

**Distribution and Life History of the Unionidae (Bivalvia: Mollusca) in the
Assiniboine River Drainage in Manitoba, with special reference to
*Anodontooides ferussacianus***

by

Ernest Thomas Watson

A thesis submitted to the Faculty of Graduate Studies in partial fulfillment of the
requirements for the degree of Master of Science

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**Distribution and Life History of the Unionidae (Bivalvia: Mollusca) in the Assiniboine River
Drainage in Manitoba, with special reference to *Anodontoides ferussacianus***

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Ernest Thomas Watson

**A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University
of Manitoba in partial fulfillment of the requirements of the degree
of
Master of Science**

ERNEST THOMAS WATSON

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ABSTRACT

This study examined the distribution of the freshwater mussels in the Assiniboine River and some of its tributaries in Manitoba, and the life history of the cylindrical floater mussel (*Anodontooides ferussacianus*) in a small prairie stream. Twelve species of freshwater mussels were found in the Assiniboine River drainage. Each species exhibited specific stream size and substrate preferences. Examination of species occurrences resulted in the identification of four species categories based on stream size preferences (small stream, medium stream, large stream, and ubiquitous categories), but some overlap existed between one category and the next. Individuals of *A. ferussacianus* in the Cypress River near St. Alfonse, Manitoba, displayed a bradyctictic breeding pattern. Fertilization of ova occurred in late July and early August, and mature glochidia were released from marsupia in May and June. Individuals in this population matured at age 1, which is the lowest recorded for any species of freshwater mussel. The growth rate and density of *A. ferussacianus* in the Cypress River is similar to other populations of freshwater mussels in lotic systems. Young individuals comprised a large proportion of the mussels collected. This age structure may be due to selective predation of older year classes. Small, one year-old mussels were found beneath the sediment surface throughout the year. Older individuals (Year 2+) occurred at the sediment surface in May and June, after which they burrowed into the sediments. The seasonal vertical migration displayed by older individuals of *A. ferussacianus* in the Cypress River probably was not a behavioral response, but rather because of high water velocities.

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CHAPTER 1 - INTRODUCTION

Adult freshwater mussels of the family Unionidae (also known as clams, unionids, or naiades) are the large (ranging in size from 4 cm to over 30 cm) bivalve fauna of permanent freshwater rivers, lakes, and ponds. Ecologically, they are important as consumers of phytoplankton (McMahon 1991) and bacteria (Nichols and Garling 2000), a food source for a variety of small mammals and fish (Fuller 1974), for sediment mixing in lakes and rivers (McCall et al. 1979), and as stable substrates for other benthic invertebrates (Beckett et al. 1996). North America has the most diverse freshwater mussel fauna in the world, including 299 species in 48 genera and 3 subfamilies (Turgeon et al. 1998). Historically, humans have harvested freshwater mussels as a food source (Parmalee and Klippel 1974), for pearls (Kuntz 1897), and for shells, which were used in the manufacture of buttons until the 1960's (Claassen 1994). Currently, the harvest of about one dozen species freshwater mussels is a multimillion-dollar business, with the shells being formed into nuclei for the Japanese cultured pearl industry (Parmalee and Bogan 1998). Freshwater mussels have become important biomonitoring tools. They have a wide geographic distribution, are relatively sedentary, and easily collected in large numbers. They can also be transplanted and held in cages, are relatively long-lived, are of moderate size, and have a high tolerance to pollution compared with other aquatic organisms. Mussels are primary consumers (filter feeders), thus providing an assessment of contamination at low levels in the food chain, and they tend to bioaccumulate

many contaminants (Fuller 1974, Havlik and Marking 1987, Green et al. 1989, Metcalfe-Smith 1994, Metcalfe-Smith et al. 1996, Salazar and Salazar 1996).

Many species and populations of this widely distributed group are endangered. Habitat destruction, pollution, commercial over-exploitation, and the introduction of the zebra mussel, *Dreissena polymorpha* (Pallas), have led to worldwide declines in freshwater mussel populations this past century (Bogan 1993, Williams et al. 1993). Nearly 72% of North American unionids are now either extinct, endangered, threatened, or of special concern (Williams et al. 1993). Metcalfe-Smith et al. (1998) categorized 15 of the 40 mussel species from the lower Great Lakes region of Canada as Extirpated, Endangered, or Threatened as defined by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). COSEWIC (1999) recently designated three of these species, the northern riffleshell (*Epioblasma torulosa rangiana* Lea), rayed bean (*Villosa fabalis* Lea), and wavy-rayed lampmussel (*Lampsilis fasciola* Rafinesque), as Endangered. The freshwater mussels of the Assiniboine River drainage are among the last unexploited mussel populations in North America. Basic distribution and life history data are needed to effectively conserve and manage the mussel resources of Manitoba. Other than the major commercial species, little is known about the growth and reproductive habits of freshwater mussels in general.

This thesis is based on two separate studies of freshwater mussels in the Assiniboine River drainage. The objective of the first study was to document the distribution mussels in the Assiniboine River drainage in Manitoba, and

investigate the correlation between these distributions and some main environmental factors. The objective of the second study was to describe the population demographics, reproductive cycle, and the pattern of seasonal vertical migration of a population of the cylindrical floater, *Anodontoides ferussacianus* Lea, in a small prairie stream. Due to the differences in objectives, methods, and results of these studies, each will be presented as separate chapters.

CHAPTER 2 - SELECTED LITERATURE REVIEW

Introduction

The basic biology of freshwater mussels is well researched, with significant contributions through research conducted during the first quarter of this century. At this time, mussels were being intensively harvested for pearls and shells (Kuntz 1897, Claassen 1994), and declining populations of commercially important mussel species prompted the U.S. Bureau of Fisheries to conduct extensive studies on mussel life histories (e.g. Simpson 1898, Lefevre and Curtis 1908, 1910, Isely 1914, Coker et al. 1921, Howard 1922, Howard and Anson 1922, Churchill and Lewis 1924). The focus of most of this early research was directed towards mussel production, propagation, and the identification of fish hosts for the parasitic larvae of commercially important mussels. Recently the interest in mussel life history, taxonomy, ecological relationships, and propagation has been renewed because of further declines in mussel populations due to severe habitat degradation, commercial harvest, and the introduction of the zebra mussel.

In order to conserve and manage endangered species effectively, an understanding of the biology of freshwater mussels is needed. This chapter provides background on aspects of the life cycle, growth, and methods of age determination of freshwater mussels relevant to this study.

Life Cycle

The basic life cycle pattern of a freshwater mussel (Figure 1) is perennial and iteroparous. Males release sperm into the water, and the eggs are fertilized internally when the female takes up the sperm via the incurrent siphon. The fertilized eggs develop into parasitic larvae termed glochidia (singular, glochidium) within modified portions of the females' gills called marsupia. Mature glochidia are expelled into the water where they must attach to, and become encysted on, the fin or gill an appropriate host, which usually is a fish. Within the cyst the glochidia transform into juvenile mussels, which then drop off the host to become free-living members the benthic community.

Hermaphroditism

Freshwater mussels are generally dioecious, but functional hermaphrodites are encountered in low frequencies in many populations (van der Shalie 1970, Heard 1975, Heard 1979, Kat 1983a). Coe (1943) categorized hermaphroditic individuals from species that are typically dioecious as "accidental" functional hermaphrodites. The incidence of accidental functional hermaphroditism may differ between populations (van der Shalie 1970, Kat 1983a, Downing et al. 1989) and between age classes within populations (van der Shalie 1970, Downing et al. 1989). Only five species of freshwater mussels are known to use hermaphroditism as their primary mode of reproduction (Kat 1983a).

