river. Much of the material in the suspended solids in inorganic in nature (low percent organic matter) and is probably fine sand (Hornbach, 1992). There was a significantly greater amount of total suspended solids as ash-free dry weight in water taken from the sediment water interface as compared to water taken 0.5 m above the bottom (least squares mean for sediment-water interface=3.15 mg/L and for 0.5 m above the bottom=2.17 mg/L; $F=5.72$, 1,89 df, $p=0.02$). This difference in the amount of total suspended solids as dry weight between water from the sediment-water interface and water taken above the bottom, coupled with the almost statistically significant difference in total suspended solids as dry weight, led to significant variations in the % organic matter in the suspended solids. The amount of organic matter significantly varied with the interaction between depth and location in the river, i.e. upstream-downstream and east to west ($F=1370$, 8,89 df, $p<0.01$). This significant interaction meant that depending on location in the river there may or may not be differences in the amount of organic content of the suspended solids in the water taken from the sediment-water interface or 0.5 above this interface. This variability is most likely due to variation in substrate type and flow which could lead to turbulence and the resuspension of deposited sediments. There indeed was a significant relationship between the rate of flow at the 0.6 depth and the % organic matter in the suspended solids collected at the sediment-water interface ($F=8.33$, 1,12 df, $p=0.01$) and close to a significant relationship between the % organic matter and the flow at the bottom ($F=3.65$, 1,13 df, $p=0.08$). At higher rates of bottom flow there was a lowered percent of organic matter in the suspended solids collected from the bottom. For water taken from 0.5 m above the sediment-water interface there was a significant relationship between depth and % organic matter of the solids from this sample with water taken from shallower areas having a greater percent organic matter ($F=7.71$, 1,13 df, $p=0.02$). However, there were no significant relationships among water velocity or depth and other measures of suspended solids the amount of suspended solids or the percent organic matter of the suspended solids at the sediment water interface (*for water from the sediment-water interface*: total as dry weight vs depth, $F=0.52$, 1,13 df, $p=0.48$; total as ash-free dry weight vs depth, $F=0.002$, 1,13 df, $p=.97$; %organic matter vs depth, $F=1.78$, 1,13 df, $p=0.21$; total as dry weight vs bottom flow, $F=0.75$, 1,13 df, $p=0.40$; ash-free dry weight vs bottom flow, $F=0.23$, 1, 13 df $p=0.64$; total as dry weight vs 0.6 flow, $F=2.26$, df=1,12, $p=0.16$; total as ash-free dry weight vs 0.6 flow, $F=0.79$ 1,12 df, $p=0.39$; *for water from 0.5 m above the sediment-water interface*: total as dry weight vs depth, $F=2.36$, 1,13 df, $p=0.11$; total as ash-free dry weight vs depth, $F=0.68$, 1,13 df, $p=.43$; %organic matter vs depth, $F=1.78$, 1,13 df, $p=0.21$; total as dry weight vs bottom flow, $F=0.04$, 1,13 df, $p=0.85$; ash-free dry weight vs bottom flow, $F=0.02$, 1; 13 df $p=0.89$, % organic vs bottom flow $F=0.16$, 1,13 df, $p=0.69$; total as dry weight vs 0.6 flow, $F=.21$, df=1,12, $p=0.66$; total as ash-free dry weight, $F=0.79$ 1,12 df, $p=0.62$; % organic matter vs 0.6 flow, $F=1.52$, 1,12 df, $p=0.24$). Thus it appears that there is a greater amount of suspended materials at the sediment-water interface and that often this material is fin sand, especially in areas of greater depth and/or greater flow.

General Community and Population Structure

Based on the examination of over 1174 mussels in the 150 0.25 m^2, we found 29 species of mussels, including 1 specimen of the endangered species, *Quadrula fragosa* (Fig. 7 - Appendix 1). The deertoe, *Truncilla* *truncata* dominated the community, comprising 58.5% of the mussels found. All other species comprised less than 10% of the individuals found.

Doolittle (1988) found 31 species of mussels at Taylor's Falls, MN. He gave *Fusconaia flava* and *Truncilla truncata* as the dominant species at this site. Doolittle (1988) showed that *Actinonaias ligamentina*, *Fusconaia flava*, *Elliptio dilatata*, *Amblema plicata* and *Lampsilis radiata* were the most common and abundant species found in the river as a whole. Also these species were often found associated with one another. He also noted, however, that less common species, such as *Truncilla truncata*, *Quadrula metanevra* and *Tritigonia verrucosa* are also found associated with one another. At Interstate Park, we found *T. truncata* as the dominant, with *T. donaciformes*, *A. carinata* and *Q. pustulosa* as abundant, subdominants. Thus at Interstate Park, there appears to be a unique mussel community composition when compared to other reaches of the St. Croix.

In Doolittle's (1988) study of the St. Croix River, the Interstate site harbored the most dense and diverse mussel community. Data from Hornbach (unpublished) supports this result. On average we found 3.25 species of mussels per 0.25 m^2 quadrat at the Interstate site. The mean mussel richness (number of species per quadrat) varied significantly with site of collection (Table 1 - Fig. 8A). The maximum number of species per quadrat was 10.

Doolittle (1988) collected two semi-quantitative samples from the Interstate site (his relative abundance samples). In one sample he found 3.73 mussels/m^2 and in the other, 16.3 mussels/m^2. These values are much lower than the overall average of 56.6 mussels/m^2 that we found. Part of the difference could be that we sieved the substrate for mussels while Doolittle only removed mussels from the river without sieving the substrate. There were significant influences of upstream/downstream location and relation to the shore (E,M,W) in mussel density (Table 1). The greatest density of mussels were found at the upstream end of the sampling site and along the eastern shore (Fig. 8B). The size of mussels found were not as influenced by location in the river (Table 1 - Fig. 8C), although there was a significant interaction between the upstream/downstream location and the relation to the shore (E,M,W).

We believe that much of the variability in mussel community richness, mussel density and size was due to differences in substrate type and water depth. We found a significant relationship between the community richness and sediment size ($F=10.22$, 1,149 df, $p=0.0001$; Fig. 9A) and between water depth and richness ($F=40.12$, 1,149 df, $p<0.0001$). Figure 10A shows that there was a significant increase in community richness with depth. Figure 9B shows the relationship between the mussel density and the average sediment particle size from each of the samples ($F=5.01$, 1,149 df, $p=0.02$). It is evident that mussel density was greatest in areas of finer substrate. A relationship between sediment size and mussel density was noted by Stern (1983) for sites in the St. Croix and Wisconsin rivers. He found the greatest density of mussels in areas where there was a mixture of sediment from mud through boulders (>64 mm), which would include the gravel substrate in which we found most of our mussels. Doolittle (1988) and Hornbach (1992) also found that the greatest percentage of mussels in the St. Croix River were found in sand/gravel and sand/rock or gravel/rock substrates. In areas with very fine sand (smaller than that found in this study), Hornbach (1992) and Stern (1988) found few mussels. At the other extreme, few mussels are generally associated with extremely large substrates (e.g. boulders), thus the Interstate site appears to represent a site with high quality substrate for mussel populations. Thin shelled species are often found in greater density in fine substrates (e.g. silt) [Ortmann's (1920) "Law of Stream Distribution" - see discussion in Mackie and Topping (1988)] but many of the species found at Interstate Park are thicker-shelled species. Mussel density was also significantly influenced by depth ($F=131.04$, 1,149 df, $p<0.0001$; Fig. 10B), with greater numbers of mussels being found in deeper areas of the river.

The average size of mussel collected was not significantly related to substrate size ($F=0.59$, 1, 149 df, $p=0.44$; Fig. 9C). Nor was there a significant relationship between mussel size and water depth ($F=1.34$, 1,149 df, $p=0.25$; Fig. 10C). It is interesting to note that while on average there was an increase in the average size of mussel collected with depth (Fig. 10C), the smallest mussels collected were only found in shallow areas.

One hypothesis for the significant relationship between sediment size and density states that course substrates are indicative of stable habitats. These stable habitats are thus inhabited by greater numbers of mussels. One might also expect that there should have been significant relationships among sediment size and mussel community richness and average mussel size. This was true fo community richness (Fig. 9B) but not for mussel size (Fig. 9C). Holland-Bartels (1990) and Duncan and Thiel (1983) however noted no difference in the community structure among different substrate types but did find that the abundance of mussels did vary among sediment types.

In this study, there were significant relationships among water depth and mussel density and community richness. Apparently, even if sediment texture is conducive to mussel habitation, the depth of water is more important in structuring mussel communities. The cause behind the relationship between water depth and increased mussel density and richness is not known. Its possible that higher summer temperatures in shallow water or ice scouring in the winter may be responsible for the noted distribution. It is also possible that differences in fish-host behavior accounts for the noted distribution. The fact that more juvenile mussels are found in shallow waters (Fig. 10C) even though density and richness is lower in these regions (Fig. 10A,B) may indicate that during the summer these shallower regions are able to be colonized by juvenile mussels, but during the winter either these juveniles die or migrate to deeper waters. Mussel migration deeper into the sediment during the winter has been documented (Amyot and Downing, 1991) but horizontal movements appear to be in response to lowering water levels and not cooler temperatures in the winter (van der Schalie, 1938).

A number of analyses were conducted to examine whether there was a relationship between the amount of suspended solids and the mussel population density or community richness. Few significant relationships were found (Table 3). This could partially be due to the fact that water samples were taken when water discharge varied greatly (Table 1). The two interesting significant relationships that were found included decreases in mussel density and mussel community richness at sites where there was high organic content of the suspended solids collected at 0.5 m above the bottom. Whether or not this is a cause-and-effect relationship or merely a coincidence is unknown. Since there was no relationship between mussel density and community richness and the amount of organic matter in the suspended solids collected at the sediment-water interface, a cause-and-effect relationship with water collected 0.5 m above where the mussels are found seems doubtful.

Quadrula fragosa distribution at Interstate Park

As mentioned earlier, only 1 *Q. fragosa* was found among the 150 quantitative quadrats taken. Because of the lack of specimens, additional searches were undertaken for *Q. fragosa*. An additional 10 *Q. fragosa* were found (Table 4). The majority of the *Q. fragosa* found were taken from between 0.5 and 1.6 m. These mussels were taken from the upstream end of the bed at the level of the B sites (including BW and BM) and along the eastern shore (especially near sites BE through DE). The other mussels found in conjunction with *Q. fragosa* were quantified (Table 4). The mussel community found in conjunction with *Q. fragosa* was similar to that found in the 150 quantitative quadrats (Fig. 11). A LogLikelihood analysis indicated that in fact there was no significant difference in community structure (X^2= 31.3 df=1,1266, p=0.26) between samples with and without *Q. fragosa*.

Making other comparisons of the community data between quadrats with and without Q. *fragosa* indicated there were significant differences in mussel density (t=2.07, 159 df, p=0.04; Fig. 12A), mussel community richness (t= 3.70, 159 df, p=0.0003; Fig. 12B) and in the sizes of mussels collected (t=3.09, 1295 df, p=0.002; Fig. 13A). Even when examining a single species, e.g. *Truncilla truncata*, larger specimens of this species were found associated with *Q. fragosa* than without *Q. fragosa* (t=2.12, 762 df, p=0.03; Fig. 13B). All of these differences indicate that *Q. fragosa* is found in high quality mussel habitat. That is, *Q. fragosa* is found in locations of high species richness and mussel density and in areas where mussels can live to an old age (greater size).

Habitat characteristics of quadrats with and without *Q. fragosa* were also made. Figure 14A shows that there were no significant differences in the size of substrate in quadrats with and without *Q. fragosa* (t=0.25. 159 df, p=0.80). This similarity was confirmed by examining the percent of substrate found in each size category of substrate measured (Table 5).

There also were no significant differences in depth between quadrats with and without *Q. fragosa* ($t=0.81$, 159 df, $p=0.42$; Fig. 14B). There were, however, differences in the flow both at the bottom ($t=2.36$, 154 df, $p=0.02$) and at the 0.6 depth ($t=1.94$, 149 df, $p=0.05$) between quadrats with and without *Q. fragosa* (Figs. 14C and 14D). These differences must be carefully examined since discharge levels varied during the sampling period (Table 4). However, as mentioned earlier, even when depth varied by over 150% at one site, the bottom velocity only varied by 13%. This may indicate that the differences noted in bottom water velocity in quadrats with and without *Q. fragosa* may indeed be significant and important.

Figure 15 shows the number of *Q. fragosa* born in varying years at Interstate Park, based on data provided by Glen Miller and David Heath (pers. comm.) and from the *Q. fragosa* collected in this study (Table 6). The age of birth was estimated by back-calculation from counting growth rings. The greatest number of individuals collected at Interstate Park were born in 1984, with fewer numbers of mussels born in other years. Figure 16 shows the relationship between age and shell-length for the *Q. fragosa* collected at Interstate Park. As expected, growth decreases with age and thus the maximum shell length reaches an asymptotic value. While there were insufficient numbers to conduct a meaningful statistical analysis, it is interesting to note that there is a great deal of variation in shell length for mussels of the same age (Fig. 16). This variation is not necessarily dependant on the year in which the mussels were born. For example, 5 year old mussels born in 1984 varied in length from about 30 to over 80 mm. The cause of this great degree of variation is unknown. Even if the example just given is an extreme example, there appears to be, at a minimum, a range of at least 10 mm in size for mussels of the same age (Fig. 16). It is clear, however, that this variation in length does not result from varying shell shape, for there is a very tight relationship between shell length and shell height (Fig. 17; shell height = 5.73 + 0.80* shell length; $r^2=0.97$, $F=2696$, 1,75 df, $p<0.0001$). Consequently mussels which show greater shell lengths are likely to have total greater biomass than mussels with smaller shell lengths.

To examine whether there were significant changes in mussel growth with time for other species of mussels at Interstate Park, we aged 27 *Truncilla* *truncata* and 13 *Fusconaia flava*, other important members of the mussel community (Fig. 7). As expected, shell growth decreased with age for both species of mussels (Fig. 18). Utilizing analyses of covariance, with shell length increase in a given year as the dependant variable, year as the independent variable, age as the covariable, and allowing for heterogeneity of slopes (age*year), we were able to examine whether there were differences in growth (increase in shell length) among years, when adjusted for the age of the mussel. Figure 19A shows that for *Truncilla truncata* there were significant differences in growth rates among years (F=3.79, 8,109 df, p=0.001), with especially reduced growth in 1984 and 1985. Both of these values are, however, based on the examination of only 5 mussels and must be interpreted with caution. For *F. flava* most of the mussels examined were fairly young and we could only reliably examine past growth for the years 1988 -1991 (Fig. 19B). There was no significant difference in growth rates among these years (F=1.01, 3,46 df, p=0.39). Apparently throughout the period 1985-1992 few *Q. fragosa* were born, however growth rates for other species of mussels did not seem to be significantly lower that for other years. Thus the reason for the lack of apparent recruitment for *Q. fragosa* is not displayed in other mussel species. It is possible that the factors that resulted in reduced recruitment may not have expressed themselves in the growth rates of other species. For example there could have be a reduced availability of fish host for *Q. fragosa* in the late 1980s, and this would not necessarily impact the growth rates of other species.

Historic patterns of Discharge at Interstate Park

There has been concern that changes in discharge patterns at Interstate Park may be partially responsible for changes in the relative abundance of *Q. fragosa* . Fortunately there is a good database available to examine changes in discharge over time at Interstate Park. Figure 20 shows the mean daily discharge levels for 1902-1991. The lack of data for the July 1905-Dec 1909 is due to construction of the dam which has been functioning continuously since 1908. In the period 1902-June 1905 the average discharge was 4961 cfs (range 251-23600) while for the period 1910-1942 the average discharge was 3339 cfs (range 75-35800) and for the period 1943-1991 the average discharge was 4875 cfs (range 296-53900). Figure 21 shows the average monthly discharge over the period

1902-1991. From this figure it is apparent that there is a strong seasonal change in discharge, with discharge levels greatest during the spring and summer. From these monthly means, the deviation that each daily discharge level deviated from its long-term monthly mean was calculated. Figure 22 shows the deviation from the monthly means. This graph accentuates that part of the reason for the low average in the 1910-1942 period was the low flow during the dust-bowl period of the late 1930s (Fig. 22). Also there was a period in the late 1980s of low water levels. Unfortunately there is no historical data on the relative abundance of *Q. fragosa* in the St. Croix River and thus we do not know whether the present levels of the winged mapleleaf found in the river are representative of historic levels.

Fuller (1974) points out that waterways below dams will occasionally dry out and that most mussels experience difficulty in escaping the consequences of falling waters. Some species are apparently able to withstand desiccation for short periods of time, but long periods of exposure are lethal. Fuller (1974) also states that some species of the mobile Lampsilinae are capable of moving to deeper areas as water levels fall, but heavier-shelled forms must be resistant to desiccation in order to survive. *Q. fragosa* is a heavier-shelled mussel and thus the likelihood that it will be able to escape low-water situations is poor. There has been some concern that low water levels, especially in the winter could reduce the number of *Q. fragosa* in the St. Croix. In the winter it is hypothesized that under low flow conditions, ice scour could reduce the number of, *Q. fragosa*. Little work has been conducted on the impact of ice scouring on mussels communities. Van der Schalie (1938) claims that there is no movement to deeper waters in winter. Both he an Amyot and Downing (1991) indicate that the major response to cooler temperatures is for mussels to burrow deeper in the sediments. Both of their studies, however, dealt with thin-shelled forms inhabiting lake systems with fairly fine sediments. The probability that a thick-shelled form like *Q. fragosa* burrowing into the fairly course sediments found in the St. Croix is most likely low.

To examine whether there is a relationship between the relative abundance of various cohorts of *Q. fragosa* and low flow years we calculated the number of days that the discharge in the river was below

2000 cfs and what proportion of those days were in November-February (when ice could be found) versus the rest of the year (Fig. 23). There are historically a large number of years when a significant number of days have mean flows below 2000 cfs. Figure 24 shows the period 1967- 1991, for which we have records for births of *Q. fragosa* (Fig. 15). It is apparent that in the years 1976, 1988 and 1989 there were a fairly large number of days with flows below 2000 cfs. When comparing these low water years with the years of birth (Fig. 15) it is obvious that there is not a one-to-one correspondence between years of low water and reductions in *Q. fragosa* births, although large numbers of *Q. fragosa* born in 1978, 1979 and 1984 do correspond to years with few days with discharges <2000 cfs.

Despite, this lack of one-to-one correspondence between low water years and low levels of birth for *Q. fragosa*, it is still possible that varying water depth does have a significant impact on the number of *Q. fragosa* found. For example, as mentioned above *Q. fragosa* is only found in areas of high quality mussel habitat. That is, *Q. fragosa* is found only where there are high densities of mussels (Fig. 12A) and where there is high mussel community richness (Fig. 12B). Figures 10A and 10B show that mussel communities in general are more dense and rich in areas of deeper water. Doolittle (1988) also state that the greatest number of mussels were collected in water around 2 m depth throughout the St. Croix. And as shown in FIgure 11, since there is no difference in mussel communities with and without *Q. fragosa*, one might expect if water depth was somewhat deeper on average, they may be greater potential habitat for *Q. fragosa* at Interstate Park.

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Table 1. Locations of sampling sites at Interstate Park, and physical characteristics of these sites at the time of sampling.

SITE	LATITUDE	LONGITUDE	DATE	Average Depth (m)	Average Bottom Flow (m/s)	Average 0.6 Flow (m/s)	TIME (UT)	USGS Discharge Gage Height (ft)	Discharge based on gage height (cfs)
AW	45°23.87	92°39.56	7/1/92	2.50	0.167	0.403	14:05	4.08	5180.842
AM	45°23.74	92°39.59	6/24/92	2.50	0.139	0.371	14:46	3.82	4430.015
AE	45°23.70	92°39.53	6/24/92	1.60	0.203	0.403	18:31	4.37	6062.219
BW	45°23.74	92°39.62	6/18/92	0.70	0.339	0.663	14:29	3.71	4127.117
BM	45°23.77	92°39.59	6/19/92	0.66	0.308	0.598	16:38	3.81	4402.017
BE	45°23.66	92°39.63	6/30/92	0.94	0.280	0.672	16:25	4.09	5210.075
CW	45°23.64	92°39.76	6/17/92	0.74	0.139	0.288	14:38	4.42	6221.245
CM	45°23.70	92°39.88	6/17/92	0.48	0.194	0.384	15:58	3.22	2853.310
CE	45°23.62	92°39.71	6/30/92	0.23	0.302	0.515	14:29	2.64	1637.449
DW	45°23.58	92°39.82	6/9/92	0.25	0.057	0.125	14:23	2.61	1584.785
DM	45°23.59	92°32.79	6/4/92	0.54	0.088	0.123	15:02	2.64	1637.449
DE	45°23.60	92°39.76	6/25/92	1.60	0.210	0.529	15:24	4.10	5239.394
EW	45°23.54	92°39.97	6/23/92	0.60	0.241	0.602	18:38	4.38	6093.855
EM	45°23.54	92°39.92	6/23/92	1.27	0.231	N/A	15:45	3.86	4542.956
EE	45°23.52	92°39.91	6/25/92	1.60	0.197	0.507	20:10	4.37	6062.219

Table 2. F-values from analyses of variance with various habitat and community parameters as dependent variables and the location in the stream (upstream-downstream, east/west/middle location and their interaction) as independent variables. In all cases (except where noted) the F-values given are statistically significant at the 0.05 level.

INDEPENDENT VARIABLES	DEPENDENT VARIABLES										
	Depth[1]	Sediment size[1]	Bottom flow[1]	0.6 depth flow[1]	Total suspended solids - 0.5 m above the bottom[2]	% Organic matter in TSS- 0.5 m above the bottom[2]	Total suspended solids - at the sediment water interface[2]	% Organic matter in TSS- at the sediment water interface[2]	Richness[1]	Density[1]	Shell Length[1]
upstream-downstream	12760.2	12.61	93.96	536.42	1.6*	4.37	0.6*	13.27	8.98	33.95	1.38*
east/west/middle	671.2	8.18	24.32	205.39	0.19*	7.05	2.67*	10.69	20.97	27.87	1.90*
Interaction	2498.2	36.1	18.82	95.51	1.01*	3.98	0.66*	12.77	8.63	13.19	3.13†

[1] degrees of freedom - upstream-downstream 4, 149; east/middle/west 2, 149; interaction 8,149.

[1] degrees of freedom - upstream-downstream 4, 44; east/middle/west 2, 44; interaction 8, 44.

*not significant at the 0.05 level

†degrees of freedom for interaction term 7, 149. Since no mussels were found at site EW, tests of significance are difficult to ascertain. The interaction term was significant while the main effects were not statistically significant.

Table 3. F-values for the relationship between various measures of the amount of suspended solids in the water column and mussel density, mussel community richness and mussel shell length. All values are not statistically significant unlesss otherwise indicated.

DEPENDENT VARIABLES	INDEPENDENT VARIABLES					
	Total suspended solids as dry weight -0.5 m above the bottom[1]	total suspended solids as ash-free dry weight - 0.5 m above the bottom[1]	% organic matter of suspended solids -0.5 m above the bottom[1]	Total suspended solids as dry weight- at the bottom[2]	total suspended solids as ash-free dry weight - at the bottom[2]	% organic matter of suspended solids - at the bottom[2]
Mussel Density	3.17	0.34	8.89*	0.48	0.63	0.38
Mussel Community Richness	2.39	0.03	5.99*	1.46	4.21	0.17
Mussel Size	0.28	0.95	0.39	0.27	4.91*	0.23

[1] 1, 41 df

[2] 1, 44 df

*indicates statisitcally significant at the 0.05 level.

Table 4. Collection data for the 10 *Quadrula fragosa* found in searches made specifically for this species.

DATE	Latitude	Longitude.	TIME	DISCHARGE (CFS)	DEPTH (m)	BOTTOM FLOW (m/s)	0.6 DEPTH FLOW (m/s)	AGE (yr)	YEAR OF BIRTH	LENGTH (mm)	WIDTH (mm)	HEIGHT (mm)	NUMBER OF SPECIES FOUND ASSOCIATED WITH *Q. FRAGOSA*	TOTAL DENSITY OF MUSSELS FOUND WITH *Q FRAGOSA* INCLUDING *Q FRAGOSA*	SPECIES FOUND IN ASSOCIATION WITH *Q FRAGOSA*[1]	MEAN SEDIMENT SIZE (Φ)
6/9/92	45°23.59N	92°39.18W	16:23 UT	3026	0.62	0.14	0.23	13	1979	73.33	44.45	68.15	4	28	ED,QM,3TT	-2.71
6/30/92	45°23.66N	92°39.53W	18:14 UT	5210	1.24	0.18	0.53	15	1977	71.2	42	68	6	28	AC,TV,2TT,TD,QP	-3.23
7/1/92	45°23.72N	92°39.65W	18:24 UT	5327	1.6	0.12	0.36	16	1976	74.5	42.55	70.35	5	64	OR,AC,2CT,11TT	-3.18
7/1/92	45°23.72N	92°39.65W	18:43 UT	5327	1.6	0.15	0.39	12	1980	70.05	38.1	64.55	4	64	2TD,2QP, 11TT	-2.46
7/11/92	45°23.72N	92°39.59W	18:32 UT	6370	0.6	0.04	0.16	9	1983	69	39.55	62.3	9	52	AC,AM,TV,LF,AP,TD,LR,6TT	-2.67
8/13/92	45°23.62N	92°39.70W	17:49 UT	5183	0.62	*	*	5	1987	34.9	22.65	32.45	6	36	2QM,2TT,2TD,PP,CP	-1.57
8/20/92	*	*	14:53 UT	*	0.8	*	*	3	1989	17.15	10.7	15.05	6	48	7TT,TD,AC,EL,PS	-2.41
8/20/92	45°23.70N	92°39.58W	15:51 UT	*	0.86	*	*	6	1986	44.85	26.75	40.15	5	40	6TT,TD,QM,TV	-2.60
8/20/92	45°23.72N	92°39.58W	17:31 UT	*	0.82	*	*	5	1987	36.7	23	34.15	6	64	2OO,2TV,9TT,TD,OR	-2.79
8/20/92	45°23.64N	92°39.57W	18:33 UT	*	0.64	*	*	6	1986	55.55	33.95	53.95	4	60	12TT,EL,TD	-3.12

[1] see Figure 11 for species designations
* missing data

Table 5. Substrate comparisons among quadrats with and without *Quadrula fragosa*.

Sieve size (mm)	Quadrats with *Q. fragosa*		Quadrats without *Q. fragosa*	
	Mean percentage of sediment wet weight	Standard deviation of sediment wet weight	Mean percentage of sediment wet weight	Standard deviation of sediment wet weight
65	0.65	2.15	0.73	5.09
57	5.75	4.04	4.59	5.18
12.7	42.44	15.60	39.77	12.12
6.35	11.62	3.71	16.64	5.26
0.5	39.55	17.63	38.26	14.76

Table 6 - Information on Quadrula fragosa collected at Interstate Park.

Year of collection	Year of Birth	Age when collected	Shell length (mm)	Shell height (mm)	Source of data
1989	1967	22	83	71	Miller/Heath†
1988	1968	20	78	70	Miller/Heath†
1988	1968	20	82	72	Miller/Heath†
1988	1968	20	91	76	Miller/Heath†
1989	1968	21	74	65	Miller/Heath†
1989	1969	20	79	69	Miller/Heath†
1989	1971	18	73	62	Miller/Heath†
1991	1973	18	91	73	Miller/Heath†
1991	1973	18	96	80	Miller/Heath†
1989	1975	14	90	72	Miller/Heath†
1991	1976	15	74	68	Miller/Heath†
1992	1976	16	75	70	This study
1989	1977	12	83	71	Miller/Heath†
1992	1977	15	71	68	This study
1988	1978	10	55	58	Miller/Heath†
1988	1978	10	73	64	Miller/Heath†
1989	1978	11	69	63	Miller/Heath†
1989	1978	11	69	64	Miller/Heath†
1989	1978	11	71	63	Miller/Heath†
1991	1978	13	67	58	Miller/Heath†
1991	1978	13	68	61	Miller/Heath†
1991	1978	13	70	61	Miller/Heath†
1991	1978	13	73	63	Miller/Heath†
1988	1979	9	58	57	Miller/Heath†
1988	1979	9	70	62	Miller/Heath†
1989	1979	10	57	52	Miller/Heath†
1989	1979	10	58	54	Miller/Heath†
1989	1979	10	67	58	Miller/Heath†
1989	1979	10	72	65	Miller/Heath†
1989	1979	10	73	62	Miller/Heath†
1989	1979	10	83	71	Miller/Heath†
1989	1979	10	83	68	Miller/Heath†
1991	1979	12	60	55	Miller/Heath†
1992	1979	13	73	68	This study
1988	1980	8	60	55	Miller/Heath†
1989	1980	9	83	71	Miller/Heath†
1992	1980	12	70	65	This study
1992	1980	12	72	66	This study
1989	1981	8	58	54	Miller/Heath†
1989	1981	8	60	54	Miller/Heath†
1990	1981	9	71	63	Miller/Heath†
1991	1981	10	54	50	Miller/Heath†

Table 6 - Information on Quadrula fragosa collected at Interstate Park.

Year of collection	Year of Birth	Age when collected	Shell length (mm)	Shell height (mm)	Source of data
1989	1982	7	51	47	Miller/Heath†
1991	1982	9	54	50	Miller/Heath†
1988	1983	5	44	40	Miller/Heath†
1990	1983	7	54	51	Miller/Heath†
1992	1983	9	69	62	This study
1988	1984	4	29	28	Miller/Heath†
1988	1984	4	35	35	Miller/Heath†
1988	1984	4	36	34	Miller/Heath†
1989	1984	5	31	30	Miller/Heath†
1989	1984	5	37	34	Miller/Heath†
1989	1984	5	38	37	Miller/Heath†
1989	1984	5	39	37	Miller/Heath†
1989	1984	5	40	37	Miller/Heath†
1989	1984	5	40	38	Miller/Heath†
1989	1984	5	44	41	Miller/Heath†
1989	1984	5	44	40	Miller/Heath†
1989	1984	5	45	42	Miller/Heath†
1989	1984	5	46	41	Miller/Heath†
1989	1984	5	46	45	Miller/Heath†
1989	1984	5	46	44	Miller/Heath†
1989	1984	5	48	45	Miller/Heath†
1989	1984	5	83	71	Miller/Heath†
1989	1984	5	83	71	Miller/Heath†
1989	1984	5	83	71	Miller/Heath†
1990	1984	6	40	38	Miller/Heath†
1990	1984	6	51	47	Miller/Heath†
1990	1984	6	54	50	Miller/Heath†
1990	1985	5	38	34	Miller/Heath†
1992	1986	6	45	40	This study
1992	1986	6	56	54	This study
1991	1987	4	19	14	Hornbach, 1992
1992	1987	5	35	32	This study
1992	1987	5	37	34	This study
1992	1989	3	17	15	This study
†reported in draft Q. fragosa recovery plan					

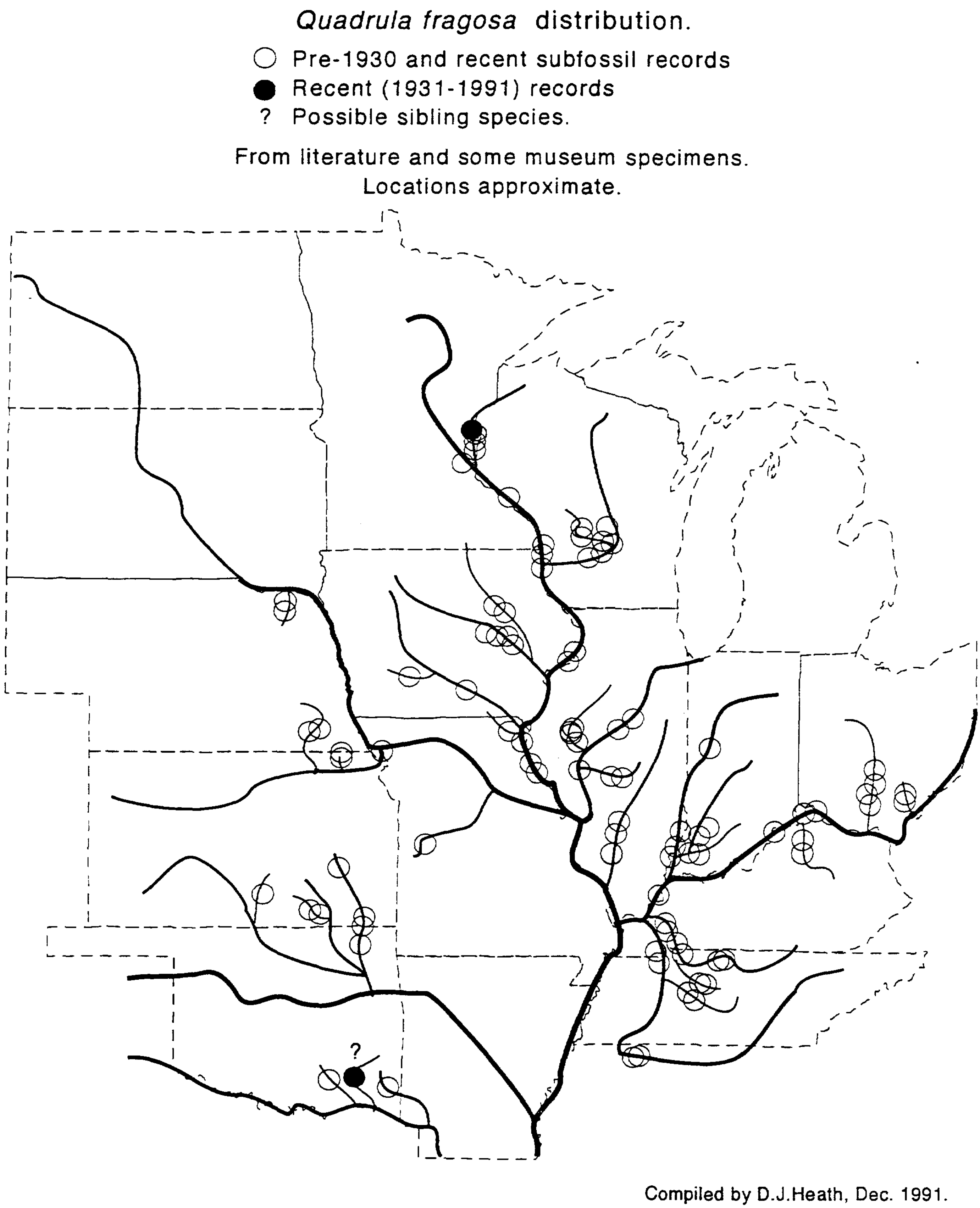


Figure 1. Past and present distribution of *Quadrula fragosa*.

INTERSTATE PARK STUDY SITE

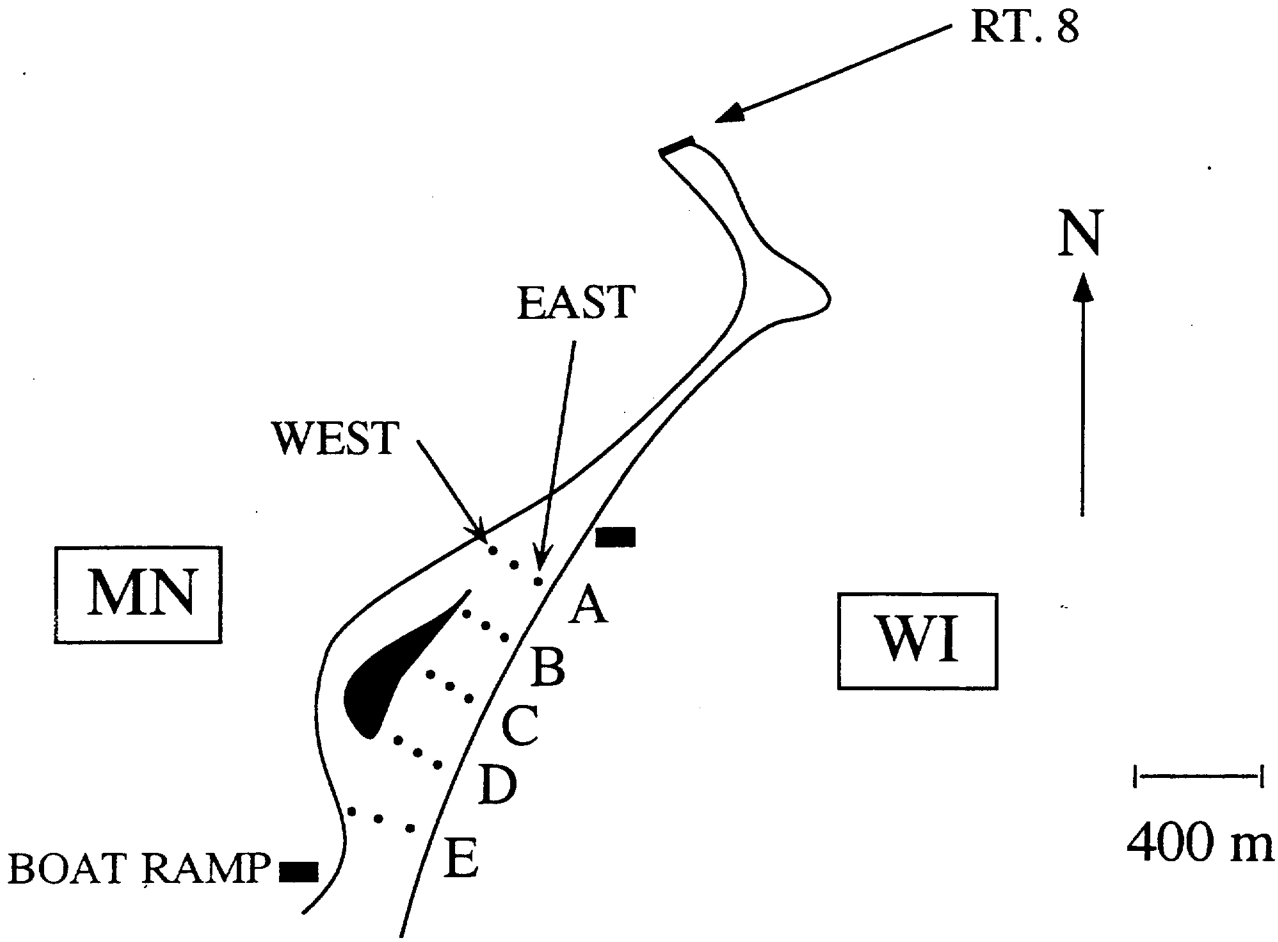


Figure 2. Map of study site. Small circles indicate the 15 locations where quantitative samples were taken.

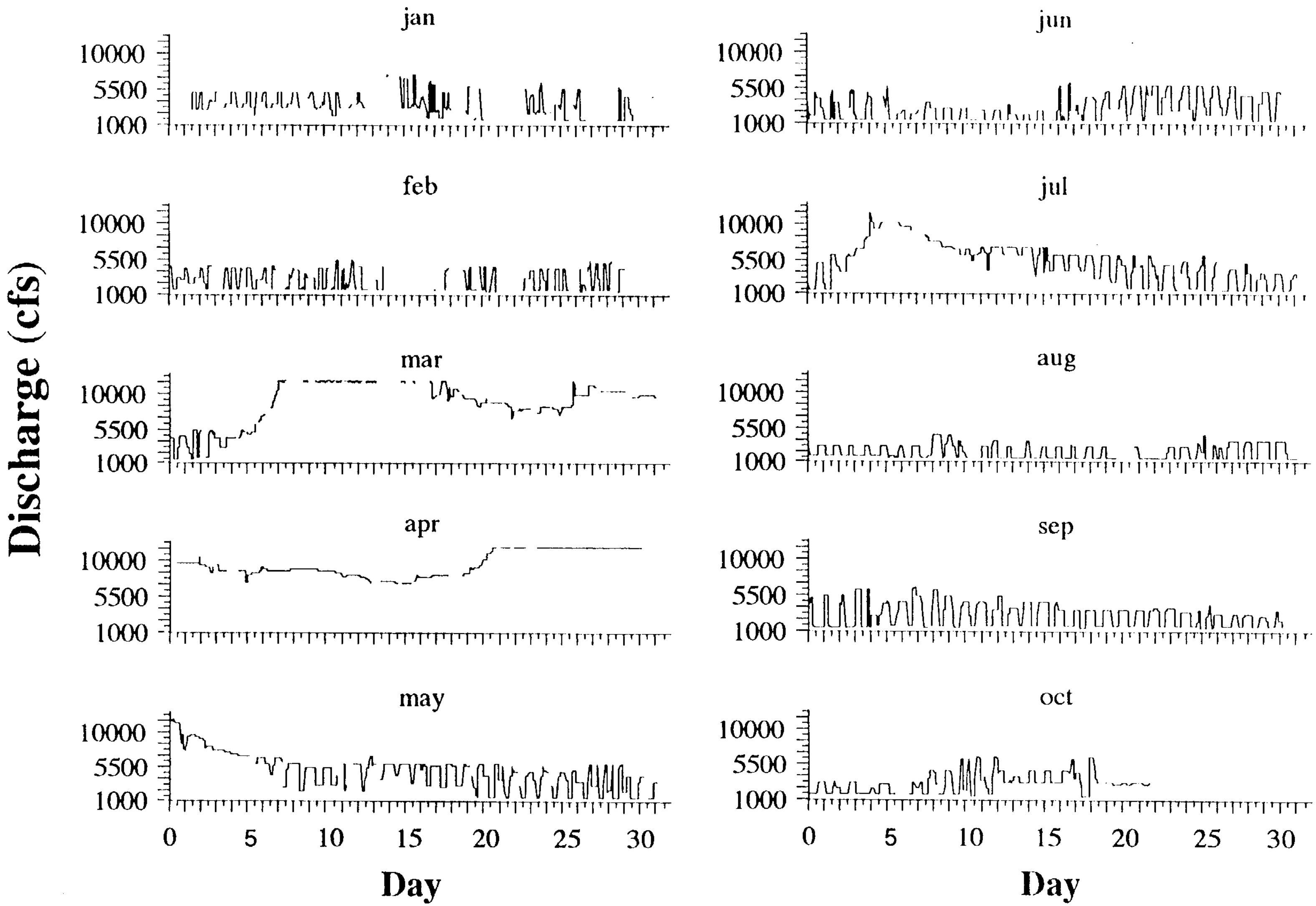


Figure 3. Mean hourly discharge levels from the USGS gage at St. Croix Falls, WI (Interstate Park) for 1992.

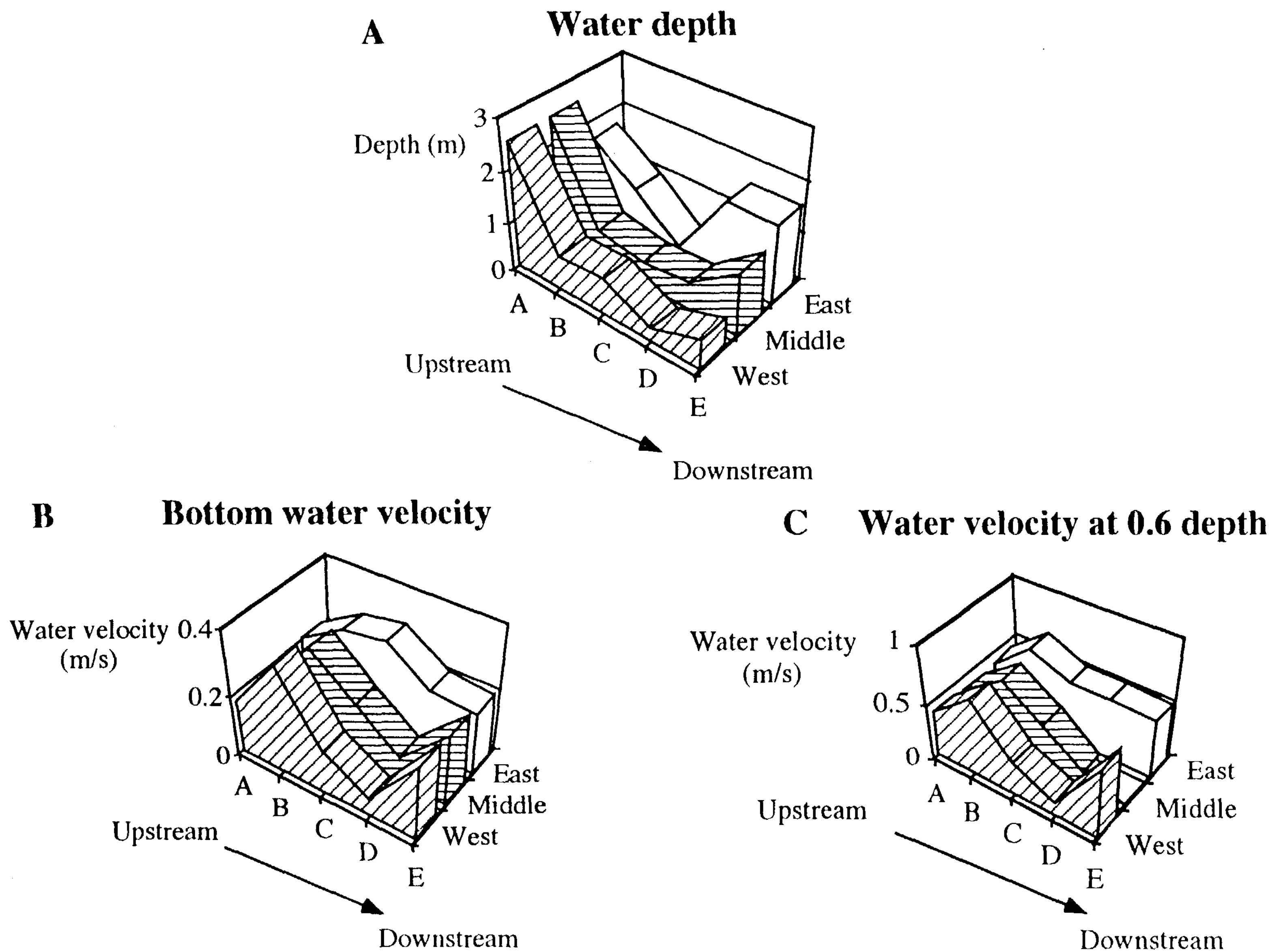


Figure 4. Habitat characteristics for the 15 sampling sites at Interstate Park. A. Water depth, B. Water velocity at the sediment water interface, C. Water velocity taken at the 0.6 depth.

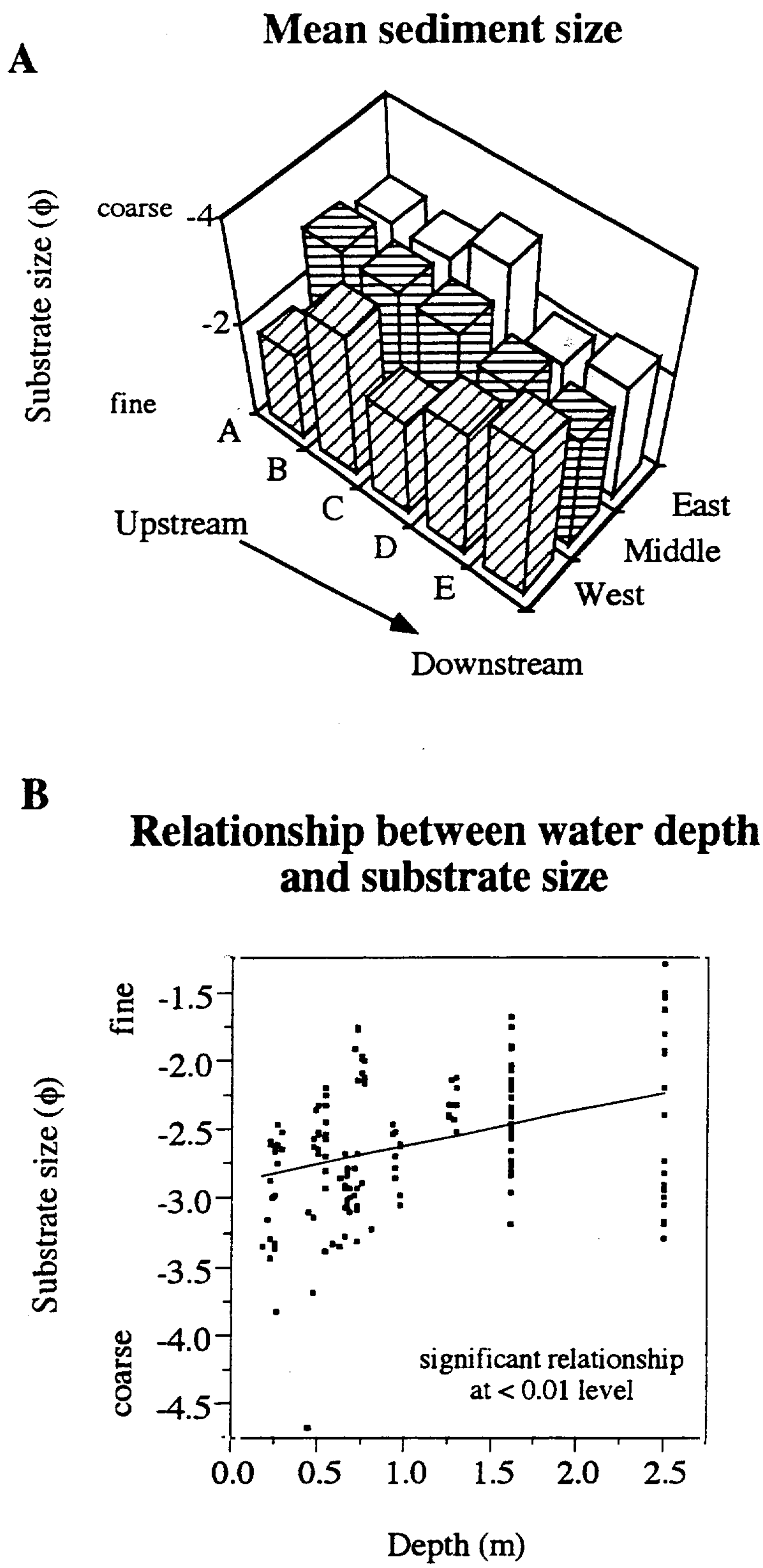


Figure 5. The mean sediment size at 15 sampling stations, Interstate Park (A) and the relationship between sediment size and water depth at these sites.

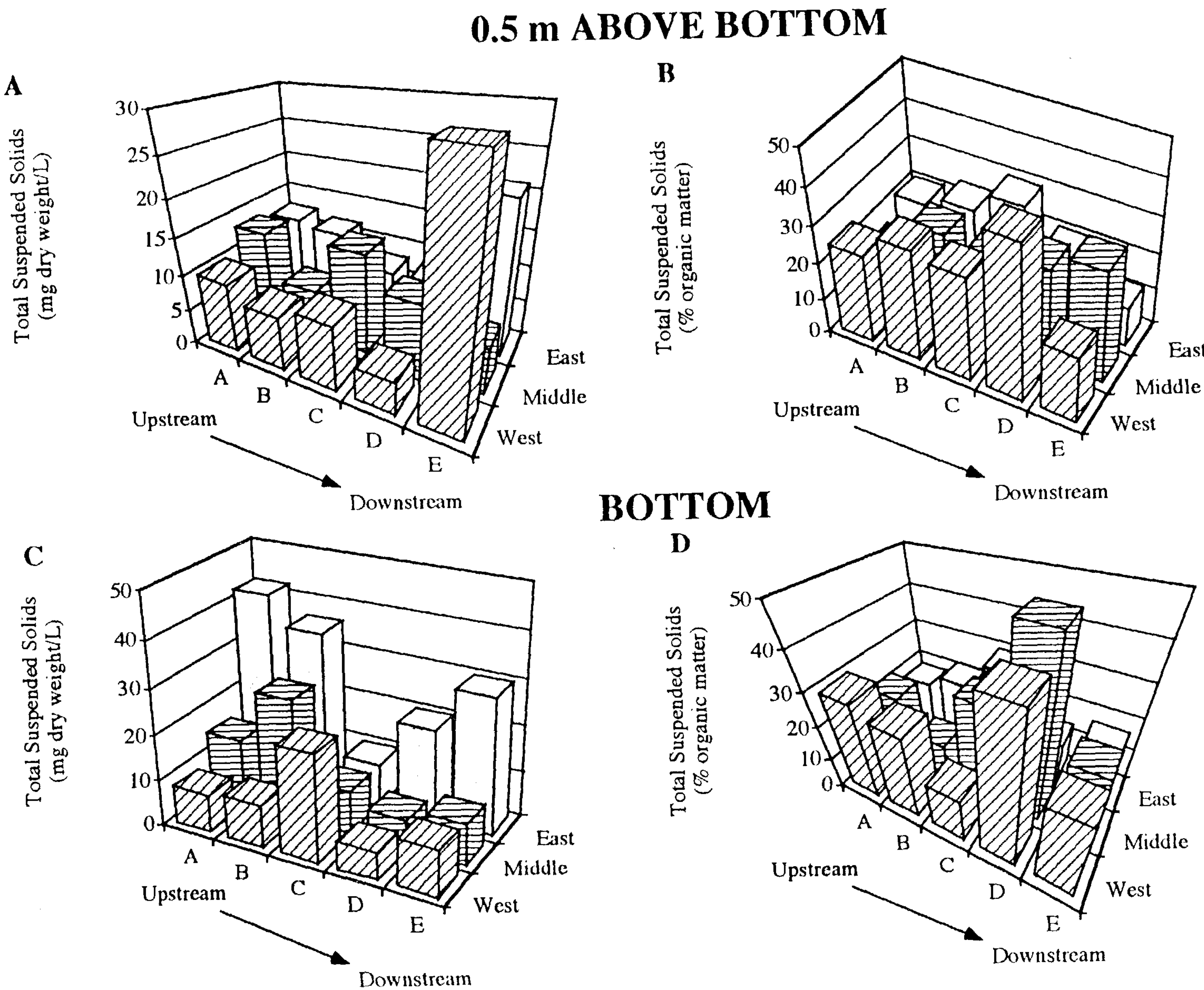


Figure 6. Measures of total suspended solids in the water column taken at 15 sampling stations, Interstate Park. A and B are from water samples taken 0.5 m above the sediment water interface; A gives the amount of total suspended solids as dry weight and B gives the % organic matter of the solids. C and D are from water samples taken at the sediment water interface; C gives the amount of total suspended solids as dry weight and D gives the % organic matter of the solids.