Hermaphroditic individuals may possess varying proportions of male and female tissue, but the gonads typically are composed mostly of tissue of

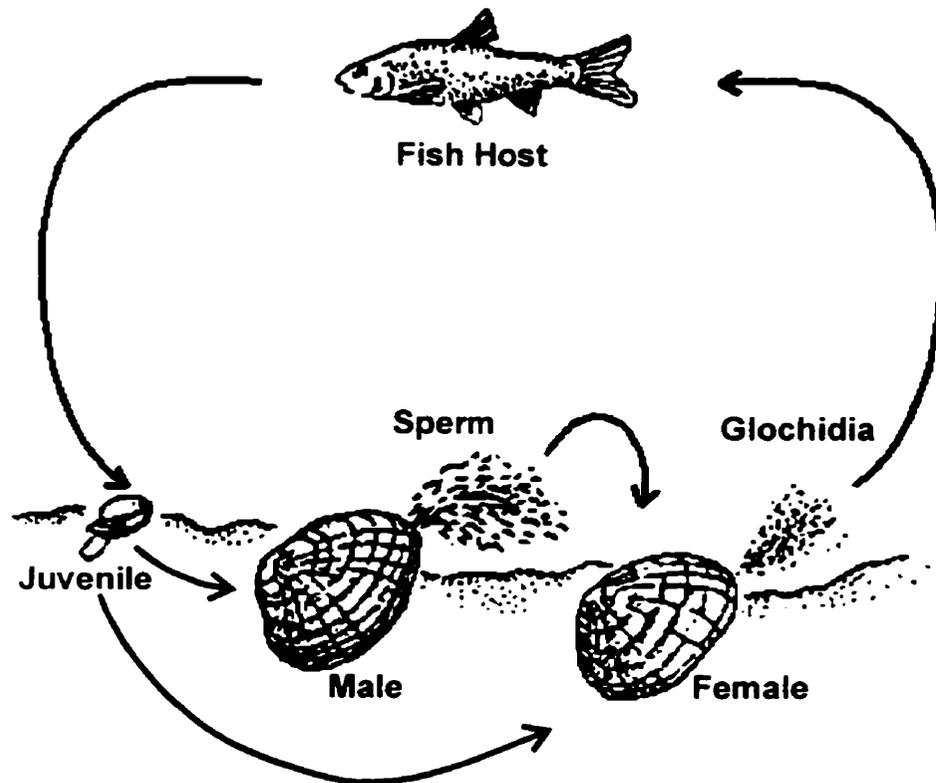


Figure 1. The life cycle of a freshwater mussel. Sperm enter the female and fertilize eggs internally. The fertilized eggs develop into parasitic larvae (glochidia) in modified portions of the gill called marsupia. Mature glochidia are released into the water where they attach to the gills or fins of an appropriate host and encyst. After a few weeks the glochidia transform into juvenile mussel, drop off the host and become freeliving. (after Martin 1997).

only one sex (van der Schalie 1970, Heard 1979, Kat 1983a). Heard (1975) subcategorizes functional hermaphrodites as female or male hermaphrodites. Functional hermaphroditism classically has been thought of as an adaptation to specific environments: it will be selected for under conditions where populations are genetically isolated, or where there is restricted contact with suitable mates (Ghiselin 1969). For example, hermaphroditism generally is more prevalent in bodies of standing water than in running waters (Heard 1975), where the transfer of sperm to females is facilitated by water currents.

Some freshwater mussel populations display protandry (van der Schalie 1970, Downing et al. 1989). In theory, serial hermaphroditism is selected for when males and females have different size-specific reproductive success rates (Ghiselin 1969). Small males can produce large amounts of sperm, and a female's capacity for egg production increases rapidly with size. Serial hermaphroditism also would decrease the probability of inbreeding in isolated and nearly sedentary mussel populations (Downing et al. 1989). Accidental hermaphrodites may arise in protandrous populations when the transition from the male to female condition overlaps (Mackie 1984).

Brooding

Two types of seasonal breeding patterns exist. In bradytictic species, fertilization occurs in the late summer, and the glochidia, which develop in the fall and early winter, are released into the water the following spring or summer. Tachytictic breeders compress the entire process into a single season, with fertilization occurring in the spring, and the glochidia being released in the fall.

Freshwater mussels have two pairs of gills. In females, depending on the species, portions of the gills are modified into marsupia that hold developing glochidia until they are released. Three patterns of gill development into marsupia are recognized. (1) Tetragenous marsupia occupy both the outer and inner pair of gills, and are a characteristic of members of the subfamily Ambleminae. This is considered the plesiomorphic condition (Kat 1984). Members of the Anodontinae have (2) homogenous marsupia, which occupy the outer pair of gills. (3) Heterogenous marsupia, a characteristic of members of the Lampsilinae, occupy only the posterior portions of the outer pair of gills. Heterogenous marsupia are considered an apomorphic characteristic.

It has been suggested that freshwater mussels began to brood their embryos to protect them from harsh environmental factors, or as a method to aid in dispersal of larvae (Kat 1984). Embryos are tightly packed in the marsupium and have a maternal epithelial connection, which may be important for the passage of nutrients to the developing larvae (Richard et al. 1991). Silverman et al. (1987) found that nearly all the calcium found in the shells of developing freshwater mussel embryos was provided maternally. As the glochidia develop, the marsupia become progressively more swollen and pad-like. The length of time required for the glochidia to become mature is dependent on the species of mussel and water temperatures during development.

Parasitic Phase of the Mussel Life Cycle

Once expelled into the water by the female, the glochidia can survive as plankton for several days but are quickly smothered by silt or consumed by

invertebrate predators once they fall to the bottom (Howard 1922). After attachment to a fish host, a glochidium causes "epithelial proliferation" (Lefevre and Curtis 1908) of host tissue and becomes completely encysted within two to 36 hours (Kat 1984). Glochidia are not host-specific in attachment, and when encystment occurs on an unsuitable host the fish will reject them, "sloughing" them off within four to seven days (Kat 1984). Freshwater mussels exhibit a remarkable variation in the degree of host specificity. Some mussels, such as *Lasmigona compressa* Lea, have only one known suitable host fish, whereas over 30 species of fish have been identified as hosts for species such as *Pyganodon grandis* Say (Watters 1994a). However, a complete list of all the potential hosts for each species freshwater mussels is far from being known.

Once encystment on a suitable host has occurred, it takes, depending on the mussel species and temperatures during which development occurs, from six days to six months to complete the metamorphosis from glochidium to juvenile mussel. During development, the glochidium is parasitic and absorbs organic molecules from host tissue (Ellis and Ellis 1926, Isom and Hudson 1982). When metamorphosis is complete, the juvenile mussel ruptures the cyst by extending its foot. It then drops off the host, and becomes a free-living juvenile mussel.

Juvenile Development

A newly metamorphosed juvenile mussel has only rudimentary gills that do not fully develop until the second month of life (Howard 1922). Once free and deposited in the specific habitat it requires to survive, the juvenile begins to feed and growth begins immediately. Age of sexual maturation is variable among

species, but usually requires several years. Factors that affect growth rates influence the age of first maturity (Jirka and Neves 1992). Growth is most rapid during the first few years. Upon maturation growth rates decline significantly, reflecting the increased energy devoted to reproductive effort rather than somatic development (see Isely 1914, Grier 1922, Howard 1922, Chamberlain 1931, St. John 1974, Hanson et al. 1988, Nalepa and Gauvin 1988, Gordon and Layzer 1989, Jirka and Neves 1992, Woody and Holland-Bartels 1993). Freshwater mussels are among the longest-lived molluscs. The average life span is around 30 years but some species may live for more than 100 years (Heller 1990). Members of the subfamily Ambleminae are generally slow growing, long-lived, and, consequently, tend to mature later in life (generally at six to eight years of age) (Stein 1973). Members of the Anodontinae are fast growing, short-lived, and usually mature within two to five years (Kat 1983a, Heard 1975, Jirka and Neves 1992). Members of the Lampsilinae are intermediate in growth, longevity, and age of maturity (Grier 1922, Kat 1983a).

Mussel Growth

The factors that influence the growth rates of freshwater mussels are well known, yet poorly understood. Unfortunately, in any given location, more than one factor may be acting to control growth rates, and their relative influences on growth rates cannot easily be distinguished from one another. Any environmental factor that causes a mussel to close its valves (and thus prevent feeding) will affect growth.

The growth of freshwater mussels is closely related to water temperature. In temperate latitudes, it is generally accepted that growth ceases during the winter months. It has been demonstrated that the yearly variation in growth in mussel populations is due to temperature differences between successive years (Negus 1966, Haukioja and Hakala 1978, Hanson et al. 1988). Negus (1966) found that freshwater mussels exposed to high temperatures in a thermal effluent experienced longer growing seasons, and therefore had larger yearly growth increments than mussels not in the effluent. Although most mussels have wide tolerances to temperature, specific seasonal changes and thresholds are required for egg, sperm, and glochidial development and release (Fuller 1974).

In rivers, mussels generally are most successful in stable, sandy/gravel substrates, and are absent from soft substrates with heavy silt loads (McMahon 1991). Fine sediments cause reduced growth rates (see Kat 1982, Hinch et al. 1986, Nalepa and Gauvin 1988). High levels of suspended solids can result in a reduction of food clearance rates and a switch to carbohydrate catabolism, a process that is consistent with starvation (Aldridge et al. 1987). Aldridge et al. (1987) showed that intermittent exposure to suspended solids caused reduced filtering clearance rates and lowered metabolic activities in freshwater mussels. The "semi-starvation" of the mussels due to high levels of suspended solids significantly decreased growth rates.

Haukioja and Hakala (1978) found that growth rates of adult *Anodonta* spp. were highest during early summer, before reproduction occurs. Brooding of glochidia in marsupia may reduce the gill's respiratory and feeding functions in

female mussels, thus reducing growth rates (Tankersley and Dimock 1992). Tankersley and Dimock (1992) predicted that water transport through the marsupia of *Pyganodon (Anodonta) cataracta* Say is reduced by about 16% when they are brooding glochidia. The growth rates of adult females may be reduced if brooding affects the ability to respire or feed.

Shell Formation and Structure

Examination of the outer surface of a unionid shell usually reveals a series of dark-colored bands that extend from the umbo outwards to the circumference of the shell (Figure 2). These conspicuous dark rings in the periostracum are similar in form to the normal shell outline, and have been called growth lines, growth rests, winter lines and annuli. Shell bands may be divided into two varieties: (1) Macroscopic lines, which are wide, darker, bands occurring at fairly regular intervals, and (2) microscopic lines which are narrower, less dark, sporadically spaced bands. They are also represented as opaque bands in shell cross-sections (Tevesz and Carter 1980, Day 1984). Some bands, which Day (1984) termed ultrastructural lines, are only visible in cross-sections using high magnification.

Shell formation

The unionid shell is complex structure composed of nonliving calcium carbonate (CaCO_3) crystals embedded in a protein matrix covered by a sheet of tanned proteins, all of which is secreted by the underlying mantle tissue (Wilber and Saleuddin 1983, McMahon 1991). Thus the shell is composed of three

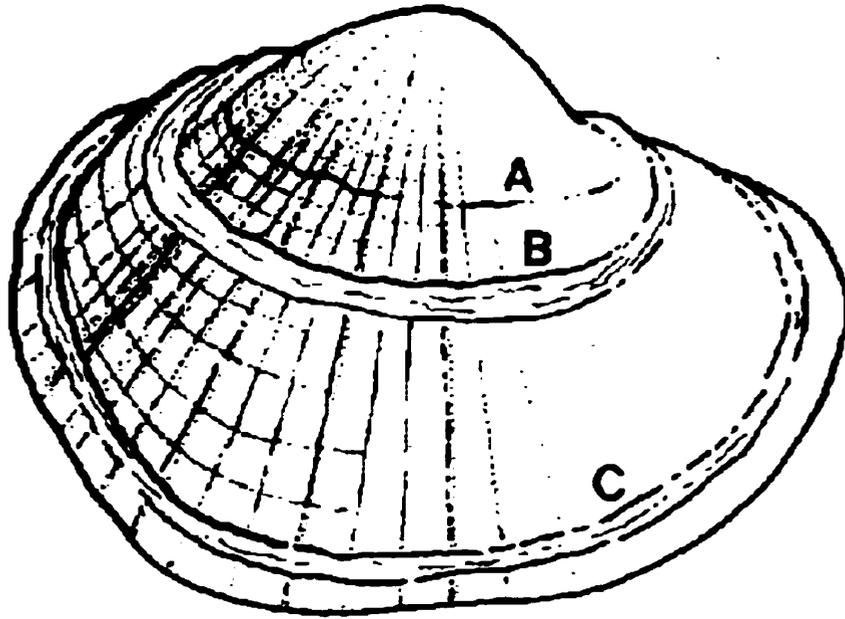


Figure 2. Macroscopic (B and C) and microscopic (A) growth lines on a freshwater mussel's valve (after Tevesz and Carter 1980).

components: (1) an outer periostracum, and an underlying calcareous layer made up of (2) a prismatic layer, and (3) an inner layer of nacre (Figure 3). Shell formation occurs through a series of cellular processes (which include ion transport, protein synthesis, and secretion) in which CaCO_3 crystals are nucleated, oriented, and deposited in association with the organic matrix (Wilber and Saleuddin 1983).

The periostracum is secreted by basal mantle epithelial cells located within the periostracal groove (Figure 3A). The periostracum is impermeable to water and functions to protect the shell from dissolution (Watabe 1983).

The inner mantle epithelium (Figure 3), which covers the body surfaces, allows the transfer of the ions involved in shell formation (calcium and bicarbonate) from the external environment to the hemolymph. The outer mantle epithelium transfers the ions from the body's hemolymph to the extrapallial space, which Wilber and Saleuddin (1983) aptly describe as the "microenvironment of shell deposition". The extrapallial space is a fluid filled space between the outer mantle epithelium and the inner shell surface. The free edge of the periostracum seals the extrapallial space between the mantle and shell, preventing contact with the external medium. This allows CaCO_3 concentrations in the extrapallial fluid to reach the saturation level required for crystal deposition (McMahon 1991).

The prismatic layer consists of "aragonite", which are aggregates of vertically oriented prisms of CaCO_3 crystals imbedded in an organic matrix

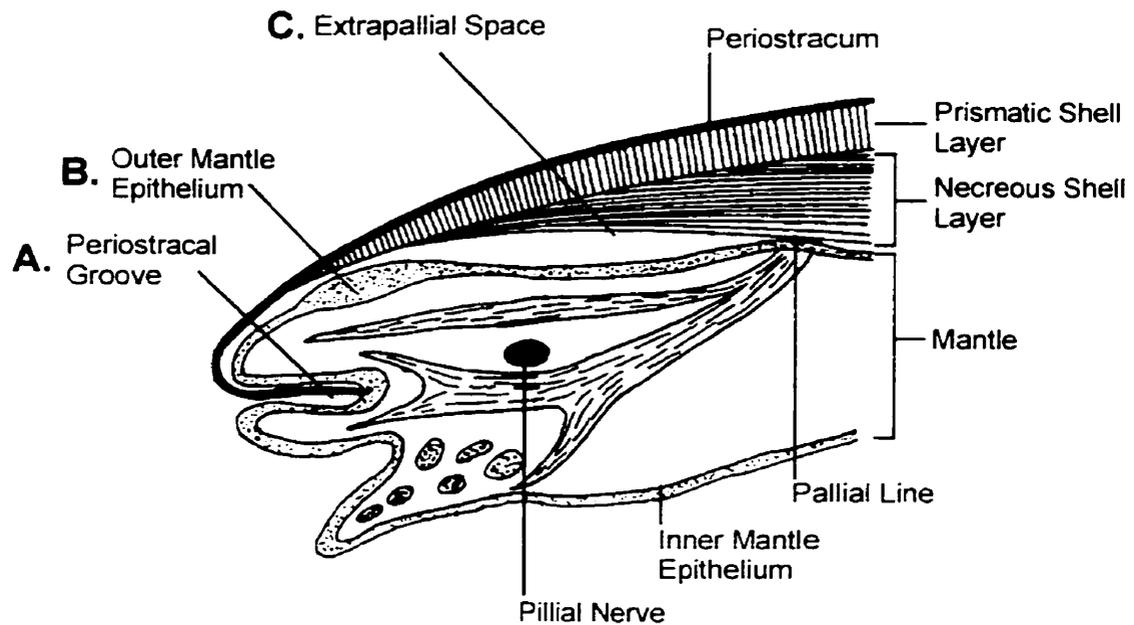


Figure 3. Cross-section through the mantle and shell edges of a freshwater mussel (after MaMahon 1990). (A) The periostracum is secreted by basal mantle epithelial cells located within the periostracal groove. (B) The prismatic layer is secreted by the outer mantle epithelium (C) Components of the nacreous shell layer are precipitated from the extrapallial fluid and deposited onto the prismatic layer.

(Watabe 1983). These columnar prisms are encased in an organic sheath that is secreted by the outer mantle epithelium (Figure 3B).

The nacreous shell layer consists of consecutive layers of small CaCO_3 crystals parallel to the plane of the shell imbedded in an organic matrix (McMahon 1991). Shell CaCO_3 and the matrix material precipitate from the extrapallial fluid and are deposited directly on the inner surface of the shell (Figure 3C) (Wilbur 1972). Accumulation of nacreous layers through time thickens the shell and gives it strength and rigidity (McMahon 1991).