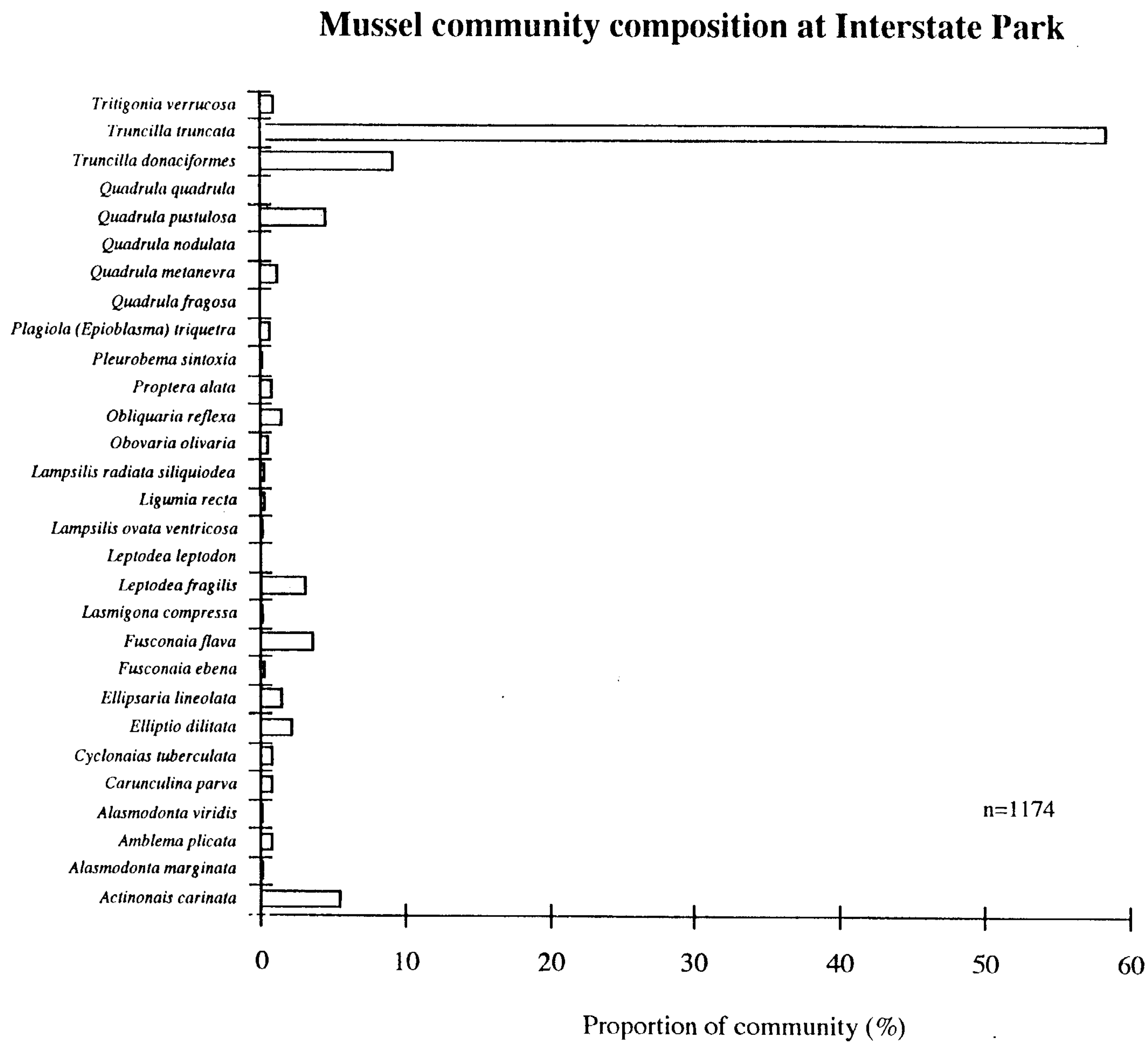


Figure 7. Mussel community structure at Interstate Park based on 150 0.25 m^2 quadrats.

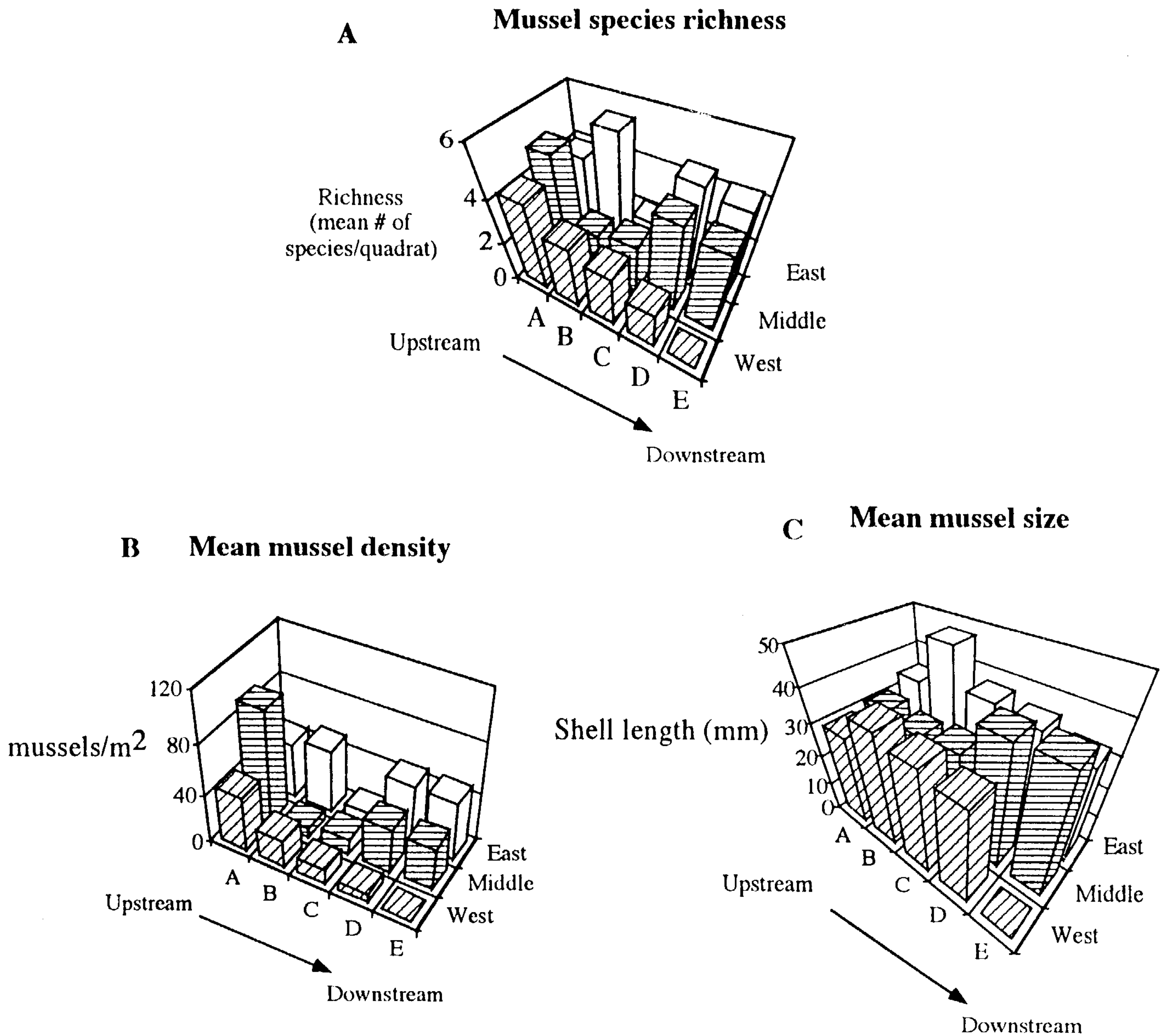


Figure 8. Mussels community structure at 15 sites, Interstate Park. A. Community richness, B. Mussel density, C. Size of mussels.

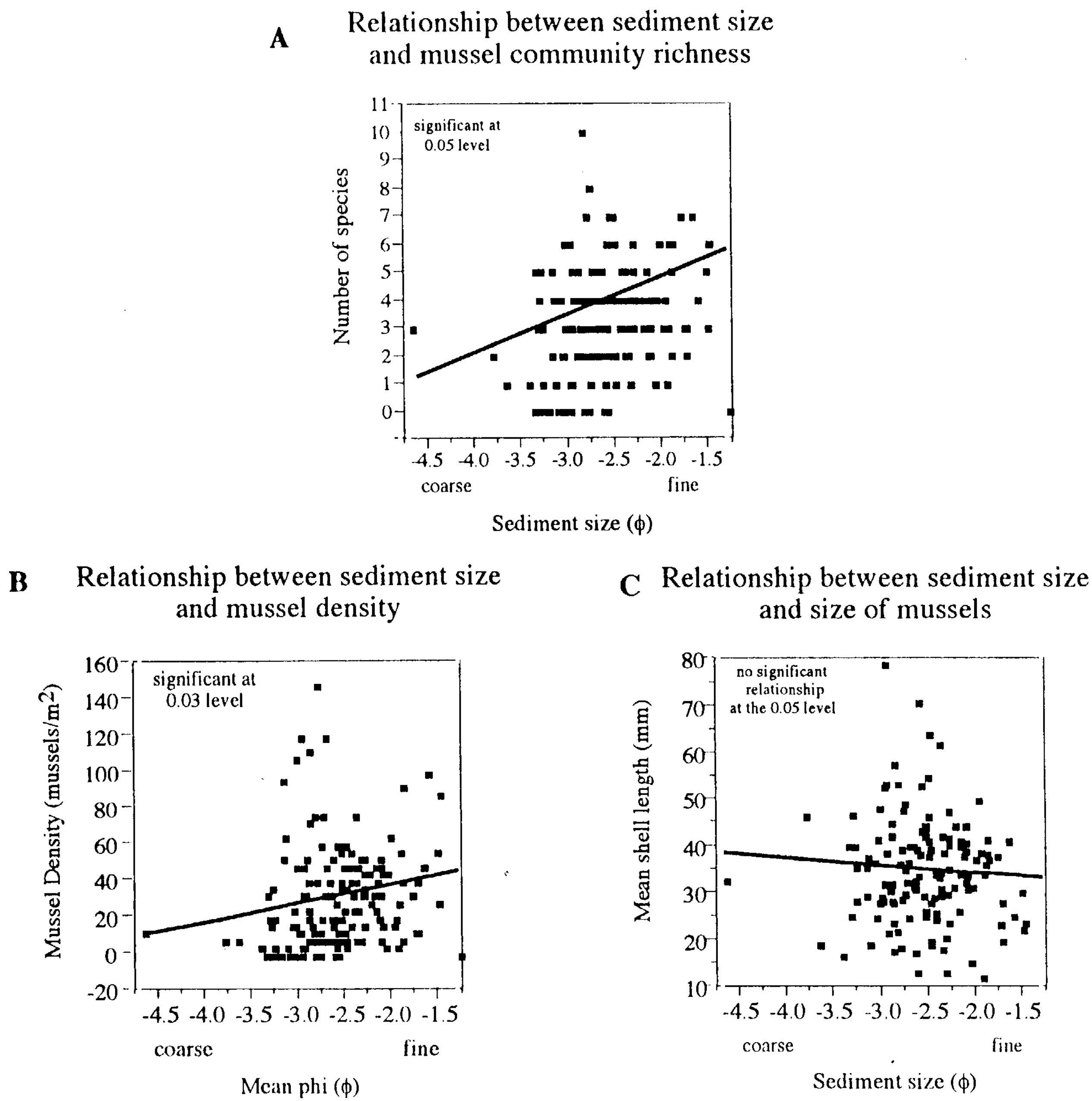


Figure 9. Relationship between sediment size and various mussel community parameters. A. Community richness, B. Mussel density, C. Size of mussels collected.

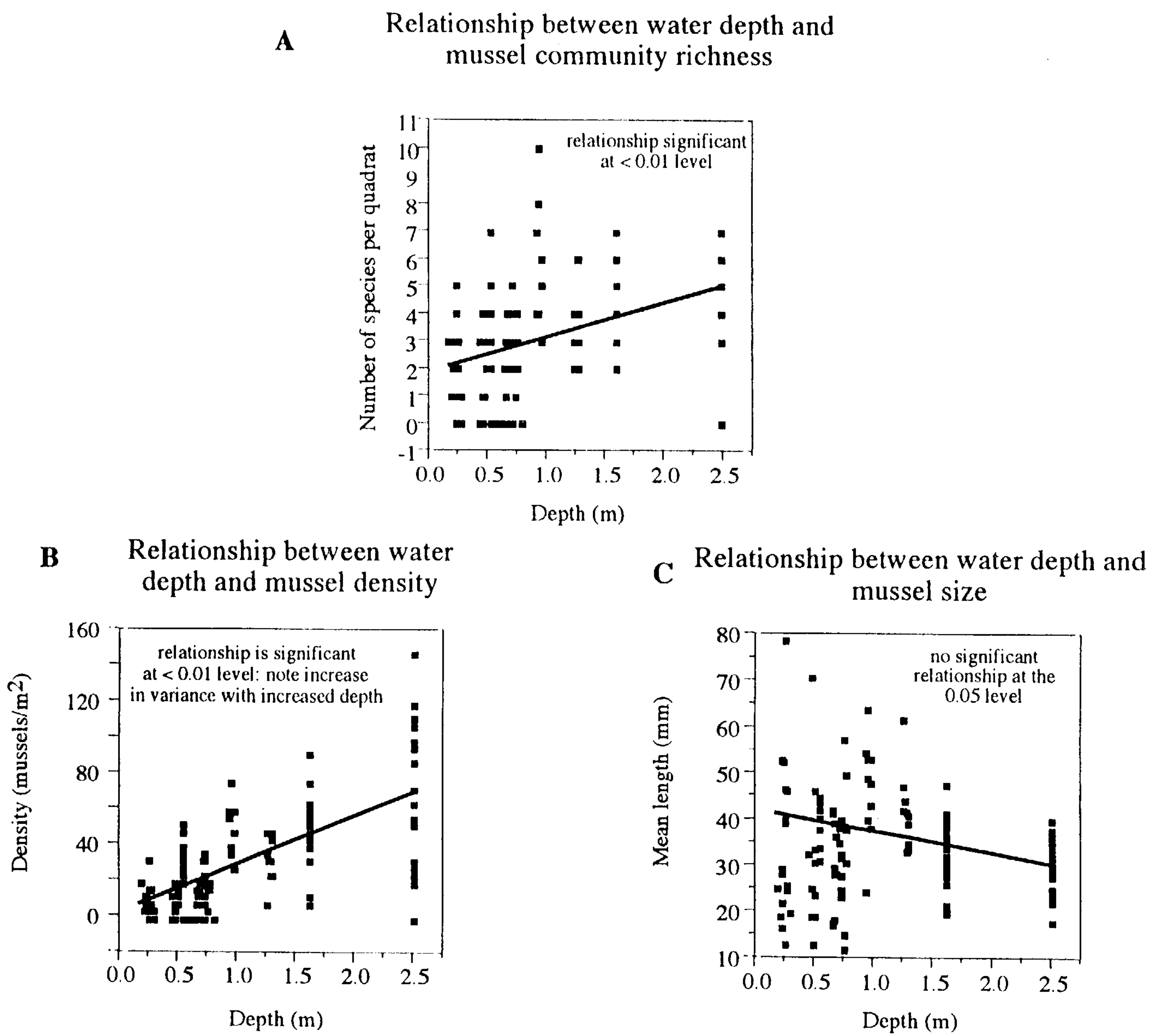


Figure 10. Relationship between water depth and various mussel community parameters. A. Community richness, B. Mussel density, C. Size of mussels collected.

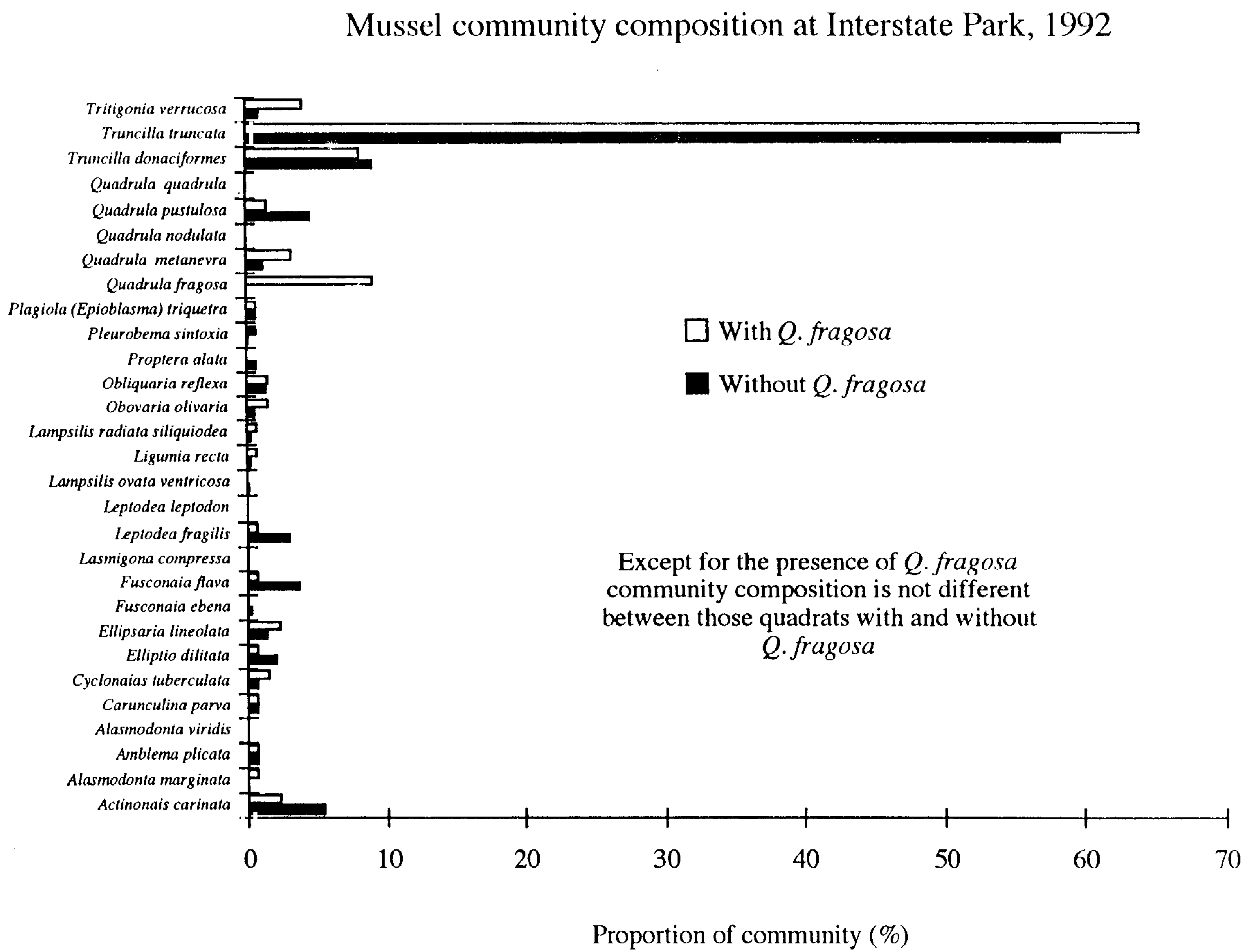


Figure 11. Comparison of the mussel community found with and without *Quadrula fragosa*

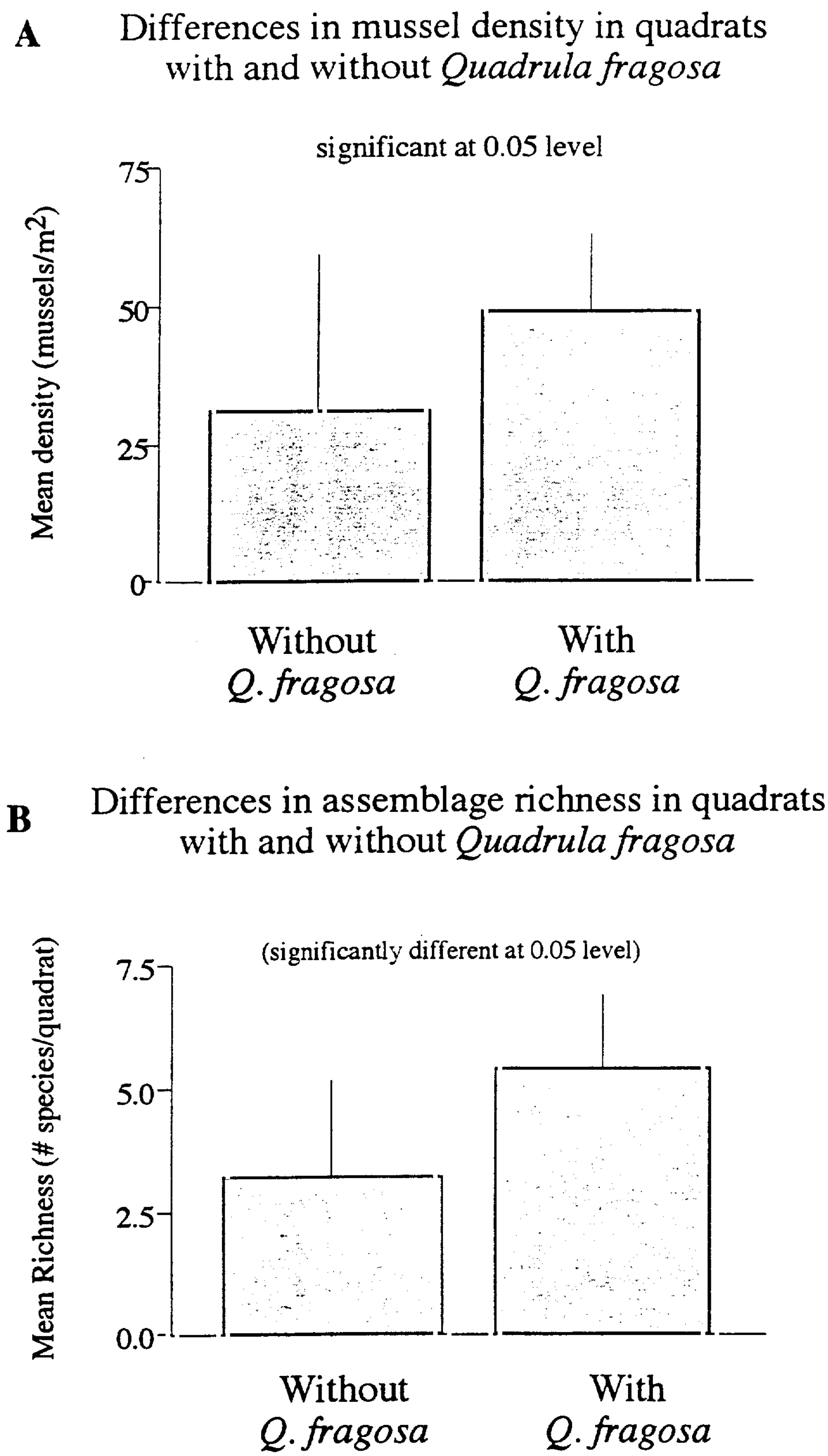
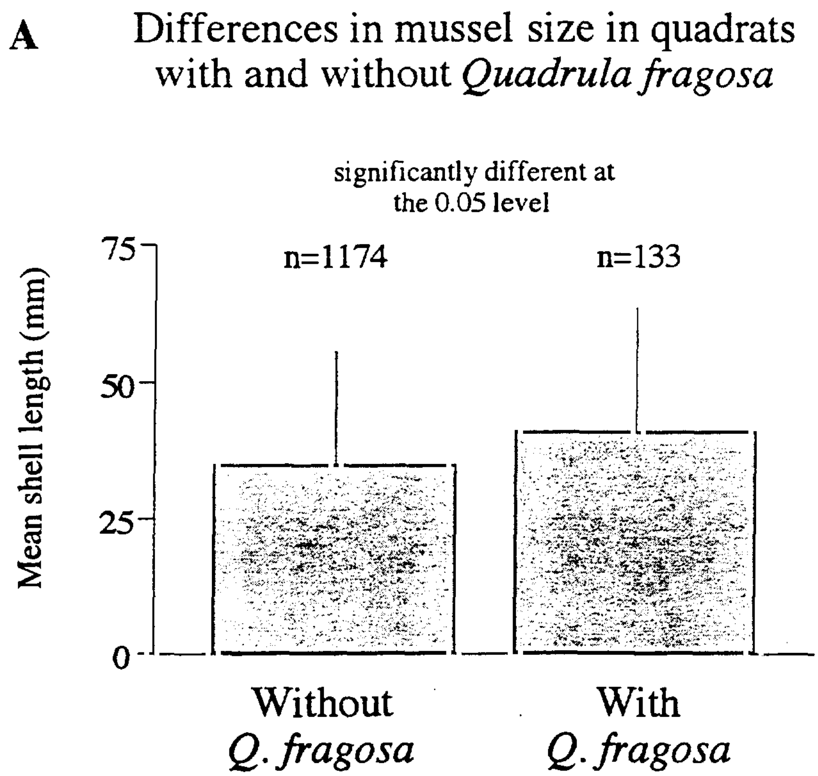


Figure 12. Comparison of mussel density (A) and community richness (B) in quadrats with and without *Quadrula fragosa*.



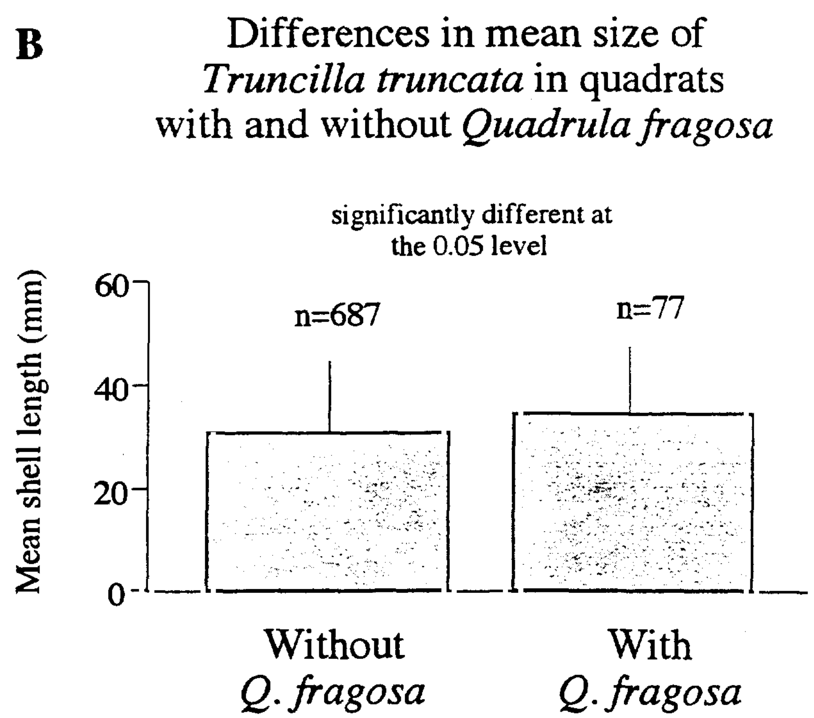


Figure 13. Difference in mussel size of all species collecred (A) and for *Truncilla truncata* alone (B) in quadrats with and without *Quadrula fragosa*.

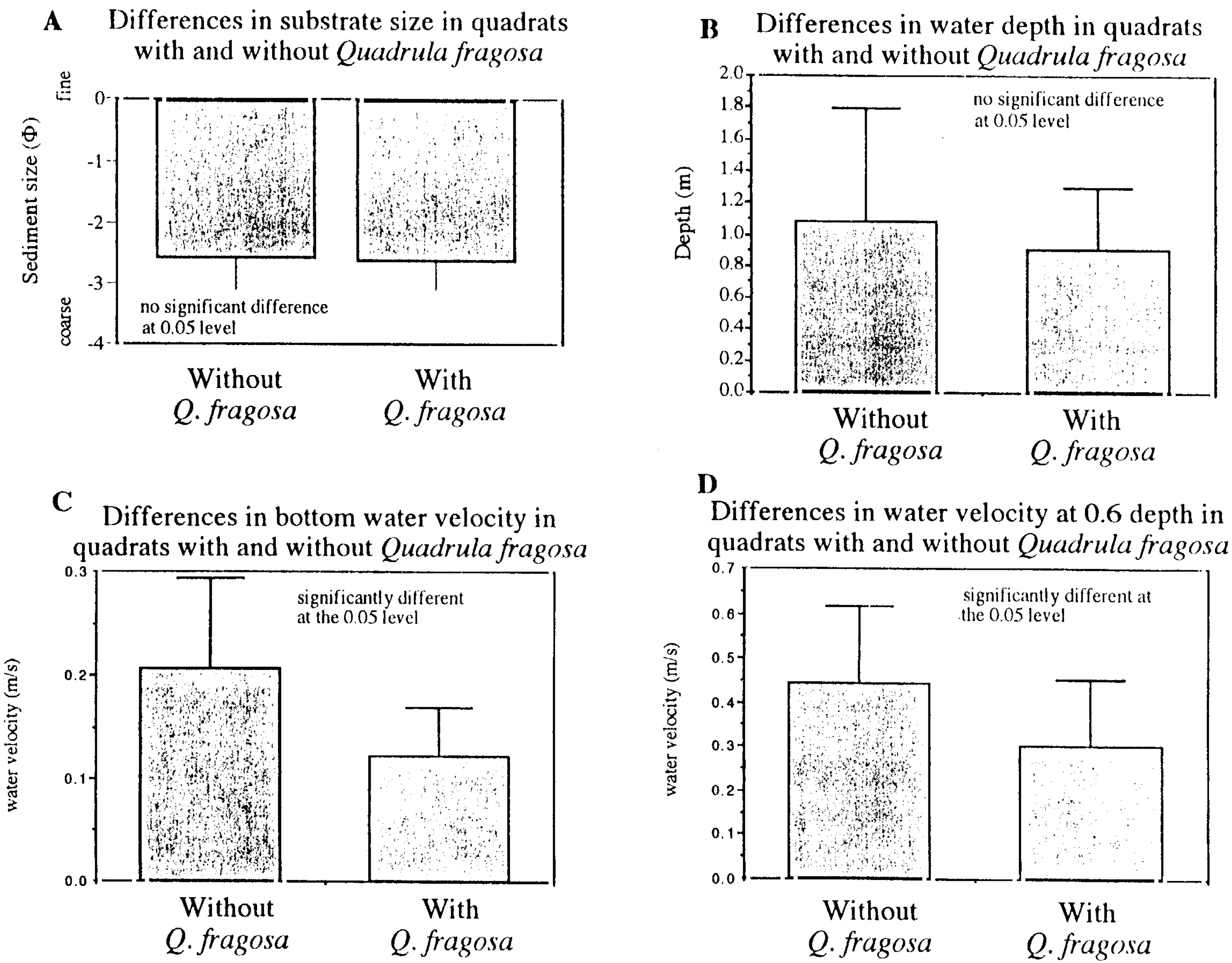


Figure 14. Differences in various habitat characteristics between quadrats with and without *Quadrula fragosa*.
A. Sediment size, B. Water depth, C. Water velocity at the sediment-water interaface,
D. Water velocity at the 0.6 depth.

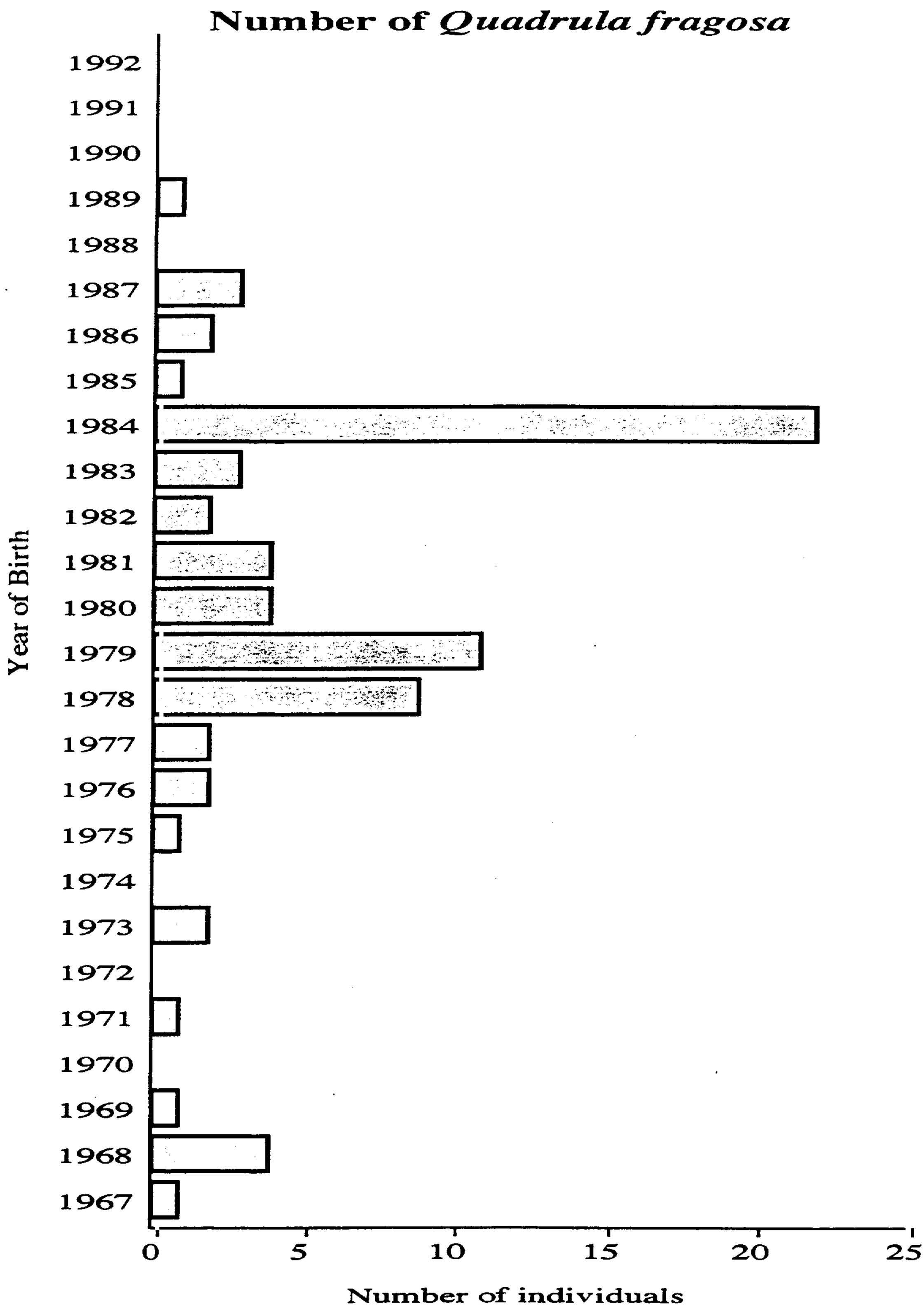


Figure 15. Number of *Quadrula fragosa* collected versus their year of birth, based on back-calculation from external growth rings.

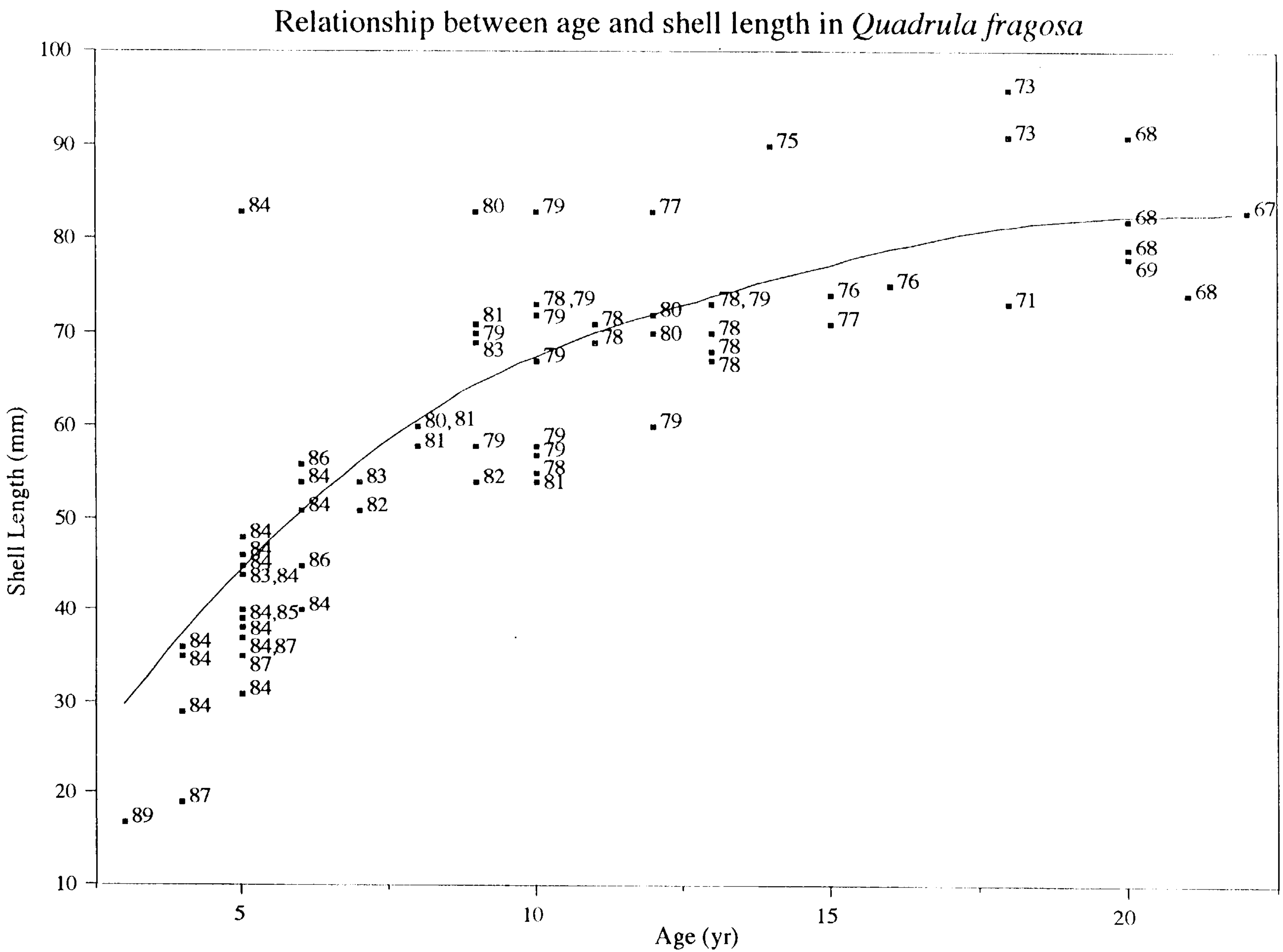


Figure 16. Relationship between age and shell length for *Quadrula fragosa*. Numbers give year of birth.

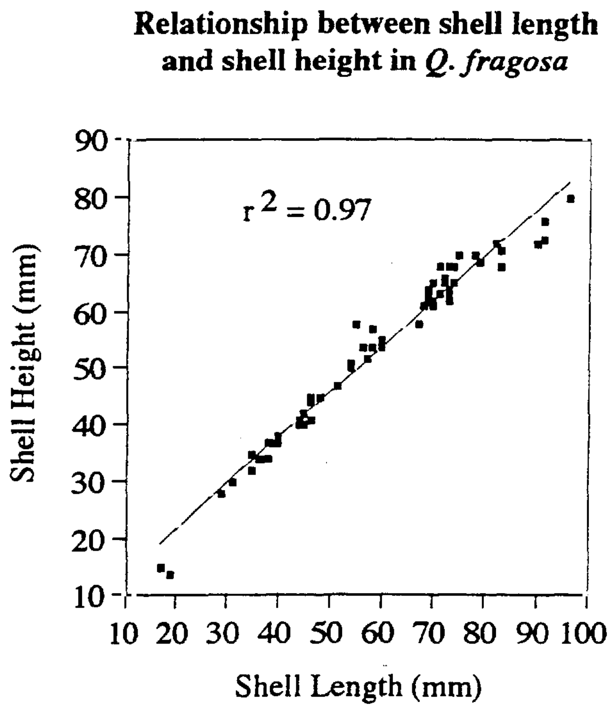


Figure 17. Relationship between shell length and shell height in *Quadrula fragosa*.

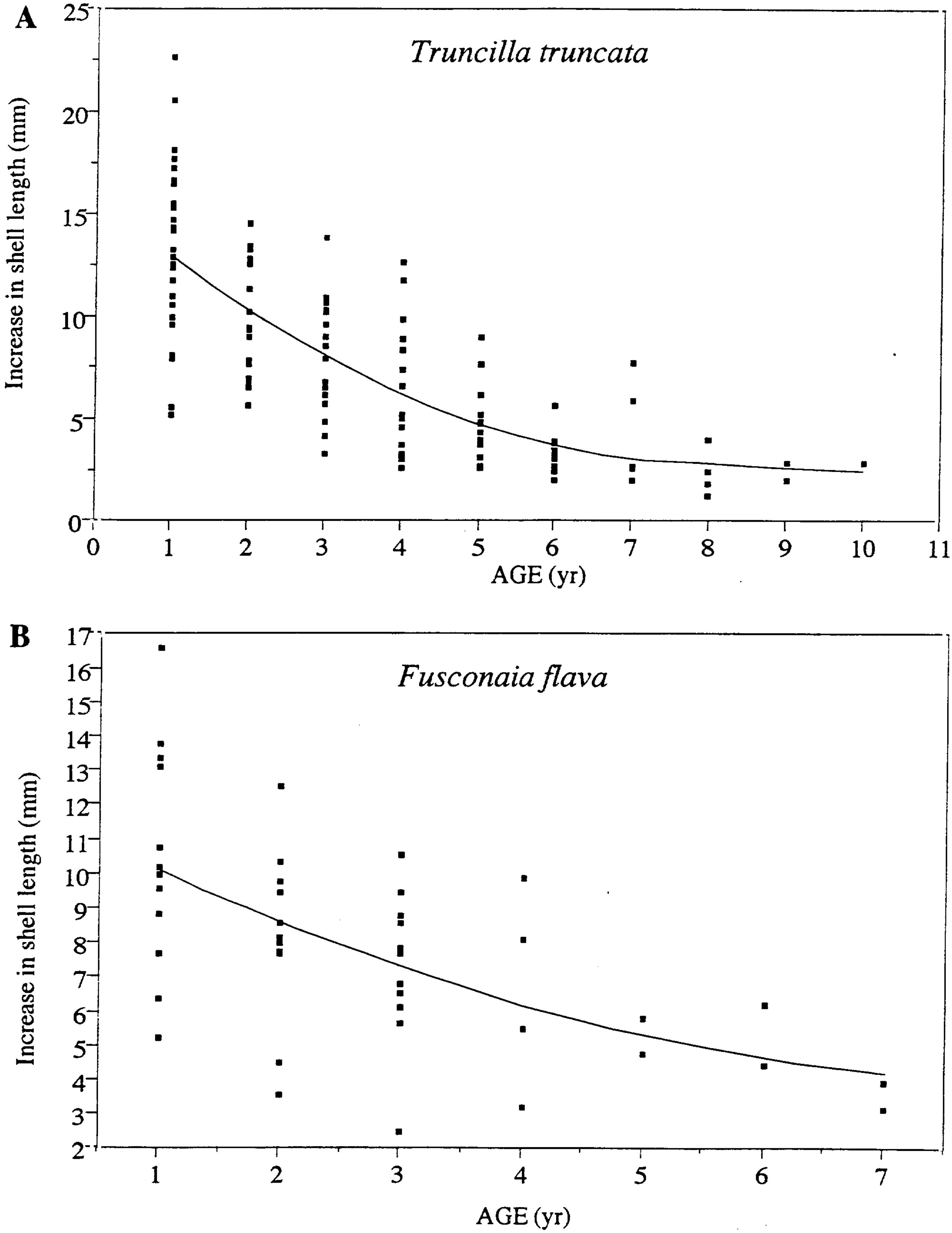
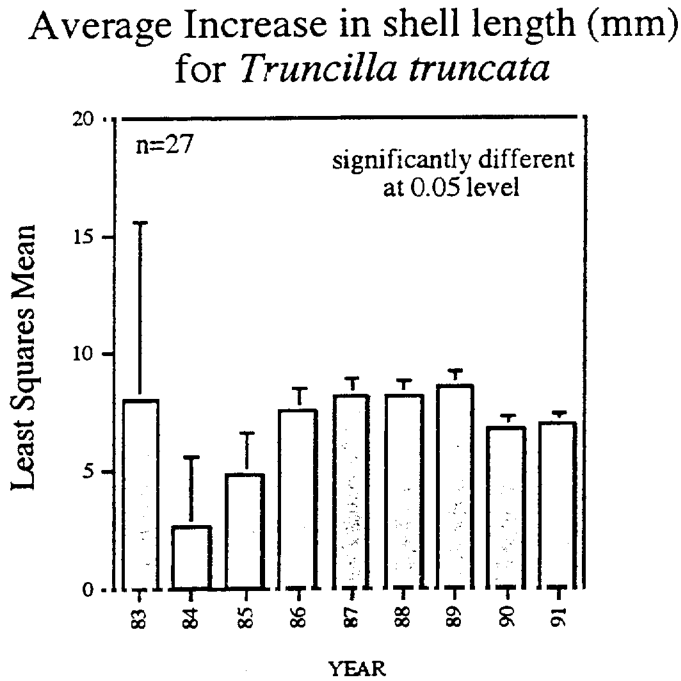


Figure 18. Relationship between age and increases in shell length for *Truncilla truncata* (A) and *Fusconaia flava* (B).

A



B

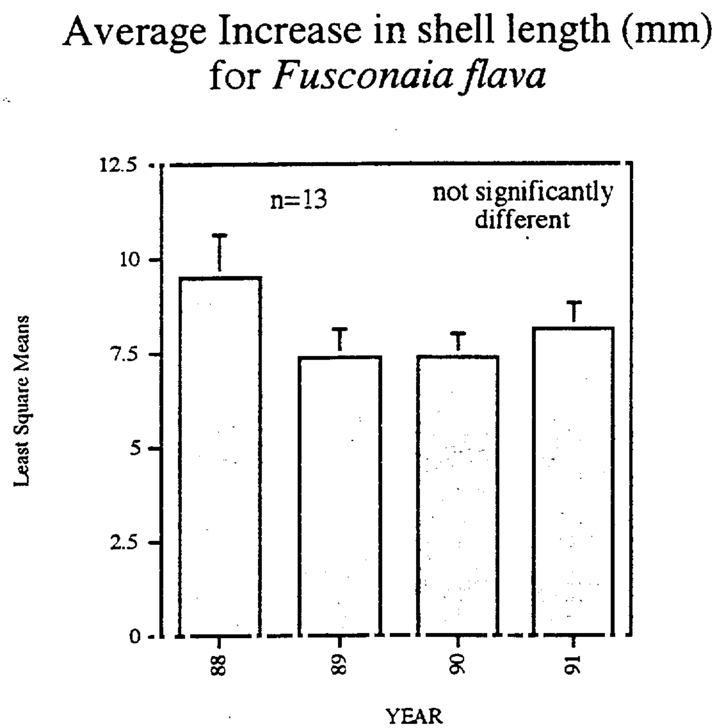


Figure 19. Variation in the increases in shell length (least squares means - mm) for *Truncilla truncata* (A) and *Fusconaia flava* (B).

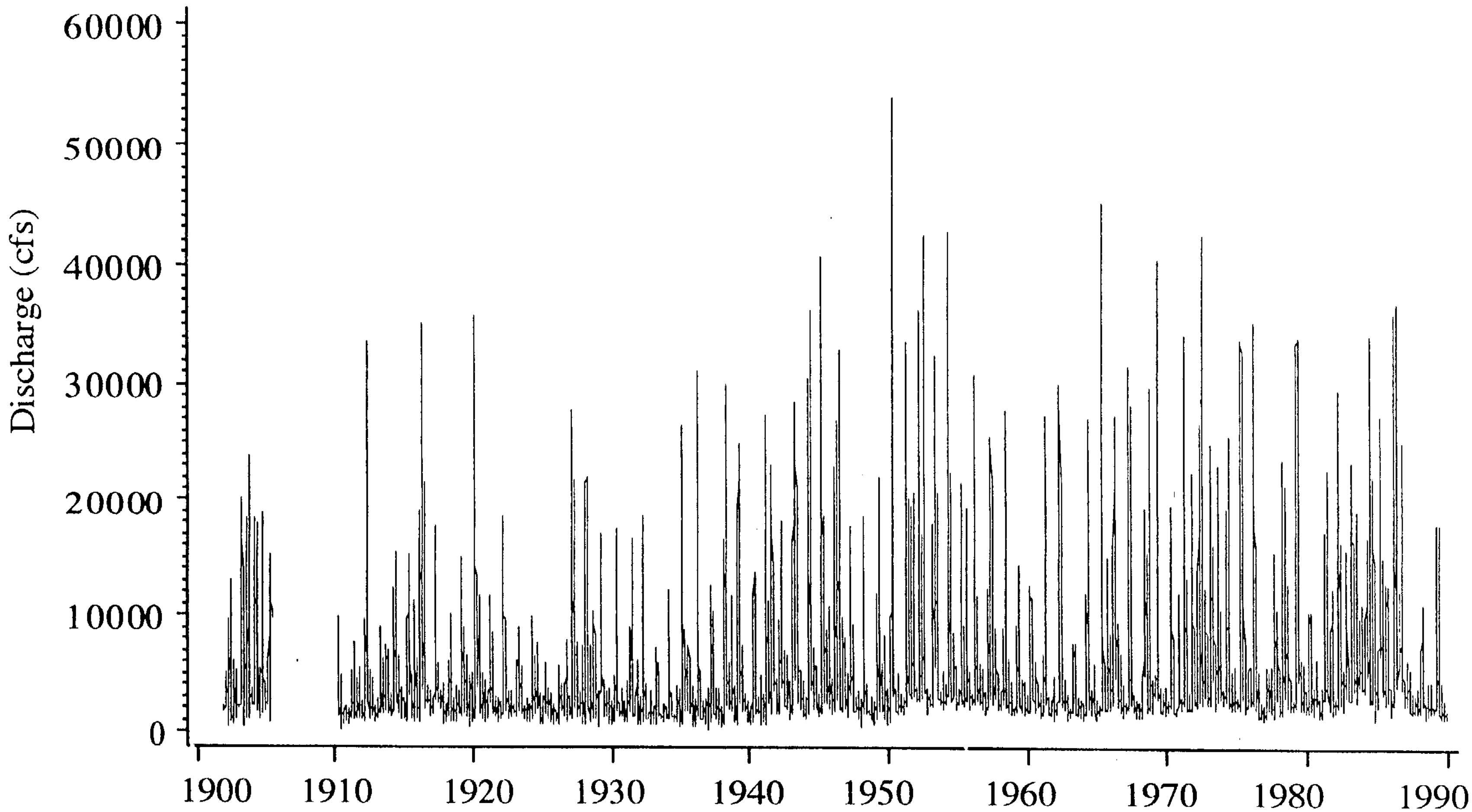


Figure 20. Mean daily discharge at Interstate Park 1902-1991.

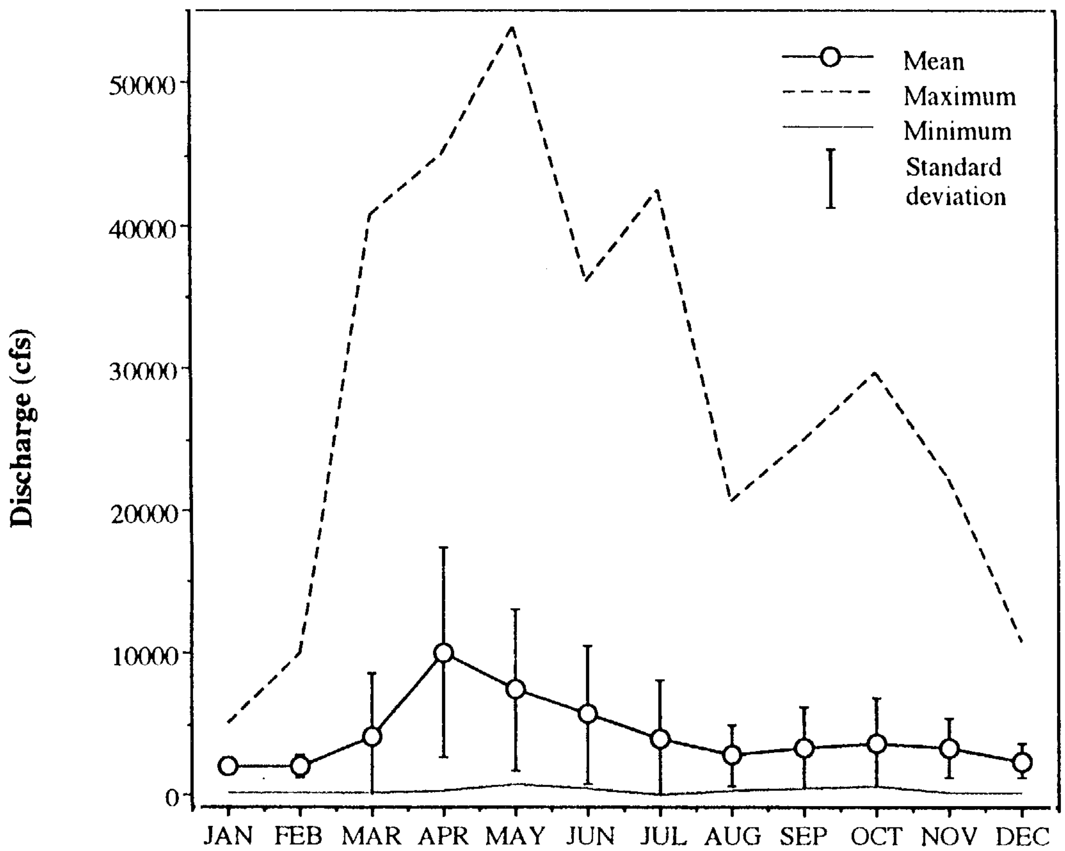


Figure 21. Average monthly discharge for the period 1902-1991. Maximum, minimum and the standard deviation of mean monthly flow are also given for the period.

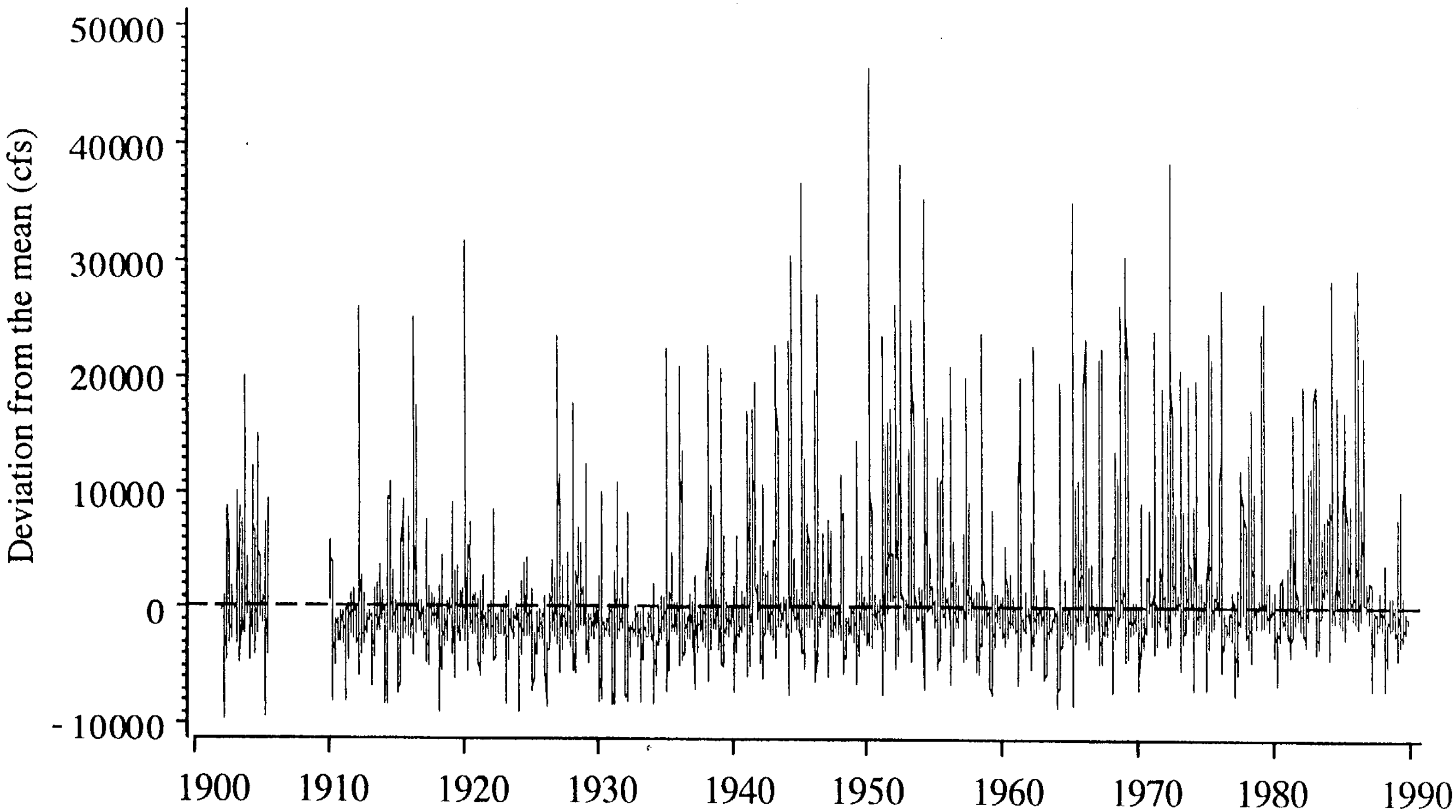


Figure 22. Deviation of the discharge from the mean discharge. The mean discharge for each month was taken from Fig. 20 and this mean was subtracted from the mean daily discharge to arrive at the deviation from the mean.