Macroscopic and Microscopic Lines

If the mantle, for whatever reason, is made to retract from the shell margin, it breaks the continuity of the periostracum with the shell margin. When the mantle is re-extended, and the deposition of shell resumes, the new prismatic layer and periostracum is not continuous with, but rather overlapped by, the older shell layers (Figure 4) (Isely 1914, Coker et al. 1921, Imaly 1982). The effect of seeing the second layer of periostracum through the outer periostracum and prismatic layers gives the appearance of a dark band on the shell. The degree of this "doubling up" depends upon the degree of disturbance and the extent to which the mantle has withdrawn (Coker et al. 1921). Macro- and microscopic lines are formed this way.

It is generally accepted that at temperate latitudes mussels experience no shell growth during the winter months (Isely 1914, Coker et al. 1921, Howard 1922, Chamberlain 1931, Negus 1966, Haukioja and Hakala 1978, Hanson et al. 1987, Michaelson and Neves 1995). When temperatures drop enough to cause

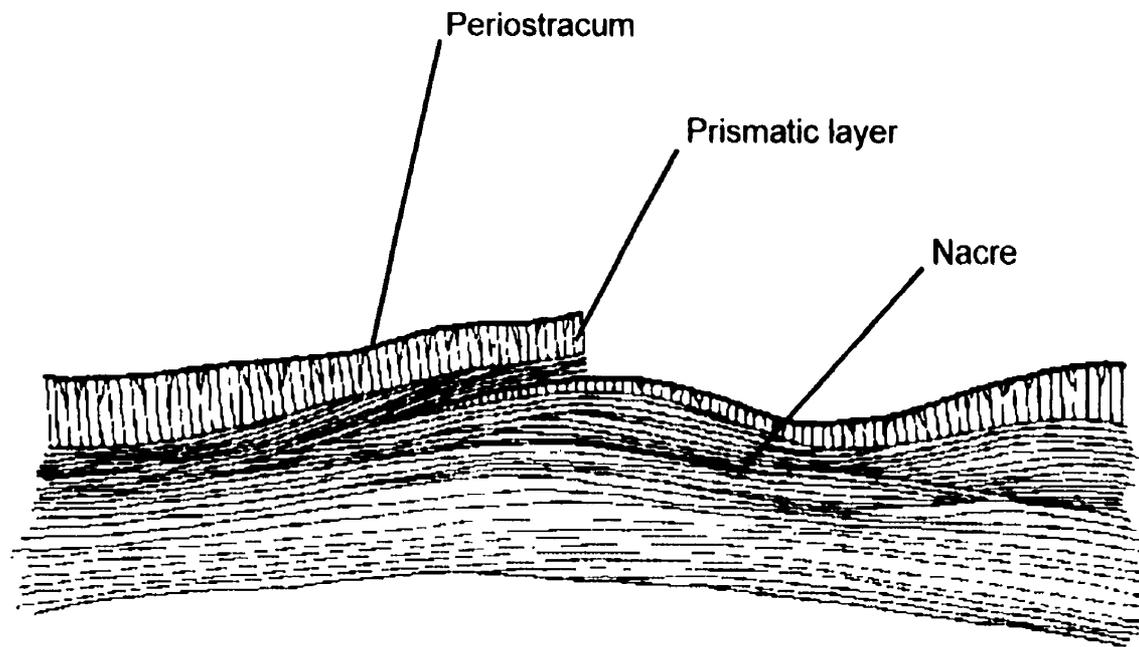


Figure 4. Cross section through a microscopic growth line (after Coker et al. 1921)

the mantle to retract from the shell edge, a microscopic line is created at the shell margin. Thus, darker macroscopic lines are the result of multiple "doubling-ups" of the periostracum at the shell margin caused by repeated growth interruptions as water temperatures gradually increase during the spring (Coker et al. 1921, Veinott and Cornett 1996). Freshwater mussels in warm climates do form macroscopic bands, which are known also as "annuli", but for different reasons. Annual events such as drought (McMichael and Hiscock 1958) or storms and floods, which cause increases in particulate matter (Tevesz and Carter 1980, Imaly 1982), cause freshwater mussels to produce similar structures on a yearly basis. For example, Adam (1990) found that true macroscopic annual bands developed on the shells of freshwater mussels in the White Nile were the result of a "silting-induced resting state" during annual flooding from July to October.

Microscopic lines are the result of any stress-related retraction of the mantle from the shell edge causing a stop in growth. These lines also have been termed "pseudoannuli" or, more accurately, "disturbance rings". Isely (1914) found that drilling a hole through the shell caused a disturbance ring so marked that it was difficult to distinguish it from an annual ring. Other microscopic lines may result from unfavorable factors such as stranding during periods of low water flow (Isely 1914, Imaly 1982), an inadequate food supply (Adam 1990), handling (Grier 1922, Chamberlain 1931, Negus 1966, Haukioja and Hakala 1978, Hanson et al. 1987), changes in water quality, floods, extreme water temperature fluctuation, storm disturbances, or any other environmental stress (Imaly 1982). The stable conditions and slow, uniform temperature changes

found in large water bodies eliminate the production of these disturbance rings. Only regularly spaced annual macroscopic lines mark the surface of the shell to interrupt periods of continuous summer growth (Greir 1922, Chamberlain 1931, Nalepa and Gauvin 1988).

In summary, the difference between a macro- and microscopic line is simply that the macroscopic line consists of a series of microscopic lines caused by repeated episodes of low temperature in spring (Veinott and Cornett 1996). In most cases major annual rings (macroscopic lines) are easily differentiated from the narrower microscopic lines created by less significant stresses.

Age Determination

The increasing appreciation of the importance of freshwater mussel populations renders the accurate analysis of age and growth essential. With absolute age information, in conjunction with information on population densities and shell weights and dimensions, one can infer life history parameters such as growth rates, population age structure, annual production, recruitment and mortality rates, and season of death (Tevesz and Carter 1980).

Ageing techniques using the mussel shell rely on the ability to discriminate between annual macroscopic lines and "pseudoannual" microscopic lines found on (or in) the shell. Therefore they are generally only useful in temperate latitudes, where seasonal periods of cold stops growth for prolonged periods and produces distinct annual bands.

External Growth Method

The external growth method of age determination involves enumerating the number of external macroscopic lines on the shell surface. In thin-shelled species, annuli may be distinguished by holding the valve up to a light source and counting the most prominent lines. For thicker-shelled forms one can hold the shell up to an ultraviolet light, which causes the shell CaCO_3 , but not the periostracum, to fluoresce (Chamberlain 1931). Again, it is assumed that the most prominent lines are annuli.

The majority of studies involving ageing of freshwater mussels have made use of this method of assessing growth. There are two assumptions upon which this method is based: that macroscopic lines can easily be distinguished from microscopic lines caused by environmental stresses, and that the macroscopic lines are annual. Imaly (1982, p. 2) has made the statement that "the method of ageing mussels by annual increment counts is perhaps 95% reliable". Although most investigators report few problems distinguishing between disturbance rings and "annuli" (Haukioja and Hakala 1978, Day 1984, Metcalfe-Smith and Green 1992), there is evidence that ages derived from external growth rings may be unreliable. Metcalfe-Smith and Green (1992) compared external age estimates to those obtained by thin-sectioning the shell of *Anodonta implicata* Say. More external than internal bands were found, suggesting that disturbance was accounting for some external rings and they were being counted as annual. Thus ages determined when using external growth lines could be overestimated if this is true. Neves and Moyer (1988) found that counts of external annuli

consistently yielded underestimates of ages, and that the older the specimens were, the greater the underestimate. Veinott and Cornett (1996) also found that annual bands were not being counted on the shell exterior. The slower growth rates of older individuals often cause crowding and indistinct separations between the most recent growth rings at the shell margin. This makes the ability to locate macroscopic lines, or to distinguish between them and microscopic lines, difficult. Ageing also is difficult when the older parts of shells (the umbo and surrounding region) are severely eroded and causes the record of growth to be destroyed (Michaelson and Neves 1995). In addition, the effectiveness of the growth line method can be hampered by obscurity of bands on dark colored shells, or by closely spaced bands in stunted populations (Haukioja and Hakala 1978).

Most authors base the assumption of annual growth on such mark-recapture studies by such as those of Chamberlain (1931), Negus (1966), and Haukioja and Hakala (1978). However, if the molluscan shell can decrease in size, then growth rates of molluscs could be overestimated. For example, Downing and Downing (1993) marked 129 freshwater mussels and then recaptured between three and six years later. More than 35% of them had decreased in size. Downing et al. (1992) marked 127 and fourteen displayed no growth after one year, and one individual failed to grow after five years. The implications of these studies are significant: if growth rates can not be calculated accurately then estimates of mussel biomass and production would be

impossible. Neves and Moyer (1988) caution that the annual nature of growth lines should be confirmed for each species and locality.

Thin-sectioning

The thin-sectioning method of age determination involves distinguishing macroscopic lines from microscopic based on internal shell structures viewed under magnification. The first step is to section a mussel valve (usually using a low-speed diamond saw) longitudinally along the desired plane of section. This plane is typically through the umbo to the growing edge along the axis of maximum growth (Figure 5). The exposed surface of the shell interior then is polished using successively finer grit sandpaper or lapidary film until a high gloss is achieved. The polished surface then is glued to a glass slide. Next, the slide is positioned parallel to the saw blade, and a second section of the valve is made close to the surface of the slide. The exposed side of the section is reduced to about 200 μm and then polished. The resulting "thin-section" is viewed under magnification using a stereoscope or light microscope. Growth lines appear as opaque bands in the shell. Putative macroscopic annuli are bands that can be traced from the umbo to shell margin while microscopic disturbance lines are incomplete (Neves and Moyer 1988). Veinott and Cornett (1996) considered an opaque band as annual if it started as a "prismatic layer discontinuity" and extended to the umbo region, or extended from the prismatic layer and "merged into a line common to several opaque bands". Neves and Moyer (1988) considered thin-sectioning to be the most consistent and accurate technique for age determination of mussels, and many investigators consider internal counts of

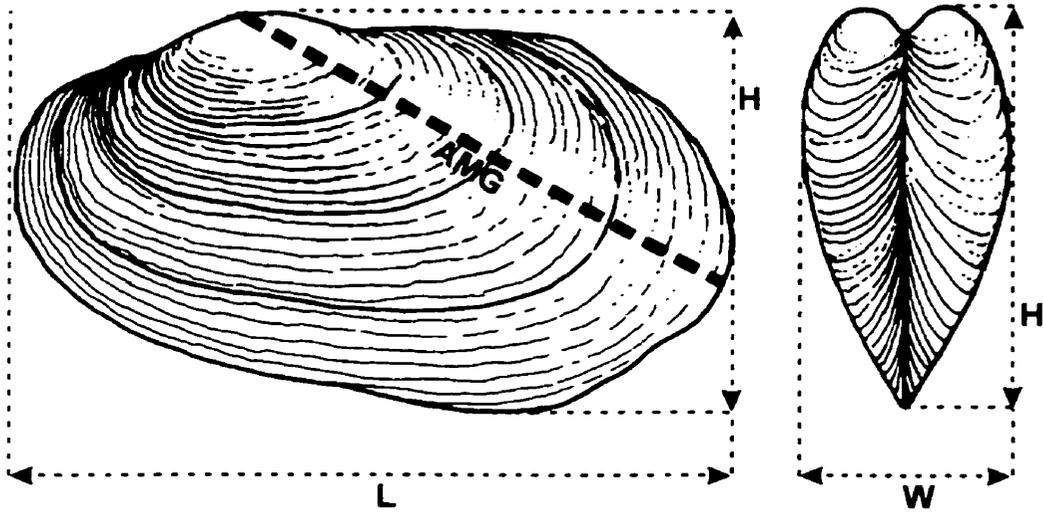


Figure 5. Axis of maximum growth (AMG) and shell dimensions of a freshwater mussel shell.. L = length; H = height; W = width. (after Tevesz and Carter 1980)

macroscopic annual bands as validation for the external growth method of age determination. For example, Woody and Holland-Bartels (1993) "validated" the ages determined by the external ageing method by regressing their external age estimates against ages determined by the thin-sectioning technique. The two methods produced similar age estimates for the freshwater mussel species *Megaloniaias nevosia* Rafinesque.

As with the external growth method, one must assume that internal "annuli" are formed on a yearly basis. A validation technique that has been used recently takes advantage of the seasonal cycle of $\delta^{18}\text{O}$ in the shell of a freshwater mussel (in this case individuals of *Elliptio complanata* Lightfoot). The $\delta^{18}\text{O}$ concentrations in the shell are directly dependent on the temperature and ^{18}O content of the water at the time of shell deposition (Veinott and Cornett 1996). Warm temperatures result in shell that is depleted in $\delta^{18}\text{O}$. Veinott and Cornett (1996) found that sequential micro-sampling across macroscopic lines (as determined in thin-sections) in shell cross-sections revealed $\delta^{18}\text{O}$ patterns that suggested that they were annual growth structures deposited in the spring as water temperatures increased.

Acetate Peels

This technique also involves sectioning the shell along the axis of maximum growth. A polished section is "etched" in a dilute acid solution, washed, and allowed to air dry. The last step involves placing the etched section on a strip of acetate covered with acetone. After being pressed firmly into the acetone for about 30 seconds, the valve is stripped off the acetate strip, leaving

an imprint or "peel" of the etched section. Macroscopic bands are counted under magnification using the same criteria as for thin-sections (Neves and Moyer 1988).

The acetate peel method of age determination has been restricted largely to marine bivalves. Neves and Moyer (1988) found that this method was less effective than thin-sectioning in the ageing of freshwater mussels. Acetate peels were more time consuming, involved experimenting with different acid concentrations and exposure durations, and often produced obscured bands that were difficult to interpret. Acetate peels also are more difficult to store, preserve, and study than thin-sections (Clark 1980).

Other Methods

Shell ashing is a method that is rarely used in the ageing of freshwater mussels. This technique involves cutting triangular wedges from a valve and separating growth layers by baking them in a muffle furnace. Heating the shell "ashes" the protein found in the microscopic lines, thus causing the shell wedges to break at the lines of growth (Neves and Moyer 1988). Neves and Moyer (1988) found that ashing was not an effective technique in ageing studies involving freshwater mussels. The ashing process made the shells to become very brittle, and they were often unable to separate the growth bands effectively.

The chondrophore method has been used extensively in marine bivalve ageing (Ropes 1985). It involves dissecting out a thin-section from only the chondrophore of a valve, which also contains a complete record of growth. Otherwise it is prepared in exactly the same way as for a complete thin-section.

Freshwater mussels (particularly species of the subfamily Anodontinae) do not possess large chondrophores, and is probably the reason why this method is not used in this group of bivalves.

Overall, thin-sectioning is the most accurate method of determining the age of freshwater mussel. However, counting the macroscopic lines on the surface of the shell is, in most cases, considered a valid method of age determination in this group of bivalves.

CHAPTER 3 - DISTRIBUTION OF UNIONIDAE IN THE ASSINIBOINE RIVER DRAINAGE

Introduction

The zoogeography of the Unionidae in the Assiniboine River drainage has not been well documented. Clarke (1973) described the known distribution of unionids within the drainage based on a limited survey and previous collections. These earlier collections (e.g. Bell 1879, Christy 1885, Whiteaves 1895, Dall 1905, and Mozley 1938) were relatively small and contained numerous misidentifications (Clarke 1973). Since Clarke's study, little work has been published on the freshwater mussel fauna of the Assiniboine River or its tributaries.

Twelve species of unionid have been recorded from the Assiniboine River drainage. Clarke (1973) reported *Fusconaia flava* Rafinesque, *Amblema plicata* Say, *Quadrula quadrula* Rafinesque (subfamily Ambleminae), *Lasmigona complanata* Barnes, *L. compressa*, *A. ferussacianus*, *P. (=Anodonta) grandis*, *Strophitus undulatus* Say (subfamily Anodontinae), *Ligumia recta* Lamarck, *Lampsilis siliquoidea (=radiata siliquoidea)* Barnes, and *Lampsilis cardium (=ovata)* Rafinesque (subfamily Lampsilinae). Scaife and Janusz (1992) collected *Potamilus (=Proptera) alatus* Say (subfamily Lampsilinae) from the Assiniboine River near Headingly, Manitoba.

Lasmigona costata Rafinesque (subfamily Anodontinae), has been collected in the Red River (Dall 1905, Cvancara 1970, Clarke 1973) and

Winnipeg River systems (Clarke 1973, L.C. Graham and E.T. Watson unpublished data). Further collections could expand its range to include the Assiniboine River drainage.

Methods

Study Area

The Assiniboine River basin (Figure 6) encompasses a drainage area of approximately 153,000 km² located in portions of North Dakota, Saskatchewan, and Manitoba (Andres and Thompson 1995). Land use in the basin is primarily agricultural. The Assiniboine River is a 7th order, low slope, turbid prairie stream, which stretches 1266 km from its headwaters at Windy Lake, Saskatchewan, to its confluence with the Red River at Winnipeg, Manitoba. Between 1913 and 1994, the mean annual discharge of the Assiniboine River was 46.2 m³/s (data provided by Manitoba Conservation, Water Resources Branch). Two major (6th order) tributaries of the Assiniboine River are the Qu'Appelle and Souris rivers (Figure 6). While most of the Assiniboine River basin in Manitoba is situated within the aspen parkland ecoregion, the lower 200 km runs through the Lake Manitoba Plain ecoregion. In Manitoba, the northern tributaries of the Assiniboine River have headwaters in the mid-boreal uplands ecoregion in the Duck and Riding Mountain regions (Ecological Stratification Working Group 1996).