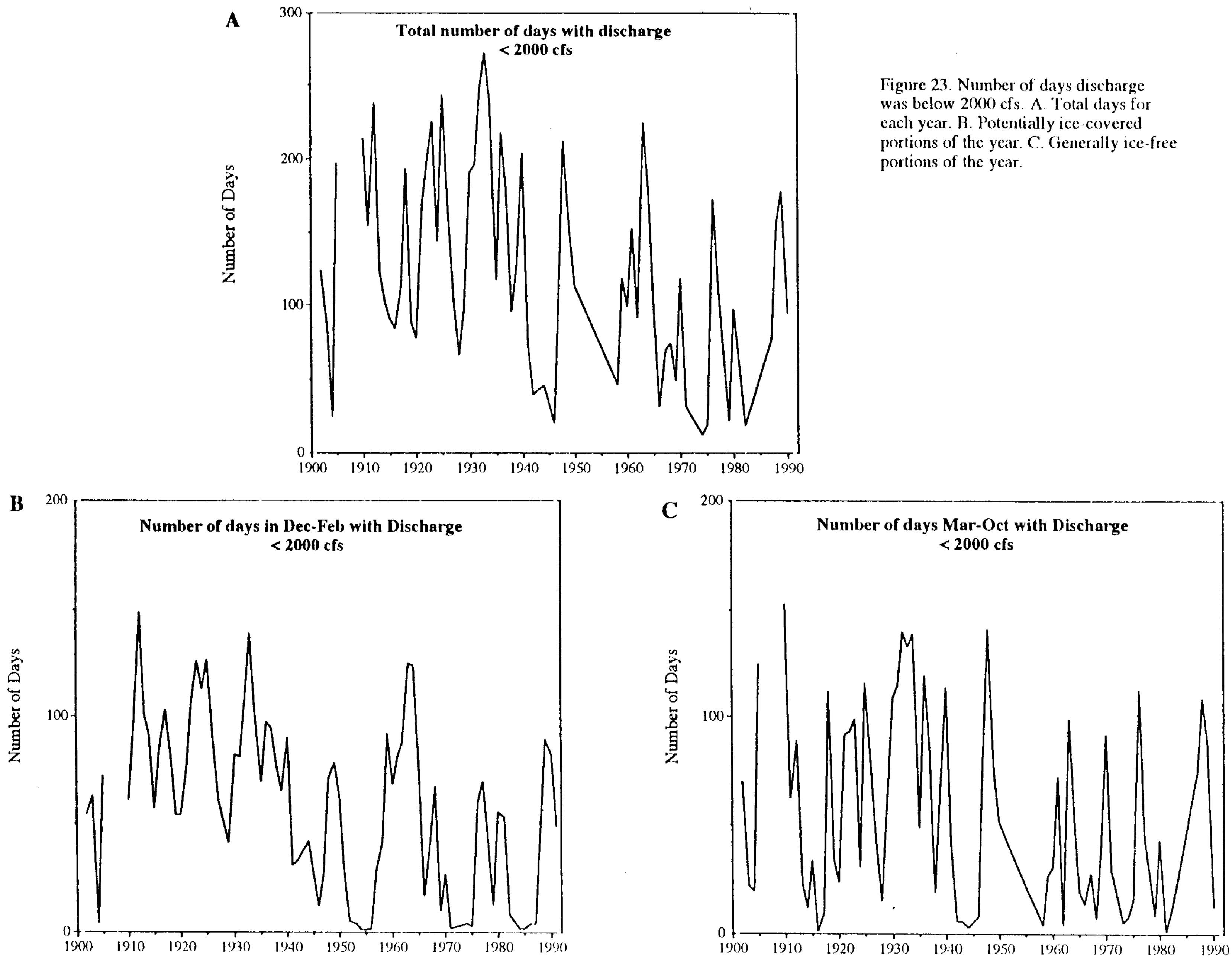


Figure 23. Number of days discharge was below 2000 cfs. A. Total days for each year. B. Potentially ice-covered portions of the year. C. Generally ice-free portions of the year.

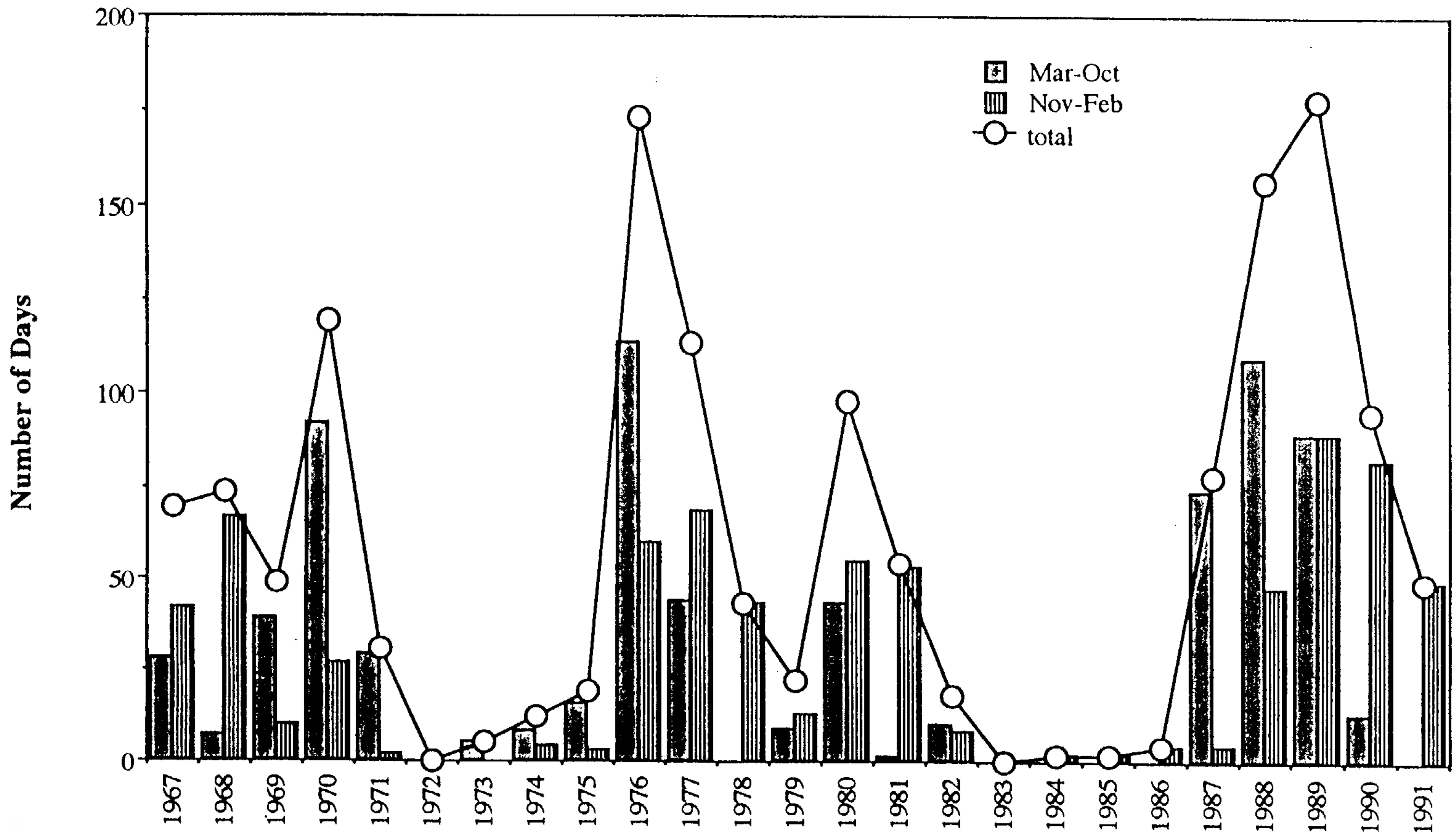


Figure 24. Number of days when mean discharge was < 2000 cfs for potentially ice-free and ice covered periods for 1967-1991. The total number of days with mean discharge < 2000 cfs is also given.

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
DM	6/4/92	*Actionais carinata*	70.83	29.57	44.66
DM	6/4/92	*Actionais carinata*	22.70	11.40	15.40
DM	6/4/92	*Actionais carinata*	57.85	24.50	36.40
CM	6/17/92	*Actionais carinata*	19.00	3.85	7.65
CM	6/17/92	*Actionais carinata*	20.00	5.75	10.75
CM	6/17/92	*Actionais carinata*	19.85	5.30	9.85
CM	6/17/92	*Actionais carinata*	18.25	5.20	10.05
CM	6/17/92	*Actionais carinata*	41.55	13.45	24.25
CM	6/17/92	*Actionais carinata*	32.95	10.60	18.70
CM	6/17/92	*Actionais carinata*	23.20	6.45	12.65
CW	6/17/92	*Actionais carinata*	49.55	11.05	30.00
CW	6/17/92	*Actionais carinata*	8.90	3.25	5.05
CW	6/17/92	*Actionais carinata*	46.10	17.50	28.95
CW	6/17/92	*Actionais carinata*	44.70	16.00	25.25
BM	6/18/92	*Actionais carinata*	39.90	13.20	31.20
BM	6/18/92	*Actionais carinata*	15.30	4.00	8.30
BM	6/18/92	*Actionais carinata*	10.90	4.30	8.90
BW	6/18/92	*Actionais carinata*	20.30	5.50	111.25
BW	6/18/92	*Actionais carinata*	16.80	4.60	9.00
BW	6/18/92	*Actionais carinata*	19.75	5.45	10.85
BW	6/18/92	*Actionais carinata*	19.85	5.90	10.50
BW	6/18/92	*Actionais carinata*	14.35	3.85	7.90
BW	6/18/92	*Actionais carinata*	14.05	3.75	8.00
BW	6/18/92	*Actionais carinata*	81.85	31.55	50.70
BW	6/18/92	*Actionais carinata*	71.25	27.70	45.80
EM	6/23/92	*Actionais carinata*	10.25	3.75	6.10
AE	6/24/92	*Actionais carinata*	21.50	6.35	12.15
AE	6/24/92	*Actionais carinata*	19.85	5.20	10.35
AE	6/24/92	*Actionais carinata*	22.50	6.30	13.50
AE	6/24/92	*Actionais carinata*	10.25	3.60	5.75
AE	6/24/92	*Actionais carinata*	20.55	6.10	10.45
AE	6/24/92	*Actionais carinata*	20.80	5.90	11.30
AE	6/24/92	*Actionais carinata*	31.95	10.10	17.60
AM	6/24/92	*Actionais carinata*	37.65	11.10	30.40
AM	6/24/92	*Actionais carinata*	88.90	44.75	74.55
AM	6/24/92	*Actionais carinata*	42.85	5.80	11.70
AM	6/24/92	*Actionais carinata*	10.90	4.05	6.35
AM	6/24/92	*Actionais carinata*	57.50	21.90	42.45
AM	6/24/92	*Actionais carinata*	19.45	5.50	10.90
AM	6/24/92	*Actionais carinata*	18.00	7.90	11.20
AM	6/24/92	*Actionais carinata*	20.25	4.00	10.70
DE	6/25/92	*Actionais carinata*	70.50	29.70	45.85
DE	6/25/92	*Actionais carinata*	8.35	2.85	4.75
DE	6/25/92	*Actionais carinata*	68.10	41.20	53.15
DE	6/25/92	*Actionais carinata*	122.45	62.20	88.95
DE	6/25/92	*Actionais carinata*	38.45	11.85	25.90
EE	6/25/92	*Actionais carinata*	39.90	13.20	23.90
EE	6/25/92	*Actionais carinata*	9.55	2.95	5.65
CE	6/30/92	*Actionais carinata*	20.75	5.45	11.25
CE	6/30/92	*Actionais carinata*	20.00	6.10	11.25
CE	6/30/92	*Actionais carinata*	17.45	4.35	9.05
CE	6/30/92	*Actionais carinata*	79.10	30.25	51.50

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
CE	6/30/92	*Actionais carinata*	41.90	13.40	24.45
BE	6/30/92	*Actionais carinata*	88.25	33.55	53.75
BE	6/30/92	*Actionais carinata*	10.40	4.15	6.50
BE	6/30/92	*Actionais carinata*	105.15	43.85	68.35
BE	6/30/92	*Actionais carinata*	49.50	16.50	29.20
BE	6/30/92	*Actionais carinata*	84.10	24.60	46.20
BE	6/30/92	*Actionais carinata*	56.75	18.80	34.90
BE	6/30/92	*Actionais carinata*	20.00	4.90	10.40
BE	6/30/92	*Actionais carinata*	79.20	35.00	52.85
BE	6/30/92	*Actionais carinata*	101.10	38.10	62.60
BE	6/30/92	*Actionais carinata*	17.30	4.80	9.50
BE	6/30/92	*Actionais carinata*	84.50	35.05	52.10
BE	6/30/92	*Actionais carinata*	14.20	3.90	7.50
BE	6/30/92	*Alasmodonta marginata*	67.40	36.55	34.60
BE	6/30/92	*Alasmodonta marginata*	45.30	17.50	22.90
DM	6/4/92	*Amblema plicata*	30.04	16.57	24.12
DM	6/4/92	*Amblema plicata*	26.80	15.40	23.45
DM	6/4/92	*Amblema plicata*	63.80	32.30	53.50
EM	6/23/92	*Amblema plicata*	11.20	5.50	9.20
DE	6/25/92	*Amblema plicata*	22.55	14.65	20.40
DE	6/25/92	*Amblema plicata*	7.80	3.00	4.35
DE	6/25/92	*Amblema plicata*	21.50	12.85	18.85
DE	6/25/92	*Amblema plicata*	99.45	51.00	72.80
DE	6/25/92	*Amblema plicata*	29.40	16.80	26.60
EE	6/25/92	*Amblema plicata*	21.15	12.30	16.60
EM	6/23/92	*Alasmodonta viridis*	17.50	8.10	11.90
AM	6/24/92	*Alasmodonta viridis*	9.75	3.35	5.75
BM	6/18/92	*Carunculina parva*	21.40	4.85	15.95
BM	6/18/92	*Carunculina parva*	46.75	13.05	21.35
BW	6/18/92	*Carunculina parva*	34.45	12.60	17.50
BW	6/18/92	*Carunculina parva*	34.50	12.10	17.00
BW	6/18/92	*Carunculina parva*	29.70	11.35	15.65
EM	6/23/92	*Carunculina parva*	28.35	9.00	16.25
AE	6/24/92	*Carunculina parva*	15.10	5.75	8.95
AM	6/24/92	*Carunculina parva*	10.35	3.90	6.05
AM	6/24/92	*Carunculina parva*	7.90	2.75	4.70
AM	6/24/92	*Carunculina parva*	17.15	3.90	8.15
DM	6/4/92	*Cyclonaias tuberculata*	70.44	44.79	63.52
EM	6/23/92	*Cyclonaias tuberculata*	82.75	47.00	79.60
AE	6/24/92	*Cyclonaias tuberculata*	74.25	39.90	70.30
AE	6/24/92	*Cyclonaias tuberculata*	84.40	48.15	80.25
AE	6/24/92	*Cyclonaias tuberculata*	80.15	43.90	81.55
AM	6/24/92	*Cyclonaias tuberculata*	9.95	5.80	8.60
DE	6/25/92	*Cyclonaias tuberculata*	16.90	10.05	15.35
AW	7/1/92	*Cyclonaias tuberculata*	12.60	7.05	10.75
BE	6/30/92	*Cyclonaias tuberculata*	74.80	46.80	65.90
BE	6/30/92	*Cyclonaias tuberculata*	86.80	43.90	79.55
EM	6/23/92	*Elliptio dilitata*	11.40	4.40	6.90
CM	6/17/92	*Elliptio dilitata*	41.90	11.35	20.25
CM	6/17/92	*Elliptio dilitata*	42.05	10.90	19.25
CM	6/17/92	*Elliptio dilitata*	43.60	12.05	20.10
CM	6/17/92	*Elliptio dilitata*	42.80	11.55	19.80
CM	6/17/92	*Elliptio dilitata*	46.90	12.05	21.40

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
CW	6/17/92	*Elliptio dilitata*	47.30	17.15	21.60
CW	6/17/92	*Elliptio dilitata*	51.30	12.45	23.00
CW	6/17/92	*Elliptio dilitata*	52.50	14.70	27.05
BM	6/18/92	*Elliptio dilitata*	36.05	9.75	12.45
BW	6/18/92	*Elliptio dilitata*	88.50	29.60	46.85
BW	6/18/92	*Elliptio dilitata*	70.30	23.45	36.00
EM	6/23/92	*Elliptio dilitata*	119.05	40.00	59.20
AE	6/24/92	*Elliptio dilitata*	92.40	31.65	48.70
DE	6/25/92	*Elliptio dilitata*	71.20	22.75	36.10
DE	6/25/92	*Elliptio dilitata*	77.25	24.05	39.45
DE	6/25/92	*Elliptio dilitata*	58.30	15.50	31.90
EE	6/25/92	*Elliptio dilitata*	118.15	34.10	57.80
EE	6/25/92	*Elliptio dilitata*	52.80	11.55	26.65
EE	6/25/92	*Elliptio dilitata*	118.50	39.90	58.85
EE	6/25/92	*Elliptio dilitata*	94.00	29.10	56.20
CE	6/30/92	*Elliptio dilitata*	53.05	15.30	29.25
CE	6/30/92	*Elliptio dilitata*	57.90	15.25	28.15
CE	6/30/92	*Elliptio dilitata*	53.55	15.20	26.05
BE	6/30/92	*Elliptio dilitata*	81.20	22.80	36.40
BE	6/30/92	*Elliptio dilitata*	104.65	35.25	54.55
DM	6/4/92	*Ellipsaria lineolata*	55.21	24.10	43.23
DM	6/4/92	*Ellipsaria lineolata*	55.00	29.30	47.40
DM	6/4/92	*Ellipsaria lineolata*	86.55	35.30	74.90
DM	6/4/92	*Ellipsaria lineolata*	27.60	19.50	19.90
BW	6/18/92	*Ellipsaria lineolata*	40.75	11.00	27.90
BW	6/18/92	*Ellipsaria lineolata*	16.50	11.05	5.50
EM	6/23/92	*Ellipsaria lineolata*	43.50	18.40	33.20
AE	6/24/92	*Ellipsaria lineolata*	68.45	25.85	53.20
AE	6/24/92	*Ellipsaria lineolata*	7.70	3.45	5.25
AM	6/24/92	*Ellipsaria lineolata*	34.70	10.25	30.05
AM	6/24/92	*Ellipsaria lineolata*	53.80	24.50	47.40
AM	6/24/92	*Ellipsaria lineolata*	48.00	23.10	41.80
DE	6/25/92	*Ellipsaria lineolata*	33.15	11.00	25.35
EE	6/25/92	*Ellipsaria lineolata*	87.30	39.40	67.60
EE	6/25/92	*Ellipsaria lineolata*	53.45	22.65	42.55
EE	6/25/92	*Ellipsaria lineolata*	58.00	32.30	53.70
CE	6/30/92	*Ellipsaria lineolata*	65.50	22.50	38.50
BE	6/30/92	*Ellipsaria lineolata*	87.40	39.60	72.85
DM	6/4/92	*Fusconaia ebena*	95.50	53.04	74.15
DM	6/4/92	*Fusconaia ebena*	71.05	42.15	68.40
EE	6/25/92	*Fusconaia ebena*	76.80	44.50	71.70
BE	6/30/92	*Fusconaia ebena*	63.00	36.30	60.30
BE	6/30/92	*Fusconaia ebena*	68.60	42.40	61.90
DM	6/4/92	*Fusconaia flava*	55.90	36.60	46.75
DM	6/4/92	*Fusconaia flava*	81.00	42.00	68.10
DM	6/4/92	*Fusconaia flava*	59.00	35.60	43.50
DM	6/4/92	*Fusconaia flava*	54.40	32.90	46.10
DM	6/4/92	*Fusconaia flava*	61.00	31.50	51.50
DM	6/4/92	*Fusconaia flava*	55.35	35.10	46.35
DM	6/4/92	*Fusconaia flava*	52.25	35.90	45.00
DM	6/4/92	*Fusconaia flava*	44.85	40.20	30.60
DW	6/9/92	*Fusconaia flava*	20.00	13.25	17.05
DW	6/9/92	*Fusconaia flava*	16.55	10.35	13.90

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
DW	6/9/92	*Fusconaia flava*	16.50	9.20	13.45
CM	6/17/92	*Fusconaia flava*	21.50	13.25	17.80
CM	6/17/92	*Fusconaia flava*	24.00	15.75	21.20
CM	6/17/92	*Fusconaia flava*	24.30	16.20	21.25
CW	6/17/92	*Fusconaia flava*	27.05	17.15	22.85
CW	6/17/92	*Fusconaia flava*	45.60	31.50	39.85
CW	6/17/92	*Fusconaia flava*	23.35	15.65	20.45
CW	6/17/92	*Fusconaia flava*	25.00	11.70	21.70
CW	6/17/92	*Fusconaia flava*	22.70	15.50	19.55
CW	6/17/92	*Fusconaia flava*	24.25	15.75	22.00
CW	6/17/92	*Fusconaia flava*	24.40	15.70	21.40
BM	6/18/92	*Fusconaia flava*	45.00	30.40	41.35
BW	6/18/92	*Fusconaia flava*	12.00	6.00	10.40
EM	6/23/92	*Fusconaia flava*	40.45	27.50	37.30
EM	6/23/92	*Fusconaia flava*	72.25	43.15	58.35
AE	6/24/92	*Fusconaia flava*	18.00	10.15	15.80
AM	6/24/92	*Fusconaia flava*	20.05	11.30	12.20
DE	6/25/92	*Fusconaia flava*	18.80	11.15	16.35
DE	6/25/92	*Fusconaia flava*	20.60	11.60	16.95
EE	6/25/92	*Fusconaia flava*	30.00	20.45	28.90
EE	6/25/92	*Fusconaia flava*	18.80	13.00	17.65
EE	6/25/92	*Fusconaia flava*	17.30	10.20	15.15
EE	6/25/92	*Fusconaia flava*	16.85	9.40	14.40
EE	6/25/92	*Fusconaia flava*	18.60	11.10	16.45
EE	6/25/92	*Fusconaia flava*	17.05	10.90	14.70
EE	6/25/92	*Fusconaia flava*	14.45	18.50	13.05
EE	6/25/92	*Fusconaia flava*	20.15	11.65	16.50
AW	7/1/92	*Fusconaia flava*	26.70	13.35	24.20
AW	7/1/92	*Fusconaia flava*	9.70	4.50	6.95
CE	6/30/92	*Fusconaia flava*	26.70	15.70	23.10
CE	6/30/92	*Fusconaia flava*	24.85	15.95	21.60
CE	6/30/92	*Fusconaia flava*	26.00	15.50	22.40
CE	6/30/92	*Fusconaia flava*	28.80	16.95	25.20
CE	6/30/92	*Fusconaia flava*	26.00	15.50	22.40
DW	6/9/92	*Lasmigona compressa*	46.65	10.75	34.30
EE	6/25/92	*Lasmigona compressa*	75.15	16.20	58.40
DM	6/4/92	*Leptodea fragilis*	11.10	3.08	6.56
DM	6/4/92	*Leptodea fragilis*	20.68	6.10	11.70
DM	6/4/92	*Leptodea fragilis*	13.95	3.45	7.84
DM	6/4/92	*Leptodea fragilis*	20.85	6.50	11.10
DM	6/4/92	*Leptodea fragilis*	14.40	4.00	8.30
DW	6/9/92	*Leptodea fragilis*	14.20	3.30	7.95
DW	6/9/92	*Leptodea fragilis*	16.00	3.75	10.10
CM	6/17/92	*Leptodea fragilis*	51.15	13.35	29.90
CM	6/17/92	*Leptodea fragilis*	18.25	4.10	10.55
CM	6/17/92	*Leptodea fragilis*	49.80	15.90	31.25
CW	6/17/92	*Leptodea fragilis*	25.00	6.00	13.80
CW	6/17/92	*Leptodea fragilis*	16.90	5.20	9.20
BW	6/18/92	*Leptodea fragilis*	24.00	6.25	13.60
EM	6/23/92	*Leptodea fragilis*	16.05	3.75	9.15
AE	6/24/92	*Leptodea fragilis*	19.00	5.60	11.30
AE	6/24/92	*Leptodea fragilis*	50.40	16.70	30.30
AE	6/24/92	*Leptodea fragilis*	23.90	6.40	12.70

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
AE	6/24/92	*Leptodea fragilis*	22.95	5.95	12.45
AM	6/24/92	*Leptodea fragilis*	24.35	6.30	12.40
DE	6/25/92	*Leptodea fragilis*	122.00	37.00	79.50
DE	6/25/92	*Leptodea fragilis*	18.65	5.25	10.40
DE	6/25/92	*Leptodea fragilis*	98.35	29.90	59.45
DE	6/25/92	*Leptodea fragilis*	23.00	6.45	12.20
DE	6/25/92	*Leptodea fragilis*	105.30	35.40	71.50
DE	6/25/92	*Leptodea fragilis*	50.90	15.80	32.25
DE	6/25/92	*Leptodea fragilis*	124.45	36.70	82.10
EE	6/25/92	*Leptodea fragilis*	10.70	4.25	6.35
EE	6/25/92	*Leptodea fragilis*	8.35	2.90	4.95
AW	7/1/92	*Leptodea fragilis*	21.00	6.25	13.20
AW	7/1/92	*Leptodea fragilis*	19.50	5.55	11.40
AW	7/1/92	*Leptodea fragilis*	26.80	7.25	16.40
CE	6/30/92	*Leptodea fragilis*	19.40	4.80	10.00
BE	6/30/92	*Leptodea fragilis*	18.80	5.40	10.45
BE	6/30/92	*Leptodea fragilis*	21.60	6.20	11.70
BE	6/30/92	*Leptodea fragilis*	68.10	23.15	41.25
BE	6/30/92	*Leptodea fragilis*	109.60	35.10	65.95
BE	6/30/92	*Leptodea fragilis*	54.25	17.35	34.00
DW	6/9/92	*Leptodea leptodon*	38.55	12.45	30.75
DW	6/9/92	*Lampsilis ovata ventrcosa*	71.70	35.50	54.95
BW	6/18/92	*Lampsilis ovata ventrcosa*	98.55	47.65	68.10
EE	6/25/92	*Lampsilis ovata ventrcosa*	119.30	36.85	65.85
EM	6/23/92	*Ligumia recta*	45.75	11.85	18.85
EE	6/25/92	*Ligumia recta*	79.30	24.55	38.35
CE	6/30/92	*Ligumia recta*	60.10	14.50	28.30
CE	6/30/92	*Ligumia recta*	47.95	13.20	22.45
BE	6/30/92	*Ligumia recta*	99.60	32.40	43.10
DM	6/4/92	*Lampsilis radiata siliquiodea*	18.02	4.92	9.97
DW	6/9/92	*Lampsilis radiata siliquiodea*	12.40	4.65	10.30
DW	6/9/92	*Lampsilis radiata siliquiodea*	18.20	4.60	9.65
EM	6/23/92	*Lampsilis radiata siliquiodea*	71.90	32.35	52.15
DM	6/4/92	*Obovaria olivaria*	61.77	39.20	55.68
EM	6/23/92	*Obovaria olivaria*	76.95	45.15	73.50
AE	6/24/92	*Obovaria olivaria*	54.15	32.00	45.70
AM	6/24/92	*Obovaria olivaria*	56.85	33.70	46.20
AM	6/24/92	*Obovaria olivaria*	15.90	8.35	11.50
DE	6/25/92	*Obovaria olivaria*	49.85	28.90	45.45
CE	6/30/92	*Obovaria olivaria*	70.55	46.00	60.00
BE	6/30/92	*Obovaria olivaria*	76.55	47.75	61.15
DW	6/9/92	*Obliquaria reflexa*	41.60	29.60	36.25
BM	6/18/92	*Obliquaria reflexa*	30.95	13.15	26.60
BM	6/18/92	*Obliquaria reflexa*	15.75	13.95	8.15
BW	6/18/92	*Obliquaria reflexa*	41.90	30.30	35.90
AE	6/24/92	*Obliquaria reflexa*	47.10	30.25	38.65
AE	6/24/92	*Obliquaria reflexa*	21.30	14.30	18.00
AM	6/24/92	*Obliquaria reflexa*	30.80	19.05	23.45
AM	6/24/92	*Obliquaria reflexa*	30.15	18.95	24.15
EE	6/25/92	*Obliquaria reflexa*	37.15	24.50	30.70
EE	6/25/92	*Obliquaria reflexa*	22.30	12.30	16.30
AW	7/1/92	*Obliquaria reflexa*	27.60	17.45	22.60
AW	7/1/92	*Obliquaria reflexa*	27.30	18.25	22.70

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
AW	7/1/92	*Obliquaria reflexa*	20.50	11.05	14.85
AW	7/1/92	*Obliquaria reflexa*	48.20	22.30	34.80
AW	7/1/92	*Obliquaria reflexa*	21.05	11.45	15.60
BE	6/30/92	*Obliquaria reflexa*	39.25	26.90	31.35
BE	6/30/92	*Obliquaria reflexa*	31.30	11.25	26.40
BE	6/30/92	*Obliquaria reflexa*	29.20	16.65	24.45
DW	6/9/92	*Proptera alata*	23.30	8.15	22.55
EM	6/23/92	*Proptera alata*	89.70	24.90	76.95
EM	6/23/92	*Proptera alata*	73.45	20.80	69.40
AE	6/24/92	*Proptera alata*	93.20	30.50	89.80
AM	6/24/92	*Proptera alata*	163.55	57.05	117.30
AW	7/1/92	*Proptera alata*	152.50	40.65	94.55
AW	7/1/92	*Proptera alata*	136.50	39.05	90.00
AW	7/1/92	*Proptera alata*	58.10	15.50	32.85
AW	7/1/92	*Proptera alata*	116.35	26.10	97.90
BE	6/30/92	*Proptera alata*	31.10	7.75	22.50
EM	6/23/92	*Pleuobema sintoxia*	75.50	61.60	41.30
AW	7/1/92	*Pleuobema sintoxia*	33.75	23.35	34.60
BE	6/30/92	*Pleuobema sintoxia*	56.55	39.50	50.90
DM	6/4/92	*Plagiola (Epioblasma) triquetra*	29.30	15.41	19.72
DM	6/4/92	*Plagiola (Epioblasma) triquetra*	13.80	6.76	10.32
DM	6/4/92	*Plagiola (Epioblasma) triquetra*	23.25	12.64	15.70
DW	6/9/92	*Plagiola (Epioblasma) triquetra*	30.05	16.25	23.65
CM	6/17/92	*Plagiola (Epioblasma) triquetra*	35.85	20.75	24.65
CW	6/17/92	*Plagiola (Epioblasma) triquetra*	35.05	18.50	20.95
DE	6/25/92	*Plagiola (Epioblasma) triquetra*	36.40	20.45	22.35
BE	6/30/92	*Plagiola (Epioblasma) triquetra*	36.05	20.50	20.90
BE	6/30/92	*Plagiola (Epioblasma) triquetra*	20.85	10.30	13.65
DM	6/4/92	*Quadrula fragosa*	72.09	43.61	65.90
DW	6/9/92	*Qudrula metanevra*	42.60	27.20	40.15
CM	6/17/92	*Quadrula metanevra*	71.10	40.05	58.75
CM	6/17/92	*Quadrula metanevra*	74.40	44.35	59.65
CW	6/17/92	*Quadrula metanevra*	52.55	31.95	46.20
BM	6/18/92	*Quadrula metanevra*	54.00	35.40	51.00
EM	6/23/92	*Quadrula metanevra*	56.50	35.55	51.45
AM	6/24/92	*Quadrula metanevra*	70.70	42.75	63.70
DE	6/25/92	*Quadrula metanevra*	44.80	28.15	39.20
DE	6/25/92	*Quadrula metanevra*	51.35	32.70	46.55
DE	6/25/92	*Quadrula metanevra*	63.85	39.50	57.15
DE	6/25/92	*Quadrula metanevra*	63.25	43.95	59.40
CE	6/30/92	*Quadrula metanevra*	34.25	21.50	31.25
BE	6/30/92	*Quadrula metanevra*	83.90	45.50	74.55
BE	6/30/92	*Quadrula metanevra*	76.90	44.45	66.90
BE	6/30/92	*Quadrula metanevra*	64.25	42.80	59.50
BE	6/30/92	*Quadrula metanevra*	64.25	41.95	54.95
DM	6/4/92	*Quadrula nodulata*	20.65	13.05	18.70
DM	6/4/92	*Quadrula pustulosa*	59.65	38.55	58.15
DM	6/4/92	*Quadrula pustulosa*	32.80	21.15	30.80
DW	6/9/92	*Quadrula pustulosa*	32.15	19.00	29.35
CW	6/17/92	*Quadrula pustulosa*	6.05	3.20	5.00
BM	6/18/92	*Quadrula pustulosa*	51.25	33.50	47.70
BW	6/18/92	*Quadrula pustulosa*	66.60	43.20	61.55
EM	6/23/92	*Quadrula pustulosa*	75.30	48.65	67.20

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
EM	6/23/92	*Quadrula pustulosa*	75.05	49.85	69.10
EM	6/23/92	*Quadrula pustulosa*	19.40	11.45	17.30
EM	6/23/92	*Quadrula pustulosa*	34.80	22.45	33.00
AE	6/24/92	*Quadrula pustulosa*	43.05	27.40	42.60
AE	6/24/92	*Quadrula pustulosa*	72.35	46.00	69.95
AE	6/24/92	*Quadrula pustulosa*	13.85	7.50	11.90
AE	6/24/92	*Quadrula pustulosa*	44.70	28.70	45.00
AE	6/24/92	*Quadrula pustulosa*	76.85	44.25	69.45
AE	6/24/92	*Quadrula pustulosa*	16.55	9.85	14.35
AM	6/24/92	*Quadrula pustulosa*	64.45	32.85	67.00
AM	6/24/92	*Quadrula pustulosa*	29.60	20.20	29.60
AM	6/24/92	*Quadrula pustulosa*	47.35	30.95	44.60
AM	6/24/92	*Quadrula pustulosa*	53.15	32.10	51.55
AM	6/24/92	*Quadrula pustulosa*	31.10	20.45	28.70
AM	6/24/92	*Quadrula pustulosa*	49.40	31.00	45.49
AM	6/24/92	*Quadrula pustulosa*	23.50	24.55	20.90
AM	6/24/92	*Quadrula pustulosa*	16.35	10.55	14.65
AM	6/24/92	*Quadrula pustulosa*	46.10	31.00	43.30
AM	6/24/92	*Quadrula pustulosa*	52.75	31.35	50.00
AM	6/24/92	*Quadrula pustulosa*	42.60	29.05	42.55
AM	6/24/92	*Quadrula pustulosa*	33.55	23.80	32.55
DE	6/25/92	*Quadrula pustulosa*	46.50	32.25	45.10
DE	6/25/92	*Quadrula pustulosa*	40.60	27.85	37.80
DE	6/25/92	*Quadrula pustulosa*	23.60	13.85	20.40
DE	6/25/92	*Quadrula pustulosa*	55.45	37.10	54.50
DE	6/25/92	*Quadrula pustulosa*	37.65	24.50	33.20
DE	6/25/92	*Quadrula pustulosa*	62.55	37.10	60.30
DE	6/25/92	*Quadrula pustulosa*	18.15	11.90	16.70
EE	6/25/92	*Quadrula pustulosa*	19.55	11.55	17.65
EE	6/25/92	*Quadrula pustulosa*	15.70	9.00	14.15
EE	6/25/92	*Quadrula pustulosa*	41.75	26.25	38.30
AW	7/1/92	*Quadrula pustulosa*	23.75	14.35	21.65
AW	7/1/92	*Quadrula pustulosa*	40.15	29.10	38.80
AW	7/1/92	*Quadrula pustulosa*	18.00	12.10	17.00
AW	7/1/92	*Quadrula pustulosa*	19.00	11.10	17.10
AW	7/1/92	*Quadrula pustulosa*	24.70	15.90	22.65
AW	7/1/92	*Quadrula pustulosa*	12.95	7.10	11.25
AW	7/1/92	*Quadrula pustulosa*	38.65	25.15	37.70
AW	7/1/92	*Quadrula pustulosa*	12.45	6.60	11.00
AW	7/1/92	*Quadrula pustulosa*	14.80	9.00	12.80
BE	6/30/92	*Quadrula pustulosa*	63.60	38.55	64.90
BE	6/30/92	*Quadrula pustulosa*	47.45	28.35	46.20
BE	6/30/92	*Quadrula pustulosa*	46.80	24.80	43.00
BE	6/30/92	*Quadrula pustulosa*	79.80	40.95	74.15
BE	6/30/92	*Quadrula pustulosa*	43.55	28.25	40.60
BE	6/30/92	*Quadrula pustulosa*	82.95	44.10	84.15
BE	6/30/92	*Quadrula pustulosa*	16.00	9.80	14.00
BE	6/30/92	*Quadrula pustulosa*	40.65	26.55	39.45
AW	7/1/92	*Quadrula quadrula*	46.55	30.05	43.40
DM	6/4/92	*Truncilla donaciformes*	22.60	12.60	16.20
CM	6/17/92	*Truncilla donaciformes*	14.90	6.80	9.60
CM	6/17/92	*Truncilla donaciformes*	17.65	7.20	11.00
CW	6/17/92	*Truncilla donaciformes*	15.50	7.35	10.45

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
BM	6/18/92	*Truncilla donaciformes*	23.45	12.30	16.55
BM	6/18/92	*Truncilla donaciformes*	19.95	8.05	13.65
BM	6/18/92	*Truncilla donaciformes*	24.05	10.90	15.60
BM	6/18/92	*Truncilla donaciformes*	22.10	13.50	15.70
BW	6/18/92	*Truncilla donaciformes*	22.40	12.00	15.95
BW	6/18/92	*Truncilla donaciformes*	23.85	13.40	16.70
EM	6/23/92	*Truncilla donaciformes*	21.30	9.10	13.05
EM	6/23/92	*Truncilla donaciformes*	19.35	10.00	12.50
EM	6/23/92	*Truncilla donaciformes*	26.05	15.55	17.85
EM	6/23/92	*Truncilla donaciformes*	14.75	6.50	10.00
EM	6/23/92	*Truncilla donaciformes*	32.40	19.15	23.65
EM	6/23/92	*Truncilla donaciformes*	23.20	13.15	15.80
EM	6/23/92	*Truncilla donaciformes*	21.70	11.80	16.20
EM	6/23/92	*Truncilla donaciformes*	23.35	11.10	14.85
EM	6/23/92	*Truncilla donaciformes*	24.60	17.75	13.80
EM	6/23/92	*Truncilla donaciformes*	30.30	16.25	21.15
EM	6/23/92	*Truncilla donaciformes*	22.70	11.60	15.40
EM	6/23/92	*Truncilla donaciformes*	22.35	13.40	16.40
AE	6/24/92	*Truncilla donaciformes*	21.70	11.05	15.15
AE	6/24/92	*Truncilla donaciformes*	20.30	11.70	15.90
AE	6/24/92	*Truncilla donaciformes*	26.60	15.75	19.05
AE	6/24/92	*Truncilla donaciformes*	24.60	14.10	17.85
AE	6/24/92	*Truncilla donaciformes*	30.80	16.80	23.35
AE	6/24/92	*Truncilla donaciformes*	16.50	7.30	10.60
AE	6/24/92	*Truncilla donaciformes*	28.80	16.90	20.95
AE	6/24/92	*Truncilla donaciformes*	24.60	13.25	17.75
AM	6/24/92	*Truncilla donaciformes*	29.05	15.10	26.35
AM	6/24/92	*Truncilla donaciformes*	14.00	6.25	11.30
AM	6/24/92	*Truncilla donaciformes*	19.70	11.15	15.95
AM	6/24/92	*Truncilla donaciformes*	19.60	10.95	15.40
AM	6/24/92	*Truncilla donaciformes*	20.30	11.70	15.20
AM	6/24/92	*Truncilla donaciformes*	21.90	12.15	18.35
AM	6/24/92	*Truncilla donaciformes*	21.80	12.20	17.55
AM	6/24/92	*Truncilla donaciformes*	21.20	14.20	17.35
AM	6/24/92	*Truncilla donaciformes*	25.75	14.75	20.40
AM	6/24/92	*Truncilla donaciformes*	27.80	14.70	21.25
AM	6/24/92	*Truncilla donaciformes*	28.10	16.50	20.70
AM	6/24/92	*Truncilla donaciformes*	20.40	14.60	18.65
AM	6/24/92	*Truncilla donaciformes*	19.35	14.85	17.55
AM	6/24/92	*Truncilla donaciformes*	39.15	18.00	26.10
AM	6/24/92	*Truncilla donaciformes*	20.35	11.15	13.65
AM	6/24/92	*Truncilla donaciformes*	20.25	12.95	14.55
AM	6/24/92	*Truncilla donaciformes*	23.10	12.01	15.55
AM	6/24/92	*Truncilla donaciformes*	22.30	13.40	15.40
AM	6/24/92	*Truncilla donaciformes*	22.55	12.60	15.65
AM	6/24/92	*Truncilla donaciformes*	27.65	14.90	20.25
AM	6/24/92	*Truncilla donaciformes*	19.05	10.80	14.05
AM	6/24/92	*Truncilla donaciformes*	23.60	16.90	14.20
AM	6/24/92	*Truncilla donaciformes*	19.95	12.75	14.05
AM	6/24/92	*Truncilla donaciformes*	24.35	14.30	17.50
AM	6/24/92	*Truncilla donaciformes*	22.90	13.30	16.40
AM	6/24/92	*Truncilla donaciformes*	21.40	11.60	15.40
AM	6/24/92	*Truncilla donaciformes*	23.75	15.05	17.50

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
AM	6/24/92	*Truncilla donaciformes*	35.90	19.50	25.00
AM	6/24/92	*Truncilla donaciformes*	27.80	14.75	19.45
AM	6/24/92	*Truncilla donaciformes*	25.05	14.80	18.15
AM	6/24/92	*Truncilla donaciformes*	24.20	11.95	17.00
AM	6/24/92	*Truncilla donaciformes*	28.05	16.30	20.05
AM	6/24/92	*Truncilla donaciformes*	24.50	14.70	16.85
AM	6/24/92	*Truncilla donaciformes*	28.40	15.20	18.55
DE	6/25/92	*Truncilla donaciformes*	25.35	15.00	17.15
DE	6/25/92	*Truncilla donaciformes*	29.15	18.15	22.10
DE	6/25/92	*Truncilla donaciformes*	22.80	12.15	15.15
DE	6/25/92	*Truncilla donaciformes*	26.15	14.40	17.75
DE	6/25/92	*Truncilla donaciformes*	21.75	11.60	15.20
DE	6/25/92	*Truncilla donaciformes*	24.40	10.05	17.75
DE	6/25/92	*Truncilla donaciformes*	22.90	12.90	16.95
DE	6/25/92	*Truncilla donaciformes*	20.55	12.40	15.90
DE	6/25/92	*Truncilla donaciformes*	19.90		13.65
EE	6/25/92	*Truncilla donaciformes*	20.30	11.10	14.15
EE	6/25/92	*Truncilla donaciformes*	21.65	10.40	14.60
EE	6/25/92	*Truncilla donaciformes*	18.75	8.65	12.75
EE	6/25/92	*Truncilla donaciformes*	25.65	14.10	17.50
EE	6/25/92	*Truncilla donaciformes*	15.65	7.20	11.20
EE	6/25/92	*Truncilla donaciformes*	24.70	14.50	17.70
EE	6/25/92	*Truncilla donaciformes*	24.45	12.10	17.30
EE	6/25/92	*Truncilla donaciformes*	21.65	12.00	16.05
EE	6/25/92	*Truncilla donaciformes*	20.20	11.20	14.95
EE	6/25/92	*Truncilla donaciformes*	22.40	12.00	17.35
AW	7/1/92	*Truncilla donaciformes*	21.10	11.80	15.80
AW	7/1/92	*Truncilla donaciformes*	15.50	8.35	11.60
AW	7/1/92	*Truncilla donaciformes*	23.80	13.50	18.45
AW	7/1/92	*Truncilla donaciformes*	19.80	12.40	15.40
AW	7/1/92	*Truncilla donaciformes*	20.80	12.85	16.45
AW	7/1/92	*Truncilla donaciformes*	31.20	15.70	20.70
AW	7/1/92	*Truncilla donaciformes*	27.70	15.70	19.60
AW	7/1/92	*Truncilla donaciformes*	17.45	9.75	13.70
AW	7/1/92	*Truncilla donaciformes*	17.95	9.25	18.10
AW	7/1/92	*Truncilla donaciformes*	23.70	14.15	17.20
AW	7/1/92	*Truncilla donaciformes*	19.70	12.50	15.55
AW	7/1/92	*Truncilla donaciformes*	19.35	10.35	14.00
AW	7/1/92	*Truncilla donaciformes*	25.60	13.25	18.25
AW	7/1/92	*Truncilla donaciformes*	26.75	13.75	18.55
AW	7/1/92	*Truncilla donaciformes*	21.25	11.80	15.20
AW	7/1/92	*Truncilla donaciformes*	19.00	10.95	13.70
AW	7/1/92	*Truncilla donaciformes*	17.35	10.10	12.30
AW	7/1/92	*Truncilla donaciformes*	24.45	13.85	16.10
AW	7/1/92	*Truncilla donaciformes*	39.15	22.90	26.35
AW	7/1/92	*Truncilla donaciformes*	30.00	18.10	20.55
AW	7/1/92	*Truncilla donaciformes*	18.00	9.20	12.05
AW	7/1/92	*Truncilla donaciformes*	35.40	17.50	23.50
AW	7/1/92	*Truncilla donaciformes*	24.70	14.35	17.40
AW	7/1/92	*Truncilla donaciformes*	15.45	8.90	11.75
BE	6/30/92	*Truncilla donaciformes*	17.60	8.90	12.90
BE	6/30/92	*Truncilla donaciformes*	26.50	14.05	18.05
DM	6/4/92	*Truncilla truncata*	41.88	28.62	38.50

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
DM	6/4/92	*Truncilla truncata*	39.90	23.64	34.60
DM	6/4/92	*Truncilla truncata*	26.56	16.62	22.50
DM	6/4/92	*Truncilla truncata*	16.30	9.06	13.87
DM	6/4/92	*Truncilla truncata*	33.54	18.85	26.62
DM	6/4/92	*Truncilla truncata*	18.14	10.42	14.24
DM	6/4/92	*Truncilla truncata*	20.75	11.55	16.00
DM	6/4/92	*Truncilla truncata*	49.70	28.85	39.38
DM	6/4/92	*Truncilla truncata*	37.45	22.06	33.15
DM	6/4/92	*Truncilla truncata*	49.06	31.00	42.88
DM	6/4/92	*Truncilla truncata*	45.78	29.60	38.68
DM	6/4/92	*Truncilla truncata*	46.00	28.15	40.70
DM	6/4/92	*Truncilla truncata*	39.97	22.24	31.85
DM	6/4/92	*Truncilla truncata*	34.04	17.32	27.78
DM	6/4/92	*Truncilla truncata*	41.35	22.75	35.00
DM	6/4/92	*Truncilla truncata*	58.30	36.30	45.55
DM	6/4/92	*Truncilla truncata*	26.49	13.65	20.38
DM	6/4/92	*Truncilla truncata*	14.04	7.12	9.95
DM	6/4/92	*Truncilla truncata*	14.34	8.75	12.51
DM	6/4/92	*Truncilla truncata*	42.84	29.34	38.57
DM	6/4/92	*Truncilla truncata*	41.06	21.92	33.45
DM	6/4/92	*Truncilla truncata*	42.76	23.57	34.17
DM	6/4/92	*Truncilla truncata*	38.95	24.35	34.02
DM	6/4/92	*Truncilla truncata*	40.78	27.86	34.80
DM	6/4/92	*Truncilla truncata*	33.46	20.87	29.10
DM	6/4/92	*Truncilla truncata*	43.60	23.00	33.55
DM	6/4/92	*Truncilla truncata*	27.30	14.90	20.30
DM	6/4/92	*Truncilla truncata*	45.45	26.50	40.85
DM	6/4/92	*Truncilla truncata*	42.20	23.75	35.40
DM	6/4/92	*Truncilla truncata*	42.30	28.10	37.15
DM	6/4/92	*Truncilla truncata*	38.25	21.40	30.65
DM	6/4/92	*Truncilla truncata*	42.80	25.70	37.10
DM	6/4/92	*Truncilla truncata*	18.70	10.15	14.65
DM	6/4/92	*Truncilla truncata*	35.70	21.80	31.50
DM	6/4/92	*Truncilla truncata*	52.00	31.60	39.75
DM	6/4/92	*Truncilla truncata*	22.50	11.75	15.00
DM	6/4/92	*Truncilla truncata*	46.95	29.75	40.50
DM	6/4/92	*Truncilla truncata*	23.80	14.00	20.05
DM	6/4/92	*Truncilla truncata*	38.65	23.55	32.90
DM	6/4/92	*Truncilla truncata*	50.90	30.65	44.80
DM	6/4/92	*Truncilla truncata*	32.10	12.50	20.65
DM	6/4/92	*Truncilla truncata*	34.30	20.70	28.00
DM	6/4/92	*Truncilla truncata*	43.90	29.70	37.35
DM	6/4/92	*Truncilla truncata*	12.15	5.75	8.15
DM	6/4/92	*Truncilla truncata*	19.70	9.75	15.20
DM	6/4/92	*Truncilla truncata*	37.00	22.45	29.65
DM	6/4/92	*Truncilla truncata*	14.05	5.75	9.55
DM	6/4/92	*Truncilla truncata*	40.30	27.85	35.60
DM	6/4/92	*Truncilla truncata*	23.15	13.30	18.60
DM	6/4/92	*Truncilla truncata*	40.50	27.25	36.30
DM	6/4/92	*Truncilla truncata*	31.30	20.70	30.10
DW	6/9/92	*Truncilla truncata*	41.85	22.75	34.60
DW	6/9/92	*Truncilla truncata*	43.05	25.05	36.55
DW	6/9/92	*Truncilla truncata*	53.95	27.75	43.85

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
CM	6/17/92	*Truncilla truncata*	15.35	6.30	10.55
CM	6/17/92	*Truncilla truncata*	14.70	11.85	10.35
CM	6/17/92	*Truncilla truncata*	12.20	6.10	8.75
CM	6/17/92	*Truncilla truncata*	14.45	7.45	10.80
CM	6/17/92	*Truncilla truncata*	20.70	11.10	16.25
CM	6/17/92	*Truncilla truncata*	16.90	8.75	12.25
CM	6/17/92	*Truncilla truncata*	15.45	7.50	11.10
CM	6/17/92	*Truncilla truncata*	39.60	22.65	34.20
CM	6/17/92	*Truncilla truncata*	16.15	7.80	11.40
CW	6/17/92	*Truncilla truncata*	43.00	25.05	35.65
CW	6/17/92	*Truncilla truncata*	40.70	21.60	33.75
CW	6/17/92	*Truncilla truncata*	41.25	19.85	30.65
CW	6/17/92	*Truncilla truncata*	15.70	6.85	10.90
CW	6/17/92	*Truncilla truncata*	12.35	11.05	14.45
CW	6/17/92	*Truncilla truncata*	20.70	10.75	13.75
CW	6/17/92	*Truncilla truncata*	35.55	18.30	26.25
CW	6/17/92	*Truncilla truncata*	12.30	5.85	8.45
BM	6/18/92	*Truncilla truncata*	7.25	2.50	4.60
BM	6/18/92	*Truncilla truncata*	22.95	11.90	17.55
BM	6/18/92	*Truncilla truncata*	12.30	9.45	14.05
BM	6/18/92	*Truncilla truncata*	46.20	25.40	39.05
BM	6/18/92	*Truncilla truncata*	44.85	25.55	38.85
BM	6/18/92	*Truncilla truncata*	15.25	8.40	11.30
BM	6/18/92	*Truncilla truncata*	24.45	13.40	21.10
BW	6/18/92	*Truncilla truncata*	47.90	26.75	37.10
BW	6/18/92	*Truncilla truncata*	44.15	26.10	38.15
BW	6/18/92	*Truncilla truncata*	40.85	23.50	34.65
BW	6/18/92	*Truncilla truncata*	41.60	22.45	32.95
BW	6/18/92	*Truncilla truncata*	39.00	23.95	34.65
BW	6/18/92	*Truncilla truncata*	37.00	20.40	31.00
BW	6/18/92	*Truncilla truncata*	32.10	18.40	25.15
BW	6/18/92	*Truncilla truncata*	34.90	17.60	26.60
BW	6/18/92	*Truncilla truncata*	45.30	29.40	40.00
BW	6/18/92	*Truncilla truncata*	44.20	23.65	36.20
BW	6/18/92	*Truncilla truncata*	40.85	22.60	34.70
BW	6/18/92	*Truncilla truncata*	16.30	10.90	8.10
BW	6/18/92	*Truncilla truncata*	39.40	20.30	30.95
BW	6/18/92	*Truncilla truncata*	35.50	18.70	27.25
BW	6/18/92	*Truncilla truncata*	20.90	12.15	16.95
BW	6/18/92	*Truncilla truncata*	23.80	12.65	18.05
BW	6/18/92	*Truncilla truncata*	14.40	7.35	9.90
BW	6/18/92	*Truncilla truncata*	44.10	22.25	34.10
BW	6/18/92	*Truncilla truncata*	52.10	29.90	43.65
BW	6/18/92	*Truncilla truncata*	45.95	22.75	34.50
BW	6/18/92	*Truncilla truncata*	40.10	24.20	33.90
BW	6/18/92	*Truncilla truncata*	38.55	21.10	30.45
BW	6/18/92	*Truncilla truncata*	20.35	10.30	15.70
BW	6/18/92	*Truncilla truncata*	50.75	27.20	40.70
BW	6/18/92	*Truncilla truncata*	43.55	24.65	33.70
BW	6/18/92	*Truncilla truncata*	32.50	20.80	28.23
BW	6/18/92	*Truncilla truncata*	38.50	22.80	32.45
BW	6/18/92	*Truncilla truncata*	42.05	24.20	34.00
BW	6/18/92	*Truncilla truncata*	18.20	9.60	14.75

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
BW	6/18/92	*Truncilla truncata*	46.10	25.90	36.60
BW	6/18/92	*Truncilla truncata*	22.75	12.25	17.70
BW	6/18/92	*Truncilla truncata*	16.50	8.70	11.40
BW	6/18/92	*Truncilla truncata*	39.00	23.30	32.30
BW	6/18/92	*Truncilla truncata*	13.00	6.60	10.05
EM	6/23/92	*Truncilla truncata*	51.40	32.50	42.85
EM	6/23/92	*Truncilla truncata*	29.45	13.95	25.00
EM	6/23/92	*Truncilla truncata*	30.80	12.70	25.20
EM	6/23/92	*Truncilla truncata*	30.30	11.95	25.25
EM	6/23/92	*Truncilla truncata*	54.05	34.95	42.05
EM	6/23/92	*Truncilla truncata*	44.05	27.10	36.45
EM	6/23/92	*Truncilla truncata*	61.40	40.55	49.60
EM	6/23/92	*Truncilla truncata*	49.95	24.25	37.85
EM	6/23/92	*Truncilla truncata*	41.45	23.75	33.90
EM	6/23/92	*Truncilla truncata*	28.60	12.55	23.50
EM	6/23/92	*Truncilla truncata*	39.25	22.45	29.35
EM	6/23/92	*Truncilla truncata*	48.40	33.10	40.35
EM	6/23/92	*Truncilla truncata*	54.60	31.75	45.60
EM	6/23/92	*Truncilla truncata*	39.35	22.20	34.05
EM	6/23/92	*Truncilla truncata*	32.75	12.05	25.20
EM	6/23/92	*Truncilla truncata*	37.70	25.10	31.85
EM	6/23/92	*Truncilla truncata*	29.45	12.25	25.80
EM	6/23/92	*Truncilla truncata*	30.05	19.25	23.85
EM	6/23/92	*Truncilla truncata*	30.95	19.65	25.75
EM	6/23/92	*Truncilla truncata*	27.05	12.05	22.75
EM	6/23/92	*Truncilla truncata*	43.05	27.05	34.35
EM	6/23/92	*Truncilla truncata*	19.35	11.50	14.95
EM	6/23/92	*Truncilla truncata*	49.65	32.65	43.55
EM	6/23/92	*Truncilla truncata*	42.00	27.45	37.35
EM	6/23/92	*Truncilla truncata*	34.15	21.15	31.15
EM	6/23/92	*Truncilla truncata*	49.10	28.70	39.05
EM	6/23/92	*Truncilla truncata*	52.75	32.50	42.60
EM	6/23/92	*Truncilla truncata*	62.20	37.45	48.10
EM	6/23/92	*Truncilla truncata*	49.40	26.20	38.10
EM	6/23/92	*Truncilla truncata*	45.30	26.85	38.20
EM	6/23/92	*Truncilla truncata*	54.35	34.40	45.50
EM	6/23/92	*Truncilla truncata*	48.50	28.90	39.15
EM	6/23/92	*Truncilla truncata*	40.30	25.15	36.10
EM	6/23/92	*Truncilla truncata*	19.30	11.55	15.45
EM	6/23/92	*Truncilla truncata*	63.20	33.75	48.50
EM	6/23/92	*Truncilla truncata*	26.15	14.30	21.00
EM	6/23/92	*Truncilla truncata*	35.15	21.15	29.15
EM	6/23/92	*Truncilla truncata*	15.60	7.65	10.80
EM	6/23/92	*Truncilla truncata*	54.90	34.55	43.75
EM	6/23/92	*Truncilla truncata*	40.55	36.00	32.60
EM	6/23/92	*Truncilla truncata*	19.80	10.65	14.50
EM	6/23/92	*Truncilla truncata*	46.94	27.20	37.75
EM	6/23/92	*Truncilla truncata*	36.75	20.50	31.90
EM	6/23/92	*Truncilla truncata*	54.20	34.90	49.70
EM	6/23/92	*Truncilla truncata*	24.70	15.40	20.20
EM	6/23/92	*Truncilla truncata*	29.80	19.10	25.90
EM	6/23/92	*Truncilla truncata*	23.20	12.80	18.55
EM	6/23/92	*Truncilla truncata*	34.20	19.20	27.50

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
EM	6/23/92	*Truncilla truncata*	29.45	17.20	23.90
EM	6/23/92	*Truncilla truncata*	29.75	19.00	25.70
EM	6/23/92	*Truncilla truncata*	44.65	25.80	37.30
AE	6/24/92	*Truncilla truncata*	69.55	38.05	51.25
AE	6/24/92	*Truncilla truncata*	39.25	23.45	33.10
AE	6/24/92	*Truncilla truncata*	23.05	12.45	13.05
AE	6/24/92	*Truncilla truncata*	55.65	37.95	48.20
AE	6/24/92	*Truncilla truncata*	33.65	20.30	28.30
AE	6/24/92	*Truncilla truncata*	32.65	17.80	27.05
AE	6/24/92	*Truncilla truncata*	21.36	11.85	12.20
AE	6/24/92	*Truncilla truncata*	26.00	14.60	20.60
AE	6/24/92	*Truncilla truncata*	29.00	16.80	23.35
AE	6/24/92	*Truncilla truncata*	22.25	11.95	12.40
AE	6/24/92	*Truncilla truncata*	26.10	13.00	20.45
AE	6/24/92	*Truncilla truncata*	13.10	6.10	9.15
AE	6/24/92	*Truncilla truncata*	47.80	28.80	38.45
AE	6/24/92	*Truncilla truncata*	22.15	12.25	17.65
AE	6/24/92	*Truncilla truncata*	22.45	11.80	17.05
AE	6/24/92	*Truncilla truncata*	49.40	33.35	44.30
AE	6/24/92	*Truncilla truncata*	39.55	24.05	32.60
AE	6/24/92	*Truncilla truncata*	45.15	23.00	33.65
AE	6/24/92	*Truncilla truncata*	53.30	37.20	46.05
AE	6/24/92	*Truncilla truncata*	48.65	27.95	39.65
AE	6/24/92	*Truncilla truncata*	22.85	13.70	17.65
AE	6/24/92	*Truncilla truncata*	20.60	9.75	14.80
AE	6/24/92	*Truncilla truncata*	14.05	6.35	9.90
AE	6/24/92	*Truncilla truncata*	18.35	11.35	14.90
AE	6/24/92	*Truncilla truncata*	45.00	24.30	35.80
AE	6/24/92	*Truncilla truncata*	35.36	23.20	30.40
AE	6/24/92	*Truncilla truncata*	22.30	12.75	17.80
AE	6/24/92	*Truncilla truncata*	33.35	20.85	29.25
AE	6/24/92	*Truncilla truncata*	28.95	16.60	24.05
AE	6/24/92	*Truncilla truncata*	27.00	16.25	23.05
AE	6/24/92	*Truncilla truncata*	30.45	17.60	26.05
AE	6/24/92	*Truncilla truncata*	26.90	17.20	23.05
AE	6/24/92	*Truncilla truncata*	18.90	7.10	9.90
AE	6/24/92	*Truncilla truncata*	21.10	12.30	17.00
AE	6/24/92	*Truncilla truncata*	20.00	11.30	15.20
AE	6/24/92	*Truncilla truncata*	47.70	29.90	36.80
AE	6/24/92	*Truncilla truncata*	49.40	29.40	41.05
AE	6/24/92	*Truncilla truncata*	23.10	13.35	16.85
AE	6/24/92	*Truncilla truncata*	38.50	24.15	32.75
AE	6/24/92	*Truncilla truncata*	33.25	19.00	26.20
AE	6/24/92	*Truncilla truncata*	19.35	10.65	14.45
AE	6/24/92	*Truncilla truncata*	44.70	28.00	37.80
AE	6/24/92	*Truncilla truncata*	41.45	25.30	33.30
AE	6/24/92	*Truncilla truncata*	38.40	23.00	32.35
AE	6/24/92	*Truncilla truncata*	48.55	28.55	39.55
AE	6/24/92	*Truncilla truncata*	21.85	11.75	17.00
AE	6/24/92	*Truncilla truncata*	22.55	12.65	17.70
AE	6/24/92	*Truncilla truncata*	18.75	11.55	15.15
AE	6/24/92	*Truncilla truncata*	19.55	12.20	14.85
AE	6/24/92	*Truncilla truncata*	50.85	30.85	42.10

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
AE	6/24/92	*Truncilla truncata*	16.25	9.50	13.70
AE	6/24/92	*Truncilla truncata*	60.10	35.20	46.00
AE	6/24/92	*Truncilla truncata*	42.00	26.05	36.05
AE	6/24/92	*Truncilla truncata*	47.30	31.80	40.45
AE	6/24/92	*Truncilla truncata*	45.35	29.50	36.85
AE	6/24/92	*Truncilla truncata*	35.90	22.60	31.80
AE	6/24/92	*Truncilla truncata*	19.65	11.70	16.00
AE	6/24/92	*Truncilla truncata*	35.50	23.10	32.25
AE	6/24/92	*Truncilla truncata*	21.80	13.45	17.90
AE	6/24/92	*Truncilla truncata*	12.95	6.65	9.45
AE	6/24/92	*Truncilla truncata*	13.60	7.95	9.95
AE	6/24/92	*Truncilla truncata*	34.80	21.65	28.95
AE	6/24/92	*Truncilla truncata*	29.50	16.25	24.00
AE	6/24/92	*Truncilla truncata*	44.85	27.35	40.00
AE	6/24/92	*Truncilla truncata*	48.45	28.05	39.70
AE	6/24/92	*Truncilla truncata*	48.35	24.55	36.85
AE	6/24/92	*Truncilla truncata*	37.45	20.90	30.70
AE	6/24/92	*Truncilla truncata*	40.40	24.05	34.20
AE	6/24/92	*Truncilla truncata*	24.50	14.95	19.20
AE	6/24/92	*Truncilla truncata*	20.75	12.65	17.10
AE	6/24/92	*Truncilla truncata*	21.90	14.45	17.60
AE	6/24/92	*Truncilla truncata*	14.05	6.45	9.75
AE	6/24/92	*Truncilla truncata*	22.40	12.85	17.30
AE	6/24/92	*Truncilla truncata*	19.45	11.05	15.20
AE	6/24/92	*Truncilla truncata*	27.75	17.80	23.90
AM	6/24/92	*Truncilla truncata*	46.70	33.10	42.35
AM	6/24/92	*Truncilla truncata*	39.60	22.50	33.15
AM	6/24/92	*Truncilla truncata*	32.70	19.50	25.80
AM	6/24/92	*Truncilla truncata*	33.20	17.95	28.95
AM	6/24/92	*Truncilla truncata*	23.50	11.55	19.70
AM	6/24/92	*Truncilla truncata*	19.50	11.50	16.20
AM	6/24/92	*Truncilla truncata*	21.05	12.25	18.25
AM	6/24/92	*Truncilla truncata*	49.45	31.75	44.35
AM	6/24/92	*Truncilla truncata*	36.35	21.90	31.40
AM	6/24/92	*Truncilla truncata*	33.15	25.40	29.35
AM	6/24/92	*Truncilla truncata*	27.45	17.10	23.20
AM	6/24/92	*Truncilla truncata*	14.90	8.10	10.65
AM	6/24/92	*Truncilla truncata*	20.00	11.60	17.20
AM	6/24/92	*Truncilla truncata*	69.95	43.20	60.20
AM	6/24/92	*Truncilla truncata*	40.90	25.15	35.80
AM	6/24/92	*Truncilla truncata*	34.80	21.85	30.30
AM	6/24/92	*Truncilla truncata*	29.50	17.70	26.30
AM	6/24/92	*Truncilla truncata*	23.90	13.15	19.20
AM	6/24/92	*Truncilla truncata*	21.40	12.10	16.40
AM	6/24/92	*Truncilla truncata*	59.60	32.20	43.85
AM	6/24/92	*Truncilla truncata*	38.90	24.05	32.85
AM	6/24/92	*Truncilla truncata*	30.45	18.10	25.95
AM	6/24/92	*Truncilla truncata*	30.55	17.55	25.65
AM	6/24/92	*Truncilla truncata*	12.80	10.60	14.00
AM	6/24/92	*Truncilla truncata*	55.65	35.25	42.70
AM	6/24/92	*Truncilla truncata*	42.60	26.05	36.35
AM	6/24/92	*Truncilla truncata*	34.35	21.15	29.00
AM	6/24/92	*Truncilla truncata*	41.60	24.15	33.55

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
AM	6/24/92	*Truncilla truncata*	41.90	24.80	36.60
AM	6/24/92	*Truncilla truncata*	27.00	17.65	22.45
AM	6/24/92	*Truncilla truncata*	33.15	21.60	28.45
AM	6/24/92	*Truncilla truncata*	34.60	23.30	30.50
AM	6/24/92	*Truncilla truncata*	31.55	19.15	25.95
AM	6/24/92	*Truncilla truncata*	37.00	21.70	32.60
AM	6/24/92	*Truncilla truncata*	20.10	11.80	16.20
AM	6/24/92	*Truncilla truncata*	33.65	22.40	29.20
AM	6/24/92	*Truncilla truncata*	34.05	20.25	28.15
AM	6/24/92	*Truncilla truncata*	33.15	27.20	20.25
AM	6/24/92	*Truncilla truncata*	22.80	13.25	19.45
AM	6/24/92	*Truncilla truncata*	26.70	15.50	22.10
AM	6/24/92	*Truncilla truncata*	22.05	12.70	17.35
AM	6/24/92	*Truncilla truncata*	25.85	16.85	22.10
AM	6/24/92	*Truncilla truncata*	30.85	11.75	24.45
AM	6/24/92	*Truncilla truncata*	23.75	12.55	13.00
AM	6/24/92	*Truncilla truncata*	24.10	14.80	20.10
AM	6/24/92	*Truncilla truncata*	19.95	12.10	16.40
AM	6/24/92	*Truncilla truncata*	14.65	7.10	10.45
AM	6/24/92	*Truncilla truncata*	26.00	13.40	20.85
AM	6/24/92	*Truncilla truncata*	21.10	11.65	16.35
AM	6/24/92	*Truncilla truncata*	26.40	15.65	21.35
AM	6/24/92	*Truncilla truncata*	23.25	13.30	18.40
AM	6/24/92	*Truncilla truncata*	20.90	12.00	12.80
AM	6/24/92	*Truncilla truncata*	22.15	11.85	16.95
AM	6/24/92	*Truncilla truncata*	24.15	12.25	17.60
AM	6/24/92	*Truncilla truncata*	13.55	7.60	9.80
AM	6/24/92	*Truncilla truncata*	10.10	3.90	6.85
AM	6/24/92	*Truncilla truncata*	5.60	2.50	3.40
AM	6/24/92	*Truncilla truncata*	7.25	2.70	4.55
AM	6/24/92	*Truncilla truncata*	38.40	23.40	32.20
AM	6/24/92	*Truncilla truncata*	31.60	12.90	25.80
AM	6/24/92	*Truncilla truncata*	37.25	22.20	30.65
AM	6/24/92	*Truncilla truncata*	43.25	26.85	34.85
AM	6/24/92	*Truncilla truncata*	54.75	41.10	46.05
AM	6/24/92	*Truncilla truncata*	27.05	11.40	23.05
AM	6/24/92	*Truncilla truncata*	55.10	36.00	43.80
AM	6/24/92	*Truncilla truncata*	34.60	27.50	28.65
AM	6/24/92	*Truncilla truncata*	21.45	11.80	17.15
AM	6/24/92	*Truncilla truncata*	25.35	15.35	20.45
AM	6/24/92	*Truncilla truncata*	28.50	17.15	29.20
AM	6/24/92	*Truncilla truncata*	22.55	14.05	18.55
AM	6/24/92	*Truncilla truncata*	29.50	28.35	25.30
AM	6/24/92	*Truncilla truncata*	24.90	13.25	19.30
AM	6/24/92	*Truncilla truncata*	55.95	32.70	45.75
AM	6/24/92	*Truncilla truncata*	46.00	28.10	40.00
AM	6/24/92	*Truncilla truncata*	40.75	25.22	34.35
AM	6/24/92	*Truncilla truncata*	44.35	29.95	39.65
AM	6/24/92	*Truncilla truncata*	39.15	18.40	26.05
AM	6/24/92	*Truncilla truncata*	26.50	14.50	22.50
AM	6/24/92	*Truncilla truncata*	32.50	19.25	26.00
AM	6/24/92	*Truncilla truncata*	16.60	8.35	13.45
AM	6/24/92	*Truncilla truncata*	22.25	12.80	18.00

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
AM	6/24/92	*Truncilla truncata*	18.70	10.95	14.00
AM	6/24/92	*Truncilla truncata*	22.70	12.25	17.70
AM	6/24/92	*Truncilla truncata*	33.00	16.40	24.90
AM	6/24/92	*Truncilla truncata*	31.70	13.25	26.10
AM	6/24/92	*Truncilla truncata*	26.60	15.65	20.75
AM	6/24/92	*Truncilla truncata*	16.45	9.15	14.15
AM	6/24/92	*Truncilla truncata*	14.55	7.00	9.90
AM	6/24/92	*Truncilla truncata*	12.40	6.65	9.60
AM	6/24/92	*Truncilla truncata*	12.90	6.65	8.55
AM	6/24/92	*Truncilla truncata*	14.30	7.85	10.80
AM	6/24/92	*Truncilla truncata*	6.30	2.65	4.15
AM	6/24/92	*Truncilla truncata*	21.40	12.10	17.50
AM	6/24/92	*Truncilla truncata*	20.90	10.50	15.45
AM	6/24/92	*Truncilla truncata*	19.65	11.40	16.60
AM	6/24/92	*Truncilla truncata*	6.50	2.65	4.30
AM	6/24/92	*Truncilla truncata*	6.45	2.35	3.75
AM	6/24/92	*Truncilla truncata*	15.75	7.50	11.20
AM	6/24/92	*Truncilla truncata*	49.50	30.10	39.65
AM	6/24/92	*Truncilla truncata*	39.65	25.95	34.50
AM	6/24/92	*Truncilla truncata*	48.40	33.45	44.85
AM	6/24/92	*Truncilla truncata*	40.40	23.75	33.10
AM	6/24/92	*Truncilla truncata*	39.30	21.55	33.00
AM	6/24/92	*Truncilla truncata*	40.95	25.15	33.15
AM	6/24/92	*Truncilla truncata*	21.70	13.35	17.40
AM	6/24/92	*Truncilla truncata*	41.85	22.50	33.40
AM	6/24/92	*Truncilla truncata*	32.55	13.20	26.00
AM	6/24/92	*Truncilla truncata*	24.55	13.50	19.25
AM	6/24/92	*Truncilla truncata*	29.00	16.65	22.65
AM	6/24/92	*Truncilla truncata*	26.15	15.50	22.85
AM	6/24/92	*Truncilla truncata*	21.40	12.45	17.20
AM	6/24/92	*Truncilla truncata*	32.25	13.25	26.85
AM	6/24/92	*Truncilla truncata*	26.10	16.15	21.20
AM	6/24/92	*Truncilla truncata*	21.95	12.10	17.45
AM	6/24/92	*Truncilla truncata*	31.70	19.55	27.10
AM	6/24/92	*Truncilla truncata*	24.10	15.35	20.55
AM	6/24/92	*Truncilla truncata*	48.50	28.45	34.60
AM	6/24/92	*Truncilla truncata*	38.65	26.45	35.15
AM	6/24/92	*Truncilla truncata*	32.40	19.60	27.45
AM	6/24/92	*Truncilla truncata*	20.40	12.15	16.50
AM	6/24/92	*Truncilla truncata*	24.40	13.05	19.25
AM	6/24/92	*Truncilla truncata*	22.65	12.05	17.70
AM	6/24/92	*Truncilla truncata*	22.55	11.90	17.00
AM	6/24/92	*Truncilla truncata*	20.05	11.30	15.30
AM	6/24/92	*Truncilla truncata*	23.30	12.50	18.40
AM	6/24/92	*Truncilla truncata*	21.40	11.70	16.40
AM	6/24/92	*Truncilla truncata*	14.30	6.80	10.20
AM	6/24/92	*Truncilla truncata*	14.80	7.70	11.00
AM	6/24/92	*Truncilla truncata*	7.00	2.65	4.30
AM	6/24/92	*Truncilla truncata*	6.55	2.55	4.20
AM	6/24/92	*Truncilla truncata*	55.20	32.00	47.10
AM	6/24/92	*Truncilla truncata*	28.95	12.15	24.50
AM	6/24/92	*Truncilla truncata*	46.35	25.60	38.60
AM	6/24/92	*Truncilla truncata*	26.95	15.35	21.50

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
AM	6/24/92	*Truncilla truncata*	39.95	25.80	34.15
AM	6/24/92	*Truncilla truncata*	23.60	13.20	19.55
AM	6/24/92	*Truncilla truncata*	29.70	17.90	26.60
AM	6/24/92	*Truncilla truncata*	26.05	13.50	20.60
AM	6/24/92	*Truncilla truncata*	24.55	16.10	20.90
AM	6/24/92	*Truncilla truncata*	20.85	11.85	16.00
AM	6/24/92	*Truncilla truncata*	22.50	12.35	17.15
AM	6/24/92	*Truncilla truncata*	21.75	11.85	17.35
AM	6/24/92	*Truncilla truncata*	13.00	6.74	9.35
AM	6/24/92	*Truncilla truncata*	21.90	11.65	15.70
AM	6/24/92	*Truncilla truncata*	21.15	13.35	16.95
AM	6/24/92	*Truncilla truncata*	49.10	32.70	43.75
AM	6/24/92	*Truncilla truncata*	37.15	21.85	32.45
AM	6/24/92	*Truncilla truncata*	48.20	29.60	42.75
AM	6/24/92	*Truncilla truncata*	37.40	22.00	30.20
AM	6/24/92	*Truncilla truncata*	38.70	30.00	37.80
AM	6/24/92	*Truncilla truncata*	23.25	12.50	18.20
AM	6/24/92	*Truncilla truncata*	4.60	2.25	3.25
AM	6/24/92	*Truncilla truncata*	28.85	16.25	23.05
AM	6/24/92	*Truncilla truncata*	51.70	41.50	42.45
AM	6/24/92	*Truncilla truncata*	35.10	20.75	30.20
AM	6/24/92	*Truncilla truncata*	40.75	22.40	33.95
DE	6/25/92	*Truncilla truncata*	40.00	24.70	33.35
DE	6/25/92	*Truncilla truncata*	28.30	11.25	24.90
DE	6/25/92	*Truncilla truncata*	38.20	22.60	32.35
DE	6/25/92	*Truncilla truncata*	17.00	10.20	13.95
DE	6/25/92	*Truncilla truncata*	21.50	11.75	16.50
DE	6/25/92	*Truncilla truncata*	19.80	10.25	15.45
DE	6/25/92	*Truncilla truncata*	48.50	28.60	40.30
DE	6/25/92	*Truncilla truncata*	22.45	12.75	18.15
DE	6/25/92	*Truncilla truncata*	21.90	11.45	16.55
DE	6/25/92	*Truncilla truncata*	21.30	11.20	17.30
DE	6/25/92	*Truncilla truncata*	23.65	13.15	18.30
DE	6/25/92	*Truncilla truncata*	46.45	24.45	35.75
DE	6/25/92	*Truncilla truncata*	41.30	25.40	33.50
DE	6/25/92	*Truncilla truncata*	40.65	23.95	32.75
DE	6/25/92	*Truncilla truncata*	55.45	32.80	44.05
DE	6/25/92	*Truncilla truncata*	40.40	26.95	36.35
DE	6/25/92	*Truncilla truncata*	32.85	18.30	25.90
DE	6/25/92	*Truncilla truncata*	36.65	21.65	29.80
DE	6/25/92	*Truncilla truncata*	27.30	16.90	24.60
DE	6/25/92	*Truncilla truncata*	27.15	15.60	22.45
DE	6/25/92	*Truncilla truncata*	50.95	28.05	39.90
DE	6/25/92	*Truncilla truncata*	14.20	8.20	11.60
DE	6/25/92	*Truncilla truncata*	14.40	8.75	12.00
DE	6/25/92	*Truncilla truncata*	15.60	7.70	10.90
DE	6/25/92	*Truncilla truncata*	6.65	2.85	4.40
DE	6/25/92	*Truncilla truncata*	41.50	28.60	38.65
DE	6/25/92	*Truncilla truncata*	22.60	13.60	18.95
DE	6/25/92	*Truncilla truncata*	45.40	27.55	40.45
DE	6/25/92	*Truncilla truncata*	51.50	34.55	43.65
DE	6/25/92	*Truncilla truncata*	32.05	17.60	25.90
DE	6/25/92	*Truncilla truncata*	30.55	18.75	26.30

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
DE	6/25/92	*Truncilla truncata*	30.55	18.90	25.25
DE	6/25/92	*Truncilla truncata*	21.85	11.50	16.55
DE	6/25/92	*Truncilla truncata*	8.05	3.40	5.10
DE	6/25/92	*Truncilla truncata*	7.40	3.40	4.70
DE	6/25/92	*Truncilla truncata*	6.60	2.80	4.55
DE	6/25/92	*Truncilla truncata*	27.45	16.35	24.35
DE	6/25/92	*Truncilla truncata*	18.95	10.40	14.10
DE	6/25/92	*Truncilla truncata*	7.00	2.65	4.55
DE	6/25/92	*Truncilla truncata*	22.90	12.70	17.20
DE	6/25/92	*Truncilla truncata*	21.00	11.60	16.05
DE	6/25/92	*Truncilla truncata*	40.60	24.10	34.50
DE	6/25/92	*Truncilla truncata*	16.65	8.40	12.25
DE	6/25/92	*Truncilla truncata*	59.85	34.10	49.75
DE	6/25/92	*Truncilla truncata*	50.25	29.55	39.40
DE	6/25/92	*Truncilla truncata*	33.15	21.15	28.50
DE	6/25/92	*Truncilla truncata*	18.70	10.70	14.00
DE	6/25/92	*Truncilla truncata*	29.65	16.10	24.25
DE	6/25/92	*Truncilla truncata*	20.85	12.55	16.55
DE	6/25/92	*Truncilla truncata*	42.70	28.40	37.90
DE	6/25/92	*Truncilla truncata*	22.95	12.75	17.95
DE	6/25/92	*Truncilla truncata*	19.40	11.55	16.05
DE	6/25/92	*Truncilla truncata*	25.25	14.40	20.80
DE	6/25/92	*Truncilla truncata*	33.65	18.70	26.95
DE	6/25/92	*Truncilla truncata*	31.10	16.50	24.65
DE	6/25/92	*Truncilla truncata*	19.70	11.75	15.70
DE	6/25/92	*Truncilla truncata*	25.65	15.05	21.35
DE	6/25/92	*Truncilla truncata*	22.75	14.25	16.70
DE	6/25/92	*Truncilla truncata*	21.45	12.70	17.10
DE	6/25/92	*Truncilla truncata*	20.25	9.80	15.75
DE	6/25/92	*Truncilla truncata*	18.50	11.40	14.20
DE	6/25/92	*Truncilla truncata*	35.05	19.75	29.00
DE	6/25/92	*Truncilla truncata*	22.65	11.65	18.15
DE	6/25/92	*Truncilla truncata*	25.00	14.85	20.15
DE	6/25/92	*Truncilla truncata*	19.00	10.55	15.20
DE	6/25/92	*Truncilla truncata*	34.70	20.90	29.55
DE	6/25/92	*Truncilla truncata*	24.50	13.35	19.15
DE	6/25/92	*Truncilla truncata*	23.10	12.25	17.00
DE	6/25/92	*Truncilla truncata*	51.60	31.50	42.60
DE	6/25/92	*Truncilla truncata*	25.50	16.20	23.15
DE	6/25/92	*Truncilla truncata*	16.05	8.35	11.10
DE	6/25/92	*Truncilla truncata*	37.55	20.55	30.10
DE	6/25/92	*Truncilla truncata*	22.80	11.70	17.15
EE	6/25/92	*Truncilla truncata*	40.60	23.00	33.15
EE	6/25/92	*Truncilla truncata*	43.00	22.90	32.90
EE	6/25/92	*Truncilla truncata*	48.60	29.40	40.25
EE	6/25/92	*Truncilla truncata*	42.25	29.65	39.25
EE	6/25/92	*Truncilla truncata*	34.40	22.25	28.20
EE	6/25/92	*Truncilla truncata*	34.60	19.50	29.75
EE	6/25/92	*Truncilla truncata*	24.45	14.80	20.45
EE	6/25/92	*Truncilla truncata*	31.50	18.10	25.85
EE	6/25/92	*Truncilla truncata*	16.95	9.80	13.25
EE	6/25/92	*Truncilla truncata*	40.40	22.55	34.05
EE	6/25/92	*Truncilla truncata*	17.40	9.65	12.70

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
EE	6/25/92	*Truncilla truncata*	22.60	12.30	17.20
EE	6/25/92	*Truncilla truncata*	34.75	21.50	29.40
EE	6/25/92	*Truncilla truncata*	14.85	7.65	10.55
EE	6/25/92	*Truncilla truncata*	27.20	11.55	22.25
EE	6/25/92	*Truncilla truncata*	14.60	7.20	10.80
EE	6/25/92	*Truncilla truncata*	14.15	8.00	10.45
EE	6/25/92	*Truncilla truncata*	38.10	24.65	35.90
EE	6/25/92	*Truncilla truncata*	20.80	11.20	15.70
EE	6/25/92	*Truncilla truncata*	34.65	20.20	29.35
EE	6/25/92	*Truncilla truncata*	16.45	10.50	19.95
EE	6/25/92	*Truncilla truncata*	58.65	38.20	46.75
EE	6/25/92	*Truncilla truncata*	27.45	17.70	22.95
EE	6/25/92	*Truncilla truncata*	30.85	18.45	26.00
EE	6/25/92	*Truncilla truncata*	14.60	8.00	10.70
EE	6/25/92	*Truncilla truncata*	19.50	11.80	15.35
EE	6/25/92	*Truncilla truncata*	23.30	13.05	19.35
EE	6/25/92	*Truncilla truncata*	32.90	17.75	25.90
EE	6/25/92	*Truncilla truncata*	20.25	12.35	16.30
EE	6/25/92	*Truncilla truncata*	12.85	6.05	9.70
EE	6/25/92	*Truncilla truncata*	37.10	19.55	27.90
EE	6/25/92	*Truncilla truncata*	12.85	6.05	9.70
EE	6/25/92	*Truncilla truncata*	35.65	18.50	28.30
EE	6/25/92	*Truncilla truncata*	19.90	10.80	16.05
EE	6/25/92	*Truncilla truncata*	22.30	10.75	16.70
EE	6/25/92	*Truncilla truncata*	14.15	7.20	9.75
EE	6/25/92	*Truncilla truncata*	55.90	34.30	44.90
EE	6/25/92	*Truncilla truncata*	24.00	12.70	18.55
EE	6/25/92	*Truncilla truncata*	22.50	11.55	17.75
EE	6/25/92	*Truncilla truncata*	34.60	21.45	29.00
EE	6/25/92	*Truncilla truncata*	14.80	7.55	10.00
EE	6/25/92	*Truncilla truncata*	10.65	4.50	6.80
EE	6/25/92	*Truncilla truncata*	8.20	2.85	4.55
EE	6/25/92	*Truncilla truncata*	46.55	30.30	39.60
EE	6/25/92	*Truncilla truncata*	46.70	30.50	39.45
EE	6/25/92	*Truncilla truncata*	26.10	14.00	21.30
EE	6/25/92	*Truncilla truncata*	44.90	27.40	39.55
EE	6/25/92	*Truncilla truncata*	40.15	23.20	33.65
EE	6/25/92	*Truncilla truncata*	21.00	10.75	15.90
EE	6/25/92	*Truncilla truncata*	16.40	7.95	11.80
EE	6/25/92	*Truncilla truncata*	20.65	11.25	16.15
EE	6/25/92	*Truncilla truncata*	14.45	5.90	9.10
EE	6/25/92	*Truncilla truncata*	35.70	25.00	34.15
EE	6/25/92	*Truncilla truncata*	46.95	28.05	33.05
EE	6/25/92	*Truncilla truncata*	13.80	6.55	9.30
EE	6/25/92	*Truncilla truncata*	41.20	28.05	31.70
EE	6/25/92	*Truncilla truncata*	19.75	10.40	15.35
EE	6/25/92	*Truncilla truncata*	18.55	11.30	14.55
EE	6/25/92	*Truncilla truncata*	24.05	12.80	16.30
EE	6/25/92	*Truncilla truncata*	55.70	31.60	43.95
EE	6/25/92	*Truncilla truncata*	18.90	11.00	15.20
EE	6/25/92	*Truncilla truncata*	16.25	8.85	12.70
EE	6/25/92	*Truncilla truncata*	12.90	10.50	14.75
EE	6/25/92	*Truncilla truncata*	21.60	11.95	16.00

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
EE	6/25/92	*Truncilla truncata*	14.60	8.05	11.05
EE	6/25/92	*Truncilla truncata*	19.85	10.55	15.45
EE	6/25/92	*Truncilla truncata*	22.20	12.70	18.10
EE	6/25/92	*Truncilla truncata*	38.50	21.70	29.60
EE	6/25/92	*Truncilla truncata*	47.15	26.50	39.05
EE	6/25/92	*Truncilla truncata*	43.00	28.60	39.05
EE	6/25/92	*Truncilla truncata*	48.55	29.30	38.65
EE	6/25/92	*Truncilla truncata*	48.05	31.65	40.60
EE	6/25/92	*Truncilla truncata*	50.05	30.80	41.55
EE	6/25/92	*Truncilla truncata*	36.60	23.25	31.95
EE	6/25/92	*Truncilla truncata*	18.75	10.75	15.70
EE	6/25/92	*Truncilla truncata*	19.60	11.55	15.75
EE	6/25/92	*Truncilla truncata*	28.65	17.00	24.50
EE	6/25/92	*Truncilla truncata*	27.60	16.85	23.40
EE	6/25/92	*Truncilla truncata*	45.00	23.20	35.40
AW	7/1/92	*Truncilla truncata*	41.35	28.20	37.50
AW	7/1/92	*Truncilla truncata*	18.90	10.95	16.20
AW	7/1/92	*Truncilla truncata*	22.95	13.45	18.00
AW	7/1/92	*Truncilla truncata*	21.50	11.10	17.30
AW	7/1/92	*Truncilla truncata*	31.25	18.25	26.90
AW	7/1/92	*Truncilla truncata*	18.50	10.95	14.50
AW	7/1/92	*Truncilla truncata*	25.40	13.50	19.70
AW	7/1/92	*Truncilla truncata*	28.25	15.40	20.00
AW	7/1/92	*Truncilla truncata*	22.90	12.65	19.20
AW	7/1/92	*Truncilla truncata*	19.60	11.00	15.00
AW	7/1/92	*Truncilla truncata*	21.00	15.60	20.70
AW	7/1/92	*Truncilla truncata*	17.20	10.30	14.65
AW	7/1/92	*Truncilla truncata*	21.80	12.50	16.70
AW	7/1/92	*Truncilla truncata*	19.25	11.90	15.70
AW	7/1/92	*Truncilla truncata*	14.80	7.85	11.50
AW	7/1/92	*Truncilla truncata*	22.25	13.55	18.45
AW	7/1/92	*Truncilla truncata*	14.90	7.50	11.00
AW	7/1/92	*Truncilla truncata*	37.45	20.80	32.00
AW	7/1/92	*Truncilla truncata*	21.75	12.30	16.60
AW	7/1/92	*Truncilla truncata*	13.35	6.65	9.50
AW	7/1/92	*Truncilla truncata*	29.65	17.55	25.85
AW	7/1/92	*Truncilla truncata*	12.50	6.10	8.70
AW	7/1/92	*Truncilla truncata*	13.80	7.20	10.35
AW	7/1/92	*Truncilla truncata*	30.25	18.05	23.45
AW	7/1/92	*Truncilla truncata*	20.80	10.70	15.85
AW	7/1/92	*Truncilla truncata*	14.55	7.10	10.70
AW	7/1/92	*Truncilla truncata*	17.35	8.70	12.40
AW	7/1/92	*Truncilla truncata*	17.45	7.80	11.95
AW	7/1/92	*Truncilla truncata*	23.70	14.00	18.85
AW	7/1/92	*Truncilla truncata*	16.00	7.75	12.50
AW	7/1/92	*Truncilla truncata*	17.00	8.30	13.10
AW	7/1/92	*Truncilla truncata*	25.50	13.30	19.90
AW	7/1/92	*Truncilla truncata*	31.15	18.00	25.80
AW	7/1/92	*Truncilla truncata*	32.65	22.95	25.95
AW	7/1/92	*Truncilla truncata*	63.60	34.00	51.30
AW	7/1/92	*Truncilla truncata*	63.35	32.90	42.55
AW	7/1/92	*Truncilla truncata*	25.55	13.60	20.85
AW	7/1/92	*Truncilla truncata*	25.15	13.90	19.60

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
AW	7/1/92	*Truncilla truncata*	34.05	19.30	28.15
AW	7/1/92	*Truncilla truncata*	43.00	26.40	36.55
AW	7/1/92	*Truncilla truncata*	28.45	27.75	24.00
AW	7/1/92	*Truncilla truncata*	23.35	12.90	18.05
AW	7/1/92	*Truncilla truncata*	29.60	7.75	23.45
AW	7/1/92	*Truncilla truncata*	20.30	12.20	15.90
AW	7/1/92	*Truncilla truncata*	22.55	13.60	18.20
AW	7/1/92	*Truncilla truncata*	19.50	11.35	16.35
AW	7/1/92	*Truncilla truncata*	15.90	9.10	12.35
AW	7/1/92	*Truncilla truncata*	21.10	11.90	17.10
AW	7/1/92	*Truncilla truncata*	70.60	42.85	53.10
AW	7/1/92	*Truncilla truncata*	50.10	28.90	42.30
AW	7/1/92	*Truncilla truncata*	15.05	8.10	11.50
AW	7/1/92	*Truncilla truncata*	37.15	22.70	32.10
AW	7/1/92	*Truncilla truncata*	29.30	18.05	25.75
AW	7/1/92	*Truncilla truncata*	20.10	12.00	17.10
AW	7/1/92	*Truncilla truncata*	27.60	17.30	21.65
AW	7/1/92	*Truncilla truncata*	33.15	12.75	17.50
AW	7/1/92	*Truncilla truncata*	19.60	11.15	15.55
AW	7/1/92	*Truncilla truncata*	21.55	12.95	17.35
AW	7/1/92	*Truncilla truncata*	14.10	7.30	10.00
CE	6/30/92	*Truncilla truncata*	16.80	9.75	13.55
CE	6/30/92	*Truncilla truncata*	25.00	16.30	22.80
CE	6/30/92	*Truncilla truncata*	23.70	14.30	18.95
CE	6/30/92	*Truncilla truncata*	28.70	17.05	23.35
CE	6/30/92	*Truncilla truncata*	36.65	18.00	28.25
CE	6/30/92	*Truncilla truncata*	27.30	12.50	23.10
CE	6/30/92	*Truncilla truncata*	39.70	21.65	31.50
CE	6/30/92	*Truncilla truncata*	22.40	11.90	16.70
BE	6/30/92	*Truncilla truncata*	45.35	31.00	41.20
BE	6/30/92	*Truncilla truncata*	52.40	32.85	46.75
BE	6/30/92	*Truncilla truncata*	54.66	30.95	45.75
BE	6/30/92	*Truncilla truncata*	27.10	16.45	21.90
BE	6/30/92	*Truncilla truncata*	39.55	25.15	36.25
BE	6/30/92	*Truncilla truncata*	52.50	31.40	44.15
BE	6/30/92	*Truncilla truncata*	48.60	24.90	38.20
BE	6/30/92	*Truncilla truncata*	41.15	24.30	33.25
BE	6/30/92	*Truncilla truncata*	48.00	28.75	39.50
BE	6/30/92	*Truncilla truncata*	54.25	34.25	46.80
BE	6/30/92	*Truncilla truncata*	45.30	24.95	36.30
BE	6/30/92	*Truncilla truncata*	35.25	19.55	28.30
BE	6/30/92	*Truncilla truncata*	28.95	14.40	21.20
BE	6/30/92	*Truncilla truncata*	26.65	12.95	20.40
BE	6/30/92	*Truncilla truncata*	50.45	27.50	39.25
BE	6/30/92	*Truncilla truncata*	52.15	27.85	38.35
BE	6/30/92	*Truncilla truncata*	40.35	23.75	33.70
BE	6/30/92	*Truncilla truncata*	57.60	34.60	41.70
BE	6/30/92	*Truncilla truncata*	20.95	12.70	17.20
BE	6/30/92	*Truncilla truncata*	51.00	29.20	39.90
BE	6/30/92	*Truncilla truncata*	24.70	13.80	19.95
BE	6/30/92	*Truncilla truncata*	16.75	9.35	12.55
BE	6/30/92	*Truncilla truncata*	14.80	7.80	10.80
BE	6/30/92	*Truncilla truncata*	69.90	40.65	48.75

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
BE	6/30/92	*Truncilla truncata*	55.85	36.90	33.90
BE	6/30/92	*Truncilla truncata*	44.80	28.85	35.70
BE	6/30/92	*Truncilla truncata*	50.45	30.00	37.95
BE	6/30/92	*Truncilla truncata*	21.09	18.10	17.90
BE	6/30/92	*Truncilla truncata*	33.20	18.45	26.60
BE	6/30/92	*Truncilla truncata*	24.10	13.00	17.95
BE	6/30/92	*Truncilla truncata*	40.70	22.30	30.00
BE	6/30/92	*Truncilla truncata*	44.10	25.30	36.80
BE	6/30/92	*Truncilla truncata*	48.30	26.45	35.30
BE	6/30/92	*Truncilla truncata*	39.30	21.60	29.30
BE	6/30/92	*Truncilla truncata*	43.15	26.30	36.20
BE	6/30/92	*Truncilla truncata*	46.40	29.35	40.25
BE	6/30/92	*Truncilla truncata*	40.20	22.55	37.80
BE	6/30/92	*Truncilla truncata*	15.30	7.85	11.00
BE	6/30/92	*Truncilla truncata*	22.40	12.20	16.95
BE	6/30/92	*Truncilla truncata*	57.25	35.55	45.60
BE	6/30/92	*Truncilla truncata*	50.15	26.60	38.20
BE	6/30/92	*Truncilla truncata*	56.75	31.00	41.70
BE	6/30/92	*Truncilla truncata*	21.10	11.25	15.85
BE	6/30/92	*Truncilla truncata*	37.35	21.85	30.75
BE	6/30/92	*Truncilla truncata*	29.65	16.50	24.00
BE	6/30/92	*Truncilla truncata*	18.00	8.20	12.65
BE	6/30/92	*Truncilla truncata*	40.95	21.45	33.35
BE	6/30/92	*Truncilla truncata*	23.00	11.70	12.45
BE	6/30/92	*Truncilla truncata*	20.40	12.00	16.50
BE	6/30/92	*Truncilla truncata*	13.70	6.70	10.10
BE	6/30/92	*Truncilla truncata*	13.65	7.45	10.20
BE	6/30/92	*Truncilla truncata*	59.70	32.85	46.15
BE	6/30/92	*Truncilla truncata*	45.70	28.80	33.70
BE	6/30/92	*Truncilla truncata*	23.85	15.00	19.50
BE	6/30/92	*Truncilla truncata*	44.55	26.75	37.05
BE	6/30/92	*Truncilla truncata*	37.65	19.00	29.70
BE	6/30/92	*Truncilla truncata*	49.50	33.15	40.60
BE	6/30/92	*Truncilla truncata*	22.50	12.10	17.05
BE	6/30/92	*Truncilla truncata*	29.00	16.25	22.15
BE	6/30/92	*Truncilla truncata*	25.30	14.85	20.75
BE	6/30/92	*Truncilla truncata*	23.05	11.70	17.75
BE	6/30/92	*Truncilla truncata*	26.70	14.50	21.00
BE	6/30/92	*Truncilla truncata*	15.80	8.35	11.50
BE	6/30/92	*Truncilla truncata*	14.25	7.15	9.90
BE	6/30/92	*Truncilla truncata*	20.50	12.05	16.50
BE	6/30/92	*Truncilla truncata*	14.25	8.40	10.60
BE	6/30/92	*Truncilla truncata*	53.25	35.50	43.40
BE	6/30/92	*Truncilla truncata*	56.20	29.40	42.95
BE	6/30/92	*Truncilla truncata*	46.15	26.60	35.30
BE	6/30/92	*Truncilla truncata*	48.30	32.35	39.90
BE	6/30/92	*Truncilla truncata*	33.80	19.10	27.65
BE	6/30/92	*Truncilla truncata*	47.05	27.30	39.95
BE	6/30/92	*Truncilla truncata*	67.55	37.40	57.15
BE	6/30/92	*Truncilla truncata*	56.20	34.00	42.45
DM	6/4/92	*Tritigonia verrucosa*	78.30	26.10	49.66
CW	6/17/92	*Tritigonia verrucosa*	81.90	23.40	48.05
CW	6/17/92	*Tritigonia verrucosa*	85.85	27.75	54.00

SITE	DATE	SPECIES	Shell Length (mm)	Shell Width (mm)	Shell Height (mm)
AM	6/24/92	*Tritigonia verrucosa*	96.45	34.70	57.50
AM	6/24/92	*Tritigonia verrucosa*	59.15	17.50	35.40
AW	7/1/92	*Tritigonia verrucosa*	81.20	24.50	50.00
AW	7/1/92	*Tritigonia verrucosa*	55.75	21.40	33.15
BE	6/30/92	*Tritigonia verrucosa*	40.05	9.35	19.00
BE	6/30/92	*Tritigonia verrucosa*	82.00	27.10	50.10
BE	6/30/92	*Tritigonia verrucosa*	86.90	30.55	55.80
BE	6/30/92	*Tritigonia verrucosa*	100.65	34.90	62.25
BE	6/30/92	*Tritigonia verrucosa*	103.50	34.30	66.60

APPENDIX 4

HORNBACH'S (1995) REPORT

ON HABITAT USE

BY

Q. FRAGOSA

The effect of water depth and velocity on mussel distributions in the St. Croix River, Interstate Park.

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Prepared for the Winged Mapleleaf Recovery Team
July 27, 1995

Introduction

The endangered mussel, *Quadrula fragosa* is currently found only in a single location in the St. Croix River. The major concentrations of this mussel have been found near Blast Island and in the east channel of the river by Folsom Island at Interstate Park. Hornbach (1992) has examined the factors which influence the distribution of this endangered mussel. They indicated that this species is found in areas of the river which harbor dense and diverse mussel communities. Johnson (1995) has conducted an instream flow study in the east channel of the St. Croix River near Folsom Island, and used the data from Hornbach (1992) to develop a PHABSIM model for mussel density and species richness. Based on this model Johnson recommended a run-of-river flow regime to meet the instream flow needs of *Q. fragosa* and the mussel community. Johnson indicated that for the east channel of the St. Croix River by Folsom Island, mussel density WUAs (weighted usable area) peaked at 6500 cfs. Currently the hydroelectric dam has a minimum summer release of 1600 cfs or run-of river if natural flows are below 1600 cfs and has voluntarily agreed to maintain a minimum winter release of 800 cfs.

A good deal of controversy has surrounded this recommendation. In order to provide additional information we conducted a semi-quantitative survey in the east channel of the River near Folsom Island.

Methods

Two transect lines (labelled Transect 3 and 4) were placed on the bottom of the river in the east channel of the river (Fig. 1). These transects were placed at locations where Johnson (1995) conducted an instream flow study (2 most downstream transects taken in the east channel by Folsom Island - Fig. 3a in Johnson (1995) - labelled Transects 1 and 3 in Fig A1 Johnson and Chisholm (1995)). Transect 3 was sampled on June 14,1995 and Transect 4 was sampled on June 16, 1995. Table 1 gives information on the sites. Every 5 m along the transect line water depth and flow were measured. In addition a SCUBA diver noted the makeup of the substrate. Also at each 5 m mark a diver spent 2 minutes collecting mussels and placing them in a labelled mesh bag. The bags were returned to the surface, the mussels were identified, shell length, width and height were measured. The mussels were then returned to the river. The number of mussels taken during a 2 min. search gives an indication of the density of mussels at various locations along the transect. Voucher specimens were taken and will be deposited at the Bell Museum at the end of the summer of 1995.

Results and Discussion

A total of 610 mussels representing 22 species were taken from the two transects. Figure 2 gives the distribution of the mussel species taken from the transects. The species makeup varied between the two transects (Fig. 3). *Truncilla truncata* dominated both transects and there was not a significant difference in the proportion of the community this species represented in the 2 transects χ^2=1.1, p=0.29. A single *Q. fragosa* was found in Transect 4 at station 31. The individual that was found was 7 years old and had a shell length of 50.01 mm. The water was 1.1 m with water flows of 0.35 m/s at the bottom and 0.45 m/s for the mean column flow (flow taken at 0.6 depth). The specimen was labelled XJ on the anterior portion of the right valve and was returned to the river.

Transect 3 had a mean depth of 1.06 m and was significantly shallower than Transect 4 with a mean depth of 1.19 m (t=3.0, 77 df, p=0.003). Transect 3 also had fewer mussels per station (0 = 6.58) and few mussels species per station (0 = 2.81) than Transect 4 (0 = 8.78 mussels per station and 0 = 4.02 mussel species per station). T-tests indicated that the number of species per station was significantly higher for Transect 4 compared to Transect 3 (t=2.67, 77 df, p=0.009) while the number of mussels per station was nearly significantly higher in Transect 4 compared to Transect 3 ($t=1.94$, 77 df, $p=0.056$).

In both transects there was an area in the center of the channel where water depth was quite shallow (Fig. 4). Figure 4 also shows the distribution of mussels across the channel. It is apparent that the number of mussels and species richness are at minimums in the middle of the channel. These trends reflect what was predicted by Johnson and Chisholm (1995) based on composite suitability indices from their PHABSIM model (Figs. A4,A5, A7, and A8 in Johnson and Chisholm (1995)). Figures 5 and 6 show that water depth significantly influenced the number of mussels collected and the richness of the mussel community. Maximum mussel density occurred at a depth of 1.55 m while the maximum number of species occurred at a depth of 1.49 m. Based on 719 0.25 m^2 quadrats taken throughout the St. Croix River (Hornbach, pers. observation) the maximum mussel density occurred at a depth of 1.75 m and the maximum species richness occurred at a depth of 1.55 m confirming the data collected in this study.

There was no significant influence of bottom flow on either the number of mussels or the number of species collected along the transects (Figures 7 and 8). Also there was no significant difference in the number of mussels or the number of mussel species among the various sediment types identified along the transect (Figures 9 and 10).

We noted that the influence of depth on mussel abundance appeared to be especially important for small mussels. Only 24 of the 79 stations had mussels < 25 mm in shell length. Figure 11 shows that the depth of stations which had small mussels was significantly greater than for those stations that did not have small mussels ($t=2.48$, 77 df, $p=0.02$). This indicates that low water levels in the east channel may have an influence on the maximum mussel recruitment potential for this area.

Three other events occurred during our June sampling at Interstate Park which merit comment. On at least two occasions, including June 16, 1995 one of the paddlewheel boats was noted moving through the east channel of the river by Folsom Island. On June 16th we were conducting our work on Transect 4. The boat moved across the transect between our stations

14 and 20 where the water was between 0.96 and 1.1 m (Fig. 12). On June 19, 1995 we saw one of the paddlewheelers run aground on the east shore of Blast Island - another area of known *Q. fragosa* populations.

Also on June 23, 1995 we noted exposed substrate in the east channel by Folsom Island in an area between where we sampled Transect 3 and 4 (Fig. 13). This exposure was noted between 9:00 and 9:30 EDT when discharge from the river was 1750 cfs which corresponds to a dam relaease of 1600 cfs, the required minimum summer release. We estimated that the exposure was in an area of the channel which was near stations 15-20 - where we had recorded the shallowest water on June 14 and 16 and also noted on the USGS Quadrangle map for this area (Fig. 14). These stations corresponded to areas with the fewest number of mussels (Fig. 4). We conclude that this type of exposure is responsible for the lack of mussels inhabiting this portion of the east channel of the St. Croix by Folsom Island.

On June 28, 1995, while conducting a species-specific search for *Q. fragosa* in the west channel by Clark Island, visitors to the park who were staying in the group camping area near Clark Island asked what we were studying. When we replied that we were examining mussel communities in the area they mentioned that they had collected a bucket of mussels. We indicated that collecting mussels in this area was illegal. As we returned the mussels to the river for them, we found that one of the mussels in their bucket was a *Q. fragosa.* This potential impact of human collectors on the endangered mussel indicates that additional information needs to be provided to visitors to Interstate Park dissuading them from collecting mussels from the river.

Based on the PHABSIM results from the model of Johnson (1995) and Johnson and Chisholm (1995), a discharge of greater than 4000 cfs would be needed to provide the maximum habitat for mussel density and species richness in the east channel of the St. Croix near Folsom Island. Since Hornbach (1992) has shown that *Q. fragosa* is associated with rich and dense mussel communities, a minimum discharge of greater than 4,000 cfs or a run-of river flow regime seems warranted.

Literature Cited

Hornbach, D.J. 1992. An examination of the population structure, community relationships and habitat characteristics for the winged mapleleaf mussel (*Quadula fragosa*) at Interstate Park, Saint Croix River, Wisconsin and Minnesota. Report submitted to Wisconsin DNR and Minnesota DNR.

Johnson, S. L. 1995. Instream flow requirments of *Quadrula fragosa* and the aquatic community in the Lower St. Croix River downstream of the Northern States Power hydroelectric dam at St. Croix Falls, Wisconsin. Report submitted to the Bureau of Endangered Resources, Wisconsin DNR.

Johnson, S.L. And I. Chisholm. 1995. Addendum to St. Croix River Instream Flow Study. Memorandum send to Winged Mapleleaf Recovery Team, April 5, 1995.

Acknowledgements

I wish to thank my research group including Tony Deneka, Patrick Baker, Megan Tyrrell, Dan Schibel, Paul Evans, Shawn Hockert, and Kevin Sloan who aided in the diving and data analysis. Also thanks to Shawn Johnson of the Minnesota DNR for providing us with the locations for collecting and for assisting us in the field. This work was conducted in conjunction with research being funded by the US Fish and Wildlife Service and the US EPA.

Table 1. Attributes of the two transects sampled in the East Channel of the St. Croix River by Folsom Island, Interstate Park.

Attribute	**Transect 3**	**Transect 4**
Date Sampled	June 14, 1995	June 16, 1995
Latitude/Longitude at East end of Transect	45°23.65'N 92°39.66'W	45°23.72'N 92°39.71'W
Latitude/Longitude at West end of Transect	45°23.60'N 92°39.75'W	45°23.66'N 92°39.83'W
Discharge	6510-6540 cfs	6480 cfs
H_2O Temperature	19°C	23.3°C
Conductivity	140 μmhos•cm^{-1}	155 μmhos•cm^{-1}
Dissolved O_2	8.5 mg•L^{-1}	8.1 mg•L^{-1}

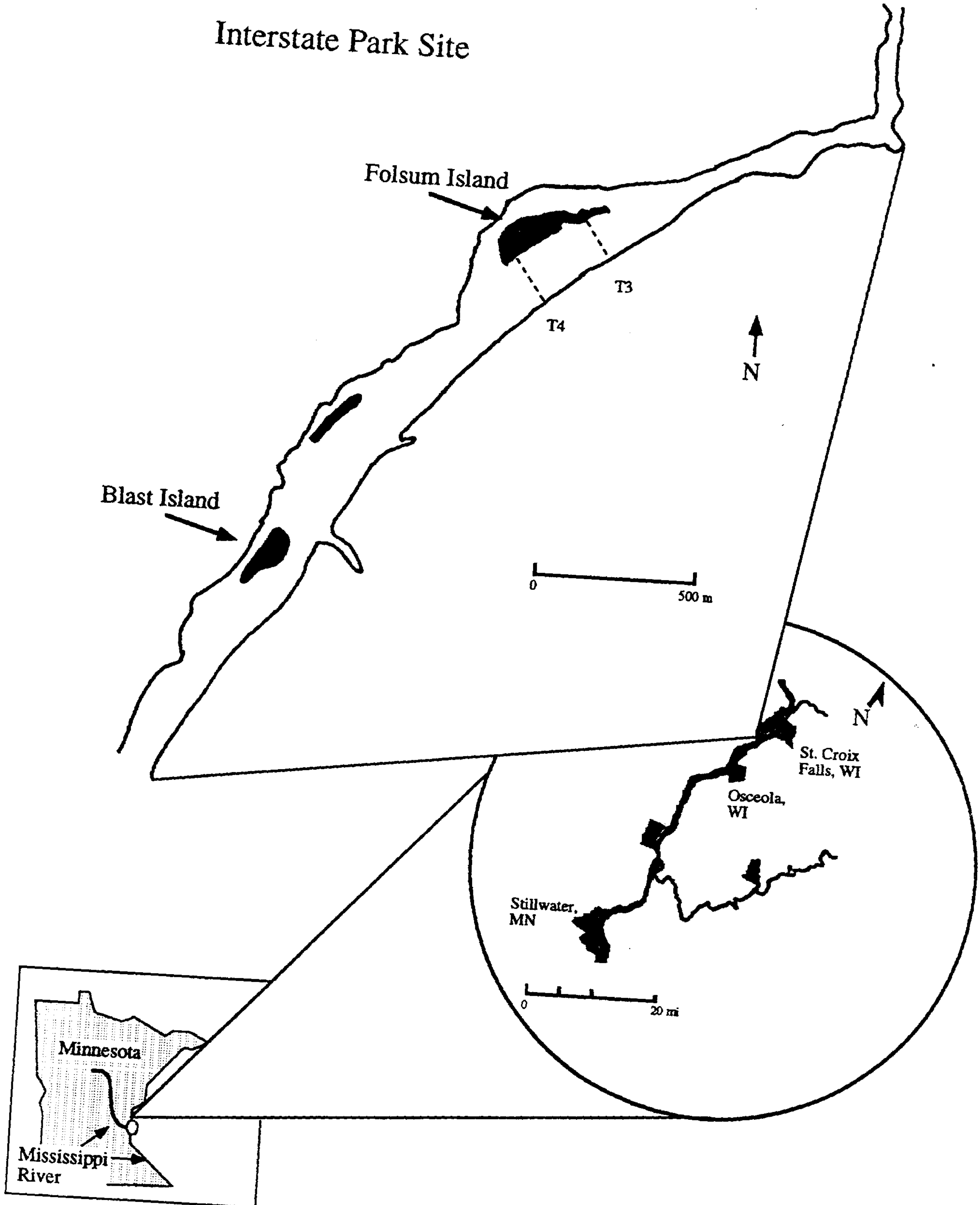

Figure 1. Map of study area.