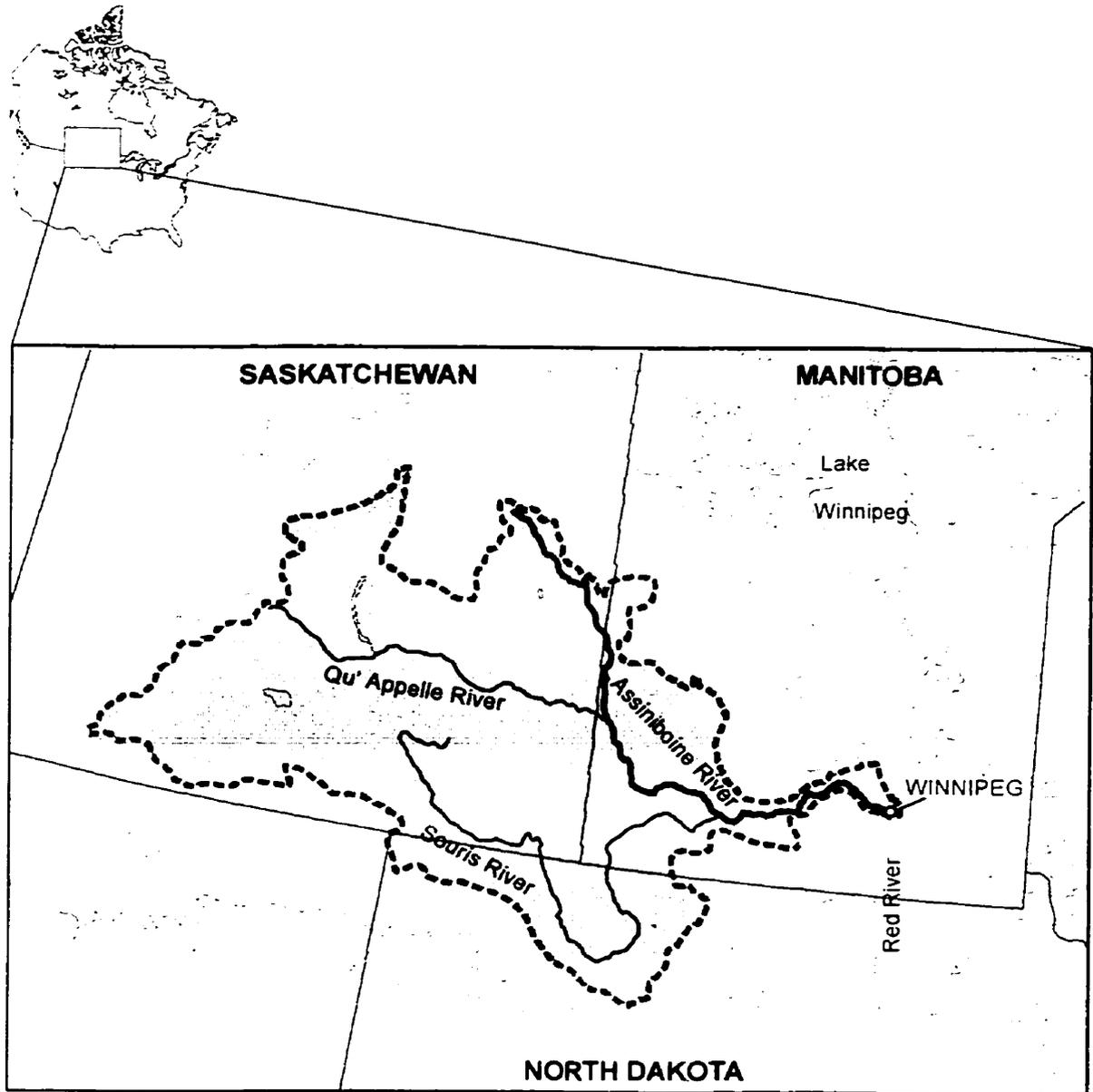


Figure 6. Assiniboine River drainage in North Dakota, Saskatchewan, and Manitoba.

Sampling

Assiniboine River Collections

Mussels were collected from the Assiniboine River, between the dam at Portage la Prairie and its confluence with the Red River at Winnipeg, on two occasions in the summer of 1995. To stratify the sampling, sampling sites were selected by dividing the river into sixteen 10-km blocks. A 1-km site within each block was then randomly selected. A transect of the river was sampled for mussels by boat at the upstream end of each 1-km site. Mussels were collected by raking the substrate with a 12-tooth mini-bullrake (width 34 cm) with a mesh bay of 1 cm hardware cloth, for a distance of approximately three meters five times at five equidistant points across the transect (i.e. 25 x 3 m x 34 cm were sampled with the rake for each trasect). Collecting took approximately 30 minutes per site. The approximately 775 kilometers of the Assiniboine River from above the dam at Portage la Prairie to the Manitoba / Saskatchewan border were not sampled due to the lack of time and resources.

Tributary Collections

During the summers of 1995 and 1996, sampling sites were selected according to accessibility at approximately 20 km intervals along all Assiniboine River tributaries that were fourth order or larger at their confluence with the Assiniboine River. Thirty person-minutes were spent searching for mussels at each site by systematically walking back and forth across each site working in an upstream direction. In areas too deep or turbid for a visual search, mussels were collected by raking the substrate with a 12-tooth mini-bullrake (width 34 cm) for

30 minutes. Where possible, location (identified by road crossing or town name) and GPS position (in latitude and longitude, to the nearest minute) were recorded for each sampling site.

Sampling modifications

All sites could not be surveyed in the same manner. The collection of mussels from the Assiniboine River could only be made from a boat with a mini-bullrake due to high water levels in 1995 (mean annual discharge of 54.7 m³/s). Consequently, the area effectively sampled at Assiniboine River collection sites was relatively small when compared to sites that were shallow enough to wade. Turbidity and depth were factors affecting the methods used to search for mussels in the smaller tributaries.. Most sites on the Souris River were very turbid (visibility <10 cm) and too deep to wade across the width of the entire stream. This necessitated searching for mussels by raking the substrate starting from first one bank and continuing towards mid-channel, then working in the same manner for the other riverbank. Therefore, mussels may not have been collected from cobble-clay substrates of the main river channel, which have been known to be important substrates for some mussels, particularly large river species. Similar problems occurred when sampling sites on other tributaries.

Processing of Collections

Living mussels were fixed with 10% formalin in the field. Fixed specimens and all empty valves encountered at each sampling site were brought to the laboratory, stored in 70% ethanol, and later identified. Nomenclature of mussels follows Turgeon et al. (1998) (see Appendix 1 for notes on nomenclature). The

total length (anterior to posterior), width (lateral thickness) and height (dorsal ventral) (Figure 5) was measured for each fixed mussel. When possible, the approximate age of each mussel was determined using the external growth method.

Habitat Characterization

Stream order was assigned to each collection site using the methods of Strahler (1952) and Manitoba Conservation, Water Resources Branch watershed maps (scale 1:100,000).

The dominant substrate types that living mussels utilized at each site were categorized qualitatively as silt, sand, gravel, cobble, or clay. A maximum combination of three substrate types was possible for any given location, and these were listed in order of their relative abundance at the site. For example, if a site had a lot of sand, some gravel, and only a small amount of cobble, the substrate was classified as sand/gravel/cobble. If the substrate was predominately sand with some gravel, it was classified as sand/gravel. For numerical analysis, the substrate categories present at each site were assigned numbers according to their relative abundance. Each site was assigned a Total Substrate Score of six. At sites with only one substrate type, a value of six was given to that substrate. At sites with two substrate types, a value of four was given to the predominant substrate, and a value of two to the less common substrate. At some two substrate sites there was no dominant substrate and each substrate was given a value of three. At sites with three substrate types, a value of three was given to the predominant substrate, two to the next most

common, and one to the least common. Thus, substrate scores reflect the habitat used by all mussels at the site, regardless of species. Where possible, stream width (measured at the middle of the sampling reach) and depth (measured at mid-channel and mid-reach) was recorded for each sample site.