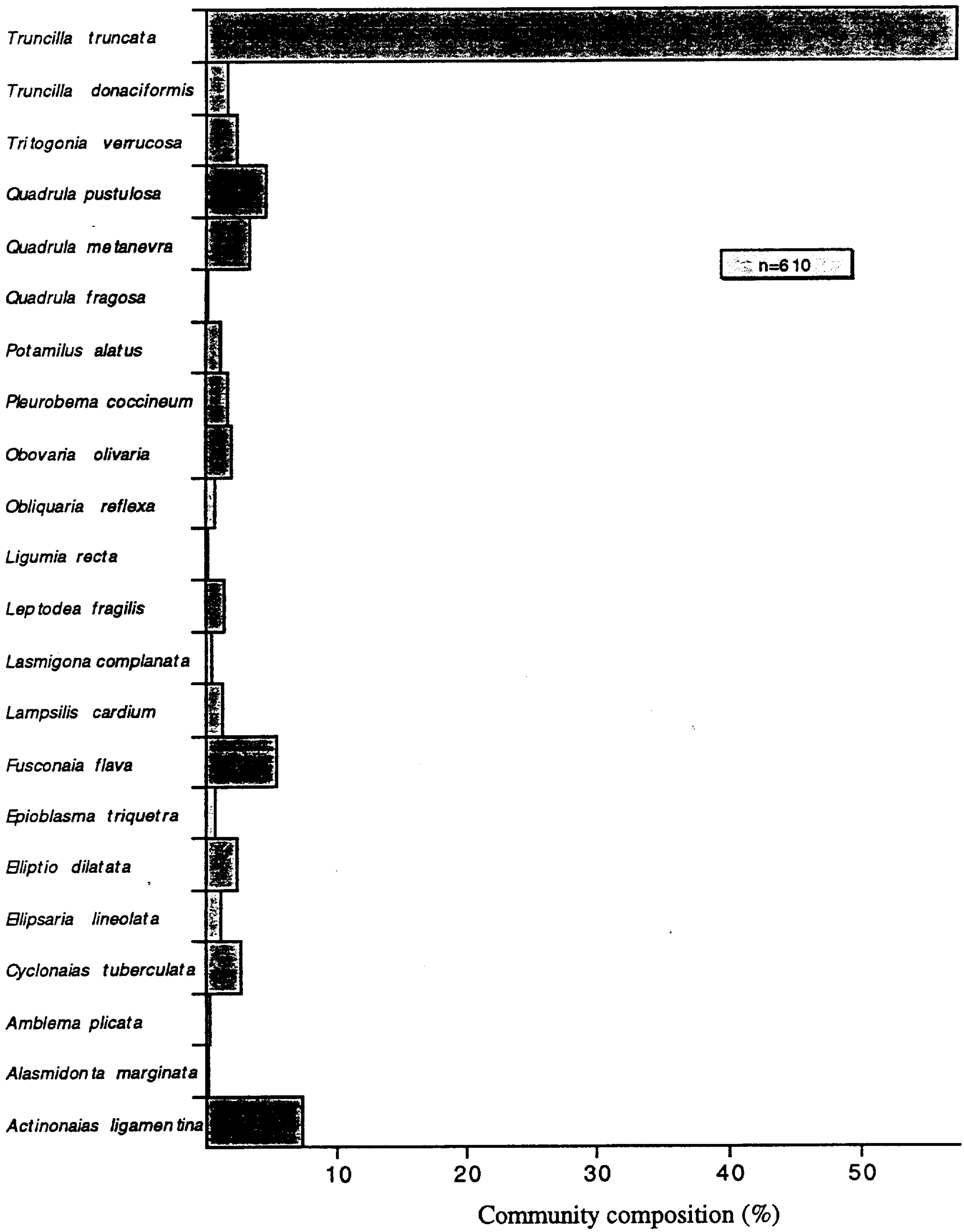

Figure 2. Mussel community structure from two transects sampled at Folsum Island.

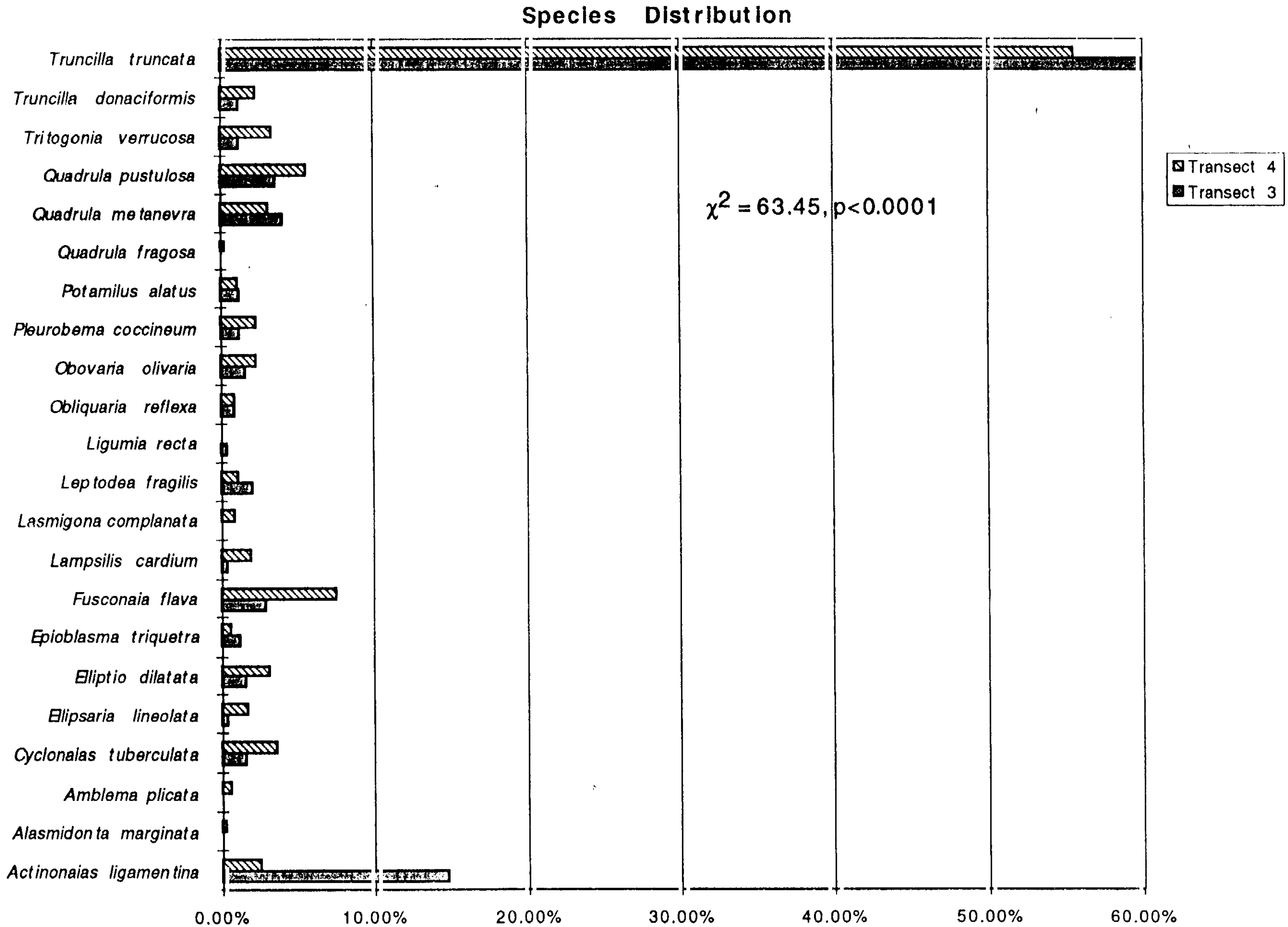

Figure 3. Variation in mussel community structure among two transects sampled at Folsum Island.

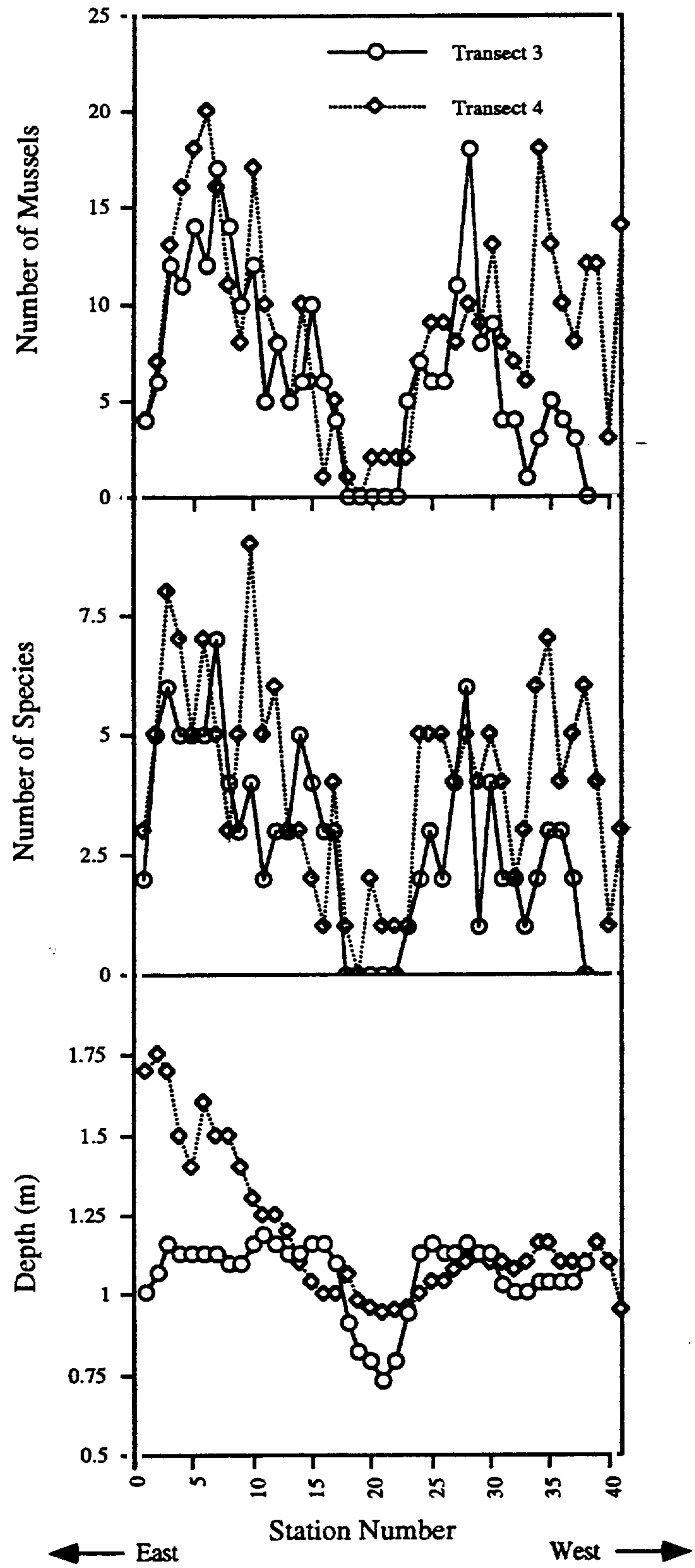

Figure 4. Variation in water depth, number of mussels collected and number of mussel species found across the transects sampled at Folsum Island.

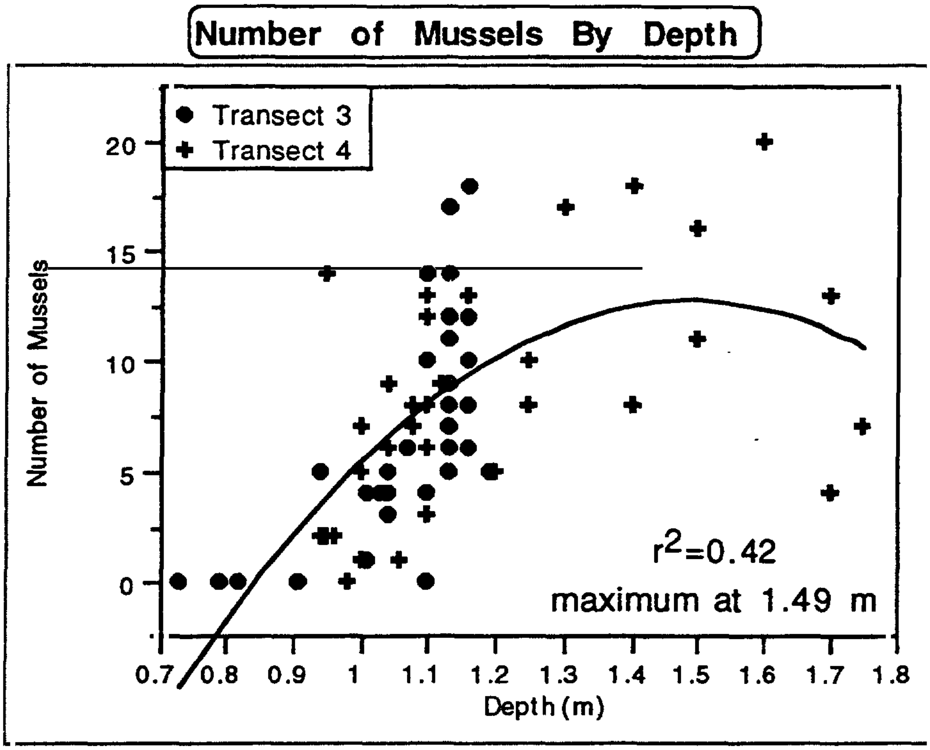

Figure 5. Relationship between water depth and number of mussels collected.

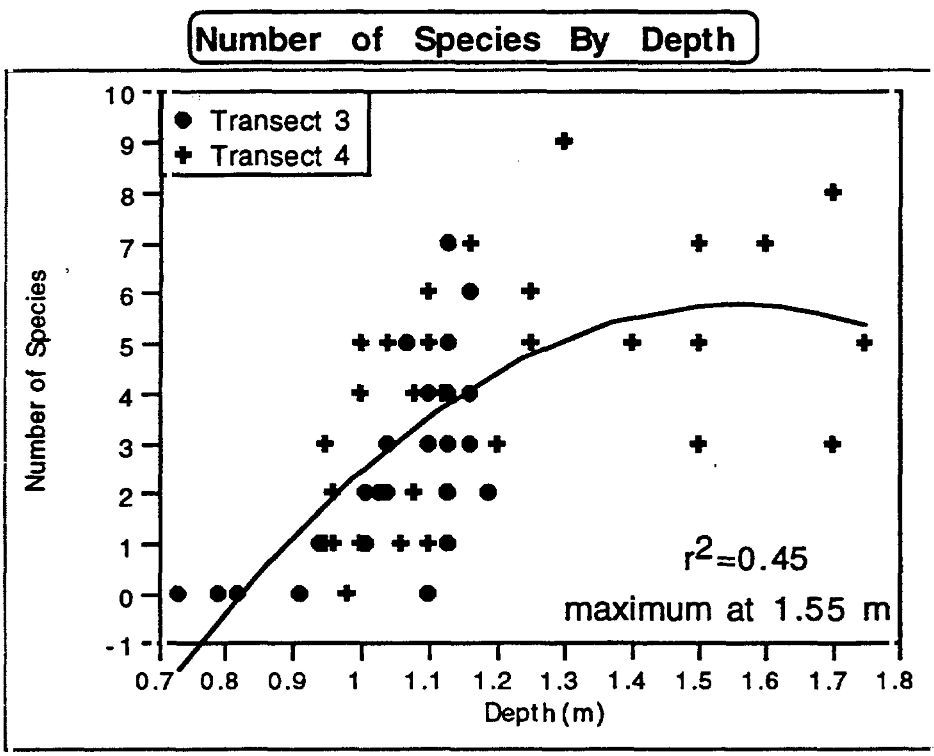

Figure 6. Relationship between water depth and number of mussel species collected.

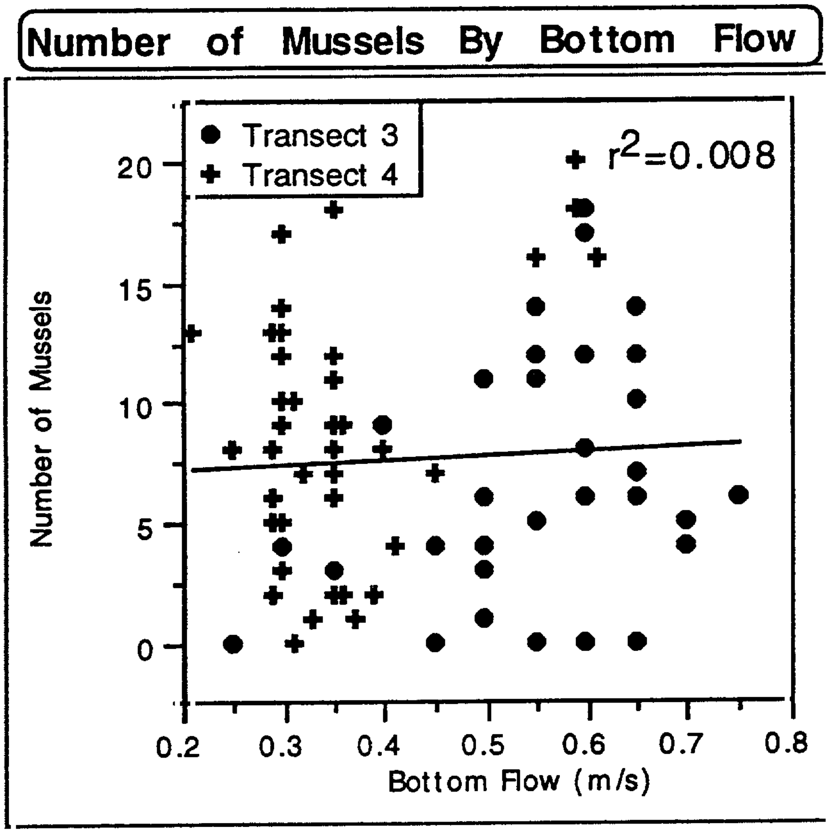

Figure 7. Relationship between water velocity and number of mussels collected.

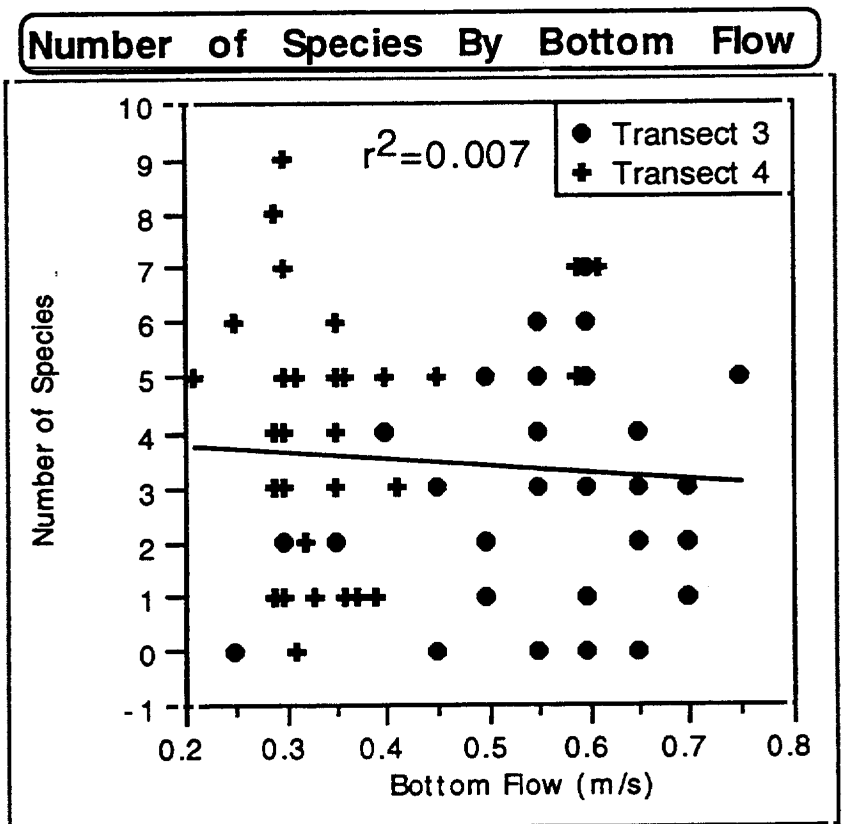

Figure 8. Relationship between water velocity and number of mussel species collected.

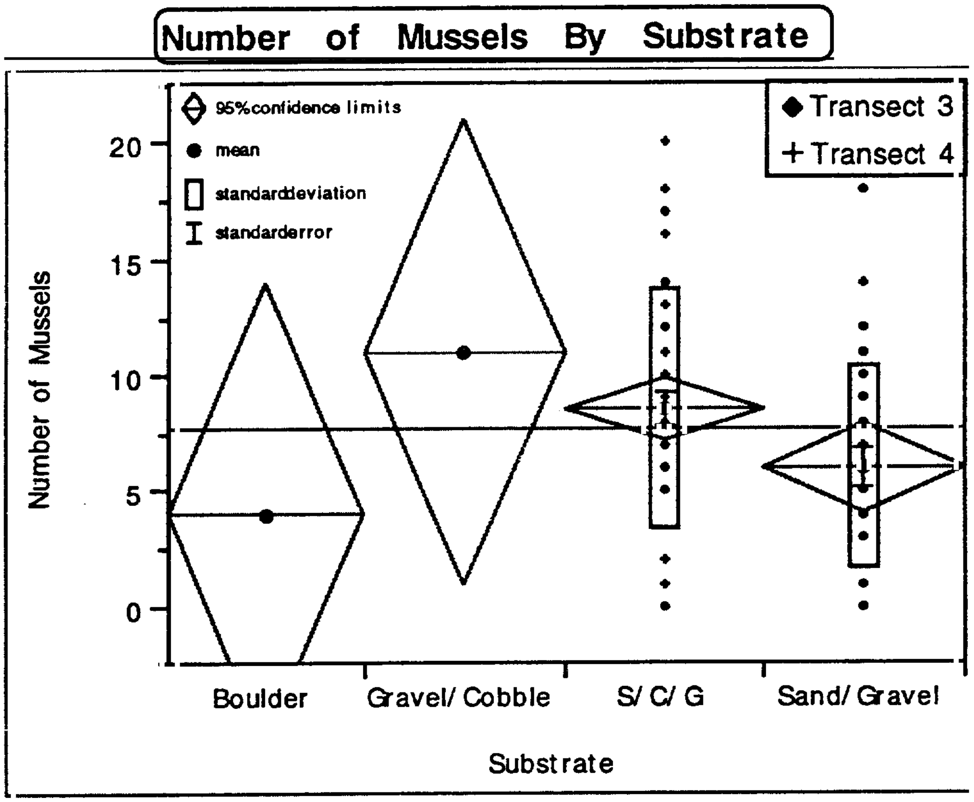

Figure 9. Relationship between substrate composition and number of mussels collected.

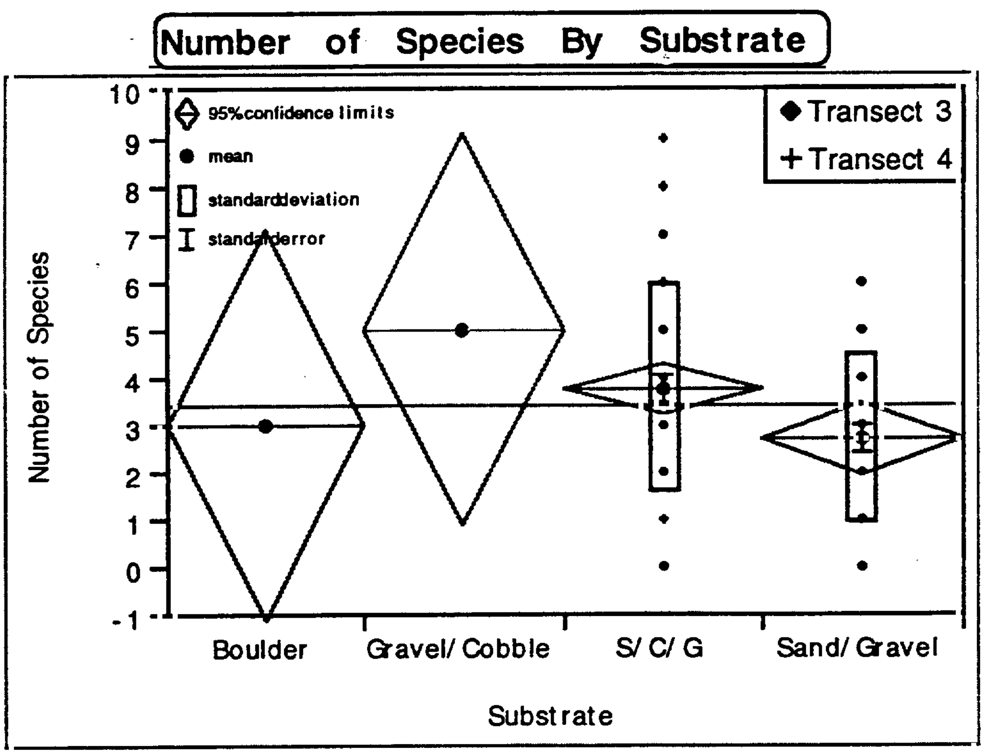

Figure 10 Relationship between substrate composition and number of mussel species collected.

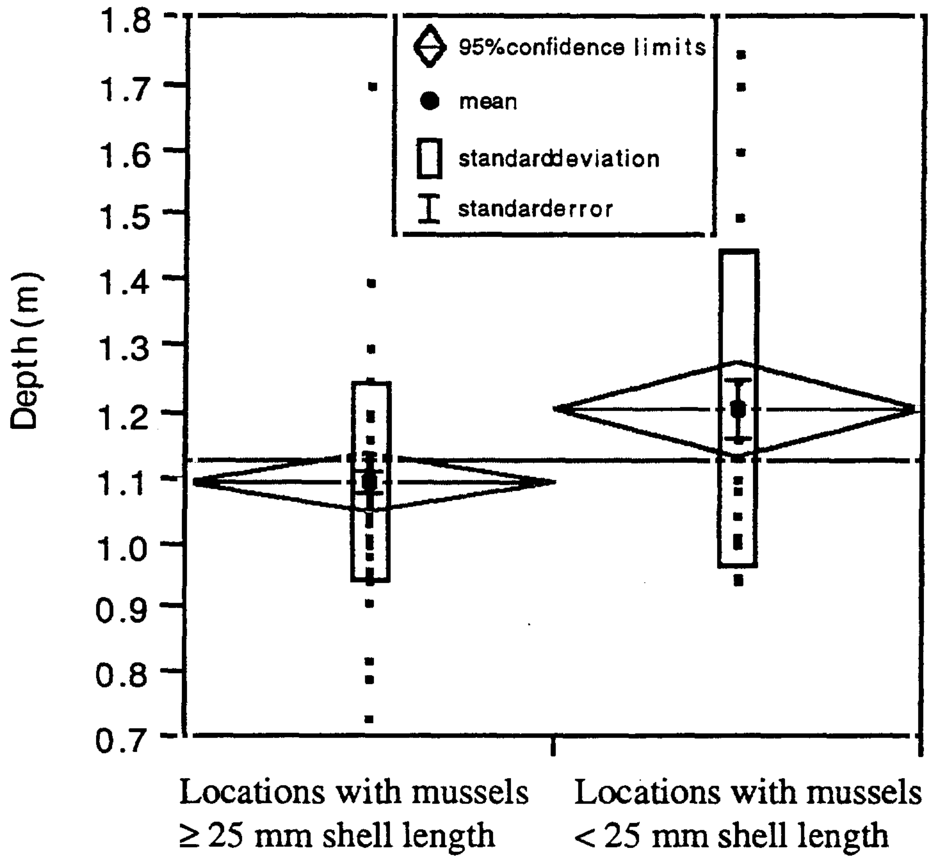

Figure 11. Relationship between locations where small mussels were collected and water depth.

APPENDIX 5

HORNBACH'S (1995b) REPORT

ON HABITAT USE

BY

Q. FRAGOSA

The effect of water depth and velocity on mussel distributions in the St. Croix River, Interstate Park. An addendum.

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Prepared for the Winged Mapleleaf Recovery Team
August 15, 1995

Introduction

On July 27, 1995 I prepared a report for the Winged Mapleleaf Recovery Team, entitled "The effect of water depth and velocity on mussel distributions in the St. Croix River, Interstate Park." On August 8, 1995, I returned to sample one additional transect in the east channel of the St. Croix River by Folsum Island. This addendum provides the additional data collected and extends the analysis prepared on July 27, 1995 to include the data from this additional transect.

Methods

The new transect (labelled Transect 5) was taken between Transects 3 and 4 reported by Hornbach (1995) (Fig. A1). This transect was placed at a location where Johnson (1995) conducted an instream flow study (labelled Transects 2 in Fig A1 Johnson and Chisholm (1995)). As in the earlier study (Hornbach,1995) every 5 m along the transect line water depth and flow were measured. In addition a SCUBA diver noted the makeup of the substrate. Also at each 5 m mark a diver spent 2 minutes collecting mussels and placing them in a labelled mesh bag. The bags were returned to the surface, the mussels were identified, shell length, width and height were measured. The mussels were then returned to the river. The number of mussels taken during a 2 min. search gives an indication of the density of mussels at various locations along the transect. Voucher specimens were taken and will be deposited at the Bell Museum at the end of the summer of 1995.

Results and Discussion

A total of 48 additional mussels were collected in Transect 5, bringing to 658 mussels in all three transects sampled in 1995. One specimen of *Epioblasma triquetra* collected in Transect 5 brings to 23, the number of species taken from the three transects. Figure A2 gives the distribution of the mussel species taken from the transects. The species makeup varied between the three transects (Fig. A3). *Truncilla truncata* dominated all transects and there was a significant difference in the proportion of the community this species represented in the 3 transects χ^2=7.93, p=0.02, but the difference was due to a smaller proportion of *Truncilla truncata* in Transect 5 compared to Transects 3 and 4.

Transect 5 had a mean depth of 1.31 m while Transect 3 had a mean depth of 1.06 m and Transect 4 had a mean depth of 1.19 m. There were significant differences in depth among transects (F=8.4, 2,111 df, p=0.0004). Transect 5 was sampled at a higher discharge period than the other two transects (Table A1) and this accounts for some of the difference in mean depths. Transect 5 had the fewest number of mussels per station (mean = 1.45) while both Transect 3 and Transect 4 had more (mean = 6.58 and 8.78 mussels per station, respectively). Transect 5 also had few mussels species per station (mean = 1.09) while Transects 3 and 4 had more mussel species per station (mean = 2.82 and 4.02 mussel species per station, respectively). ANOVA indicated that both the number of mussels per station and the number of species per station was differed significantly among transects (F=26.97, 2,111 df, p<0.0001 and F=24.30, 2, 11 df, p<0.0001).

In all transects there was an area in the center of the channel where water depth was quite shallow (Fig. A4). Transect 5 had a deep hole near the shore of Folsum Island. Figure A4 also shows the distribution of mussels across the channel. It is apparent that the number of mussels and species richness are at minimums in the middle of the channel in Transect 5 as they were for Transects 3 and 4 (Hornbach, 1995). As Hornbach (1995) noted, these trends reflect what was predicted by Johnson and Chisholm (1995) based on composite suitability indices from their PHABSIM model for Transects 3 and 4 and this prediction was also upheld for Transect 5

(Figs. A4, and A7 in Johnson and Chisholm (1995)). Figures A5 and A6 show that water depth still significantly influenced the number of mussels collected and the richness of the mussel community as was true for when data from Transects 3 and 4 were analyzed alone (Hornbach 1995). Maximum mussel density still occurred at a depth of 1.55 m while the maximum number of species occurred at a depth of 1.58 m rather than the 1.49 m determined when only data from Transect 3 and 4 were used (Hornbach 1995). The r^2 for the relationships were lower when Transect 5 data were included in the analysis, probably because of there were a number of locations along Transect 5 where the water depth was average but where few mussels were found. Again, part of this variance is due to the fact that Transect 5 was sampled when there was a higher discharge from the river (Table A1) and thus if the depth values were adjusted it is likely the r^2 would be higher.

There was still no significant influence of bottom flow on either the number of mussels or the number of species collected along the transects (Figures A7 and A8) as reported by Hornbach (1995) when only data from Transects 3 and 4 were used. Also there was no significant difference in the number of mussels or the number of mussel species among the various sediment types identified along the transect (Figures A9 and A10) if you adjust for the difference in number of mussels or number of species per station among transects (2-way ANOVA).

Hornbach (1995) noted that the influence of depth on mussel abundance appeared to be especially important for small mussels. In Transects 3 and 4 only 24 of the 79 stations had mussels < 25 mm in shell length. The depth of stations which had small mussels was significantly greater than for those stations that did not have small mussels ($t=2.48$, 77 df, $p=0.02$). However, when Transect 5 data are included in this analysis, there is no significant difference in the depth of stations with and without small mussels (Figure A11). This change is mainly due to the increase in the average depth for locations with mussels only > 25 mm in shell length, mostly due to the deep hole in Transect 5 where only large mussels where found and the increase depth do to the higher discharge level when Transect 5 was sampled. There were still no small mussels found in shallow areas (< 0.94 m), which still supports Hornbach's (1995) hypothesis that small mussels are excluded from very shallow areas.

Based on the PHABSIM results from the model of Johnson (1995) and Johnson and Chisholm (1995), a discharge of greater than 4000 cfs would be needed to provide the maximum habitat for mussel density and species richness in the east channel of the St. Croix near Folsum Island. Since Hornbach (1995) recommended a minimum discharge of greater than 4,000 cfs or a run-of river flow regime based on the examination of Transects 3 and 4. The additional data provided for Transect 5 in this addendum supports that recommendation.

Literature Cited

Hornbach, D.J. 1992. An examination of the population structure, community relationships and habitat characteristics for the winged mapleleaf mussel (*Quadula fragosa*) at Interstate Park, Saint Croix River, Wisconsin and Minnesota. Report submitted to Wisconsin DNR and Minnesota DNR.

Hornbach, D.J. 1995. The effect of water depth and velocity on mussel distributions in the St. Croix River, Interstate Park. Report submitted to the Winged Mapleleaf Recovery Team, July 27, 1995.

Johnson, S. L. 1995. Instream flow requirements of *Quadrula frugosa* and the aquatic community in the Lower St. Croix River downstream of the Northern States Power hydroelectric dam at St. Croix Falls, Wisconsin. Report submitted to the Bureau of Endangered Resources, Wisconsin DNR.

Johnson, S.L. And I. Chisholm. 1995. Addendum to St. Croix River Instream Flow Study. Memorandum send to Winged Mapleleaf Recovery Team, April 5, 1995.

Acknowledgements

I wish to thank my research group including Tony Deneka, Patrick Baker, Megan Tyrrell, Dan Schibel, Paul Evans, Shawn Hockert, and Kevin Sloan who aided in the diving and data analysis. Also thanks to Shawn Johnson of the Minnesota DNR for providing us with the locations for collecting and for assisting us in the field. This work was conducted in conjunction with research being funded by the US Fish and Wildlife Service and the US EPA.

Table A1. Attributes of the two transects sampled in the East Channel of the St. Croix River by Folsum Island, Interstate Park.

Attribute	**Transect 3**	**Transect 4**	**Transect 5**
Date Sampled	June 14, 1995	June 16, 1995	August 9,1995
Latitude/Longitude at East end of Transect	45°23.65'N 92°39.66'W	45°23.72'N 92°39.71'W	45°23.62'N 92°39.67W
Latitude/Longitude at West end of Transect	45°23.60'N 92°39.75'W	45°23.66'N 92°39.83'W	45°23.73'N 92°39.80W
Discharge	6510-6540 cfs	6480 cfs	7310-7340 cfs
H_2O Temperature	19°C	23.3°C	22°C
Conductivity	140 μmhos•cm^{-1}	155 μmhos•cm^{-1}	135 μmhos•cm^{-1}
Dissolved O_2	8.5 mg•L^{-1}	8.1 mg•L^{-1}	7.05 mg•L^{-1}

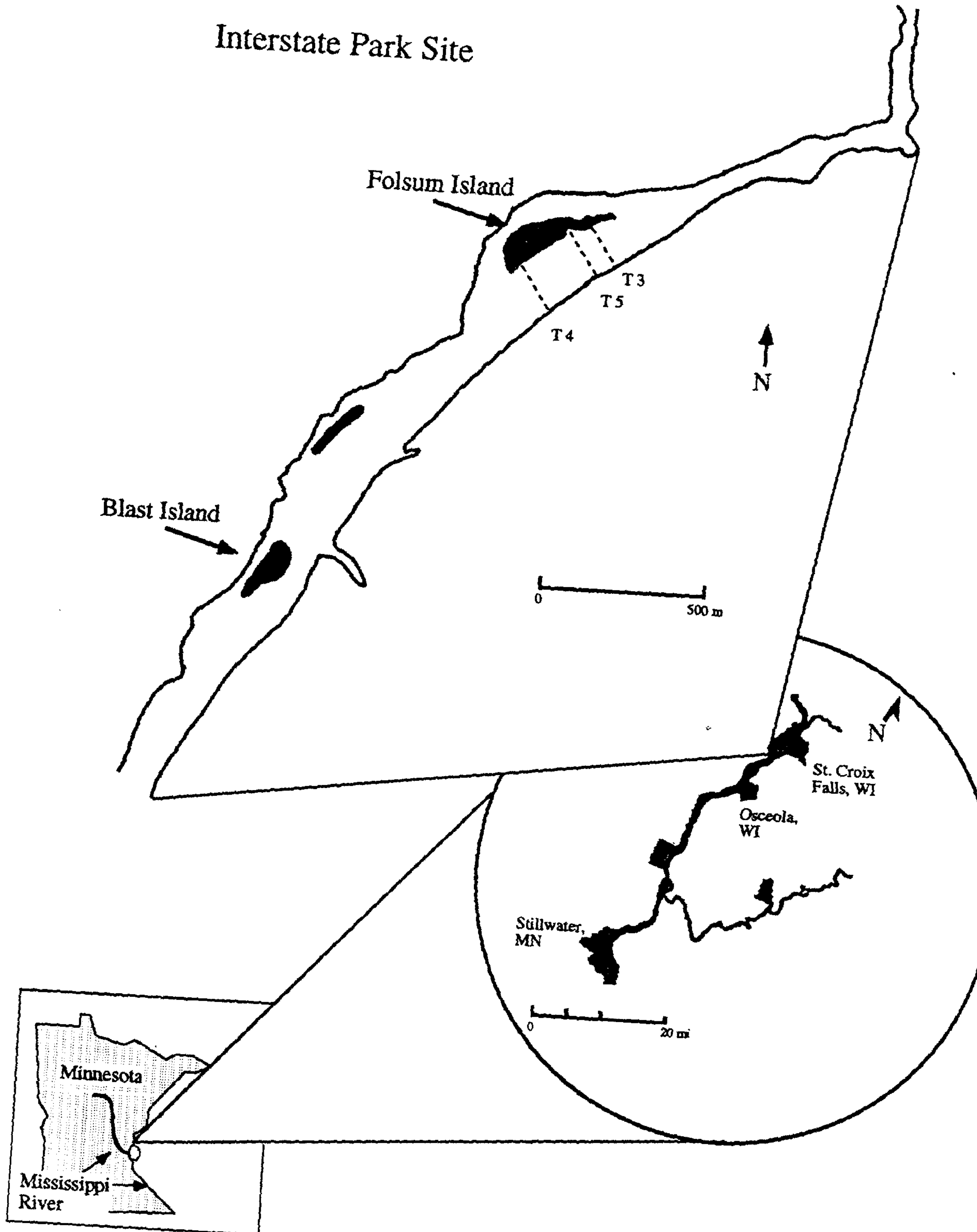

Figure A1. Map of study area.

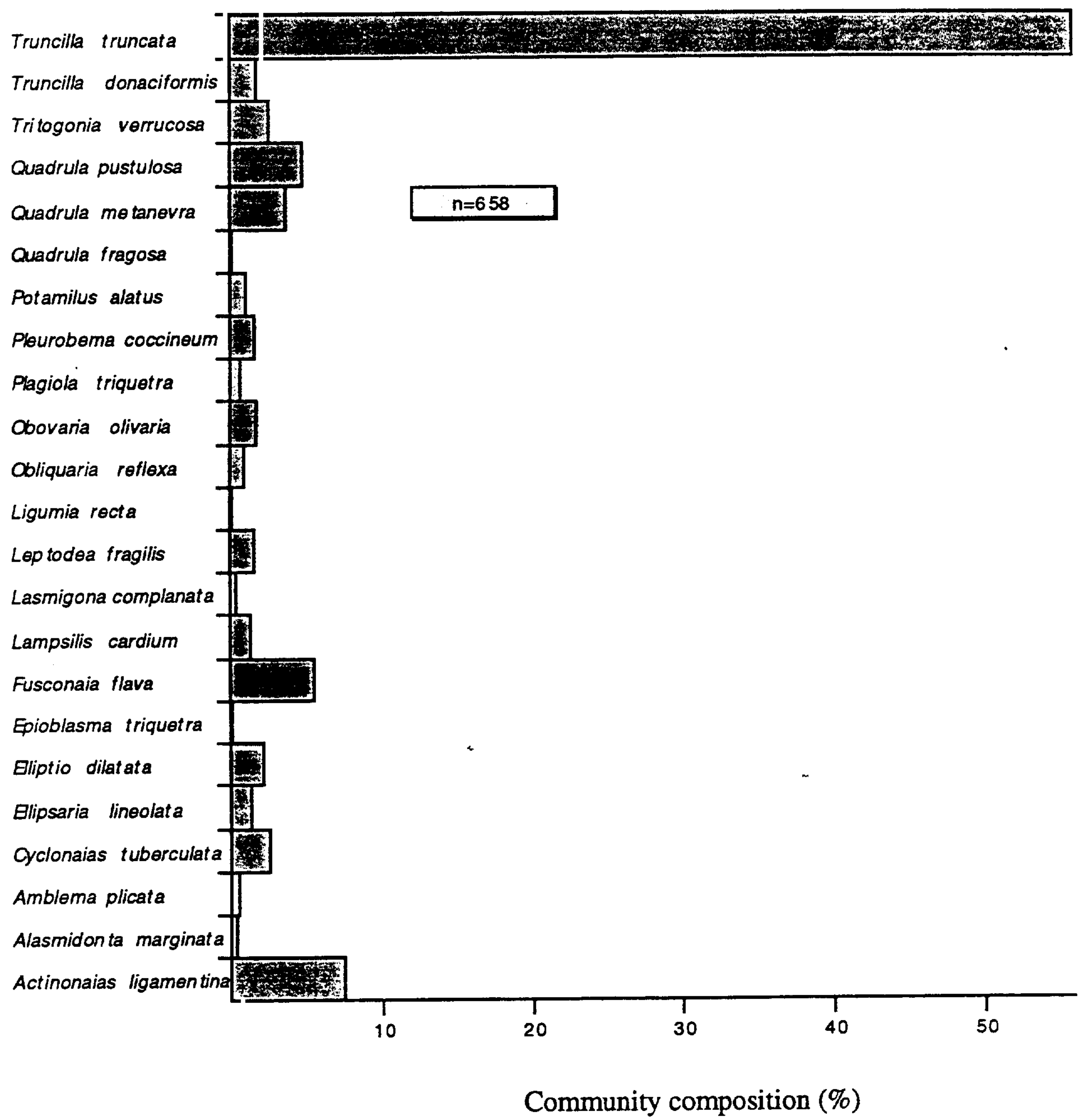

Figure A2. Mussel community structure from three transects sampled at Folsum Island.

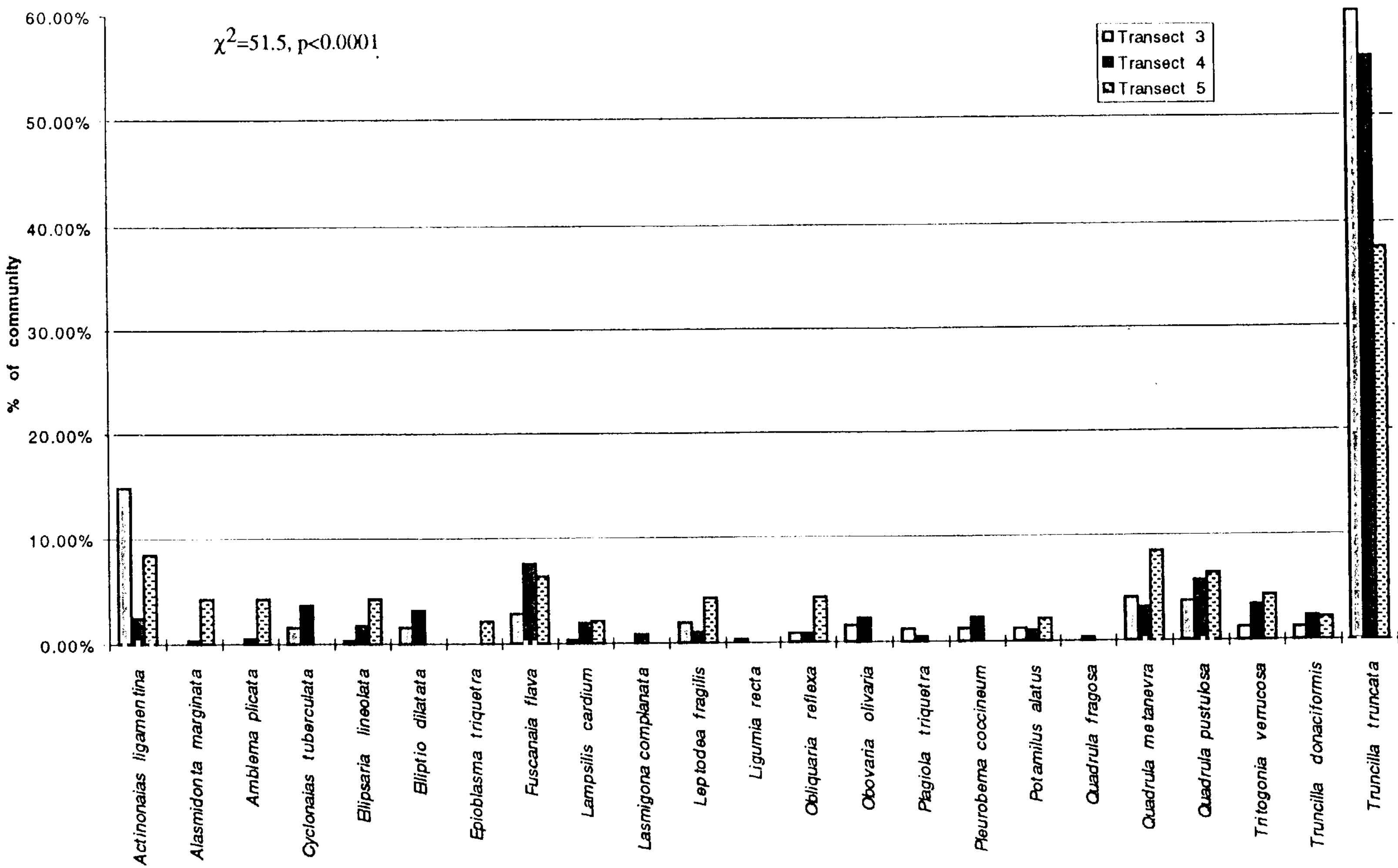

Figure A3. Variation in mussel community structure among two transects sampled at Folsum Island.

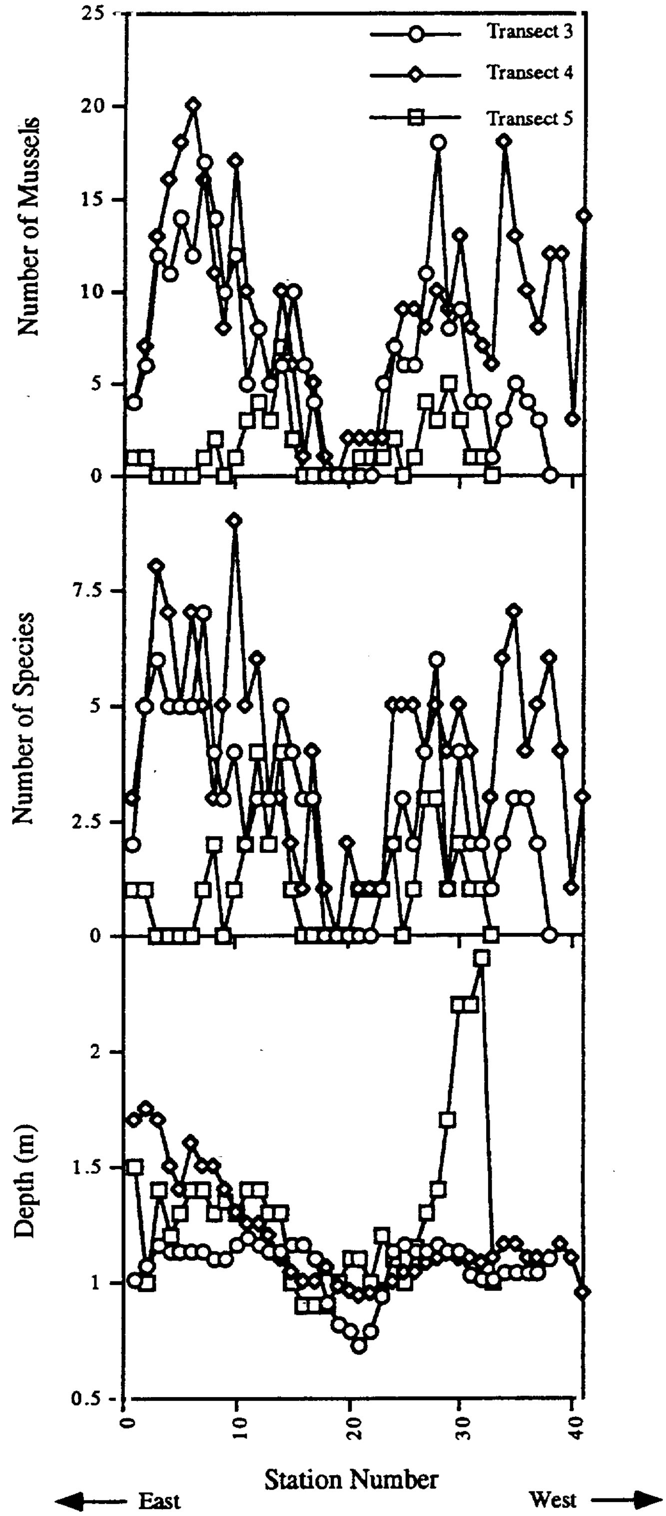

Figure A4. Variation in water depth, number of mussels collected and number of mussel species found across the transects sampled at Folsum Island.

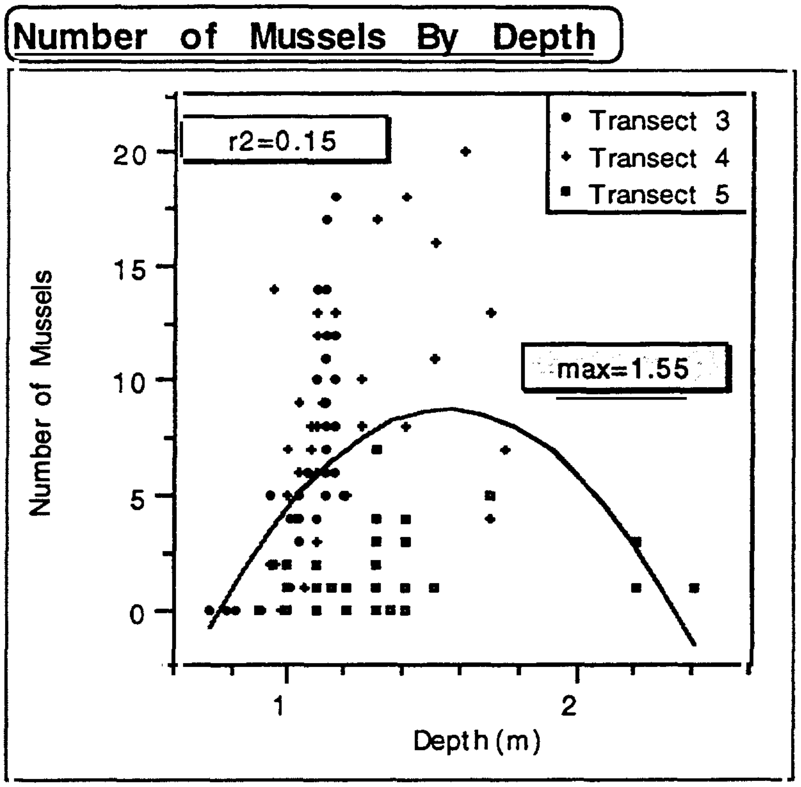

Figure A5. Relationship between water depth and number of mussels collected.

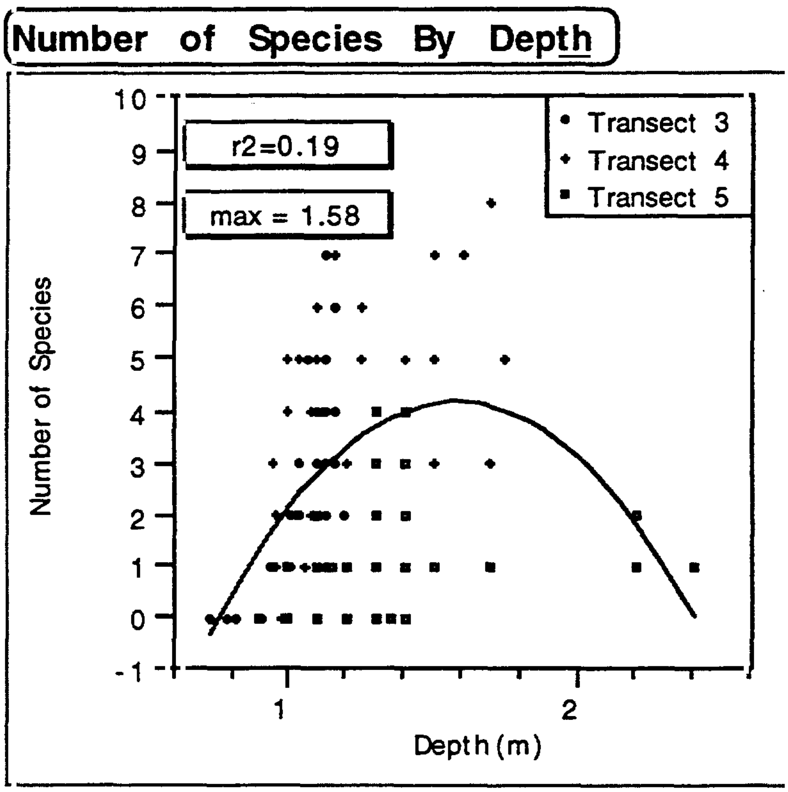

Figure A6. Relationship between water depth and number of mussel species collected.

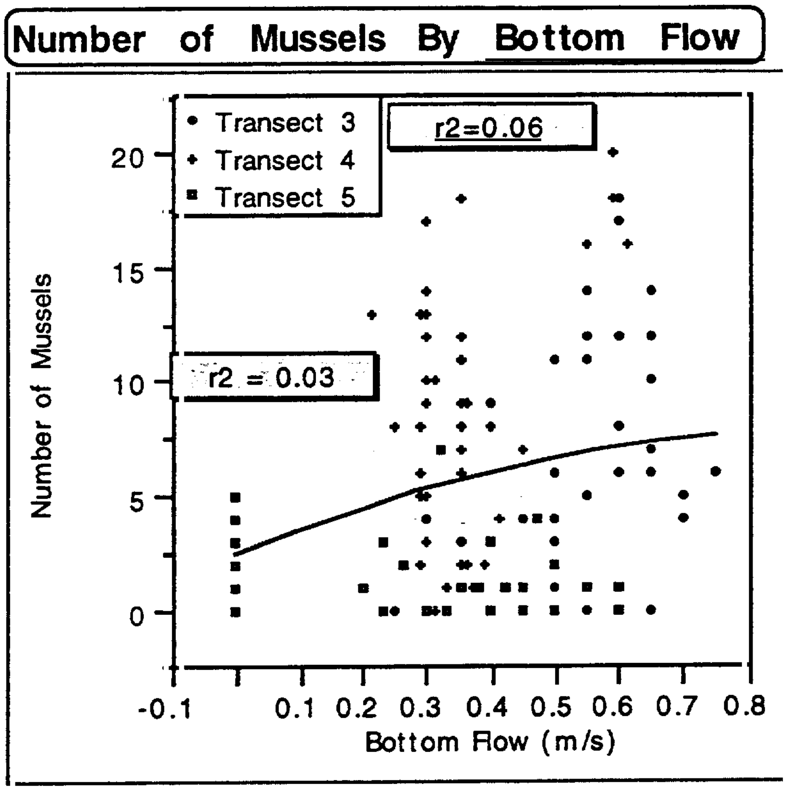

Figure A7. Relationship between water velocity and number of mussels collected.

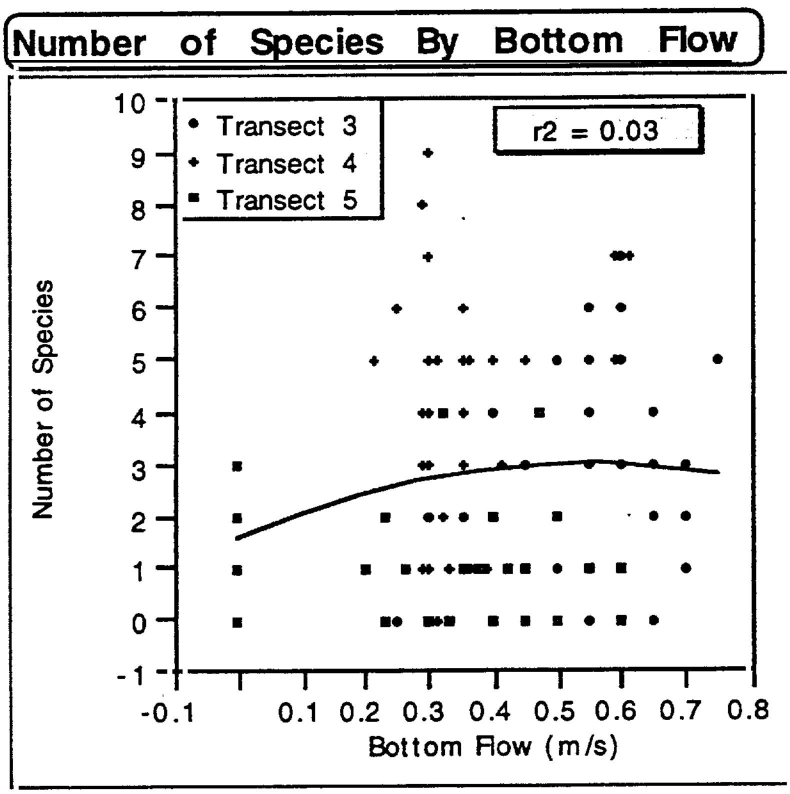

Figure A8. Relationship between water velocity and number of mussel species collected.

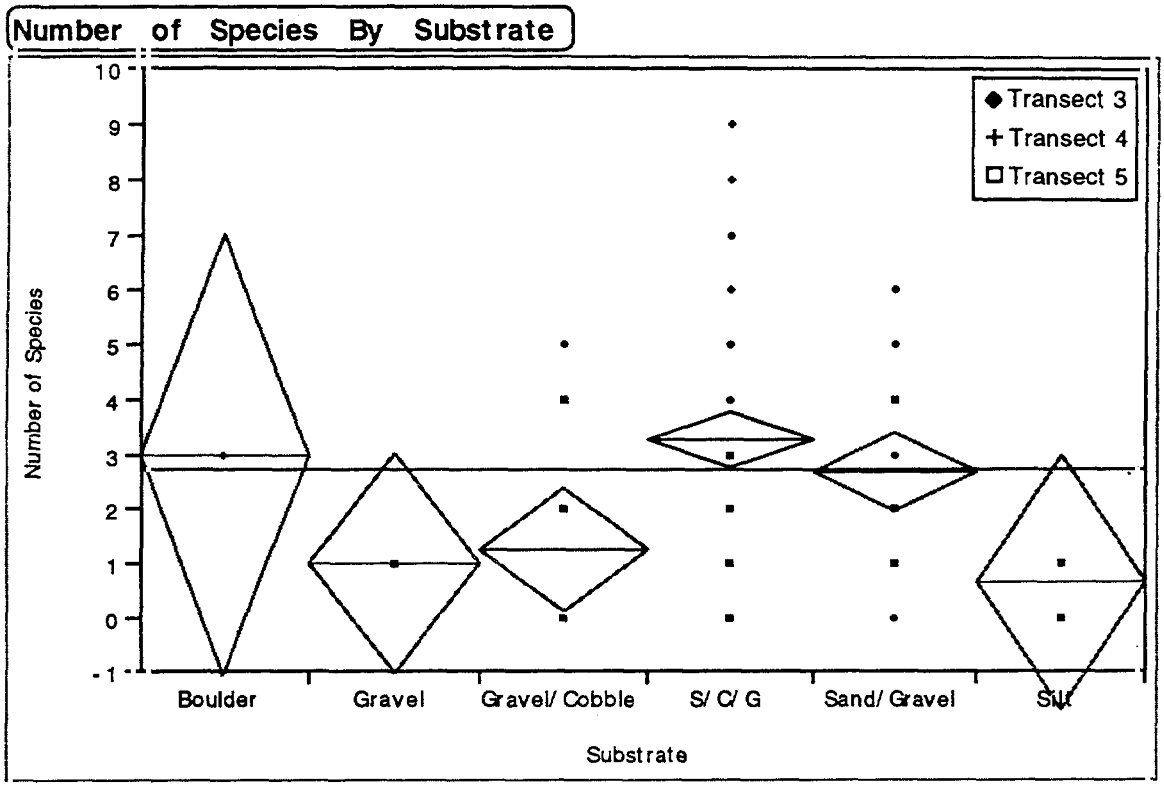

Figure A9. Relationship between substrate composition and number of mussels collected.

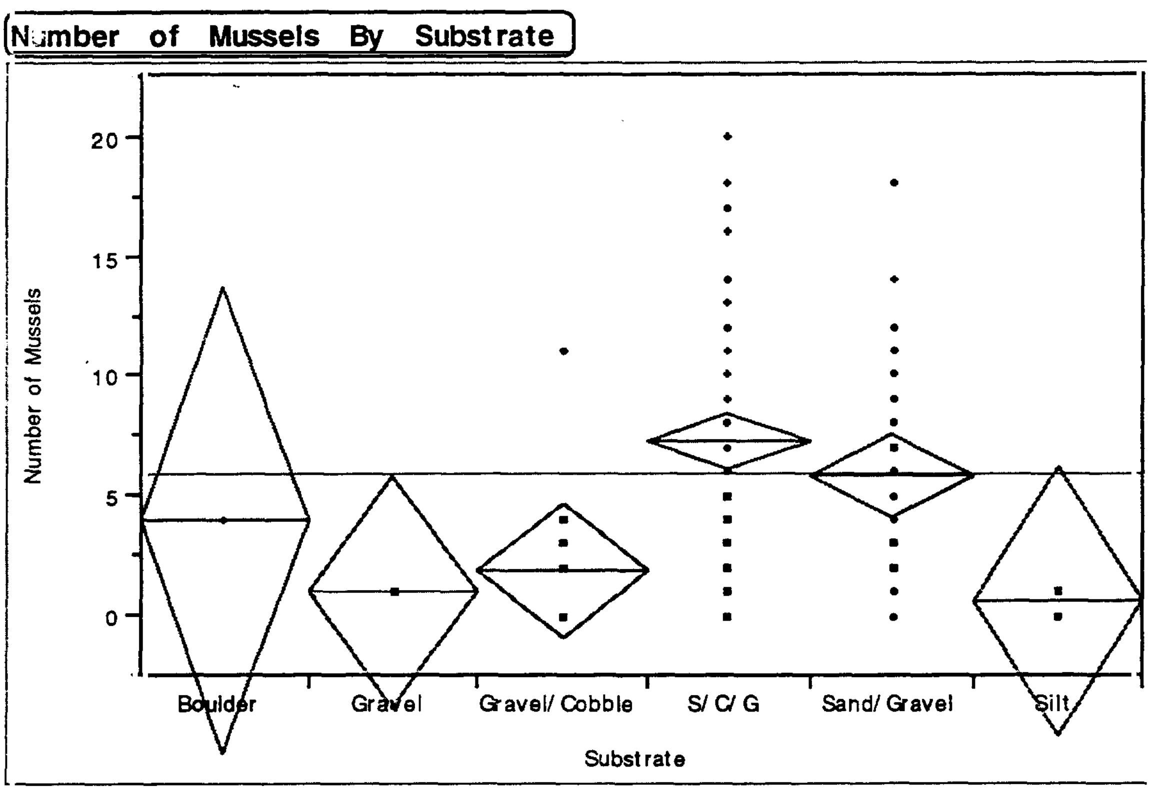

Figure A10 Relationship between substrate composition and number of mussel species collected.

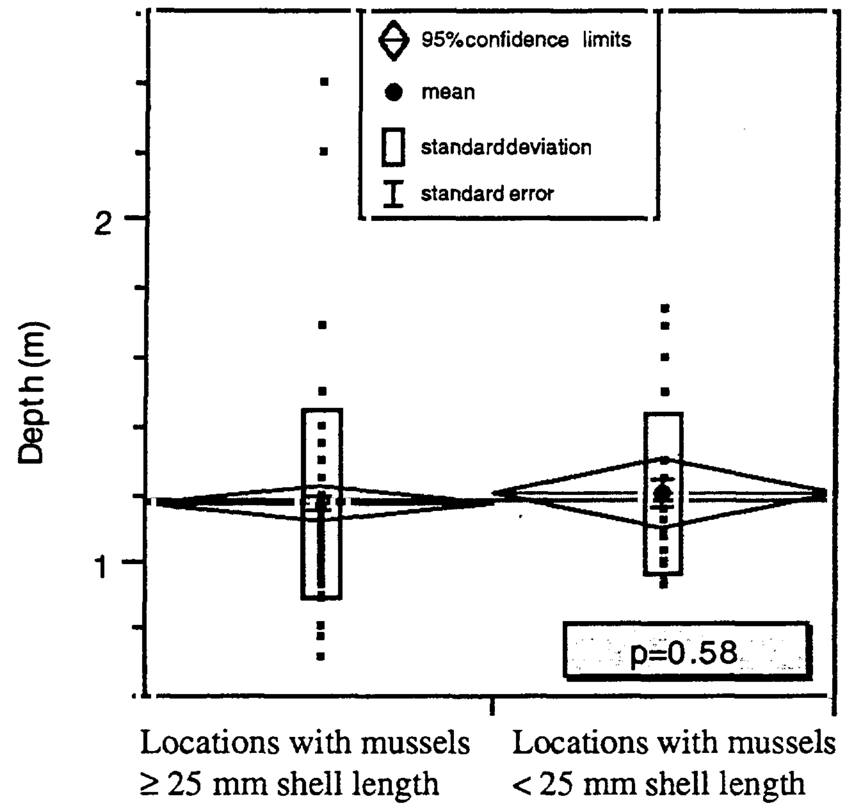

Figure A11. Relationship between locations where small mussels were collected and water depth.

APPENDIX 6

HORNBACH *ET AL.* (1996) REPORT

ON HABITAT

USE BY

Q. FRAGOSA

Factors Influencing the Distribution and Abundance of the Endangered Winged Mapleleaf Mussel, *Quadrula fragosa* in the St. Croix River, Minnesota and Wisconsin

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ABSTRACT.—We examined physical and biological factors that may influence the distribution of the endangered winged mapleleaf mussel *Quadrula fragosa* (Conrad, 1835). Quantitative sampling of the mussel community was undertaken at two sites in the St. Croix River known to harbor *Q. fragosa*. Additional searches were conducted specifically for *Q. fragosa* individuals. For each quantitative sample of mussels, substrate composition, water velocity and depth were assessed and mussels were identified and measured. In general, *Q. fragosa* does not have habitat requirements different than the rest of the mussel community. *Quadrula fragosa* occurred in shallower areas with lower bottom current velocity compared to the overall mussel community. There was no difference in substrate composition in areas with and without *Q. fragosa*. Mussel community density and richness were higher in areas where *Q. fragosa* was found. The mussel community associated with *Q. fragosa* was not significantly different from the general mussel community in the area. However three species (*Truncilla truncata, Truncilla donaciformis* and *Quadrula metanevra*) were significantly associated with *Q. fragosa*. Due to its association with dense and diverse mussel communities, management that benefits the entire mussel community should be effective in protecting this endangered species.

INTRODUCTION

North America has the largest number of species of fresh water mussels in the world. Unfortunately, of the 297 species and subspecies of freshwater mussels found in North America, 43% of the taxa are either extinct, endangered, threatened, or candidates for federal endangered species listing (Williams *et al.*, 1993). To reduce risk of extinction for these species, it is necessary to understand how physical habitat characteristics and mussel community composition affect the distribution and population characteristics of these species.

Habitat characteristics such as water velocity (Fuller, 1974; Horne and McIntosh, 1979; Salmon and Green, 1983; Way *et al.*, 1989; Holland-Bartels, 1990), depth (Brönmark and Malmquist, 1982; Stern, 1983; Doolittle, 1988; Strayer, 1983; Johnson, 1995), and substrate type (Harman, 1972; Brönmark and Malmquist, 1982; Vannote and Minshall, 1982; Salmon and Green, 1983; Strayer and Ralley, 1991) and fish host distribution (Fuller, 1974; Watters, 1992, 1993) are commonly thought to influence mussel abundance and distribution. These factors appear to have their influence at both the macro- and microhabitat level (Holland-Bartels 1990; Strayer, 1993; Strayer and Ralley, 1993; Strayer *et al.*, 1994; Di Maio and Corkum, 1995) .

Mussel community characteristics have been shown to be good predictors of the presence of endangered mussels. The endangered Higgins' eye pearly mussel (*Lampsilis higginsi*) is usually found in local habitats that appear to be optimal for the majority of sympatric unionacean species

(Holland-Bartels, 1990; Wilcox *et al.*, 1993; Hornbach, *et al.*, 1995; Miller and Payne, 1995). Vaughn and Pyron (1995) found that mussel species richness at a given site is the best individual predictor of the occurrence of the endangered Ouachita rock-pocketbook mussel (*Arkansia wheeleri*). Also, Miller *et al.* (1986) found that the habitat characteristics for the endangered mussel *Plethobasus cooperianus* were similar to other mussels and that this species primarily was found in very diverse and densely populated mussel beds.

Quadrula fragosa is an endangered mussel about which we know little. It was frequently reported until the 1920's (Eldridge, 1991) and formerly occurred extensively in the Mississippi, Tennessee, Ohio and Cumberland River drainages (Eldridge, 1991). *Quadrula fragosa* was listed as an Endangered Species on 22 July 1991 (Eldridge, 1991). Presently, the only known population of *Q. fragosa* is found in the St. Croix River, from Interstate Park to Osceola, Wisconsin (Fig. 1). The significant decrease in number and range of *Q. fragosa* is thought to be due to destruction and modification of its habitat (Eldridge, 1991). Recent reports of zebra mussels (*Dreissena polymorpha*) approximately 80 km downstream in the lower St. Croix River (Baker *et al.*, 1996), pose a further risk to this isolated population of *Q. fragosa*.

The St. Croix River contains many diverse and dense mussel beds (Dawley, 1947; Fuller, 1980; Stern, 1983; Doolittle, 1988; Hornbach, 1992). There have been only two recent unpublished studies of the last known population of *Q. fragosa*, 1990 (David Heath, pers. comm.) and 1992 (Glen

Miller, pers. comm.) together reporting 59 live individuals. Unfortunately the objective of these studies did not include the assessment of physical habitat characteristics. The objective of this paper is to characterize *Q. fragosa* habitat and community relationships in the St. Croix River.

MATERIALS AND METHODS

Study sites.—This study was conducted at two areas in the St. Croix River: 1) Interstate Park near Taylor's Falls, Minnesota and St. Croix Falls, Wisconsin, and 2) Franconia, MN (Fig. 1). The Interstate Park study site (River Mile 49.5-50.5) is located approximately 3.5 km downstream of a hydroelectric peaking dam. The Franconia site (River Mile 47.5-48.5) is approximately 3.2 km downstream of the Interstate site. These sites were chosen because of the presence of *Q. fragosa* (David Heath, pers. comm.).

Sampling took place during 1991, 1992, 1993 and 1995. We took a large number of quantitative samples (0.25 m^2 quadrats) at each area in order to locate *Q. fragosa* and to characterize the mussel habitat. This required multiple samples to be taken at each site to characterize spatial variability in habitat characteristics. We also resampled a number of sites to characterize temporal variability in habitat characteristics. At Franconia, we sampled ten sites in 1991 and returned to these sites in 1995 (Fig. 1). At each site, ten individual quadrats were sampled giving a total of 200 quadrats sampled. At Interstate Park, we sampled fifteen sites near the channel east of Folsum Island in 1992 (Fig. 1) and resampled the middle and eastern sites in 1995. As at Franconia, we took ten individual quadrats at each site. In 1993 three sites. near Blast Island (about 500 m downstream) were sampled, with eight quadrats taken per site. Finally in 1995, two sites upstream of Blast Island were sampled, with ten quadrats per site. This gave a total of 294 quadrats sampled at Interstate Park.

Sampling.—The sampling method at each quadrat was consistent among years. A 0.25 m^2 metal frame was placed on the sediment and the top ten centimeters of substrate and all mussels were removed by researchers using SCUBA. The substrate and mussels were placed into a 19 l plastic bucket which was lifted to the surface. The contents of each bucket were passed through a series of four sieves with openings of 77, 12.7, 6.35 and 0.5 mm, respectively. The substrate in each sieve was weighed to the nearest 0.25 kg using a hanging spring scale. These wet weights were used to calculate the percent substrate size composition and an average sediment diameter (phi size (ϕ) = ($-\log_2$(sediment diameter)) (Lewis, 1984). All mussels were removed from the sieves and identified. Care was taken to collect juvenile mussels hanging from the sieves by their byssal threads. The shell length of each was measured to the nearest 0.01 mm using dial calipers. Water velocity at each quadrat was measured using a Marsh-McBirney, model 201-D or Global Water 201 flow meter at the substrate water interface; the depth was measured to the nearest 0.02 m using a calibrated metal rod.

Sampling specifically for Quadrula fragosa.—In the sampling regime noted above, only three *Q. fragosa* were found (one at Interstate Park and two at Franconia). Consequently, a specific search for *Q. fragosa* was instituted. The water clarity was sufficient to differentiate species underwater, thus divers searched by sight and touch for *Q. fragosa*. At Interstate Park, 36 diving hours were spent searching specifically for *Q. fragosa* in 1992, 11.3 hours in 1993 and 7.25 hours in 1995. At Franconia, we spent 9.25 diver hours conducting species-specific searching in 1995. When a *Q. fragosa* individual was located, researchers marked the exact location with a buoy. A 0.25 m^2 quadrat was centered where each *Q. fragosa* was found and the substrate and mussels within were removed and analyzed in the manner mentioned above. The depth and water velocity were also measured as described above. Each *Q. fragosa* found was measured, and returned to the substrate by hand.

Statistical analysis.—Statistical analyses were conducted using JMP 3.0 (SAS. 1994) on a Macintosh 8100. The following working hypotheses were tested:

1) Within established mussel beds there was no significant difference in habitat characteristics (sediment type, water velocity and water depth) between locations where *Q. fragosa* was or was not found; and.

2) Within established mussel beds there was no significance difference in the mussel community (species composition, species richness, mussel density, and mussel size) where *Q. fragosa* was or was not found.

For hypothesis 1 and for the species richness and mussel density comparisons in hypothesis 2, two types of statistical analysis were conducted. First, standard non-parametric tests (Wilcoxon rank score test) were used to compare habitat characteristics and community measures between quadrats with and without *Q. fragosa*. Non-parametric tests were used because there was no *a priori* reason to suspect that the distributions were normal (e.g. species richness, substrate size, etc.) or the distributions were not normal (Shapiro-Wilk W test). Since we were dealing with a rare and endangered species, few quadrats with *Q. fragosa* were found. Consequently, sample sizes varied considerably between quadrats with and without *Q. fragosa*. To develop confidence limits for any differences found we used the bootstrap method (Manly, 1991). We took 1000 bootstrap samples to calculate the differences and their standard deviations between quadrats with and without *Q. fragosa*. To compare mussel communities in quadrats with and without *Q. fragosa* a chi-square analysis was conducted.

RESULTS

Water velocity and depth.—The water velocity at the sediment-water interface varied considerably ranging from 0-0.6 m/s. Some of this variability is due to the presence of a hydroelectric peaking plant just upstream of the Interstate Park site. The average discharge was 26% higher for the times we collected quadrats without *Q. fragosa* (average=117.8 m^3/s, standard deviation=55.2 m^3/s) compared to the times we collected quadrats with *Q. fragosa* (average= 93.7 m^3/s, standard deviation=44.6 m^3/s). The percent change in water depth and velocity is less than the change in discharge (see discussion). Thus, we would have expected differences in water velocity and depth for quadrats with and without *Q. fragosa* to be 26% or less, if all of the variance was due to difference in discharge at the times of collection.

The water velocity at the sediment-water interface was 32% lower for quadrats where *Q. fragosa* was found than in quadrats where *Q. fragosa* was not found (Wilcoxon Z=-1.97, P=0.049, Table 1). The depth ranged from 0.17 m to 4.7 m with 97.5% of the measurements less than 2.7 m. The water depth was 45% lower at sites where *Q. fragosa* was found (Wilcoxon Z=-3.09, P=0.002; Table 1).

Substrate composition.—The percentage of sediment in each sieve was calculated for each quadrat and expressed as the mean phi for the whole quadrat. The mean phi for quadrats containing *Q. fragosa* ranged from 0.49 (sand) to -5.1 (large cobble). There were no significant differences found between quadrats with *Q. fragosa* and those without *Q. fragosa* (Wilcoxon Z=0.30, P=0.76; Table 1).

Community composition.—Quantitative sampling resulted in the collection of 2869 individual mussels representing 30 species (Table 2). Overall, the average density was 22.1 mussels/m^2 with a maximum density of 148 mussels/m^2. Average richness was 2.7 species/0.25 m^2 quadrat, with as many as 12 species present in a single quadrat. Only 26 specimens of *Q. fragosa* were found: 23 were found at Interstate Park and three were found at Franconia. All but three of the *Q. fragosa* specimens were found as a result of species specific searching.

Mussel density was significantly greater in quadrats where *Q. fragosa* was present (Wilcoxon Z=4.34, P<0.0001; Table 1). Also, quadrats containing *Q. fragosa* had more mussel species than did quadrats without *Q. fragosa*

(Wilcoxon Z=5.26, P<0.0001, Table 1).

Mussel communities in quadrats with and without *Q. fragosa* were significantly different (χ^2 = 31.16 10 df, P<0.0006; Table 2). This is primarily due to the larger number of species found in quadrats with *Q. fragosa* (Table 1). We attempted to determine spatial associations among *Q. fragosa* and other mussel species using a chi-square test of association (Ludwig and Reynolds, 1988). Three species were significantly associated with the presence of *Q. fragosa*: *Quadrula metanevra* (χ2=4.39, 1 df, P=0.036), *Truncilla donaciformis* (χ2=13.20, 1 df, P=0.0003), and *Truncilla truncata* (χ2=6.06, 1 df, P=0.014).

The mean shell length of all mussels found in quadrats with *Q. fragosa* was larger than that of mussels found in quadrats without *Q. fragosa* (Wilcoxon Z=3.91, P=0.001; Table 1). Of the three species significantly associated with *Q. fragosa*, *T. truncata* had significantly larger individuals in quadrats with *Q. fragosa* compared to quadrats without *Q. fragosa* (Wilcoxon Z=2.53, P=0.011; Table 1).

Discussion

Quadrula fragosa is limited in its current distribution to a small area just below the St. Croix Falls Dam on the St. Croix River (Fig. 1). The exact reasons for this limited distribution are unknown. This study indicates that *Q. fragosa* is found in areas of slightly lower water velocity and shallower depth than other areas that we sampled (Table 1). Part of the reason for this result is that we collected quadrats with *Q. fragosa* at times when the discharge was less than those times when we collected other quadrats. However, when Johnson (1995) conducted an instream flow study at the same sampling sites where we conducted this study, he found that with a change in discharge from approximately 94 m^3/s to 120 m^3/s, depth increased less than 20% and mean column velocity increased less than 15%. Because the differences between depth and water velocity between quadrats with and without *Q. fragosa* were larger than these percentages, it appears that these physical habitat differences are real.

Depth has an important impact on the mussel community. A number of studies have shown that desiccation can lead to high mortality of mussels (Fuller, 1974; Strayer, 1983; Miller *et al.*, 1984). Doolittle (1988) found most mussels in the St. Croix River at a depth near 2.0 m. In a study on the Wisconsin and St. Croix Rivers, Stern (1983) found the maximum density of mussels at a depth of approximately 1.7 meters. In this study, we also found that species richness and density peaked at depths near 2.0 meters. No *Q. fragosa* were found in depths less than 0.42 m.

Q. fragosa in the St. Croix River had similar substrate preferences to other mussels (Table 1). In the St. Croix River, Doolittle (1988) indicated that the majority of mussels are found in stable substrates, such as those found at Interstate Park and Franconia. Strayer and Ralley (1993) hypothesized that the correlations between mussel communities and substrate may be related to substrate stability and the habitat it provides rather than its particle size. A recent study by Strayer (1993) supports this hypothesis. Vannote and Minshall (1982) also found substrate stability to be an important factor affecting mussel distribution.

Three species of mussel, *Quadrula metanevra, Truncilla truncata* and *Truncilla donaciformis*, were significantly associated with *Q. fragosa*. The nature of that association is unknown. Doolittle (1988) found associations between *Truncilla truncata* and *Quadrula metanevra* in the St. Croix River. *Truncilla truncata* is the dominant species at Interstate Park (Table 2), so one might expect a correlation between it and *Q. fragosa*. However, *Q. metanevra* and *T. donaciformis* are comparatively rare. A common fish host(s) or similar environmental requirements may explain the correlation between *Q. fragosa* and these other species. *Truncilla truncata, T. donaciformis* and *Q. metanevra* all share as a fish host the sauger, *Stizostedion canadense* (Watters, 1994), which is found in the St. Croix River (Fago and Hatch, 1993). The fish host for *Q. fragosa* is unknown.

We intentionally sampled in areas with known high mussel species diversity and density in the St. Croix River. Doolittle (1988) found that the Interstate Park area had the highest species density and richness of the entire St. Croix River basin. This site is downstream of a hydroelectric peaking dam which formerly was a low waterfall. Fuller (1974) attributed increased density below dams to the maintenance of a stable substrate, increased food availability due to phytoplankton growth in reservoirs behind dams and highly oxygenated water. However, other studies have shown that regulation of streamflow by dams can adversely influence mussel populations (Tudorancea, 1972; Fuller, 1974; Miller *et al.*, 1984; Williams *et al.*, 1993). Thus, the positive and negative effects of dams on mussel communities are dependent on site-specific riverine and management conditions.

Within this rich and dense area of the St. Croix River, *Quadrula fragosa* was found in areas of highest mussel density and species richness (Table 1). Similar findings have been reported for other endangered species of mussels (Holland-Bartels, 1990; Wilcox *et al.*, 1993; Hornbach *et al.*, 1995; Vaughn and Pyron, 1995; Miller *et al.*, 1995). Due to the association of *Q. fragosa* and other endangered species with dense and diverse mussel communities, management that benefits the entire mussel community should be effective in protecting the endangered species that reside within these communities.

The viability of *Q. fragosa* populations seems uncertain. After 494 quantitative samples and 63.8 diver-hours of specific searching, only 26 specimens of *Q. fragosa* were found. The population of *Q. fragosa* appears to be very small and localized, making it prone to stochastic disturbances. The impending invasion of the zebra mussel to the St. Croix River (Baker *et al.*, in press), and its detrimental effects on unionids (Mackie, 1991; Hunter and Bailey, 1992) seems to further decrease *Q. fragosa*'s chances of survival.

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Table 1. — Summary of habitat characteristics for the Quadrula *fragosa* community and for the "average unionid site" as sampled in the St. Croix River. Variables with asterisks are significantly different at P<0.05. All variables are expressed as mean ± one standard deviation

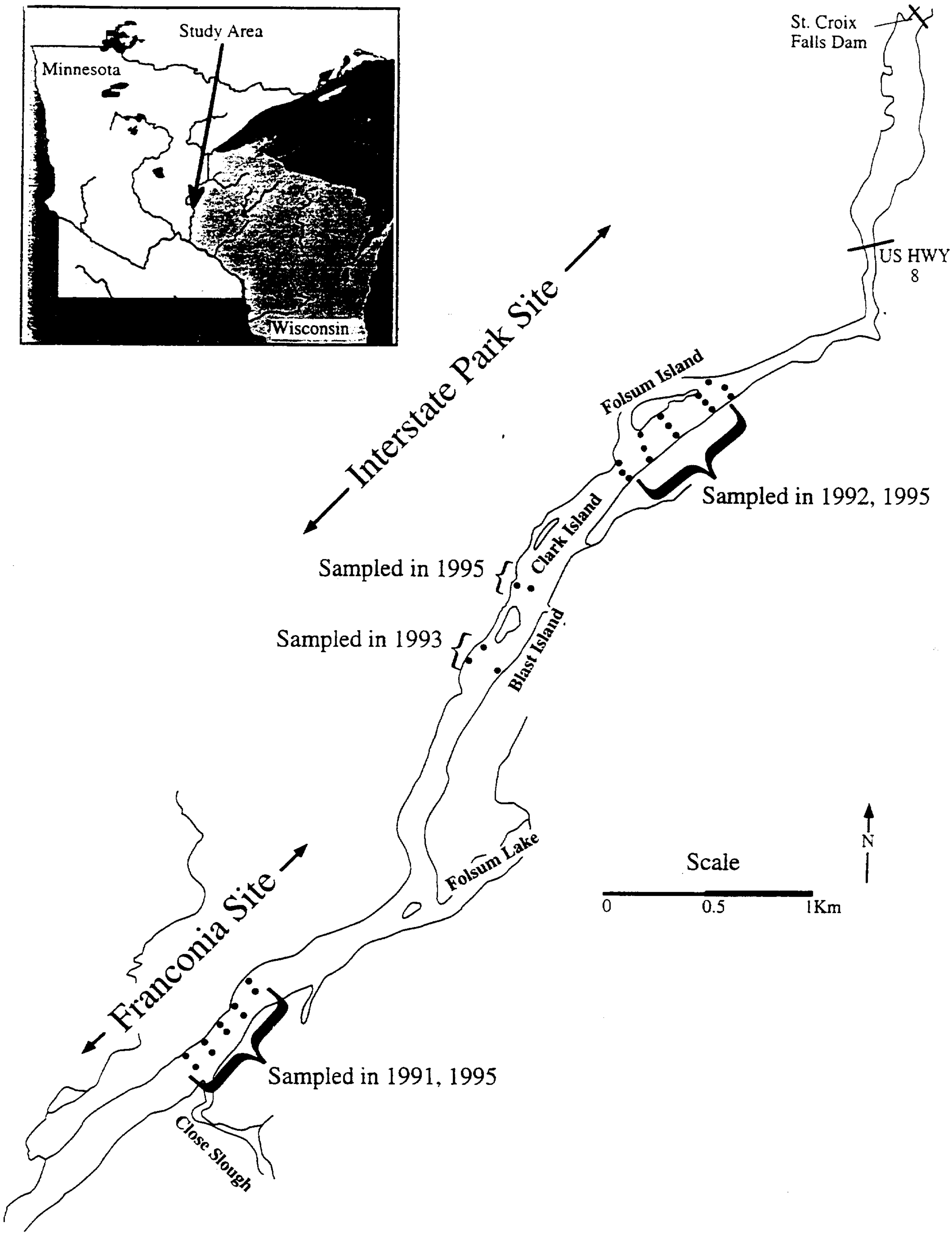
Variable	*Q. fragosa* community	Overall unionid community	Difference based on bootstrap analysis
Water Depth (m)*	0.98 ± 0.46	1.42 ± 0.79	0.48 ± 0.19
Velocity at sediment-water interface (m/s)*	0.19 ± 0.10	0.25 ± 0.13	0.05 ± 0.04
Substrate size (ϕ)	-1.9 ± 1.1	-1.9 ± 1.4	0.01 ± 0.34
Unionid density (mussels/m^2)*	37.5 ± 18.2	21.3 ± 22.6	16.7 ± 5.5
Unionid richness (species/0.25 m^2)*	4.9 ± 1.8	2.6 ± 2.0	2.3 ± 0.5
Unionid shell length (all species - mm) *	44.6 ± 22.3	40.0 ± 23.5	4.5 ± 2.2
Truncilla truncata shell length (mm)*	36.8 ± 12.8	33.9 ± 12.7	2.9 ± 1.6

Table 2. — Mussel community composition in the St. Croix River from Franconia; MN to Interstate Park, MN and WI comparing quadrats with and without *Quadrula fragosa*.

Species	*Quadrula fragosa* Absent		*Quadrula fragosa* Present		All quadrats	
	Number	%	Number	%	Number	%
Actinonaias ligamentina	115	4.38	7	2.87	122	4.25
Alasmidonta marginata	11	0.42	1	0.41	12	0.42
Amblema plicata	28	1.07	3	1.23	31	1.08
Cyclonaias tuberculata	26	0.99	4	1.64	30	1.05
Ellipsaria lineolata	32	1.22	4	1.64	36	1.25
Elliptio dilatata	77	2.93	3	1.23	80	2.79
Epioblasma triquetra	50	1.9	4	1.64	54	1.88
Fusconaia flava	131	4.99	9	3.69	140	4.88
Lampsilis cardium	18	0.69	1	0.41	19	0.66
Lampsilis higginsi	6	0.23	0	0	6	0.21
Lampsilis siliquoidea	15	0.57	2	0.82	17	0.59
Lasmigona complanata	1	0.04	0	0	1	0.03
Lasmigona compressa	2	0.08	0	0	2	0.07
Lasmigona costata	5	0.19	0	0	5	0.17
Leptodea fragilis	64	2.44	1	0.41	65	2.27
Ligumia recta	8	0.3	1	0.41	9	0.31
Obliquaria reflexa	34	1.3	2	0.82	36	1.25
Obovaria olivaria	21	0.8	4	1.64	25	0.87
Pleurobema coccineum	47	1.79	2	0.82	49	1.71
Potamilus alatus	24	0.91	1	0.41	25	0.87
Pyganodon grandis	1	0.04	0	0	1	0.03
Quadrula fragosa	0	0	26	10.66	26	0.91
Quadrula metanevra	81	3.09	9	3.69	90	3.14
Quadrula pustulosa	131	4.99	8	3.28	139	4.84
Quadrula quadrula	2	0.08	0	0	2	0.07
Strophitus undulatus	2	0.08	0	0	2	0.07
Toxolasma parvus	12	0.46	1	0.41	13	0.45
Tritogonia verrucosa	42	1.6	5	2.05	47	1.64
Truncilla donaciformis	197	7.5	17	6.97	214	7.46
Truncilla truncata	1421	54.13	129	52.87	1550	54.03
Unknown Juvenile	9	0.34	0	0	9	0.31
unidentified	12	0.46	0	0	12	0.42
TOTAL	2625		244		2869	

FIGURE CAPTIONS

Figure 1.—Map of study area. Dots indicate areas where multiple 0.25 m^2 quadrats were sampled


Study Area
Minnesota
Wisconsin
St. Croix
Falls Dam
US HWY
8
Interstate Park Site
Folsum Island
Sampled in 1992, 1995
Clark Island
Sampled in 1995
Sampled in 1993
Blast Island
Folsum Lake
Scale
0
0.5
1Km
N
Franconia Site
Sampled in 1991, 1995
Close Slough

APPENDIX 7

HANSON AND LEONARD'S (1995) CRITICAL REVIEW

OF

JOHNSON'S (1995) REPORT

Review of an Instream Flow Study Performed on *Quadrula Fragosa* in the Lower St. Croix River, Wisconsin

Prepared for

Northern States Power Company

Prepared by

Dave Hanson, EA Engineering, Science, and Technology
Paul Leonard, EDAW, Inc.

August 1995 *12610.01.0000*

CONTENTS

REVIEW OF AN INSTREAM FLOW STUDY PERFORMED ON *QUADRULA FRAGOSA* IN THE LOWER ST. CROIX RIVER, WISCONSIN

This report presents a review of an instream flow study performed on the winged mapleleaf mussel (*Quadrula fragosa*) in the St. Croix River. The study of interest (Johnson 1995) consisted of an application of the Instream Flow Incremental Methodology (IFIM) to determine the flows needed to restore and protect habitat for winged mapleleaf mussels and other biota of the river. The focus of the IFIM study was the effect of fluctuating flows resulting from the operation of Northern States Power St. Croix Falls Hydroelectric Project. The IFIM study relied on data collected in another study (Hornbach 1992), and the extent to which these data were used by Johnson dictated the level of our review of the Hornbach study.

In general, the IFIM report is a well-written document, but it provides very little in the way of details regarding how the IFIM modeling was performed. This is an important issue, because IFIM studies involve large amounts of field data and a significant level of analysis. Typically, IFIM reports provide much more information on study design and model calibration than that contained in Johnson's report. Our detailed evaluation of the report is centered on four primary topics: (1) study site selection and representativeness, (2) habitat suitability criteria, (3) PHABSIM model calibration, and (4) the proper approach for evaluating impacts of hydroelectric peaking operations within an IFIM framework.

1. STUDY SITE REPRESENTATIVENESS

IFIM study sites are generally selected on the basis of two guiding principles: representativeness and critical habitat. Both have been used in this study, but neither was supported by sufficient data or justification to adequately address site selection. The Franconia Site was selected because it represented a 12-mile stretch of the St. Croix River. This is a straightforward use of the representative reach approach, but no objective basis was presented for the selection of this site over any other. The application of this approach could have been strengthened by habitat mapping (Morhardt et al. 1983). The Folsum Island site was selected, according to the report, "to encompass the critical riffle located in the east channel". The reason for labeling the east channel as a critical habitat is presumably based on Hornbach's view that it supports one of the most abundant and diverse assemblages of mussels in the St. Croix River. Neither report (Hornbach or Johnson) provide much in the way of explanation as to why density and species richness is so great in this area, and herein lies a contradiction. On the one hand, the site was selected because it contains one of the best assemblages of mussels in the river; yet on the other hand, the report repeatedly refers to the east channel habitat as severely degraded, not only because of flow fluctuation, but also more importantly, to dewatering of much of its area at low flows.

These apparent contradictions in the value of mussel habitat in the east channel raise questions about the validity of using this site to develop instream flow recommendations for the St. Croix River. Does preferred mussel habitat exist in deep pools or riffles? At all sites except the east channel, as flows increase, deep pool habitat becomes dominant (Figures 15–18 of the report).

Despite these concerns, the question remains how much weight should be placed on the WUA dynamics of the Folsum Island site, in particular the east channel. Are there other islands in the river with similar channel hydraulic conditions. Should decisions regarding flow management at the project be determined largely on the basis of this single site? The dewatering of large segments of the east channel at low flows may be a phenomenon that is unique to this one place in the river. The navigation channel is configured (naturally or by dredging) to take most of the water at low flows to provide for boat passage. It stands to reason that the other channel (east channel) would be dewatered at low flows.

The Folsum Island site also raises questions regarding conflicting information and statements made in the report regarding optimal habitat for mussels in the St. Croix River. Based on the suitability criteria presented by Johnson, mussels would not be expected to live in riffles, at least as they are defined by Aadland (1993). This seems to be in direct opposition to statements made in the document that the Folsum Island area represents a "critical riffle" in the St. Croix River and other statements made about the importance of riffles as habitat for mussels, fish, and invertebrates. Reviewing the IFIM model results, it seems reasonable to conclude that the east channel critical riffle is too shallow, and perhaps to swift, for mussel density, regardless of the flow. This is confirmed by the cell-specific data provided in Addendum A to the report, where we find most cells to have a composite suitability of between 0.2-0.4 for mussel density. The overall shallowness of the east channel is demonstrated in the bed profile plots provided in the Addendum. It is also strongly reflected in the macroinvertebrate WUA curves provided in the report, which show this study area to be the only one containing adequate habitat (see Figure 10a). The large amount of habitat in the east channel for invertebrates is due to a combination of substrate type and depth, but, we suspect, more depth than anything else.

2. HABITAT SUITABILITY CRITERIA

The validity and applicability of habitat suitability criteria (HSC) is one of the most important issues in any IFIM study. This is because the suitability criteria represent the rules by which physical parameters are transformed into habitat. There are several potential problems and/or areas requiring clarification relative to the development of HSC for mussel density and species richness in the St. Croix River study. These can be divided into five general areas: (1) theoretical problems with developing HSC for complex biological parameters (i.e., mussel density and species richness), (2) use of preference functions for HSC, (3) use of the mussel HSC to represent *Q. fragosa*, and (4) insufficient information on the analytical methods used to develop HSC.

The methods by which HSC were developed for mussel density and richness raise serious questions. To begin with, the notion of suitability criteria for complex biological parameters of largely sessile organisms is a dubious concept. Attempts to develop HSC for similar parameters for macroinvertebrates have been largely unsuccessful (EA 1991). The root of the problem lies in attempting to correlate instantaneous measures of different river parameters (depth and velocity) with "long-term" measures of community structure (density and richness). Unless the river parameters of interest do not vary significantly over time, the density/richness ultimately achieved by a mussel assemblage is a function of a large number of depths and velocities that have occurred over time, not to mention other factors such as water temperature, silt load, and host habitat. Johnson has attempted to correct for this inherent variability in habitat, at least with respect to depth, by "standardizing" depth measurements to "a dam release of 1,600 cfs". However, no justification is given in support of this assumption (that the mussel communities sampled by Hornbach were responding to a flow of 1,600 cfs). Actually, prior to 1989 this section of river had no flow during winter months. No similar adjustment was attempted for velocity. In fact, velocity HSC were only developed for mussel density because "There was no observed velocity preference for species richness." No explanation is given as to why velocity would be a determinant of species density but not species richness. These general problems discussed above are essentially the result of taking data that were developed for one purpose and using them for another purpose. Hornbach's study was simply not designed to collect data for use in the development of mussel HSC.

We also have reservations regarding the use of availability data to generate "preference" functions for mussel density and richness depth and velocity suitability criteria. The analytical procedure used for the St. Croix IFIM calculates a "preference" value by dividing habitat use by habitat availability. The theoretical basis of this analytical procedure has been questioned in the literature (Morhardt and Hanson 1988; Parsons and Hubert 1988). The hypothesis underlying the procedure is that habitat types (i.e., depth and velocity intervals) that are high in availability, or abundant, but little used are not preferred, whereas habitat types that are low in availability but highly used are preferred. In order for this hypothesis to work, the organism must be capable of "observing" or "experiencing" all or most of the available habitat and then make a conscious decision to pass over less-preferred habitat in favor of more-preferred habitat. It is this hypothesis that has been questioned in the literature. It may not apply to fish species, as argued by Morhardt and Hanson (1988), and it certainly does not apply to relatively sessile organisms such as mussels.

One of the more important assumptions made in the IFIM study is that the HSC developed for mussel density and species richness are essentially representative of *Q. fragosa* habitat requirements. This assumption was required because only ten *Q. fragosa* were found by Hornbach, thereby precluding the development of species-specific HSC, and it was supported by Johnson on the basis of statements made by Hornbach that *Q. fragosa* was associated with high quality mussel habitat. Hornbach's conclusion was based on a series of comparisons made between samples that contained *Q. fragosa* and samples that did not. We believe there are sufficient number of uncertainties and contradictions in Hornbach's work to question the validity of Johnson's assumption. First, the sampling strategy used by Hornbach differed between the 10 "with" *Q. fragosa* samples and the 149 "without" *Q. fragosa* samples. The 149 "without" samples were collected using a transect and grid scheme, while 9 of the 10 "with" samples were collected by actively seeking out *Q. fragosa*. While this difference in sampling procedure is understandable given the scarcity of *Q. fragosa* in the St. Croix River, it does, nonetheless, lead us to become less certain of the value of the comparisons. Furthermore, the fact that no statistically significant difference in depth was found between the "with" and "without" samples clouds the issue, as does the fact that the "with" samples exhibited slower water (0.3 m/s) than the "without" samples (see Hornbach's Figure 14d). Collectively, these aspects of Hornbach's study raise questions regarding the validity of the basic assumption of applying the mussel species richness and density HSC to *Q. fragosa*, and also of the applicability of the IFIM results as an accurate index of habitat for *Q. fragosa*.

In general, not enough information is provided in the report to evaluate the analyses and techniques that were used to develop the HSC for mussel density and species richness. For example, in the section of the report describing the curve-fitting procedures, the resulting functions are given but the raw data on which they were based have been omitted. No goodness-of-fit statistics are provided. It is not possible to evaluate the development of the HSC functions without this information.

3. PHABSIM MODEL CALIBRATION

The report provides little in the way of calibration details of the use of the PHABSIM hydraulic models. The general models selected for use appear appropriate, but little is offered to evaluate whether they were appropriately calibrated or performed acceptably. The two models used to predict water surface elevations (WSP and MANSQ) were appropriate, given that only two water surface elevation measurements were taken at both the Folsum Island and Franconia sites. These models are hydraulic models based on the "step-backwater" approach and the Manning Equation, and, as such, should only be used by hydraulic engineers or hydrologists familiar with open channel hydraulics. Use of the IFG-4 model to simulate velocities and HABTAE to predict WUA is also appropriate.

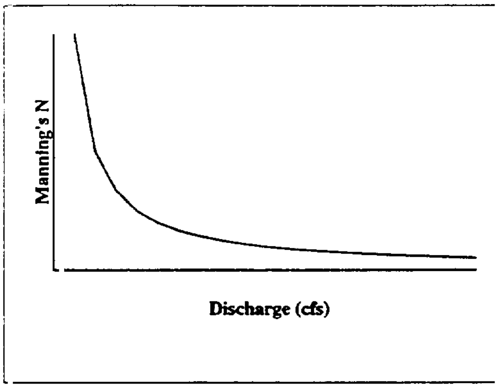
Model-calibration is a critical element of IFIM studies. Accurate simulation of transect depths and velocities is essential to ensuring accurate predictions of WUA. The St. Croix IFIM report provides very little in the way of calibration details. The only information provided consists of the details of the Velocity Adjustment Values (VAF), given in Appendix D of the report. Unfortunately, the VAF values given suggest irregularities or errors in model simulations.

Basically, VAFs are an internal correction feature of the IFG-4 model that compensate for the fact that the Manning "n" values are held constant in the model as a function of flow when in reality, according to hydraulic theory, they should change as a function of flow. The Manning "n" values are sometimes referred to as roughness coefficients, because they represent river friction, or resistance to flow. The IFG-4 model computes separate n values for each transect cell based on field-measured velocities and depths, using the following modification of the basic Manning equation:

$$n = 1.49/v * d^{2/3} * s^{1/2}$$

where:

n = n value
v = cell velocity
d = cell depth
s = water elevation slope



The theoretical relationship between n values and flow is expressed in the generalized figure shown.

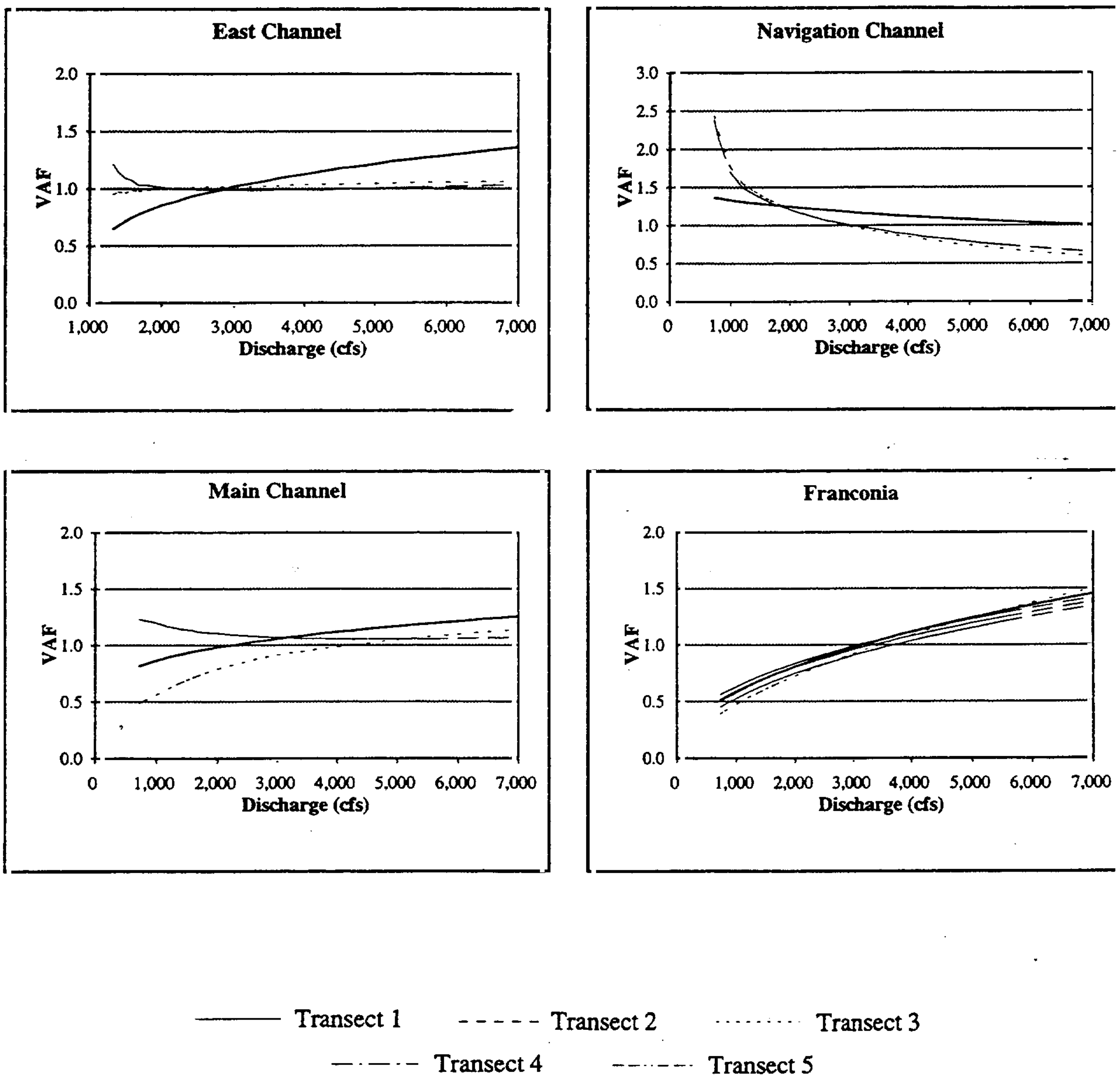
At low flows a large portion of the flow volume comes in contact with the substrate (i.e., bouncing into rocks), and as a result the water velocity is significantly slowed. Hence, flow resistance (and correspondingly, n values) are high at low flows. At high rates of flow, a much smaller portion of the flow volume comes in contact with the substrate, and thus resistance to flow (and n values) are low. The IFG-4 model, however, does not contain a mechanism to alter n values as a function of flow. It simply holds constant the n values that are computed at the field-measured flow level (3,200 cfs in the case of the St. Croix River IFIM) across all simulation flows. Thus, the model violates the theoretical relationship shown above by failing to increase n values at flows below 3,200 cfs and, conversely, to decrease n values at flows above 3,200 cfs. The inevitable outcome is the model will over-predict velocities at low flows and under-predict velocities at high flows. Recognizing this potential problem, the model developers (the USFWS) created the VAF as a compensating mechanism. Not only do the VAFs compensate for constant n values, but they also provide insight into model calibration. For a well-calibrated model, the VAF-vs.-streamflow relationship should be a mirror i· ge of the theoretical n value-vs.-streamflow relationship. That is, the VAFs should be small at low flows (i.e., less than 1.00), pass through 1.00 at the field measurement flow (3,200 cfs in this case), and be large at high flows (i.e., greater than 1.00). Transects exhibiting these dynamics reflect a well-calibrated model. Deviations from this behavior reflect problems with model calibration that can lead to erroneous model predictions.

Such deviations are present in the VAF values of the St. Croix River IFIM study. For example, all transects in the Navigational Channel, two in the East Channel, and one in the Main Channel at Folsum Island exhibit VAF-vs.-streamflow relationships that reflect data and/or model calibration problems. This represents more than half the transects at the Folsum Island site. On the other hand, all the Franconia transects exhibit normal VAF dynamics.

In nearly all the cases of deviant VAF behavior, the shape of the VAF curve is directly opposite to what it should be, as seen in the figures given on Page 6. In other words, at low flows VAF values are high, whereas at high flows they are low.

When VAF dynamics have a pattern like those in the navigation channel, the IFG-4 model is over predicting river stage (water surface elevation) at high flows and underpredicting stage at low flows. This leads to errors in both depth and velocity predictions. At low flows, the model predicts depths that are too shallow and velocities that are too swift. Conversely, at high flows the model predicts depths that are to deep and velocities that are too slow. These errors can have significant effects on predictions of WUA.

The calibration errors may lie in a number of areas, including (1) errors with the regression model used to partition flow between the navigation channel and east channel, (2) application of the WSP or MANSQ models, or (3) application of the IFG-4 flow model. Model calibration details should be evaluated by a hydrologist or hydraulic engineer familiar with hydraulic simulation to uncover the source of the errors. The effects of these errors on model simulations should be examined as well.