Data Analysis

The presence of a species at any given sampling site was based on living mussels. Evidence of mussels in the form of empty valves may not indicate their current distributions. River currents may carry the shells of thin-shelled species or small individuals far downstream. The shells of larger individuals and thick-shelled species may take a number of years to decompose, and the microhabitat at a site may have become unsuitable for those species in the intervening period.

Freshwater mussel substrate preferences were examined by expressing each substrate as a proportion of the cumulative Total Substrate Scores (TSS) for each species collected. For example, say that mussel species "A" was collected from three sites. The cumulative TSS for all three sites would be 18 (TSS of six for each site, three sites in all). The Substrate Scores for a substrate (silt, sand, gravel, cobble or clay) would be totaled across all three sites that species "A" was collected from, and divided by the cumulative TSS. This gives us the relative frequency that a given substrate contributed to the cumulative TSS. By comparing the amounts the different substrates contributed to the cumulative TSS, the general substrate preference may be inferred for species "A".

Cluster analysis (Systat 8.0, Wilkinson 1998) using Wards Method (minimum variance clustering) was conducted on species presence-absence data. This classification technique allowed the grouping of species based upon their occurrences together among the different sampling sites. Correspondence analysis (SYN-TAX 5.0, Podani 1984) was conducted using square root transformed species abundance data. The square root transformation was used to compensate for extreme outliers in the data set. This ordination method allowed the testing of the hypothesis that mussel distributions are linked to stream size (order). Shannon's (1948) index of diversity was used in conjunction with species richness and the correspondence analysis to examine longitudinal trends (sites with the same stream order value) in species diversity. Mussel abundance data for sites with the same stream order value were pooled before the calculation of Shannon's diversity index. The calculation for Shannon's index of diversity is as follows:

$$H = -\sum p_i \ln p_i$$

where H = Shannon's Index of diversity

p_i = proportion of species i in the community

Results

Of the 185 sites visited, 63 yielded evidence of mussels (Figure 7), and 47 yielded 523 live freshwater mussels representing 12 species (Table 1). *Lasmigona costata* was not found in the drainage. The raw data for the 63 sites is given in Appendix 2. A list of the sites from which each mussel species was

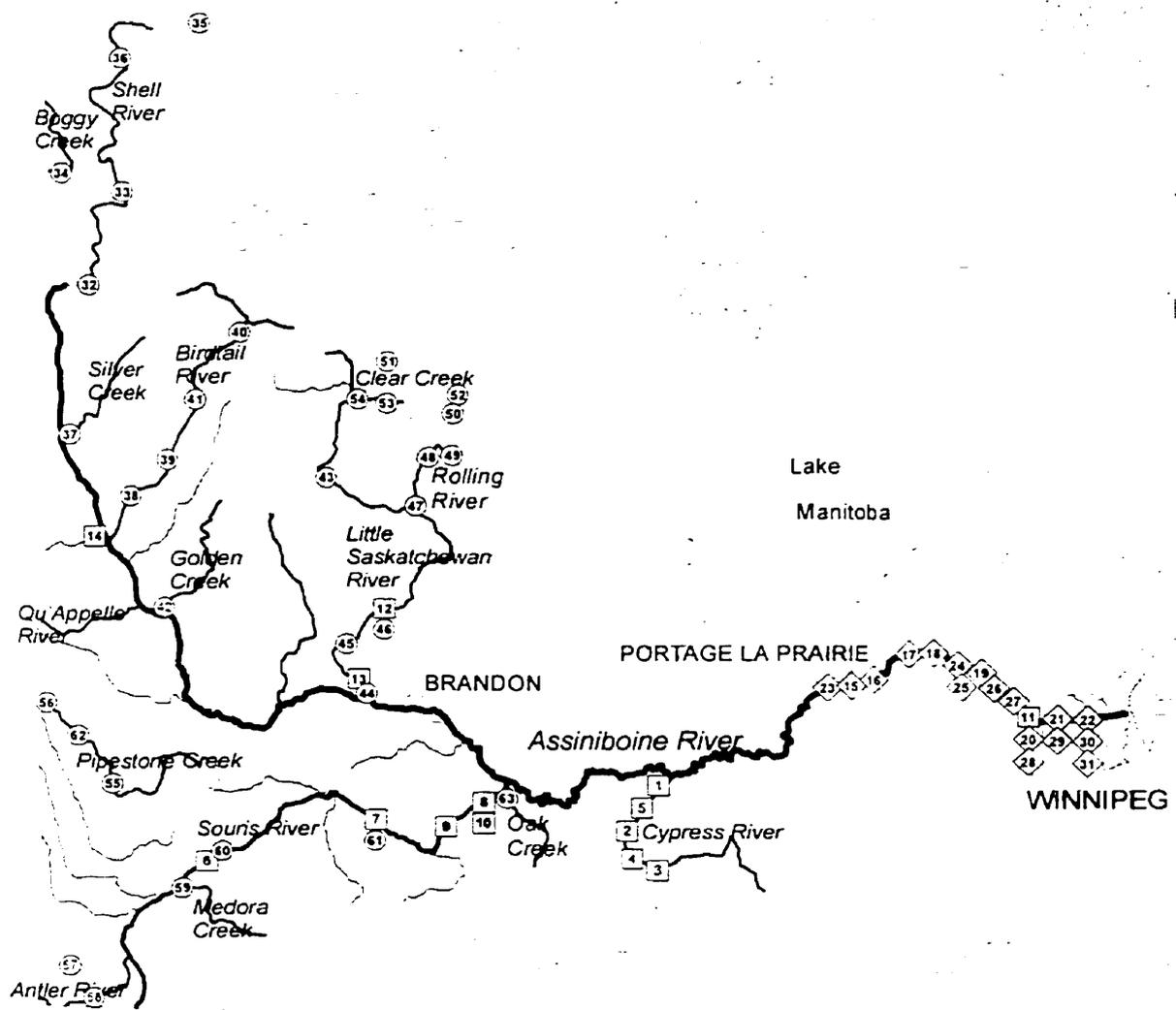


Figure 7. Sites of the 1995 (□), Assiniboine River (◇) and 1996 (○) mussel collections. Numbers refer to collections described in Appendix 4.

Table 1. Classification, common names, and abbreviations used for freshwater mussels (Bivalvia: Unionidae) found in the Assiniboine River drainage.*

Species	Common Name	Abbreviation
Subfamily Ambleminae		
<i>Fusconaia flava</i> (Rafinesque, 1820)	Wabash pigtoe	F.fla
<i>Amblema plicata</i> (Say, 1817)	threeridge	A.pli
<i>Quadrula quadrula</i> (Rafinesque, 1820)	mapleleaf	Q.qua
Subfamily Anodontinae		
<i>Lasmigona complanata</i> (Barnes, 1823)	white heelsplitter	L.cpl
<i>Lasmigona compressa</i> (Lea, 1829)	creek heelsplitter	L.cpr
<i>Anodontoides ferussacianus</i> (Lea, 1829)	cylindrical papershell	A.fer
<i>Pyganodon grandis</i> (Say, 1820)	giant floater	P.gra
<i>Strophitus undulatus</i> (Say, 1817)	creeper	S.und
Subfamily Lampsilinae		
<i>Potamilus alatus</i> (Say, 1817)	pink heelsplitter	P.ala
<i>Ligumia recta</i> (Lamarck, 1819)	black sandshell	L.rec
<i>Lampsilis siliquoidea</i> (Barnes, 1823)	fatmucket	L.sil
<i>Lampsilis cardium</i> Rafinesque, 1820	plain pocketbook	L.car

* See Appendix 1 for notes on classification used.

found is given in Appendix 3. Distribution maps for living and non-living mussels collected in this survey are found in Appendix 4.

Evidence of freshwater mussels was found from 20 streams in the Assiniboine River drainage in Manitoba (Table 2). Only five of these streams (the Assiniboine River, Souris River, Little Saskatchewan River, Shell River and Birdtail Creek) had previous documented records of mussels (Appendix 5). All mussels that had been previously recorded for these five streams were found again in this survey (Table 2). Seven additional species were found in the Souris and Little Saskatchewan rivers, six more were recorded from the Birdtail River, and two more for the Shell River. This study produced no new species records for the Assiniboine River.