4. THE PROPER PERSPECTIVE FOR EVALUATING FLUCTUATING FLOW IMPACTS

Perhaps the most significant problem with the St. Croix IFIM study is its narrow focus in considering alternative flow regimes and its apparent bias in support of the run-of-the-river flow recommendation. Johnson does not develop a defensible argument in support of the recommended run-of-the-river operational mode, and in fact the recommendation does not appear to be based on the IFIM analysis. On page 28 of the report, Johnson states, "An important step in the instream flow assessment is to compare habitat conditions under the recommended flow regime (run-of-the-river) to habitat conditions under the existing flow regime (peaking)." This statement leaves the impression that comparing habitat under these two conditions was an afterthought to the recommendation rather than the basis for making it.

The document inadequately addresses alternative peaking regimes in the St. Croix River. The IFIM data are nearly ignored as the author considers only two possible alternatives: continued peaking operation with a 800 cfs minimum flow vs. run-of-the-river operation. Data available from the PHABSIM modeling are significantly under-utilized in this regard. This simplistic view of alternatives ignores a number of analyses that should be performed when evaluating the effects of fluctuating flo. .egimes below peaking hydroelectric projects.

IFIM studies that are designed to evaluate habitat changes under fluctuating flows and develop flow recommendations downstream of peaking hydroelectric plants routinely use a variety of approaches to consider changing location of habitat for selected species. The "dual flow" and "effective habitat" modeling techniques, among others, were specifically developed for evaluating alternative flow regimes in such situations (Gore et al. 1989). Resource agencies in Wisconsin and Minnesota typically request such modeling techniques when evaluating flow regimes. Habitat modeling programs are available within PHABSIM to perform these analyses (Milhous et al. 1989).

Other issues noticeably missing from the report include wetted width and cell-specific suitability analyses. IFIM studies performed to evaluate the effects of fluctuating flows routinely evaluate changes in these parameters. For example, the report should have contained information on changes in wetted width under different peaking alternatives. This is particularly important information in the light of statements made in the report that dewatering is the primary source of habitat degradation. Two forms of output that are commonly included in IFIM study reports are wetted perimeter vs. discharge data (for each transect and for all transects combined) and total river surface area vs. discharge. Information of this type is often presented in graphical and tabular form. An omission of this type of information should be corrected so that the conclusions contained in the report can be evaluated properly. Of greater importance is an evaluation of the cell-specific habitat at different flows. Comparisons of cell suitabilities at the high and low ends of a given peaking regime should be examined to determine if the dewatered areas represent high quality habitat at high flows or not. The failure to perform such an analysis is a major deficiency of the St. Croix River IFIM study. Some information of this type was provided in Addendum A, in the form of cell-specific graphs. However, these graphs were limited to the east channel transects. They should be provided for all transects, and they should be accompanied by an analysis of the usable area lost under different peaking regimes. This is particularly critical in this study, as the dewatered areas most likely include shallow margins of the river that at high flows are outside the optimal depth range of mussels.

5. CONCLUSION

In evaluating the need to alter operation of the Northern States Power St. Croix Falls Hydroelectric Project, it is important to consider certain facts. No data are provided by Hornbach or Johnson to suggest that the mussel community (including *Q. fragosa*) was more abundant prior to project operation. As stated by Hornbach, there are no pre-dam records of this species in the project area of the St. Croix River. In lieu of any other evidence, it is reasonable to assume that this species has always been rare in the St. Croix River. The fact that it now occurs there in concentrations higher than anywhere else cannot be used to predict past abundance. Secondly, there is no evidence to determine if the mussel community in the study areas inhabited a greater area prior to project operation, or if they even existed in greater numbers, or greater diversity. The studies of Hornbach and Johnson carefully document where mussel communities are now, and suggest plausible reasons for why they are there, but there is no evidence that this was not always the case.

These facts notwithstanding, the question remains, Has Johnson demonstrated that flow modifications (i.e., run-of-the-river) will improve conditions in the St. Croix River for the winged mapleleaf mussel, the general mussel community, or other aquatic organisms, including macroinvertebrates and fish? While peaking operations have the potential to negatively affect river biota, as described in detail by Johnson, has it had a detrimental affect in the St. Croix River? Apparently not, given that the Folsum Island site supports a robust population of mussels, including *Q. Fragosa*, which has been widely extirpated from its original range in 17 states. Interestingly, neither Hornbach or Johnson provide an explanation for this phenomenon, and their silence on the issue leads to a fundamental contradiction in Johnson's work. On the one hand, he selects the Folsum Island site because it contains one of the best assemblages of mussels in the river, but on the other, he repeatedly refers to the east channel habitat as severely degraded. This apparent contradiction in the value of mussel habitat in the east channel raise questions about the validity of using this site to develop instream flow recommendations for the St. Croix River.

If, in fact, it is believed that flow modifications could improve habitat conditions, the question then becomes, Is the IFIM study presented by Johnson valid and does it provide sufficient evidence to support the recommendation that the only plausible solution is a run-of-the-river operational mode? Our conclusions relative to these issues are (1) problems exist with the application of the hydraulic models that must be corrected prior to further evaluation of results, (2) problems exist with the development of the mussel HSC, particularly in relation to the practical and theoretical problems with developing HSC for complex biological parameters, (3) the IFIM study has not adequately made use of standard techniques for evaluating peaking power operations, and (4) no compelling argument has been made in support of the run-of-the-river operational mode as compared to the existing or alternative peaking operational modes.

Clearly, more information needs to be provided. Justification or documentation should be provided to demonstrate that the Folsum Island site is representative of the river, rather than unique or unusual, before flow recommendations for the entire river section are made on the basis of this site. Alternatively, some basis for establishing that the site is somehow critical for mussels or *Q. fragosa* should be made in order to justify basing flow recommendations for the river on this one site.

More modeling also needs to be performed. Inherent problems with model calibration need to be corrected. The validity of the depth and velocity suitability criteria for mussel density and species richness need to be examined from the perspective of preferred habitat. And finally, a thorough examination of modified peaking operations should be performed that examines changes in wetted width at different flows and, even more important, more in the way of cell-specific analyses to evaluate the habitat value of wetted areas that are dewatered at low flows.

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Parsons, B.G.M., and W.A. Hubert. 1988. Influence of habitat availability on spawning site selection by kokanee in streams. North Amer. J. Fish. Manage. 8:426-431.

Paul M. Leonard
Senior Associate

Paul Leonard is a certified fisheries scientist and senior project manager with 14 years of experience managing and performing environmental assessments related to hydroelectric power and other water resource development projects. Mr. Leonard manages the activities of multi-disciplinary teams of fisheries biologists, hydrologists, water quality experts, planners, recreation specialists, and other environmental and resource specialists on various projects. His particular areas of expertise include hydropower project licensing, instream flow studies, fish community based biological assessments, aquatic habitat evaluation and enhancement, and the ecology of regulated streams.

Experience

- Project Manager, **Sinclair Hydro Environmental Assessment**, Georgia Power Company. Responsible for preparation of scoping documents and the Draft Environmental Assessment (DEA), general consultation on FERC relicensing issues, strategy, and NEPA compliance activities. Preparation of the DEA involved numerous tasks, including the identification and description of resource issues, identification and evaluation of potential resource enhancements, FERC coordination meetings to understand the evolving process of applicant-prepared DEAs at FERC, development of the proposed action based on the client's needs, identification of alternatives based on the resource agencies and other parties concerns, and description the affected resources and positive and negative impacts of the proposed action and alternatives.

- Task Manager, **Flint River Hydroelectric Project Relicensing,** Georgia Power Company. Performed an environmental audit and assisted in the preparation of an Initial Consultation Package. Environmental audit was designed to identify existing information and reveal issues that would be central to assist Georgia Power's in making study proposals in the ICP and strategic decisions for the relicensing process. Key issues were the need for instream flow studies and anadromous fish.

- Project Manager and Technical Studies Coordinator, **Relicensing of the Sinclair Hydroelectric Project** (FERC Project No. 1951), Georgia Power Company. A large multidisciplinary environmental assessment for the relicensing of a 45-MW hydroelectric plant in central Georgia. Responsible for a large set of complex tailwater and river corridor studies focusing on fluctuating flow effects on a 70-mile Oconee River corridor in the Piedmont and Coastal Plain with extensive bottomland hardwood forests. Includes specific studies of fluvial geomorphology, fisheries, wildlife, and botanical resources, protected species, wetlands, hydrology, water quality, and recreational boat passage.

- Project Manager and Lead Technical Coordinator, **Flambeau River Instream Flow Study**, Northern States Power Company. Instream flow study performed in response to a FERC Additional Information Request. Project involved analysis of the effects of peaking hydropower operations on habitat for aquatic biota and evaluation of alternative operational and minimum flow scenarios and was successfully completed under a demanding schedule with extensive agency consultation. Innovative approaches included the application of habitat-use guilds and "dual-flow" habitat modeling.

- Project Manager and IFIM Specialist, **North Georgia Hydro Group Project Relicensing** (FERC Project No. 2354), Georgia Power Company. Project involved a large set of relicensing activities, instream flow, and special fisheries investigations at this 166-MW project in North Georgia that includes seven dams and six powerhouses. Responsible for scoping, resource agency consultation, and drafting portions of the Exhibit E. The IFIM study for this project was one of the first and most complete applications of this methodology in the southeast U.S.

- Project Manager, **James River Instream Flow Study and Environmental Impact Statement,** Henrico County, Virginia: Camp Dresser & McKee. Managed a large and complex multidisciplinary assessment of existing and proposed water supply withdrawals and cumulative water withdrawals at the Falls of the James River, Richmond, Virginia and produced the Affected Environment and Environmental Consequences sections of the Draft Environmental Impact Statement (DEIS). This study included an in-depth application of the Instream Flow Incremental Methodology (IFIM) to produce flow-habitat relations for eighteen warmwater fish species in four habitat-use guilds and flow-suitability information for nine recreational activities. The study included extensive hydrologic analyses, anadromous fish passage evaluations, recreational use and preference studies, fisheries biological assessments, and temperature/water quality modeling. The James River Report received commendations from state and federal resource and regulatory agencies.

- Project Manager, **Lloyd Shoals Hydroelectric Project Relicensing** (FERC Project No. 2336), Georgia Power Company. Environmental studies (fisheries, instream flow, and water quality) for relicensing of this 14-MW hydroelectric facility in central Georgia, with emphasis on evaluation of peaking operations. Responsible for supervising environmental studies, participating in agency consultation and negotiation, drafting portions of the Exhibit E, and responding to FERC and agency comments and information requests.

- Principal Investigator, **Development of an Index of Biotic Integrity for Wadable New Jersey Streams,** New Jersey Department of Environmental Protection, Division of Science and Research. Research project designed to produce the basic results needed to apply the Index of Biotic Integrity (IBI) in new Jersey wadable streams and provide a basis for further testing and validation. The research includes four components: acquisition and review of available fisheries data; establishment of a fisheries expert panel to oversee assignment of fish to ecological guilds; identification of IBI modifications necessary for application to New Jersey; and calibration of IBI metrics in a pilot watershed in two ecoregions. The work represents a significant milestone in the development of aquatic bioassessment methods and biological criteria for New Jersey.

- Project Manager, **Hydroelectric Relicensing Services,** Southern Company. Provided technical and strategic assistance in preparing Exhibit E's, responding to FERC additional information requests, and negotiating with resource agencies. Conducted assessment of biological and physical impacts of hydropower peaking operation and negotiated project operational changes and impact mitigation with resource agencies.

- Lead Fisheries Biologist, **Red Run Dam Environmental Assessment**, Baltimore County, Maryland, Rummel Klepper and Kahl, Inc. Responsible for assessing aquatic impacts of land development and stormwater management alternatives in a rapidly developing urban watershed with a naturally reproducing trout stream, managed aquatic habitat and fisheries characterization and monitoring components. Evaluated potential impacts and mitigative measures for alternatives and assisted in coordinating expert review of feasibility of managing reservoir, headwater, and tailwater trout populations.

- Project Supervisor, **Evaluation of Behavioral-Based Fish Protection Systems for Allegheny Lock and Dam No. 5 and 6 Hydro,** Mitex, Inc. In response to FERC license articles, provided an evaluation and recommendations for behavioral-based fish protection systems during design and construction phases of the project. Scope of work included agency consultation, site-specific evaluations of candidate state-of-the-art fish protection systems, recommendations for a system offering the greatest potential for biological effectiveness and site feasibility, and conceptual designs and cost estimates for implementing the technology. The final report was submitted in fulfillment of the license article, and the recommendations were implemented at Allegheny Lock and Dam No. 5.

- Project Manager, **Water Supply Impoundment Baseline Environmental Studies**, Black and Veatch, Inc. Managed and conducted a set of studies to characterize existing aquatic environmental conditions in the Gillis Falls watershed in support of state and federal permits for construction of a 420-acre water supply impoundment and a potential Environmental Impact Statement (EIS). Conducted seasonal surveys of fish and macroinvertebrate populations and designed and implemented an aquatic habitat sampling and evaluation protocol to determine habitat quality and suitability for trout.

- Instream Flow Specialist, **Streamflow Evaluation of the Oconto River Below Stiles Dam,** Oconto Electric. Reviewed an instream flow study conducted by the Wisconsin DNR and evaluated the technical basis for their flow recommendations for the hydroelectric facility at Stiles Dam. Used EA's in-house physical habitat simulation models and sensitivity analyses to critique the study and provide an objective evaluation of the study results and assumptions.

- Fisheries Research Workshop Leader, **Development of Biological Assessment Methods and Biocriteria,** Environmental Protection Agency. Assisted in the development of the Rapid Bioassessment Protocols under contract with the Environmental Protection Agency and conducted 12 EPA-sponsored national workshops for state and federal agencies and private firms. Organized and moderated a special symposium entitled "Fish Assemblages and Biocriteria".

- Co-Principal Investigator and Project Supervisor, **Upper James River Instream Flow**, State of Virginia, Virginia Water Resources Research. Research designed to develop relationship between basin hydrology and flows providing selected levels of fish habitat as determined by IFIM. Authored reports and journal publications. Innovative/Unique Technology, Equipment, Problem-Solving Capability: The method is now used for initial instream flow recommendations by the Virginia Department of Game and Inland Fisheries.

- Research Associate, **Marine and Coastal Species Information System/ Biota of Virginia**, Virginia Department of Game and Inland Fish/Multistate Fish and Wildlife Information Systems. Provided training, technical assistance, and research coordination to agencies interested in developing and implementing natural resource data bases. Researched and reviewed existing data bases for development of the Marine and Coastal Species Information System (MACSIS) data base.

- Fisheries Research Aid, **Flathead River System Investigations,** Bureau of Reclamation, Bonneville Power Administration. Assisted in evaluation of Hungry Horse Dam hydro-peaking operations on Kokanee salmon spawning/incubation success and year-class strength; monitored spawning and juvenile migrations of adfluvial cutthroat trout through tagging studies and radiotelemetry.

- Fisheries Biologist, **Protected Species Surveys** for various public and private entities. Conducted surveys of rare, threatened, or endangered fish and mussel species in various streams in Virginia and Tennessee river drainages.

Education

MS-Fisheries Science/Statistics, Virginia Polytechnic Institute and State University, 1983
BS-Aquatic Science/Biology, Allegheny College, 1978

Additional Training

Project Manager Training Seminar
Fish Diversions and Passageways Course
American Fisheries Society Fish Disease and Health short course
U.S. Fish and Wildlife Service Training:

- IF 200 Designing and Conducting Studies with IFIM
- IF 201 Problem Solving with the Instream Flow Incremental Methodology
- IF 305 Field Techniques for Stream Habitat Analysis
- IF 310 Use of the Computer Based Physical Habitat Simulation System
- IF 312 Stream Network Temperature Model
- IF 403 Species Habitat Suitability Criteria

Certifications

American Fisheries Society, Certified Fisheries Scientist (Tier II)
NAUI and PADI Certified Scuba Diver

Professional Affiliations

Member, American Fisheries Society
Member, Ecological Society of America

Selected Publications

Leonard, P.M., C. Bell, and J. Boltz. 1995. Habitat modeling in a Southeastern Alluvial Floodplain River. Waterpower 1995.

Boltz, S., P.M. Leonard, and C. Bell. 1995. Using the 1992 Energy Policy Act Provisions for Preparation of Environmental Assessments. Waterpower 1995.

Boltz, S., C. Bell, and P.M. Leonard. 1995. The Challenges of Developing Habitat Suitability Criteria for a Large Southeastern River. Waterpower 1995.

Boltz, S.E., P. M. Leonard, and C. Bell. 1995. Draft EA Preparation Under New FERC Guidelines. Waterpower 1995.

Leonard, P.M. 1993. Combining Fish/Recreation Considerations: Need for Integrated Approach. Presented at Recreation and Instream Flow Workshop, San Francisco, California. December 1993.

Leonard, P.M. 1992. Opportunities and Potential Conflicts Between Instream Flows for Fish and Recreation. Presented at Eastern Instream Flow Conference, Williamsburg, Virginia. March 1992.

Barbour, M.J. and P.M. Leonard. 1991. Rapid Bioassessment Training: Concepts, Approaches, and Protocols. Co-leader of 12 national EPA-sponsored workshops held throughout the U.S. 1989-91.

Leonard, P.M. 1991. Use of Fish Assemblages in Biological Assessment: State Experiences and Perspectives. Annual meeting of the American Fisheries Society, San Antonio, Texas, September 1991. Organizer and moderator for session entitled "Fish Assemblages and Biocriteria".

Orth, D.J. and P.M. Leonard. 1990. Comparison of Instream Flow Methods for Western Virginia. Biological Report 90(5):29. U.S. Fish and Wildlife Service.

Barbour, M.J. and P.M. Leonard 1990. Rapid Bioassessment for Water Quality Monitoring. National Biology Workshop, Harrisburg, Pennsylvania.

Orth, D.J. and P.M. Leonard. 1990. Comparison of Discharge Methods and Habitat Optimization for Recommending Instream Flows to Protect Warmwater Streams. Regulated Rivers: Research and Management 5:129-138.

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Miller, D.L., P.M. Leonard, and 12 co-authors. 1988. Regional Applications of an Index of Biotic Integrity for use in Water Resource Management. Fisheries 5:12 20.

Ferris, J.S. and six co-authors. 1988. A Proposed Model to Rank Inactive Hazardous Waste Sites for Biological Threat. EA Engineering, Science, and Technology.

Orth, D.J. and P.M. Leonard. 1987. An Approach for Recommending Minimum Instream Flows for Virginia Streams. Virginia J. Sci. 38(2):122.

Orth, D.J. and P.M. Leonard 1987. Developing Instream Flow Recommendations for Multi-Species Assemblages. An instream flow workshop for fisheries biologists. Warmwater Streams Committee, Southern Division of the American Fisheries Society. October 1987.

Leonard, P.M. and D.J. Orth. 1986. Application and Testing of an Index of Biotic Integrity in Small, Coolwater Streams. Trans. Am. Fish. Soc. 115:401 414.

Leonard, P.M. 1986. Book review of "A Conceptual Approach for the Application of Biological Indicators of Ecosystem Quality in the Great Lakes Basin." Trans. Am. Fish. Soc. 115:500 501.

Leonard, P.J., D.J. Orth, and C.J. Goudreau. 1986. Development of a Method for Recommending Instream Flows for Fishes in the Upper James River, Virginia. Bulletin 152. Virginia Water Resources Research Center.

Orth, D.J. and P.M. Leonard. 1985. Comparisons of Fish Assemblages in the New River Above and Below Polluted Tributaries. Fourth Annual New River Symposium, U.S. Department of Interior, National Park Service, Oak Hill, West Virginia.

Leonard, P.M. 1984. The Use of Fish Communities in the Evaluation of Biotic Integrity. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Leonard, P.M. and D.J. Orth. 1984. Are Your Streams Healthy ... Ask the Fish! Virginia Wildlife 46(4):14 17. (Circulated by National Wildlife Foundation to affiliates for republication.)

Leonard, P.M. 1984. Evaluation of the Use of Fish Community Attributes to Determine the Biotic Integrity of Small, Coolwater Streams. Presented at the 114th Annual Meeting of the American Fisheries Society, 13 16 August 1984, Cornell University, Ithaca, New York.

Leonard, P.M. and D.J. Orth. 1983. Biotic Integrity of Fish Communities and Cultural Pollution Problems in Tributaries of the New River Gorge National River. Second Annual New River Symposium, U.S. Department of Interior, National Park Service, Oak Hill, West Virginia.

Graham, P.J., S.L. McMullin, S. Appert, K.J. Frazer, and P.M. Leonard. 1980. Impacts of Hungry Horse Dam on the Aquatic Life in the Flathead River. Montana Department of Fish, Wildlife, and Parks, Kalispell.

David F. Hanson
Senior Fisheries Biologist/Project Manager

Mr. Hanson is a nationally recognized leader in the application of instream flow and other quantitative methodologies used to evaluate the relationship between streamflow and fish habitat. Mr. Hanson is a fisheries biologist with a high level of experience in mathematical modeling and quantitative analysis of data related to fish populations and habitat. As a regional manager of EA's Environmental Assessment and Management Business, Mr. Hanson supervises a 21-member multidisciplinary team of resource experts in the areas of fisheries, botany, wildlife, recreation, aesthetics, water quality, and socioeconomics. He is an experienced project manager, directing complex field and analytical studies for the licensing of large-scale hydroelectric projects.

Education:

M.S.; Utah State University; Wildlife Science/Fisheries; 1978
B.A.; University of California, Santa Barbara; Zoology; 1973

Training:

40-hour OSHA Hazardous Waste Health and Safety Training, 1988
EA Expert Witness Training, 1992
EA Project Management Training, 1993

National Ecology Research Center Training:
IFG 310 - Users Guide to PHABSIM, 1980
IFG 315 - Adv. Analytical Techniques (SNTEMP) in IFIM, 1985
IFG 321 - Seminar on Hydraulics in PHABSIM, 1985
IFG 215 - Problem Solving with the IFIM, 1986
IFG 403 - Habitat Suitability Criteria, 1986
IF 402 - Hydraulics in PHABSIM, 1987
IF 310 - Using the Computer Based PHABSIM (Version II) 1990

Experience:

Hydroelectric Power/Instream Flow—Highly experienced in all phases of environmental components of hydroelectric licensing/relicensing projects, including project management, resource agency consultation, field study implementation, and Exhibit E production. Has also made regular presentations of scoping material and technical study results to agency representatives and different public entities as part of public involvement programs. Mr. Hanson has 12 years of experience in performing fisheries and instream flow studies related to hydroelectric power development. Over this period, Mr. Hanson has participated in instream flow studies on more than 50 streams and rivers in California, Montana, Oregon, Georgia, West Virginia, Virginia, Pennsylvania, and Ohio, and in New Zealand. Much of Mr. Hanson's strength in instream flow studies was gained from his work in developing an EA in-house Pascal computer program patterned after the USFWS IFIM models. He has also performed several habitat suitability criteria studies, including development of bivariate exponential polynomial models for trout species and multiple regression models for aquatic insect functional feeding groups.

APPENDIX 8

JOHNSON'S (1996) RESPONSE

TO

HANSON AND LEONARD'S

(1995) CRITIQUE

Response to the Review of an Instream Flow Study
Performed on *Quadrula fragosa*
in the Lower St. Croix River, Wisconsin

Shawn L. Johnson

The following is my response to the review of Instream Flow Requirements of *Quadrula fragosa* and the Aquatic Community in the Lower St. Croix River Downstream of the Northern States Power Hydroelectric Dam at St. Croix Falls, Wisconsin. The review was prepared by Dave Hanson (EA Engineer, Science, and Technology) and Paul Leonard (EDAW, Inc.) at the request of NSP. In their review, they emphasized the need for additional analyses, much of which I have provided here. Results from these analyses further support the conclusions and recommendations included in the original report. They also expressed concern about the validity of the approach used to make flow recommendations. Flow recommendations were based on the best available information and science. Given that the Winged Mapleleaf Recovery Team needs to make a recommendation to protect the instream flow needs of *Q. fragosa* and the aquatic community in the Lower St. Croix River, the reviewers offer no alternative approaches or information upon which to make flow recommendations. Much of my response reiterates what I said in the original report. I have not, however, recited the literature cited in the original report. I have organized my comments using the same main headings as the reviewers. The text in quotation is taken verbatim from the review, and my comments follow in bold font.

1. Study Site Representativeness

a) "The Folsum Island site was selected, according to the report, "to encompass the critical riffle located in the east channel". The reason for labeling the east channel as critical habitat is presumably based on Hornbach's view that it supports one of the most abundant and diverse assemblages of mussels in the St. Croix River."

..."how much weight should be placed on the WUA dynamics of the Folsum Island site, in particular the east channel?"

"Should decisions regarding flow management at the project be determined largely on the basis of this single site?"

Based on the best available information (Hay et al. 1995), the Folsum Island site, particularly the east channel, is considered critical habitat for the last known population of *Q. fragosa*. The main purpose of the study was to assess the instream flow needs of *Q. fragosa*, and it would be illogical to do so at a site which was not considered important to this rare mussel. This area also supports a very rich and diverse mussel community, and mussel habitat-use studies have been conducted here. I assume these are the reasons why the winged mapleleaf recovery team and concerned resource agencies specifically asked the MNDNR to examine the relation between the availability of mussel habitat and discharge at Folsum Island. The Folsum Island site is not only important for mussels, but it

is also important for its recreational and aesthetic values, all of which are affected by flow regulation at the dam. Folsum Island is a very appropriate site at which to develop flow recommendations.

It should be noted that flow recommendations were not based solely on the east channel but also on the main channel at Folsum Island and at Franconia, and not just on WUA dynamics for mussels, but also for other invertebrates, the fish community, and habitat diversity.

b) "Are there other islands in the river with similar channel hydraulic conditions?"

"The dewatering of large segments of the east channel at low flows may be a phenomenon that is unique to this one place in the river."

As the reviewers observed, the riffle in the east channel is sensitive to changes in flow, becoming dewatered at low flows. Riffles are generally the most flow sensitive habitat type, being scarce or absent at both low and high flows. Consequently, habitat for riffle-dwelling fishes and invertebrates is very limited at low flows (Leonard and Orth 1988: Orth and Leonard 1990). Many states base flow protection on wetted perimeter analyses conducted in riffles because they are flow sensitive and ecologically important. The wetted perimeter method assumes that flows which protect riffle habitat will also protect other habitat types, such as pools and runs. Often, the widest, shallowest cross-section of the riffle, the most flow sensitive section, is selected for wetted perimeter studies. Flows which maintain the east channel riffle should also maintain other riffles and habitat types downstream from the NSP dam.

Leonard has previously emphasized the need to include flow sensitive riffle species when developing flow recommendations (Leonard and Orth 1988). He cautioned that basing flow recommendations on flow insensitive species would result in inadequate flow protection for the river community. Similarly, it is important to include the flow sensitive east channel when developing flow recommendations for the Lower St. Croix River to ensure adequate protection of the aquatic community.

It is highly unlikely that the east channel is the only area of the Lower St. Croix River that dewaters at 800 cfs, given that this is an extreme drought flow. Other riffles downstream from the dam, such as the large riffle just upstream from the Highway 8 bridge, should respond similarly to drought flows. Large areas of the shoreline along the main channel are dewatered at 800 and 1600 cfs, including a large gravel bar located just upstream of the boat landing at MN Interstate Park.

c) "Neither report (Hornbach or Johnson) provide much in the way of explanation as to why density and species richness is so great in this area (referring to the Folsum Island site), and herein lies a contradiction. On the one hand, the site was selected because it contains one of the best assemblages of mussels in the river; yet on the other hand, the report repeatedly refers to the east channel habitat as severely degraded, not only because of flow fluctuations, but also more importantly, to dewatering of much of its area at low flows."

While it is true that the Folsum Island site as a whole supports a rich and diverse mussel assemblage and is important for *O. fragosa*, degraded mussel habitat exists in those areas dewatered during peaking operations. Of the 150 quadrat samples taken by Hornbach at Folsum Island, 16 contained no live mussels. Fifteen of these 16 samples were in areas (both in the main channel and east channel) that are dewatered, or nearly so, at 800 cfs. Samples taken in areas that remain inundated during low peaking flows, especially areas deeper than 0.5 m, contained high numbers of mussels. Hornbach reported similar results during a 1995 mussel survey conducted along the three east channel PHABSIM transects. During a dam release of 800 cfs, the MNDNR crew observed no mussels in dewatered areas. Glen Miller noted that *O. fragosa* found during a 1991 mussel survey at Folsum Island were in areas that remained inundated during low flows. Biological reasons for these observations, as well as supporting literature, are provided in the original report. The frequency of dewatering, and the amount of area dewatered, would be drastically reduced under the recommended run-of-the-river flow regime as compared to the existing peaking flow regime.

c) "Reviewing the IFIM model results, it seems reasonable to conclude that the east channel critical riffle is too shallow, and perhaps to swift, for mussel density, regardless of the flow. This is confirmed by the cell-specific data provided in Addendum A to the report, where we find most cells to have a composite suitability of between 0.2-.04 for mussel density."

The cell-specific composite suitability factors provided in Addendum A represent the product of the individual suitability values for depth, velocity, and substrate. These individual suitability values range from 0.0 to 1.0. A suitability value of 0.0 indicates the least preferred or least suitable habitat; a value of 1.0 indicates the most preferred or most suitable habitat. The three suitability values are multiplied together to determine the composite suitability weighting factor for each cell. For cells to have composite values of 0.2 - 0.4 requires individual values of 0.58 - 0.74 assuming, for illustration, that each of the three individual values are the same (the cube root of 0.2=0.58 and 0.4=0.74) . This range of individual suitability values represents high quality habitat. As will be discussed in section 4e, the composite suitability factors for cells in the east channel indicate that suitable mussel habitat is very limited at low base flows but not at higher flows.

Hornbach found high mussel densities in the east channel except in areas dewatered or very shallow at low peaking flows. Therefore, quality mussel habitat does exist in the east channel.

2. HABITAT SUITABILITY CRITERIA (HSC)

a) ..."the problem lies in attempting to correlate instantaneous measures of different river parameters (depth and velocity) with "long-term" measures of community structure (density and richness)."

..."the density/richness ultimately achieved by a mussel assemblage is a function of a large number of depths and velocities that have occurred over time"

"Johnson has attempted to correct for this inherent variability in habitat, at least for depth, by "standardizing" depth measurements to a dam release of 1600 cfs".

The habitat-use data used to generate the suitability criteria were collected over a wide range of flows. Ten samples were collected at each of the following 15 flows: 1585, 1637, 1637, 2853, 4127, 4402, 4430, 4543, 5181, 5210, 5239, 6062, 6062, 6093, and 6221 cfs. The data were therefore collected over the range of flows that the mussel community has been exposed to over a long period of time. The average of these 15 flows (4352 cfs) is similar to the mean annual flow of the Lower St. Croix River (4301 cfs).

As the reviewers noted, the depth curves in the report were standardized to a dam release of 1600 cfs. After the report was sent out, I developed a depth curve for mussel density based on actual, or unstandardized, depth measurements. This curve, which I sent to Leonard about a year ago, was nearly identical to the standardized depth curve. The depth curve would be similar regardless of the flow at which the data are collected in that the shallowest depths would have the lowest suitabilities and the deepest depths would have the highest suitabilities.

When scrutinizing the validity of any habitat suitability criteria, the main question that needs addressing is whether the criteria make biological sense. Do the curves reflect the best available biological information concerning the animal in question? The mussel habitat suitability criteria developed for the St. Croix River are similar to criteria developed from extensive mussel habitat-use studies conducted in other Minnesota rivers and are also well supported by the literature. The reviewers did not question the biological validity of the criteria or offer any alternative criteria. The recovery team needs to make a flow recommendation based on the best available information. The St. Croix criteria reflect the best available information concerning the instream flow needs of the St. Croix River mussel community.

b) "The analytical procedure used for the St. Croix IFIM calculates a "preference" value by dividing habitat use by habitat availability."

..."In order for this hypothesis to work, the organism must be capable of "observing" or "experiencing" all or most of the available habitat and then make a conscious decision to pass over less-preferred habitat in favor of more-preferred habitat. It is this hypothesis that has been questioned in the literature. It may not apply to fish species, as argued by Morhardt and Hanson (1988), and it certainly does not apply to relatively sessile organisms such as mussels."

I did develop "use" curves from the St. Croix data and they were very similar to the preference curves used in the modeling except that the velocity use curve had lower suitability values for low velocities than the velocity preference curve.

A fundamental problem with habitat-use curves is that they often reflect the type of habitat the researcher likes to sample in rather than the type of habitat the target organism likes to live in. For example, many biologists studying habitat requirements of aquatic

invertebrates only sample in riffle habitat. It is not surprising then that criteria developed from this sampling show that invertebrates prefer riffle habitat and not pool habitat. If the researcher just sampled pool habitat, he/she would conclude just the opposite. Only when habitat availability is accounted for can a true picture of the habitat needs of an organism be identified. The MNDNR has developed use curves for fishes in special cases, such as spawning lake sturgeon, which migrate long distances up rivers to spawn. In this case, describing available habitat is not appropriate. Leonard has used a similar approach in that he developed use curves for spawning and young-of-year northern hog suckers and preference curves for all other species and life stages (Leonard and Orth 1988).

I disagree with the logic that preference criteria do not apply to mussels because they are relatively sessile. I will explain why by way of example. Assume that a million glochidia were stocked in equal densities in all available habitats in a stretch of river with no resident mussels. Also assume that these mussels never moved from the location where they were stocked (I have observed mussels actively moving to deeper water in response to declining flows, suggesting that mussels can seek out "preferred' habitat) and no new mussels were added to the population. It would be expected that mussels stocked in the highest quality mussel habitat would experience higher survival rates than mussels stocked in low quality habitat. Over time, the observed distribution and density of these non-sessile mussels would be an excellent indicator of the quality of habitat that they were stocked in (i.e., mussel densities would be highest in their most "preferred" habitat).

I believe differential survival explains the observed distribution and abundance of mussels at Folsum Island in that mussels are scarce or absent in habitat that is periodically dewatered at low flows while mussel densities are highest in habitat that maintains suitable conditions at low flows. This supports NSP's position that habitat conditions during low flows are critical in limiting the distribution of mussels to wetted areas of the stream channel downstream of the dam. Changing from the existing peaking flow regime to run-of-the-river should increase the survival of mussels, including *Q. fragosa*, in that the frequency of dewatering and the area dewatered would be drastically reduced.

c) "One of the more important assumptions made in the IFIM study is that the HSC developed for mussel density and species richness are essentially representative of Q. fragosa habitat requirements."

..."supported by Johnson on the basis of statements made by Hornbach that Q. fragosa was associated with quality mussel habitat."

"We believe there are sufficient number of uncertainties and contradictions in Hornbach's work to question the validity of Johnson's assumption."

..."the sampling strategy used by Hornbach differed between the 10 "with" Q. fragosa samples (sampled by actively searching for Q. fragosa) and the 149 "without" Q. fragosa samples" (sampled using a transect/grid scheme).

The best available information concerning the habitat requirements of *Q. fragosa* is from the research done by Dr. Dan Hornbach who, as the reviewers noted, concluded from his research that *Q. fragosa* is found in "high quality" mussel habitat. While it is true that Hornbach has employed different sampling methods to find *Q. fragosa*, this in no way belies the fact that *Q. fragosa* has been found in association with dense, diverse mussel beds: *Q. fragosa* was not found off by itself using habitat different from the rest of the mussel community. This is supported by the observation that the mean depth (95 cm) and velocity (41 cm/s) used by the 19 *Q. fragosa* found at Interstate State Park in 1992 and 1993 correspond to very high suitability values for both mussel density and species richness. From this, it does not require a big leap of faith to assume that flow conditions that provide suitable habitat for the mussel community should also provide suitable habitat for *Q. fragosa*. There is no information to suggest otherwise.

3. PHABSIM MODEL CALIBRATION

a) "These models (WSP and MANSQ) are hydraulic models based on the "step-backwater" approach and the Manning Equation, and, as such, should only be used by hydraulic engineers or hydrologists familiar with open channel hydraulics."

PHABSIM was designed and developed for use by biologists and other natural resource personnel charged with the responsibility of managing instream resources. I, and the team of biologists who worked on this project, have completed all the relevant PHABSIM courses dealing with the use and application of WSP and MANSQ and have years of experience in stream hydrology, hydraulics, and habitat modeling. I feel confident that I can successfully use and understand these models. To say that only engineers should use these models is similar to saying that only people trained in the inner workings of the internal combustion engine should be allowed to operate motor vehicles.

a) "The St. Croix IFIM report provides very little in the way of calibration details. The only information provided consists of the details of the Velocity Adjustment Values (VAF), "

"Unfortunately, the VAF values given suggest irregularities or errors in model simulations."

As the reviewers are aware, PHABSIM modeling produces voluminous amounts of calibration details and other output. I certainly could have provided a lot more modeling details, but I am not sure this would have provided most readers with useful information. The reviewers provide a good description of the theory behind VAFs and their relationship to Manning "n" values. Irregular VAF plots often occur when measured discharges differ among transects at a given calibration discharge. This is not unusual in that some transects are much better suited for measuring discharge than others. In the WSP model, the same "best estimate" of discharge must be used for all transects at a given calibration discharge. When the measured discharges are dissimilar, VAF values outside the expected range can occur which can not be corrected with model calibration. These irregular values do not necessarily represent errors in model simulations but simply differences in discharge measurements among transects at a given calibration discharge.

Stream cross sections that have uniform channel characteristics are the best place to accurately measure discharge. This was the case for all five transects at Franconia. This site has uniform channel characteristics and simple hydraulics and, consequently, all five transects produced very similar discharge values. In this situation, "nice" VAFs were generated with no tweaking of the hydraulic models. Unfortunately, this was not the case for all the Folsum Island transects where there were differences in measured discharge values among the different transects at the calibration flows. Because VAFs maintain the mass balance of discharge flowing through a PHABSIM study site, irregular VAFs were generated for some of the transects at Folsum Island, particularly in the navigation channel. The upstream most transect in the navigation channel was placed along the wing dam which serves as a hydraulic control. This dam constricts most of the flow to the far west bank and creates very complex hydraulics. The downstream most transect was located just upstream of another wing dam. This part of the channel also has complex hydraulics, including strong undercurrents. For these reasons, the navigation channel was difficult to model.

While the technical details of any PHABSIM application could be debated *ad infinitum*, the important question to keep in mind is whether the habitat vs. discharge relations seem reasonable given what is known about the hydraulics of the river and about the suitability criteria of the target organisms. We have measured hydraulic data at the calibration flows of 1600 and 3200 cfs. These flows provide good insight into hydraulic conditions at 2400 cfs so even in the absence of any hydraulic models, we have a good understanding of the flows of interest except for 800 cfs. Visual observations at 800 cfs suggest that the models are describing hydraulic conditions at this low flow fairly well. Any potential problem with model calibration would not change the general habitat vs. discharge relations predicted by the models to a degree that it would change the basic conclusion that mussel habitat is limited at 800 cfs and is substantially more abundant at run-of-the-river flows.

4. THE PROPER PERSPECTIVE FOR EVALUATING FLUCTUATING FLOW IMPACTS

a) "perhaps the most significant problem with the St. Croix IFIM study is its narrow focus in considering alternative flow regimes"

..."the author considers only two possible alternatives: continued peaking operation with a 800 cfs minimum flow vs. run-of-the-river operation."

It is often true that numerous alternative peaking regimes are possible for hydropeaking dams. In the case of the NSP dam, however, there is a limited number of alternatives given that: 1) the capacity of the turbines is 6400 cfs, 2) reservoir storage is limited, 3) only 800 cfs (the capacity of each turbine) increments are being considered, and 4) a minimum release of 1600 cfs is currently required from April through October. These factors, combined with the hydrology of the Lower St. Croix River, limit the number of alternative peaking regimes.

From late March through early July, flows are typically close to or greater than the capacity of the turbines so little or no peaking can occur. From mid-summer through fall, flows are usually less than 4000 cfs. The possible minimum dam releases during this time include 1600, 2400, and 3200 cfs (a 3200 cfs minimum would be tantamount to run-of-the-river conditions for much of this time period). During winter, when natural flows are

around 2400 cfs or less, the choices include 800, 1600, and possibly 2400 cfs. These were the main alternatives considered in my report, not just 800 cfs vs. run-of-the-river.

b) "The IFIM data are nearly ignored as the author considers only two possible alternatives: continued peaking operation with a 800 cfs minimum flow vs. run-of-the-river operation."

..."the recommendation (run-of-the-river) does not appear to be based on the IFIM analysis."

The IFIM analyses suggested that habitat is limited for mussels, other invertebrates, and the fish community at the existing winter minimum discharge of 800 cfs. Habitat diversity is also limited at this low drought flow. Habitat conditions are improved, but still limited, for the aquatic community at the existing summer minimum discharge of 1600 cfs. Flows between 2000 and 4000 cfs provided good habitat conditions for all things considered. Other than during spring, this range of flows represents typical run-of-the-river conditions. Because the IFIM data suggest that this range of flows provides good habitat conditions for the aquatic community, and considering the impacts of rapidly fluctuating peaking flows (see section 4c), a run-of-the-river flow regime was recommended to protect mussel habitat and the integrity of the aquatic community downstream from the dam. I strongly disagree with the reviewers' statements that the IFIM data were ignored. The reviewers' statement that "no compelling argument has been made in support of the run-of-the-river operational mode as compared to the existing or alternative peaking operational modes" completely ignores the IFIM data, as well as the relevant literature.

c) "This simplistic view of alternatives ignores a number of analyses that should be performed when evaluating the effects of fluctuating flow regimes below hydropeaking projects. IFIM studies that are designed to evaluate habitat changes under fluctuating flows and develop flow recommendations downstream of peaking hydroelectric plants routinely use a variety of approaches to consider changing location of habitat for selected species. The "dual flow" and "effective habitat" modeling techniques, among others, were specifically developed for evaluating alternative flow regimes in such situations."

I agree that the effective habitat model (HABEF) could have been used in this study so I have included it here. The HABEF model is used to examine the effect of different combinations of base and generation flows on habitat availability. Option 2 of this model was used here to model the effective habitat for mussels. This option is recommended for modeling relatively non-motile organisms which can not respond to rapidly fluctuating flows by seeking out changing locations of suitable habitat. Available habitat (WUA) is computed on a cell by cell basis at both the base flow and the generation flow and the minimum of these two values is selected as the effective habitat for that cell. The minimum WUA values for all cells are summed to produce the effective habitat for the study reach for a given base flow-generation flow combination. The base flows modeled included 800, 1600, 2400, and 3200 cfs. Generation flows ranged from 2400 to 6400 cfs (6400 cfs is the maximum capacity of the turbines).

effective habitat for mussel density

The effective habitat available to mussels is driven by base flows (i.e., the availability of mussel habitat is more limited at low base flows than at high generation flows) (Table 1). As base flows increase from 800 to 3200 cfs, there is a corresponding increase in available habitat. Mussel habitat is most limited in the east channel at low base flows. At a given base flow, changing generation flows has little or no effect on effective habitat for mussels. These findings support the conclusion contained in the original report that the large areas of unsuitable habitat at low base flows are of little value even at high generation flows.

effective habitat for the fish community

Most of the fish species life stages modeled in the main report exhibited one of three general WUA vs. discharge relations: 1) WUA peaked at low flows and was limited at high flows (e.g., sand shiner young-of-year, a shallow pool species), 2) WUA peaked at high flows and was limited at low flows (e.g., shorthead redhorse adult, a raceway species, and 3) WUA peaked at moderate flows and was limited at both low and high flows (e.g., smallmouth bass fingerling, a riffle species).

Although I have not run the HABEF model for fishes, it would be expected that under a peaking flow regime, when flows are rapidly changing between low and high flows, effective habitat would be limited at some point in the peaking cycle for fishes exhibiting all three types of habitat vs. discharge relations. The impacts of peaking flows on fish communities is well known. As pointed out by Leonard and Orth (1988), "temporal changes in species richness and abundance are likely in streams with greatly altered flow regimes". Maybe of greatest concern is the impact of fluctuating flows on shallow, shoreline fish communities. Leonard and Orth (1988) emphasized that: 1) shoreline habitats of large streams are important for smaller fishes, 2) shoreline and other shallow areas are the habitats most affected by fluctuating flows, and 3) inhabitants of shallow, slow-water stream margins are the most negatively affected by flow modifications. For these reasons, they highlighted the need to consider inhabitants of shoreline habitat when developing flow recommendations.

effective habitat for habitat types

I agree with Leonard and Orth (1988) that habitat diversity is an important factor governing the number of fish species found in warmwater streams. Results from modeling the availability of habitat types in the Lower St. Croix River also support their observation that habitat diversity is typically maximized at intermediate flows and minimized at low and high flows.

Peaking operations at the NSP dam result in downstream habitat conditions rapidly fluctuating between shallow pool habitat at low base flows and deep pool and raceway habitats at high generation flows. When considered from a dual flow perspective, none of these habitat types are usable to the aquatic community because they are "effectively" rendered unusable by peaking operations. Riffle habitat is also unusable during peaking operations.

d) ..."Two forms of output that are commonly included in IFIM study reports are wetted perimeter vs. discharge data (for each transect and for all transects combined) and total river surface area vs. discharge."

The wetted perimeter method is used to identify the point at which rapid changes in the wetted area of riffles occurs with small changes in discharge. Because riffles are typically the most flow sensitive habitat type, this method assumes that flows which maintain riffle habitat will also maintain pool and raceway habitats. It is well established that riffle habitat serves important functional roles in maintaining healthy river communities. Consequently, many states establish protected flows based on protecting riffle habitat using the wetted perimeter method.

Of the transects modeled in the St. Croix study, the three east channel transects are most appropriate for wetted perimeter analyses. Two transects had well defined inflection points at 1800 cfs: as flows drop below 1800 cfs, large losses in the wetted area of the channel occur at these cross sections (Figure 1). Losses in wetted width for the third transect starts as flows drop below 3400 cfs and rapid losses occur as flows drop below 1800 cfs. A wetted perimeter study conducted by the MNDNR in 1990 just upstream of Folsum Island found that a rapid loss of wetted channel occurs as flows dropped below 2000 cfs. These results suggest that the existing minimum winter base flow of 800 cfs does not maintain suitable habitat conditions for the aquatic community.

e) "Of greater importance is an evaluation of the cell-specific habitat at different flows. Comparisons of cell suitabilities at the high and low ends of a given peaking regime should be examined to determine if the dewatered areas represent high quality habitat at high flows or not. The failure to perform such an analysis is a major deficiency of the St. Croix River IFIM study."

..."This is particularly critical in this study, as the dewatered areas most likely include shallow margins of the river that at high flows are outside the optimal depth range of mussels."

The vast majority of cells, especially in the east channel, that are dewatered (cell suitability=0) at low base flows provide quality mussel habitat at higher flows with the exception of a few cells along the shoreline that only become inundated at relatively high flows (Figures 2a-2n). Under a run-of-the-river flow regime, many of these cells would rarely be dewatered. In general, the suitability of most cells is substantially higher at high generation flows as compared to low base flows. However, the suitability of some cells, particularly along the Franconia transects, peak at moderate flows (e.g., 2000-4000 cfs) and decline at higher flows.

5. Conclusions

a) "No data are provided by Hornbach or Johnson to suggest that the mussel community (including Q. fragosa) was more abundant prior to project operation... In lieu of any other evidence, it is reasonable to assume that this species has always been rare in the St. Croix River."

Since there is no pre-operation information on mussels, we could not provide data to indicate whether mussels were more abundant prior to dam operation. Consequently, we agree that the pre-project distribution and abundance of *Q. fragosa* and the mussel community is unknown. Given the lack of historical data, I am unclear as to why the reviewers feel it is reasonable to assume that *Q. fragosa* has always been rare in the St. Croix River. Regardless, the question at hand is not whether this mussel has always been rare, but how do we protect this last known population based on the best available information and science.

b) "While peaking operations have the potential to negatively affect river biota, as described in detail by Johnson, has it had a detrimental affect in the St. Croix River? Apparently not, given that the Folsum Island site supports a robust population of mussels, including Q. fragosa, which has been widely extirpated from its original range in 17 states."

Although the Folsum Island site supports a rich mussel community, mussels are rare or absent from areas that are dewatered (or very shallow) during peaking operations. Given that the frequency and magnitude of dewatering and low flow events were drastically lower under the pre-project flow regime (run-of-the-river), I would argue that peaking has had a detrimental effect on the mussel community in the St. Croix River. My mussel research and the literature support this argument. Is there any information to suggest that peaking flows are beneficial to mussels? It is illogical to assume that peaking has not impacted this last known population of *Q. fragosa* simply because this species has been extirpated from its entire range except for the Lower St. Croix River. All species that have gone extinct have had one last population located somewhere prior to extinction. This does mean that this last population is healthy and does not need protection.

c) ..."the question remains, has Johnson demonstrated that flow modifications (i.e., run-of-the-river) will improve conditions in the St. Croix River for the winged mapleleaf mussel, the general mussel community, or other aquatic organisms, including macroinvertebrates and fish?"

All of the IFIM modeling results demonstrate that flow modifications, such as changing from the highly unnatural peaking regime to the natural run-of-the-river flow regime under which the St. Croix community evolved and adapted, would improve conditions for the entire aquatic community. These results make biological sense and are well supported by the literature.

d) "Is the IFIM study presented by Johnson valid and does it provide sufficient evidence to support the recommendation that the only plausible solution is a run-of-the-river operational mode?"

Run-of-the-river may not be the only "plausible solution" if the problem is how to maintain a peaking operation while providing some minimal level of habitat protection. The problem the study focused on, however, was to identify a flow regime that protects the habitat of *Q. fragosa* and the aquatic community. The results from this study, which I believe is a valid one, provides ample evidence that the best solution is run-of-the-river.

e) ..."no compelling argument has been made in support of the run-of-the-river operational mode as compared to the existing or alternative peaking operational modes."

The IFIM analyses and the literature provide compelling arguments that peaking operations are adversely impacting habitat conditions for the fish and invertebrate communities in the Lower St. Croix River and that restoring a run-of-the-river flow regime would improve these conditions. The reviewers provide no compelling arguments to the contrary. In their 1988 paper, Leonard and Orth provide strong arguments that river regulation, especially peaking flows, can adversely impact stream communities. I used many of these same arguments, as well as site-specific data, to support my conclusions and recommendations. Can Leonard explain why his published views on the impacts of peaking flows do not hold true for the Lower St. Croix River?

Even in the absence of the site-specific data, the simple undisputed fact is that daily low flows during existing winter peaking operations subject mussels and other aquatic organisms to severe drought conditions, similar to the most severe drought that has occurred during the 90-year period of hydrologic record. These low flow conditions have not occurred naturally since the dust bowl era of the 1930s. I would argue that a river subjected daily to its worst drought has degraded habitat conditions. Based on an extensive survey of mussels in the Minnesota river, Bright (1990) concluded that the drought of 1976 caused massive mortality of mussels due to desiccation, high water temperatures, and low dissolved oxygen concentrations. There is no reason to believe that droughts would not have similar impacts on the St. Croix mussel community.

LITERATURE CITED

Hay, R. W., D.J. Hornbach, S.L. Johnson, and G.A. Miller. 1995. Distribution, status and life history of the Winged Mapleleaf mussel *Quadrula fragosa* in the St. Croix River, Minnesota and Wisconsin. Final report submitted to U.S. Fish and Wildlife Service, Office of Endangered Species, St. Paul, MN.

Leonard, P.M., and D.J. Orth. 1988. Use of habitat guilds of fishes to determine instream flow requirements. North American Journal of Fisheries Management 8 (4): 399-409.

Orth, D.J., and P.M. Leonard. 1990. Comparison of discharge methods and habitat optimization for recommending instream flows to protect fish habitat. Regulated Rivers: Research and Management 5: 129-138.

Table 1. Effective habitat (WUA) for mussel density under various base flow vs. generation flow peaking combinations, Lower St. Croix River.

EAST CHANNEL

	GENERATION Q (cfs)					
BASE Q (cfs)	2400	3200	4000	4800	5600	6400
800	6237	6237	6237	6237	6237	6237
1600	92954	92954	92954	92954	92954	92923
2400		159743	158096	157529	157392	158205
3200			189573	187850	186570	185716

NAVIGATION CHANNEL

	GENERATION Q (cfs)					
BASE Q (cfs)	2400	3200	4000	4800	5600	6400
800	54025	53810	53621	53432	53312	53081
1600	71063	70685	70511	70252	70113	69830
2400		81503	81239	80977	80838	80516
3200			90477	90203	90027	89676

MAIN CHANNEL

	GENERATION Q (cfs)					
BASE Q (cfs)	2400	3200	4000	4800	5600	6400
800	180044	179882	179447	179180	178953	178008
1600	251881	251182	249636	247640	246790	245470
2400		307013	304639	302187	301141	299175
3200			346459	343783	342566	340288

FRANCONIA

	GENERATION Q (cfs)					
BASE Q (cfs)	2400	3200	4000	4800	5600	6400
800	130560	130560	130518	129947	129011	128683
1600	177098	176987	175909	172465	166966	165502
2400		211752	208544	202775	195106	192353
3200			230393	223837	213696	208917

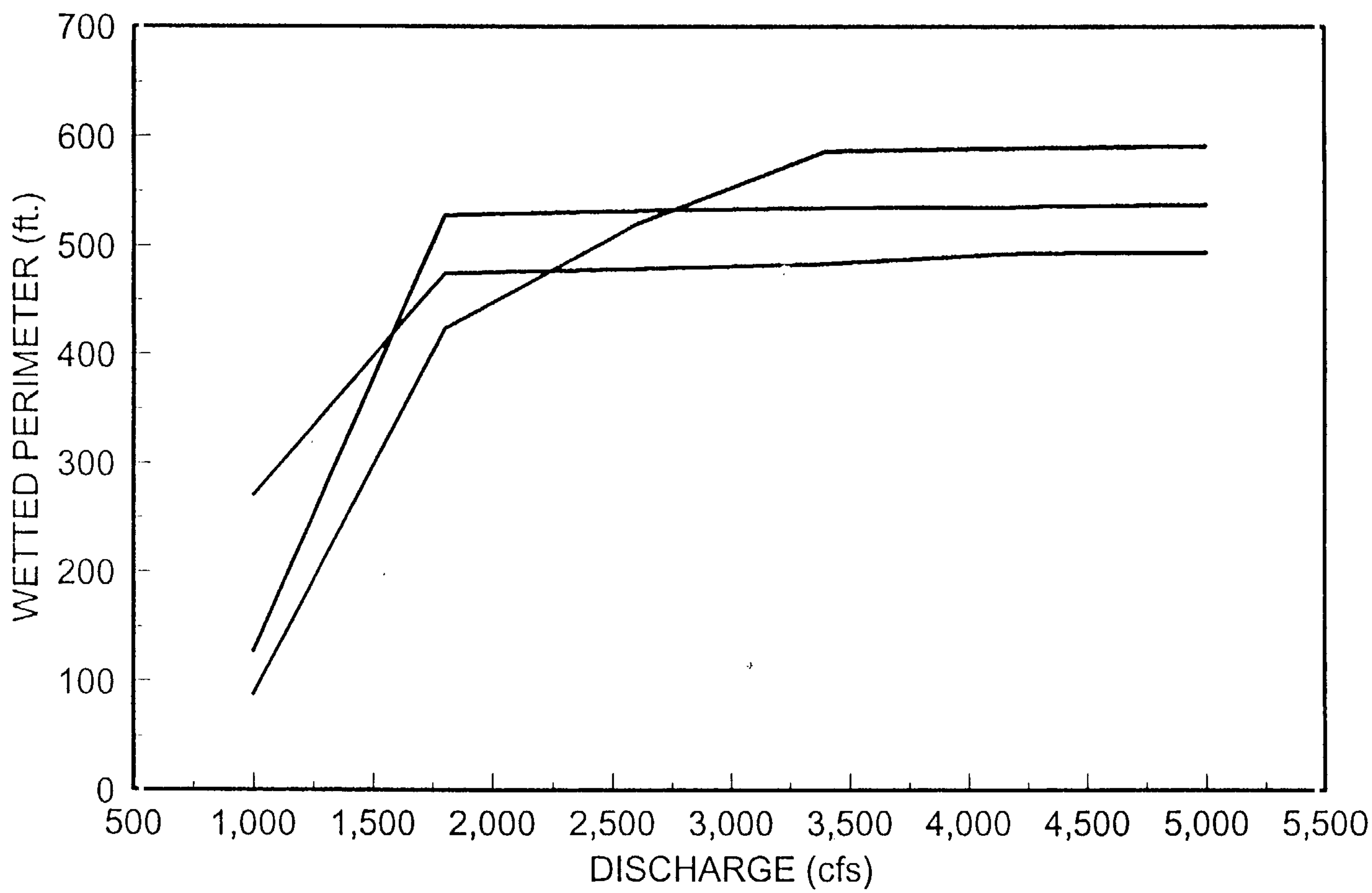

Figure 1. Wetted perimeter in relation to discharge for the three east channel PHABSIM transects, Folsum Island, Lower St. Croix River.

The following figures (2a through 2n) illustrate the composite suitability factors of individual cells along each PHABSIM transect in relation to discharge for mussel density. These composite factors represent the product of the individual suitability values for depth, velocity, and substrate. Individual suitability values range from 0.0 to 1.0. A suitability value of 0.0 indicates the least preferred or least suitable habitat; a value of 1.0 indicates the most preferred or most suitable habitat. The three suitability values are multiplied together to determine the composite suitability factor for each cell. Because there were too many cells along each transect to include in one graph, each transect was divided into four equidistant sections for graphing purposes: the east shore, east mid-channel, west mid-channel, and west shore sections.

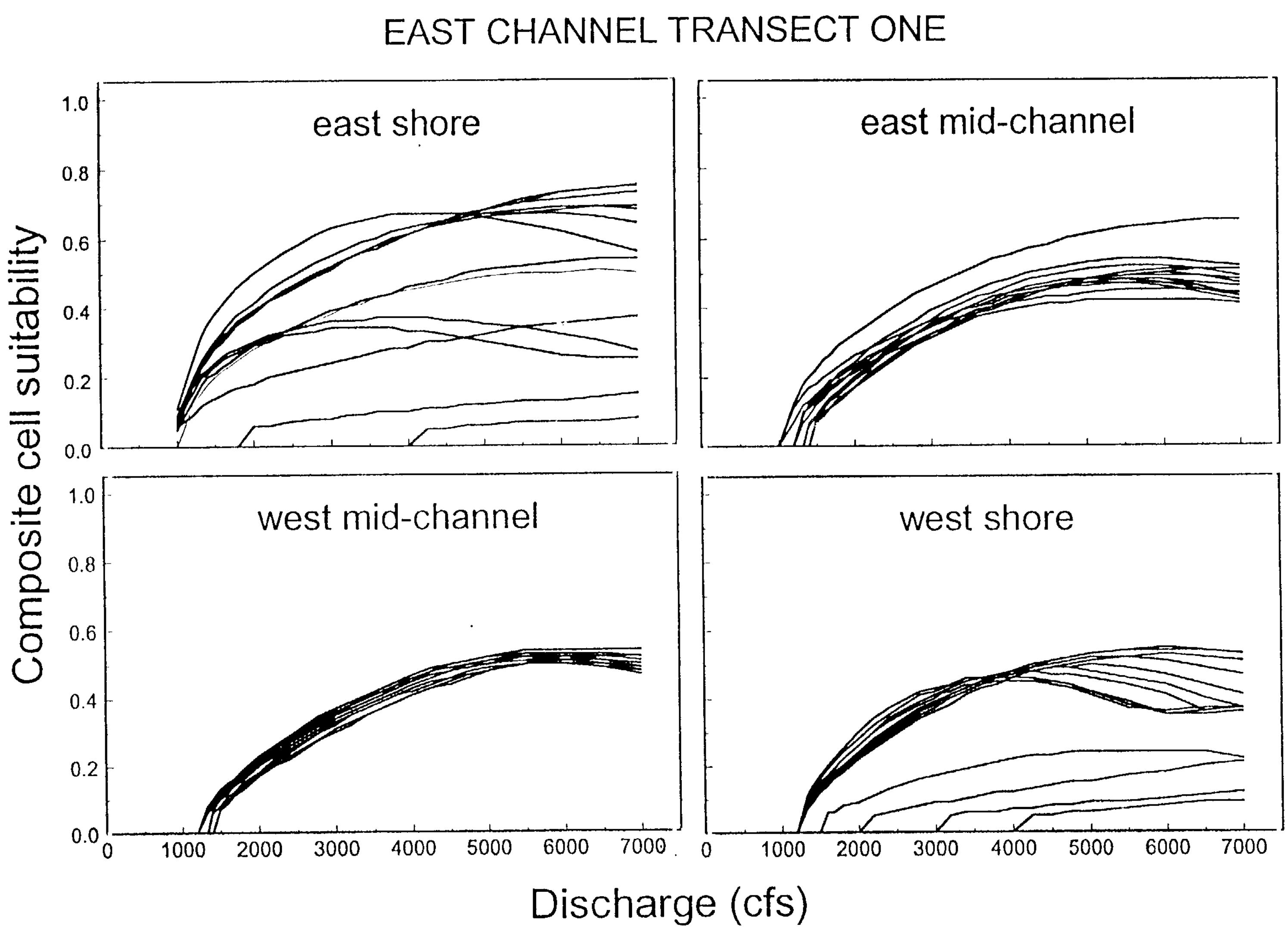

Figure 2a. The composite cell suitability for mussel density along transect one in the east channel in relation to discharge, Lower St. Croix River.

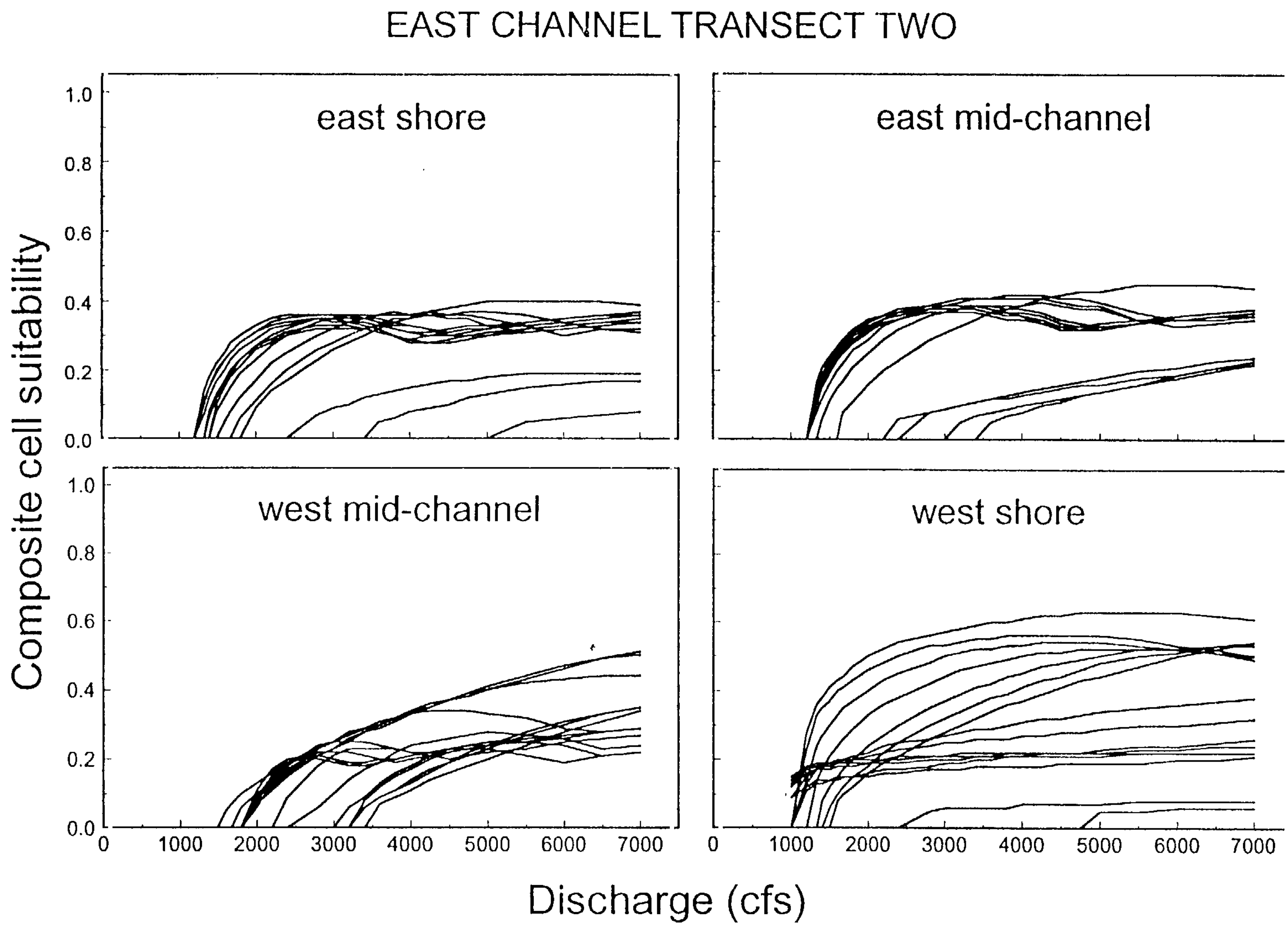

Figure 2b. The composite cell suitability for mussel density along transect two in the east channel in relation to discharge, Lower St. Croix River.

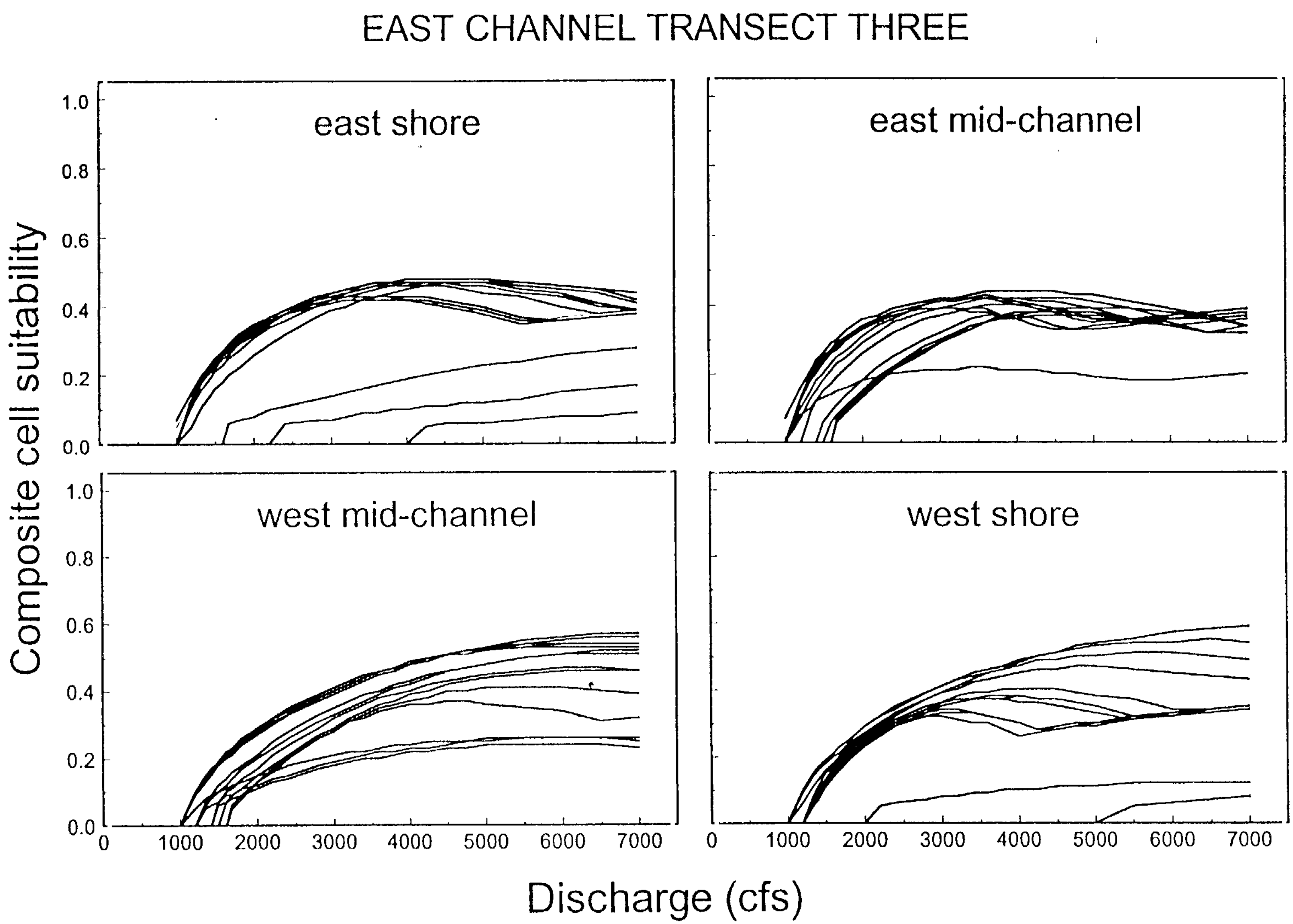

Figure 2c. The composite cell suitability for mussel density along transect three in the east channel in relation to discharge, Lower St. Croix River.

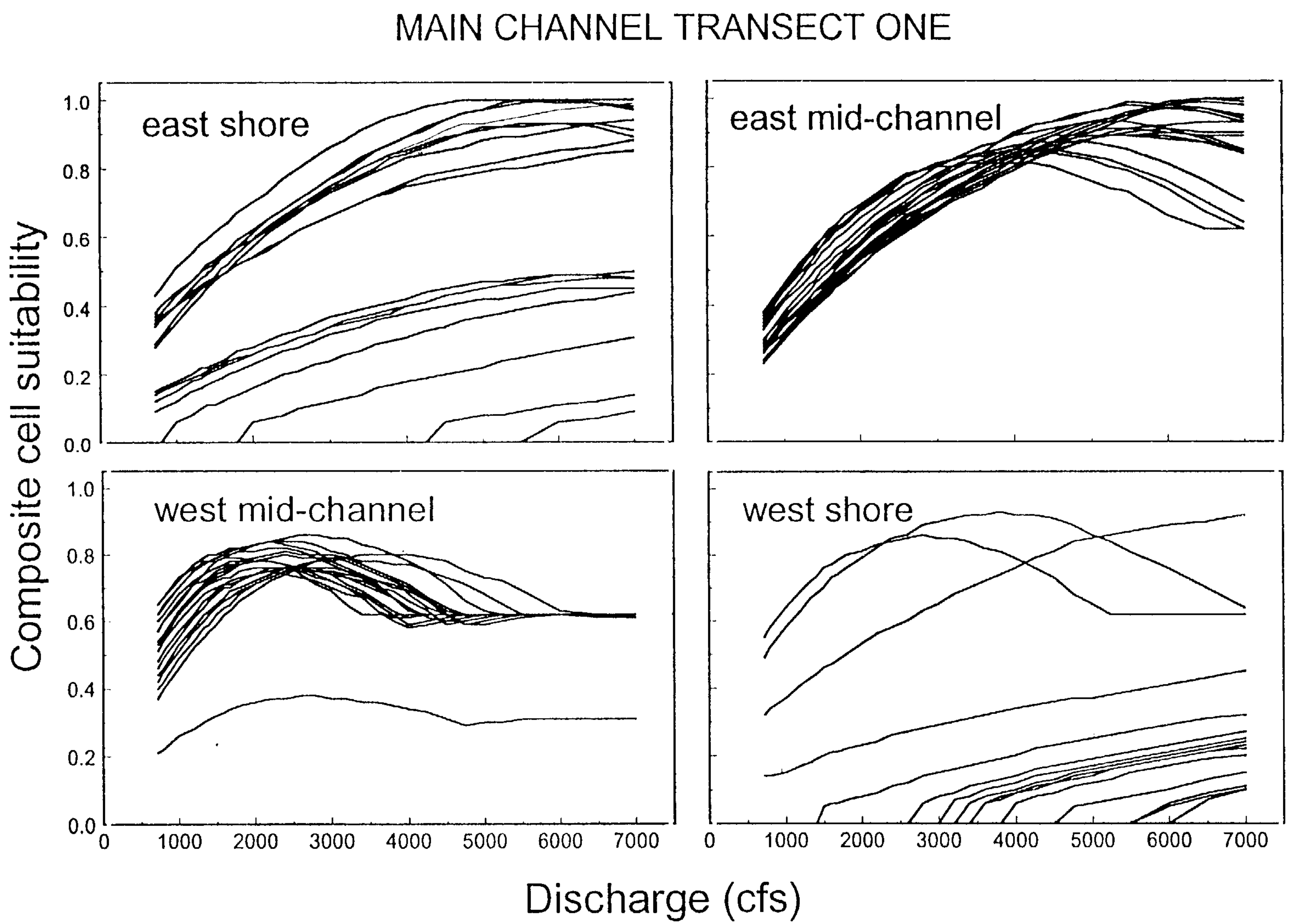

Figure 2d. The composite cell suitability for mussel density along transect one in the main channel in relation to discharge, Lower St. Croix River.

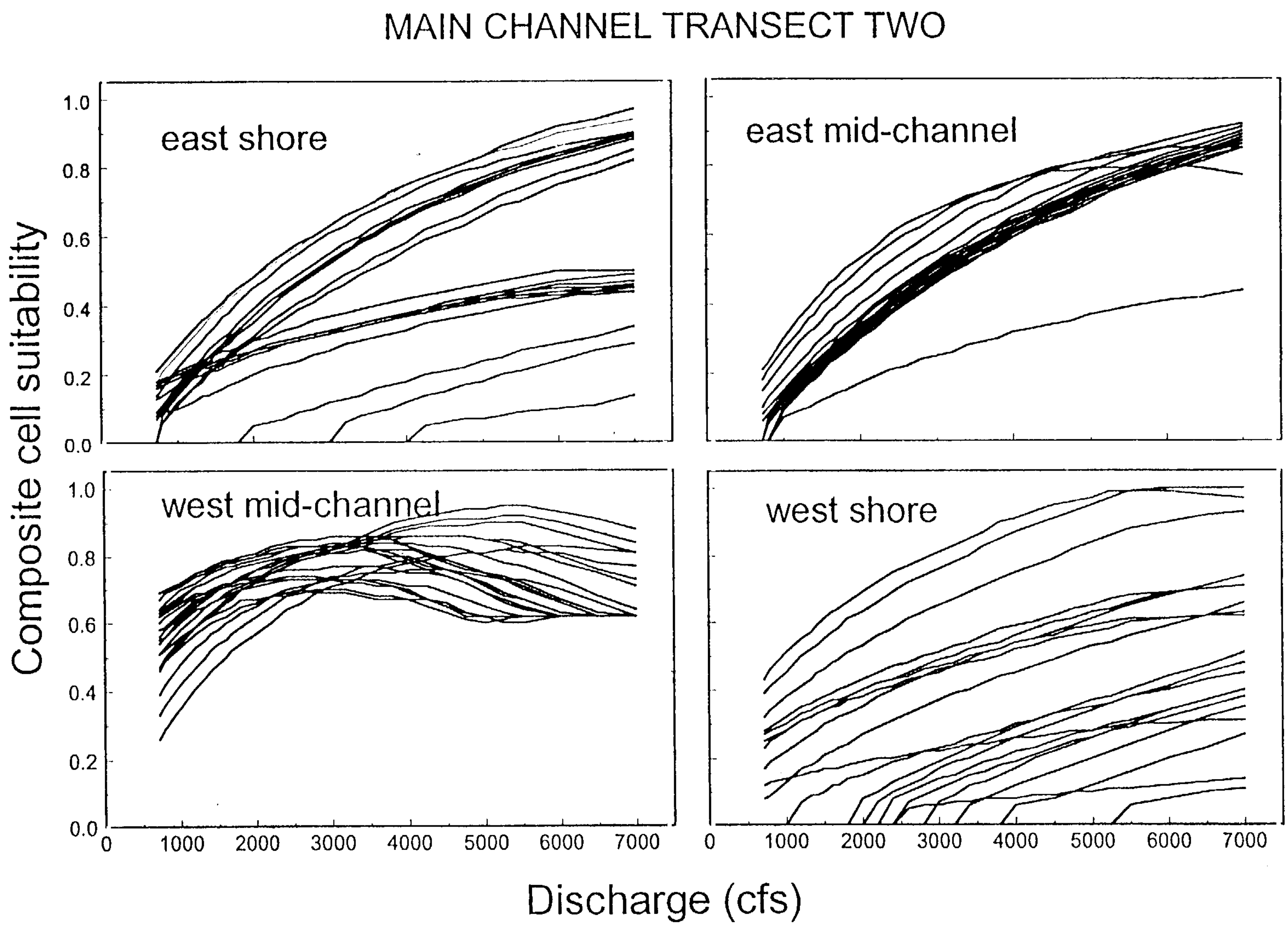

Figure 2e. The composite cell suitability for mussel density along transect two in the main channel in relation to discharge, Lower St. Croix River.

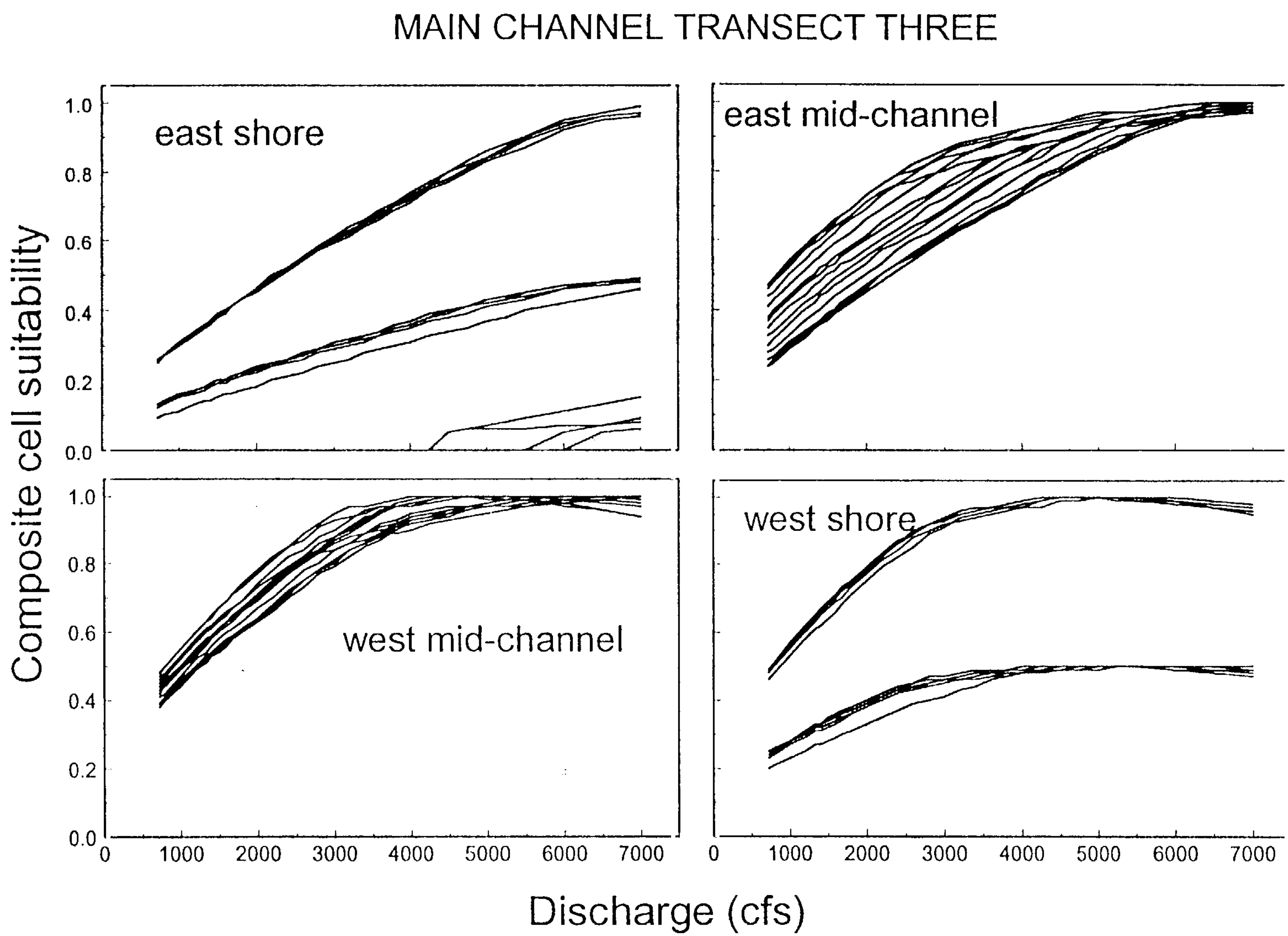

Figure 2f. The composite cell suitability for mussel density along transect three in the main channel in relation to discharge, Lower St. Croix River.

NAVIGATION CHANNEL TRANSECT ONE

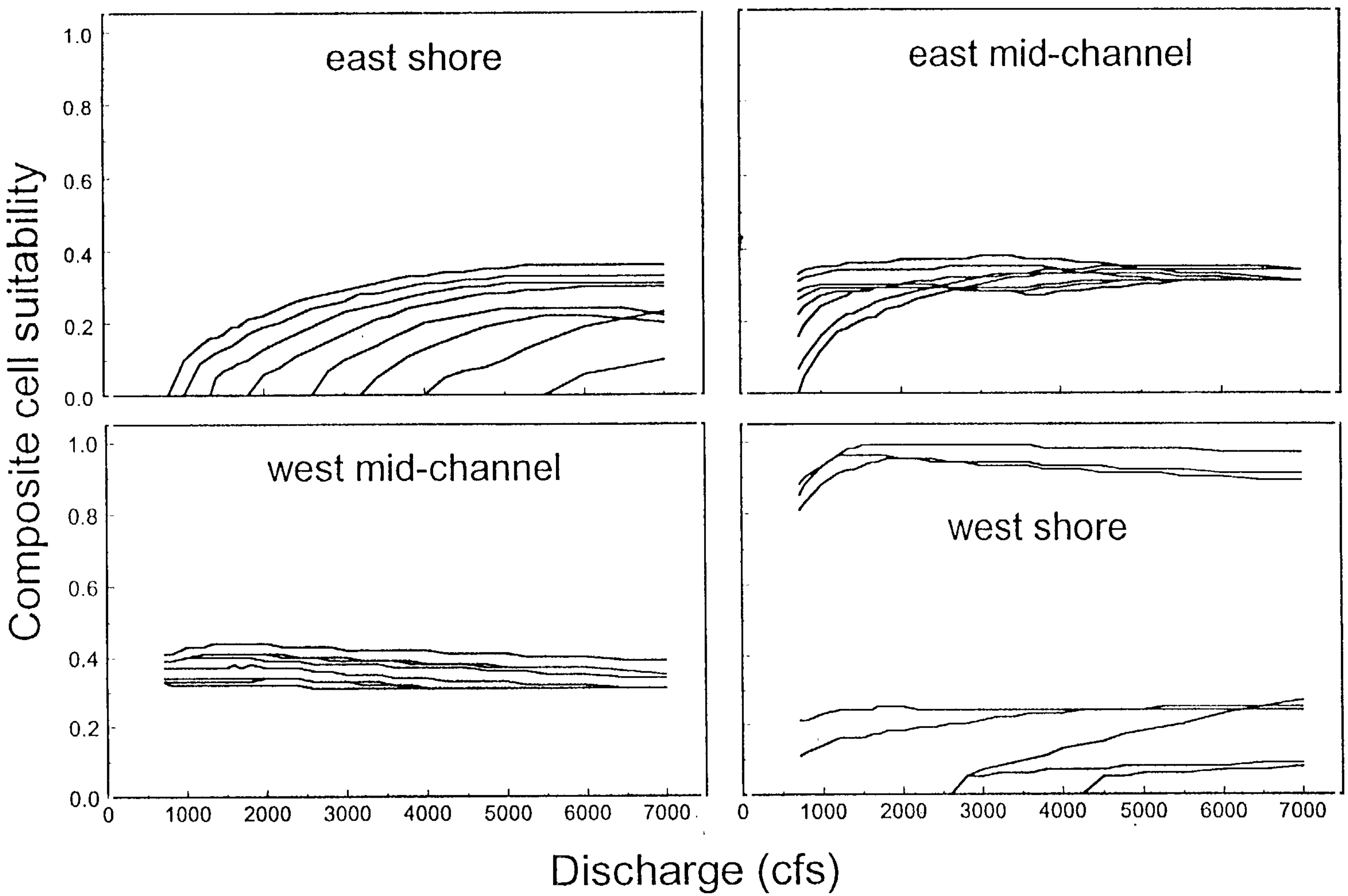

Figure 2g. The composite cell suitability for mussel density along transect one in the navigation channel in relation to discharge, Lower St. Croix River.

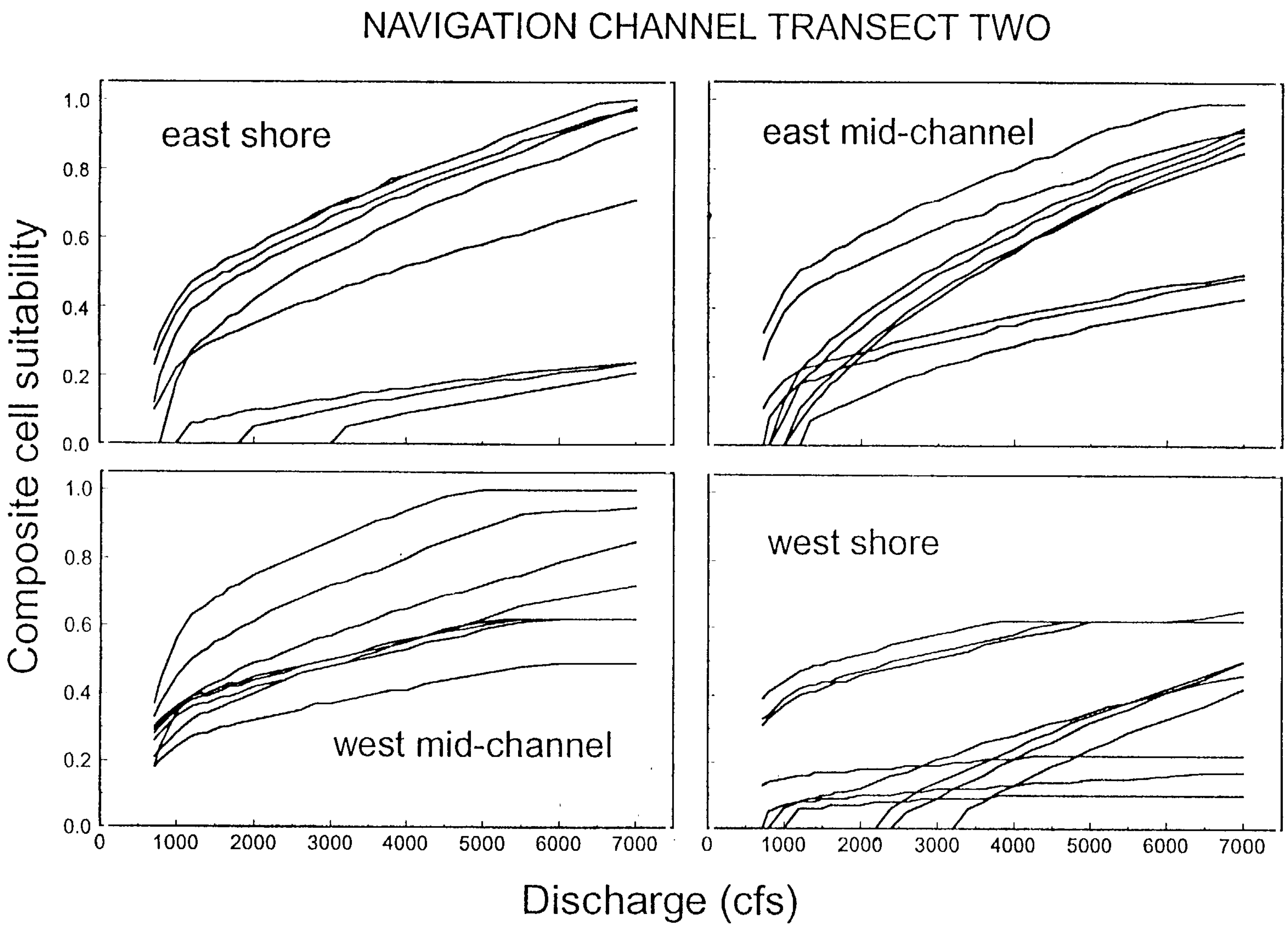

Figure 2h. The composite cell suitability for mussel density along transect two in the navigation channel in relation to discharge, Lower St. Croix River.

NAVIGATION CHANNEL TRANSECT THREE

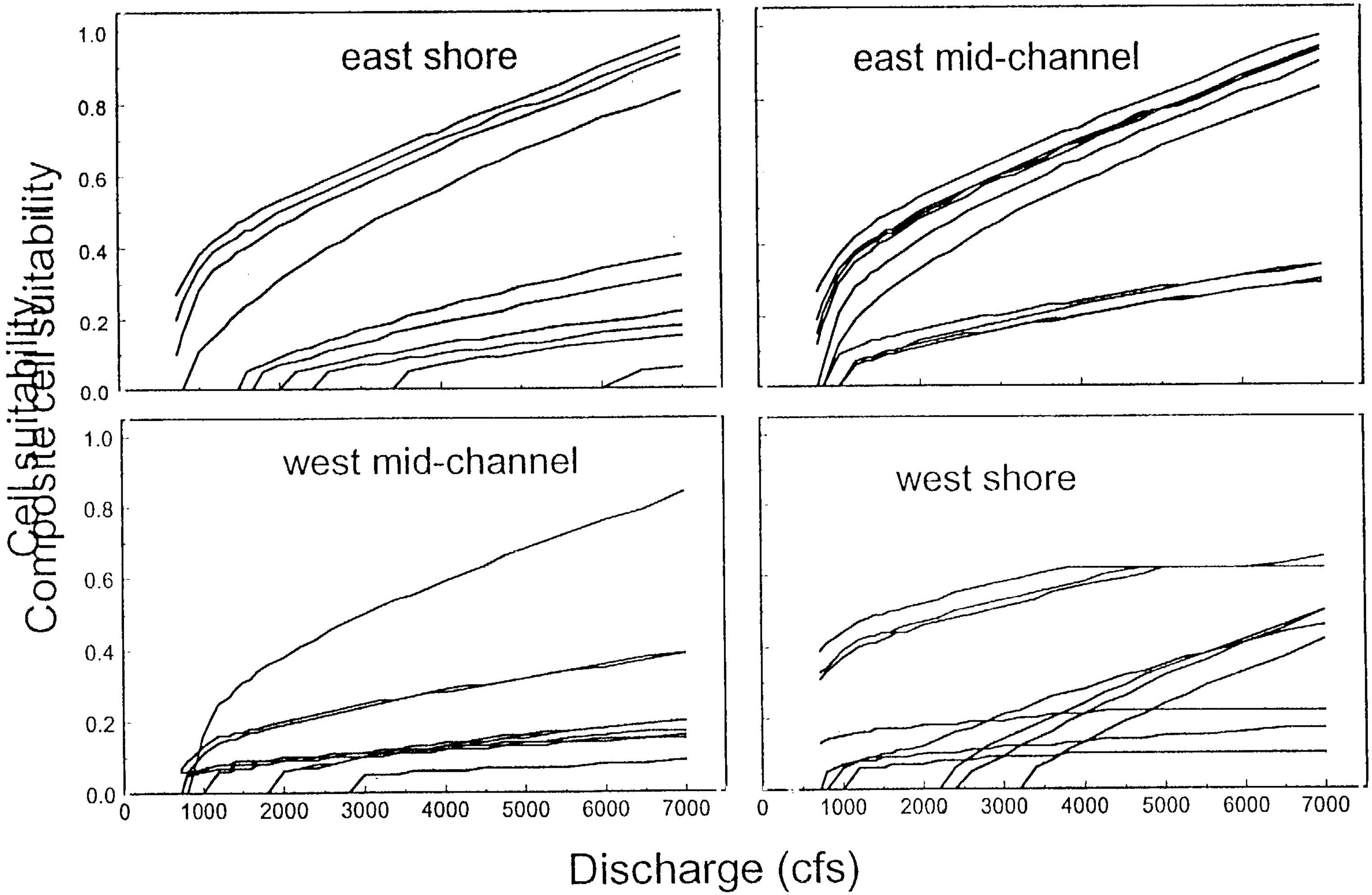

Figure 2i. The composite cell suitability for mussel density along transect three in the navigation channel in relation to discharge, Lower St. Croix River.

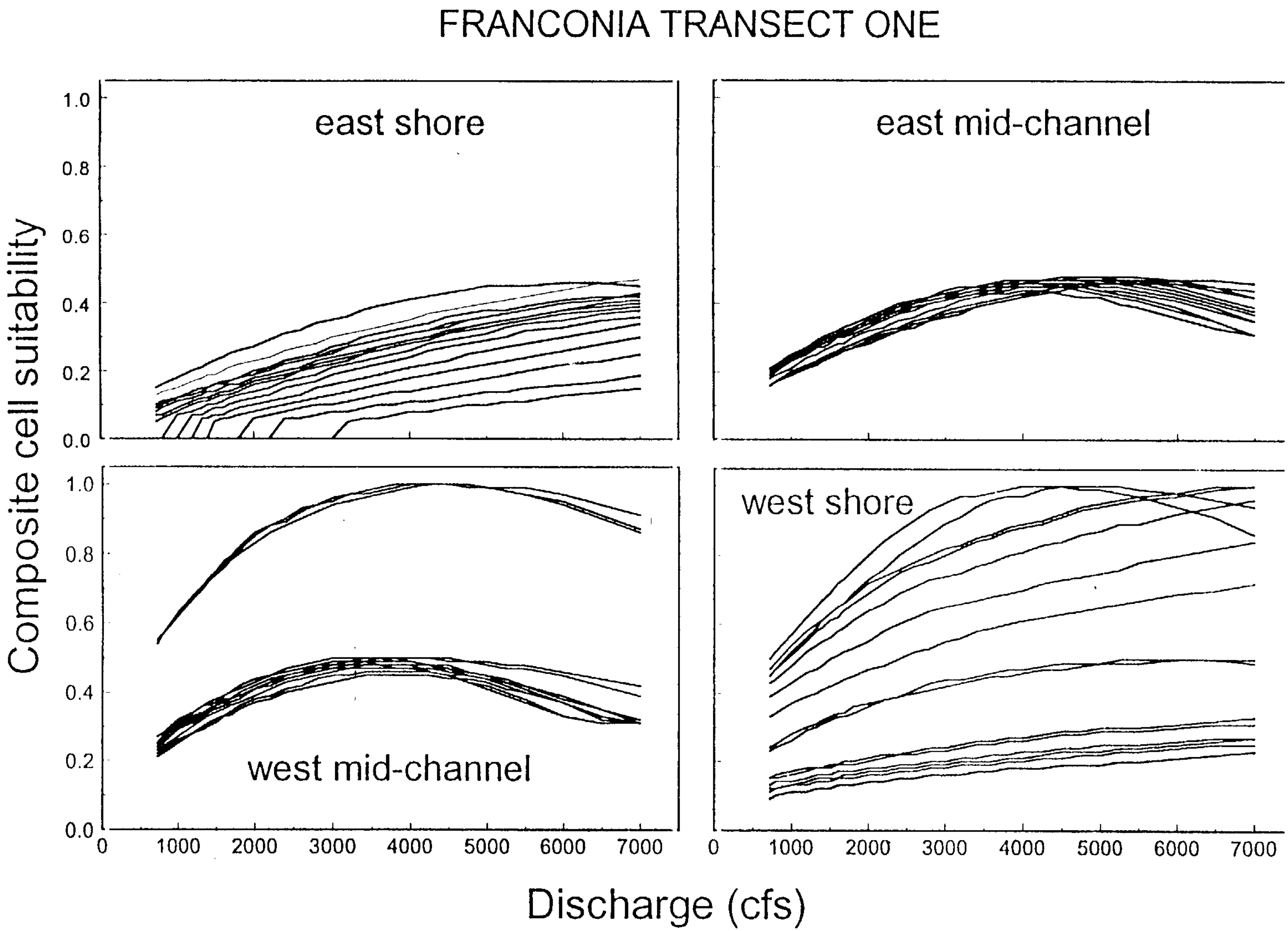

Figure 2j. The composite cell suitability for mussel density along transect one at Franconia in relation to discharge, Lower St. Croix River.

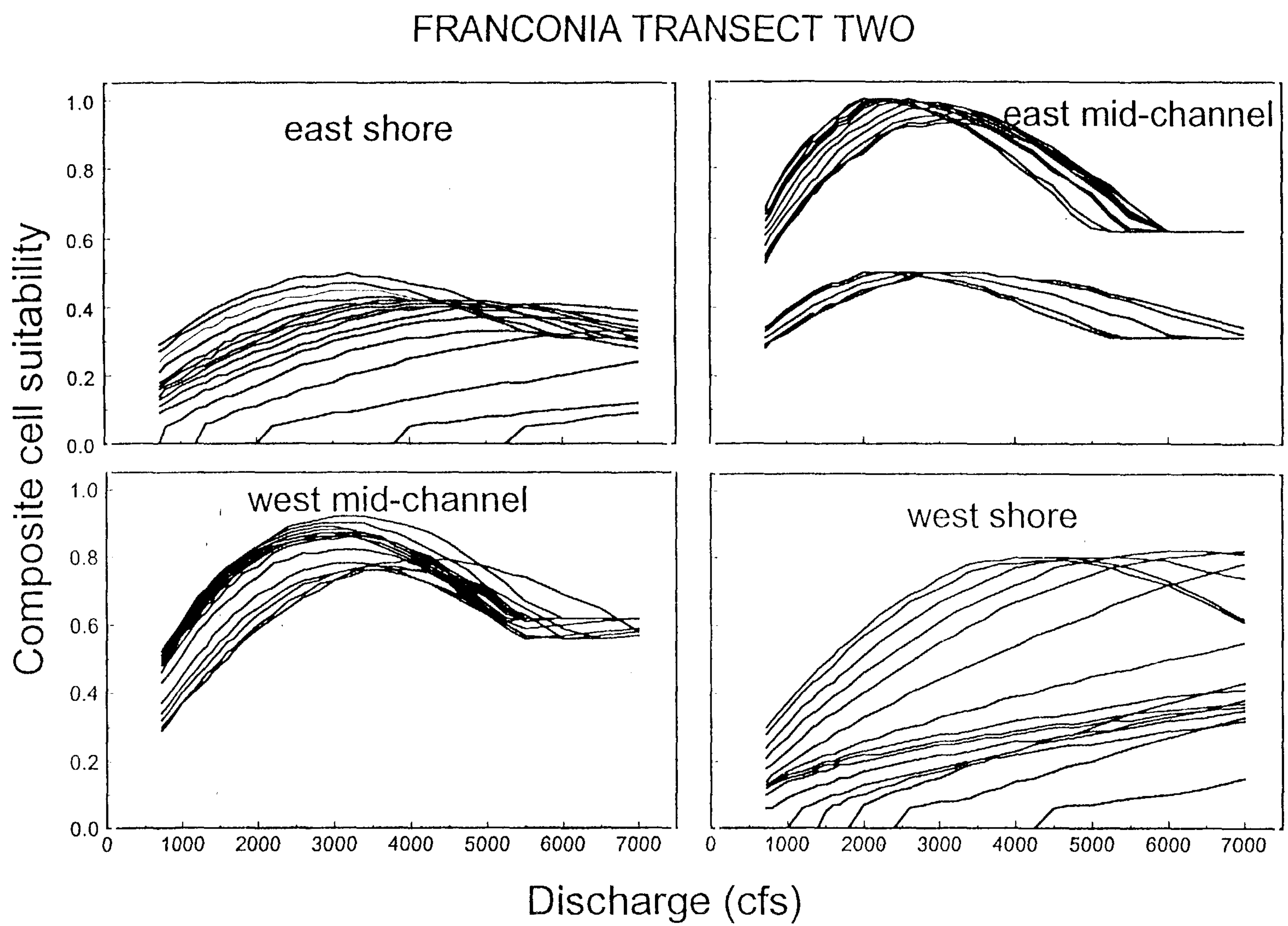

Figure 2k. The composite cell suitability for mussel density along transect two at Franconia in relation to discharge, Lower St. Croix River.

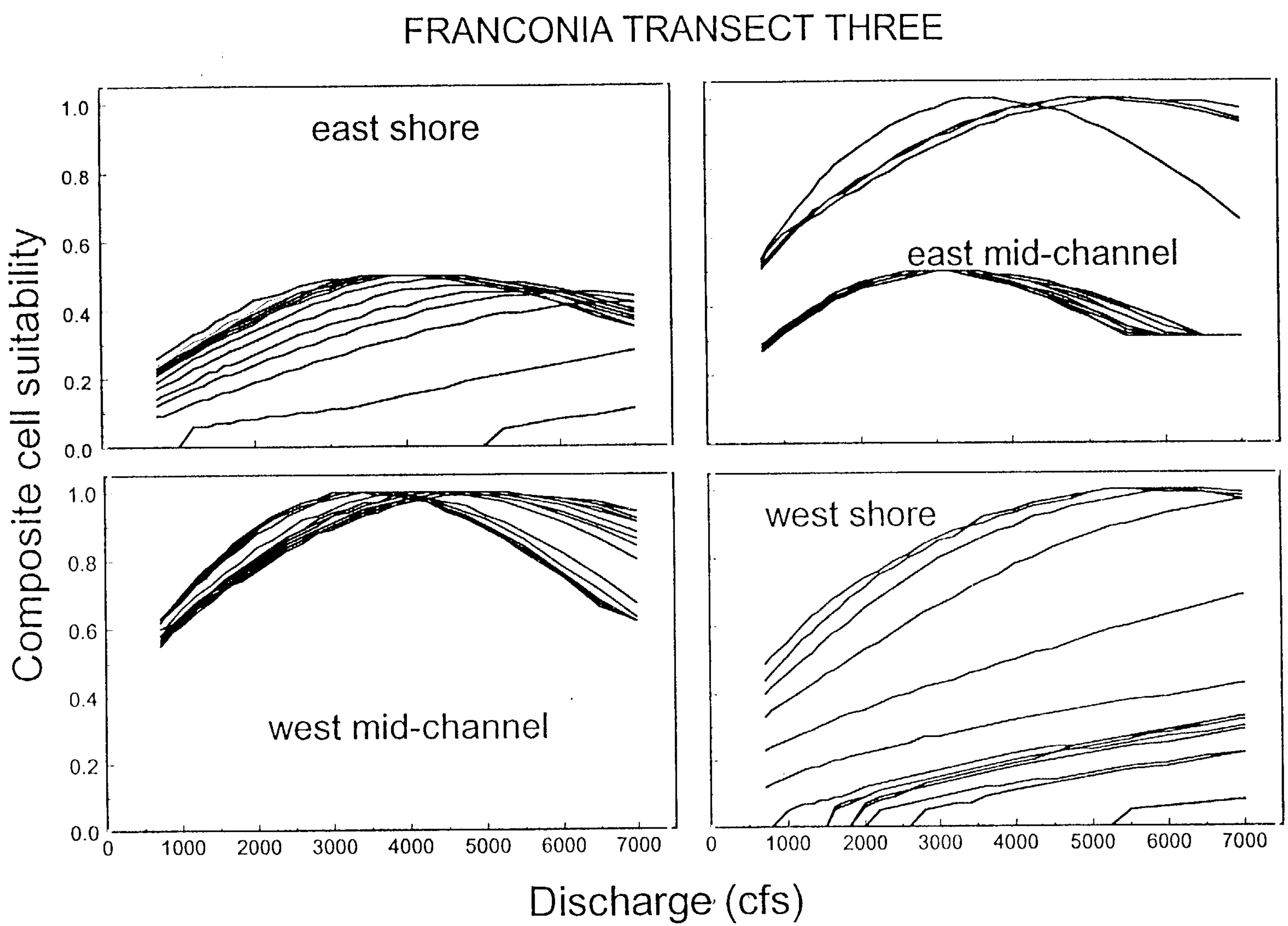

Figure 2l. The composite cell suitability for mussel density along transect three at Franconia in relation to discharge, Lower St. Croix River.

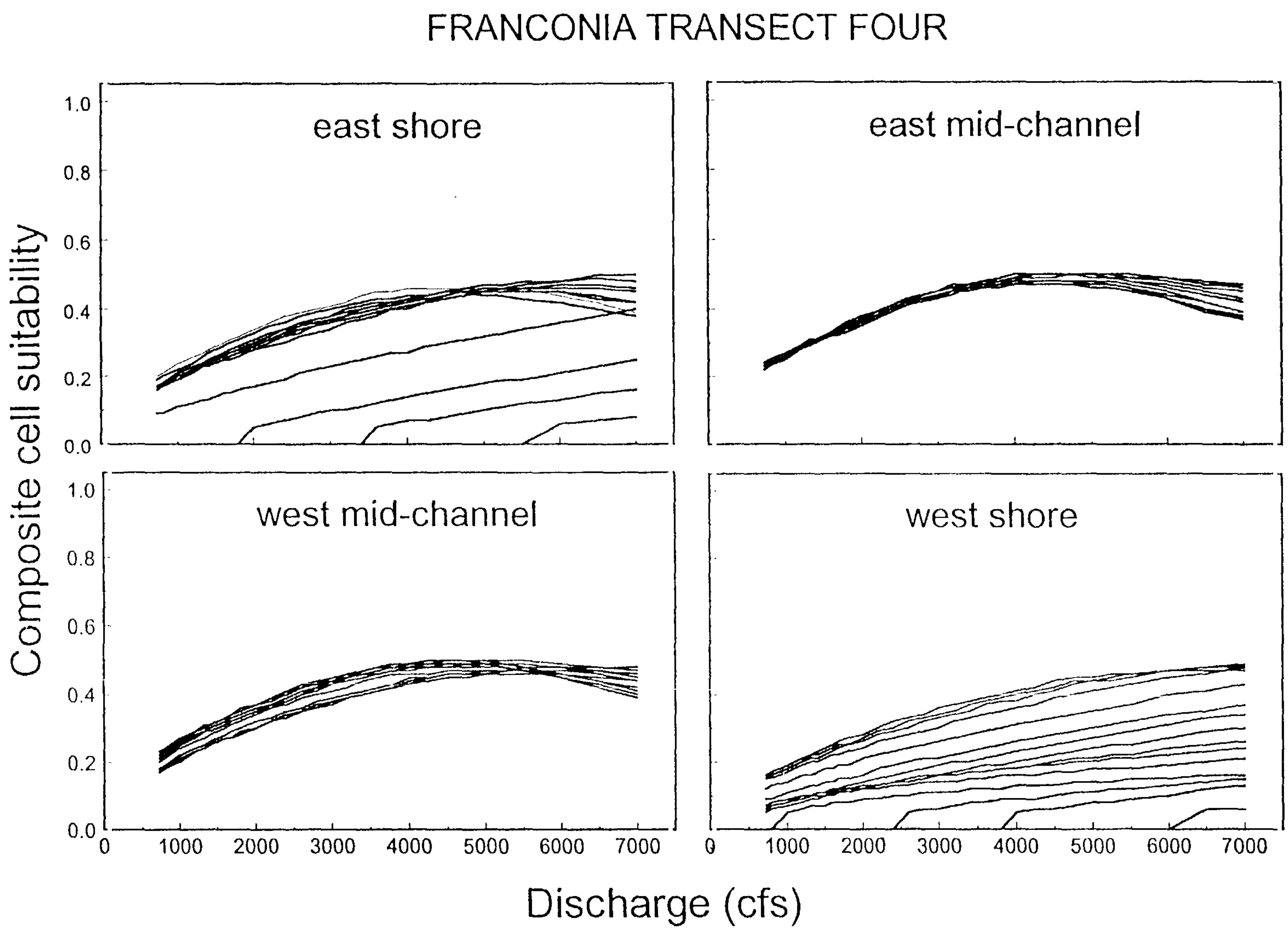

Figure 2m. The composite cell suitability for mussel density along transect four at Franconia in relation to discharge, Lower St. Croix River.

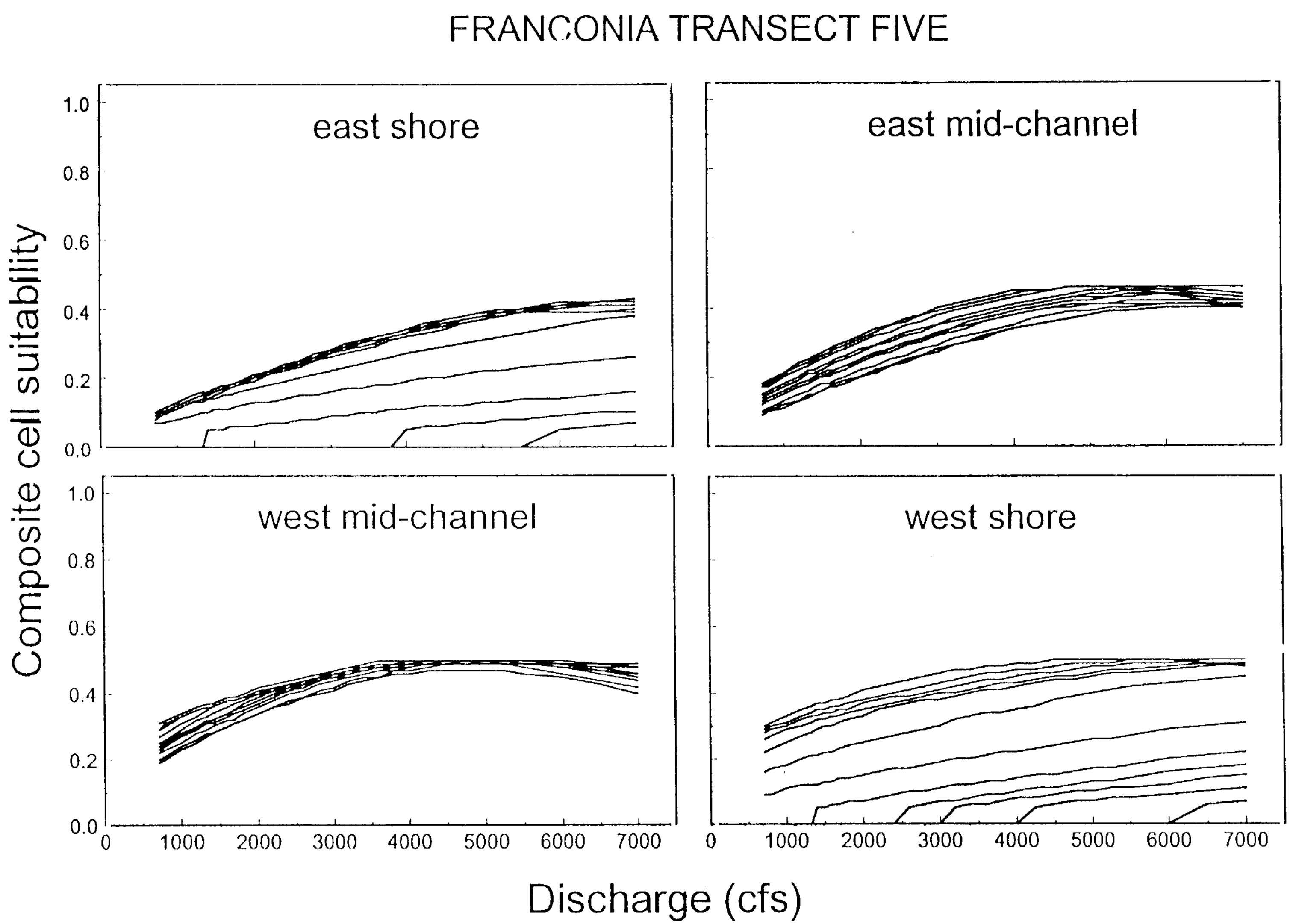

Figure 2n. The composite cell suitability for mussel density along transect five at Franconia in relation to discharge, Lower St. Croix River.

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