Most of the 122 sites at which no evidence of mussels was found were either third or fourth order. The lack of mussels at a significant proportion of these low order sites probably was due to habitat degradation caused by agricultural practices (altering stream channels to form "dug-outs" for cattle, allowing cattle access to the river, and stream channelization for better drainage) frequently were observed at these sites. First and second order sites were intermittent, and thus yielded no evidence of mussels. Mussels were found in streams that had orders of three to seven, and those that were 2.5 meters to over 80 meters in width. Mussels occurred on all types of substrates. The occurrence of species (based on the living mussels) at sites of different orders is represented graphically in Figure 8. The substrates that living mussels of each species utilized (expressed as the proportion of cumulative Total Substrate Score) are

Table 2. Abundance of freshwater mussels collected from streams in the Assiniboine River basin in Manitoba. Abbreviations for mussels species are given in Table 1.

Stream	Order	Sites ¹	Species		Species ^{2,3}											Totals
			Richness	F.fla	A.pli	Q.qua	L.cpl	L.cpr	A.fer	P.gra	S.und	P.ala	L.rec	L.sil	L.car	
Assiniboine River	7	18 (15)	10	3*	19*	6*	3*	-	-	1*	1*	22*	3*	10	11*	79
Qu'Appelle R.	6	1(1)	3	-	-	-	-	-	-	-	-	-	2	11	2	15
Souris R.	6	7 (7)	9	26*	3	-	26*	ev	6*	3	11	-	4	37	7	123
Pipestone Cr.	4	3 (2)	3	-	-	-	1	-	13	4	-	-	-	ev	-	18
Antler R.	4	1 (0)	0	-	-	-	-	ev	-	ev	-	-	-	ev	-	-
Gainsborough Cr.	4	1 (0)	0	-	-	-	-	-	ev	ev	-	-	-	-	-	-
Oak Cr.	4	1 (1)	5	2	-	-	2	-	2	8	-	-	-	9	ev	23
Medora Cr.	3	1 (0)	0	-	-	-	-	-	-	ev	-	-	-	-	-	-
Shell R.	5	3 (3)	6	-	-	-	3*	1*	ev	7*	2*	-	-	6	1*	20
East Shell R.	4	1 (1)	2	-	-	-	-	-	16	1	-	-	-	-	-	17
Little Saskatchewan R.	5	6 (4)	8	2	ev	-	1*	2	-	6*	1	-	5	41	12	70
Rolling R.	5	3 (1)	2	-	-	-	-	-	5	2	-	-	-	ev	-	7
Whirlpool R.	4	2 (2)	2	-	-	-	-	-	-	31	-	-	-	11	-	42
Clear Cr.	3	2 (1)	3	-	-	-	-	-	2	5	-	-	-	1	-	8
Jackfish Cr.	3	1 (1)	2	-	-	-	-	-	4	1	-	-	-	ev	-	5
Cypress R.	4	5 (5)	4	-	-	-	1	1	59	10	-	-	-	ev	-	71
Golden Cr.	4	1 (0)	0	-	-	-	-	-	ev	-	-	-	-	-	-	-
Birdtail R.	4	4 (2)	2	ev	-	-	-	ev	ev	8	ev*	-	-	6	ev	14
Silver Cr.	4	1 (1)	1	-	-	-	-	-	4	-	-	-	-	-	-	4
Boggy Cr.	4	1 (0)	0	-	-	-	-	-	-	ev	-	-	-	-	-	-
Totals		63 (47)	12	33	22	6	37	4	111	87	15	22	14	132	33	516

¹ Number of sites with evidence of mussels (number of sites with live mussels).

² ev = empty valves.

* Indicates previous records exist for that species. See Appendix 3 for list of sources.

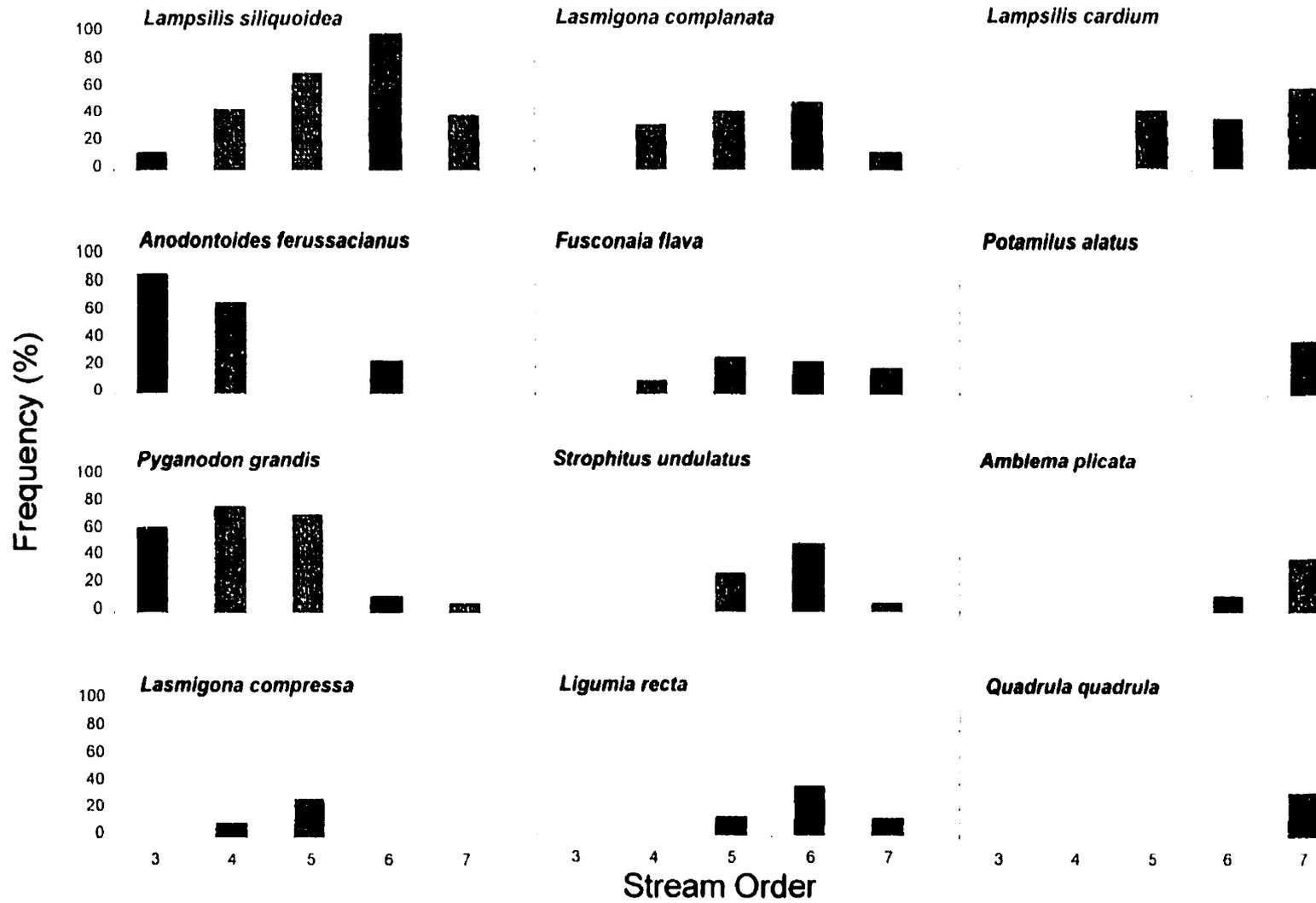


Figure 8. Frequency of occurrence (percentage of sites in which living mussels were present) of the 12 mussel species collected from the Assiniboine River drainage as a function of stream order.

presented graphically in Figure 9.

Cluster analysis (Wards method, Euclidean distance) results are represented by the dendrogram in Figure 10, which shows the hierarchical relationships among the different species based on the occurrence (presence or absence) at the different sites. Four species categories can be derived based on similarity: (1) *L. siliquoidea*, a single species category; (2) *L. cardium*, *L. recta*, *F. flava*, *Q. quadrula*, *A. plicata*, and *P. alatus* category; (3) *L. compressa*, *S. undulatus*, and *L. complanata* category; and a (4) *P. grandis* and *A. ferussacianus* category.

The results of correspondence analysis are represented graphically in Figure 11, which describe the relationships among the species and their occurrence (based on square-root transformed abundance data) at sites of different orders. The first two axes accounted for 39.5% of the variance in the data.

Shannon's index of species diversity (H) and species richness increased with increasing stream order in the study area (Table 3).

Species Accounts

Fusconaia flava (Wabash pigtoe)

Fusconaia flava accounted for 6.4% of the total mussels collected from the Assiniboine River drainage in this survey. It was found alive in four streams, and empty valves were recorded from one additional stream (Table 2). *Fusconaia flava* was most abundant in the Souris River, representing 21.1% of the mussels collected from that stream. It was found in streams of order four to seven (Figure

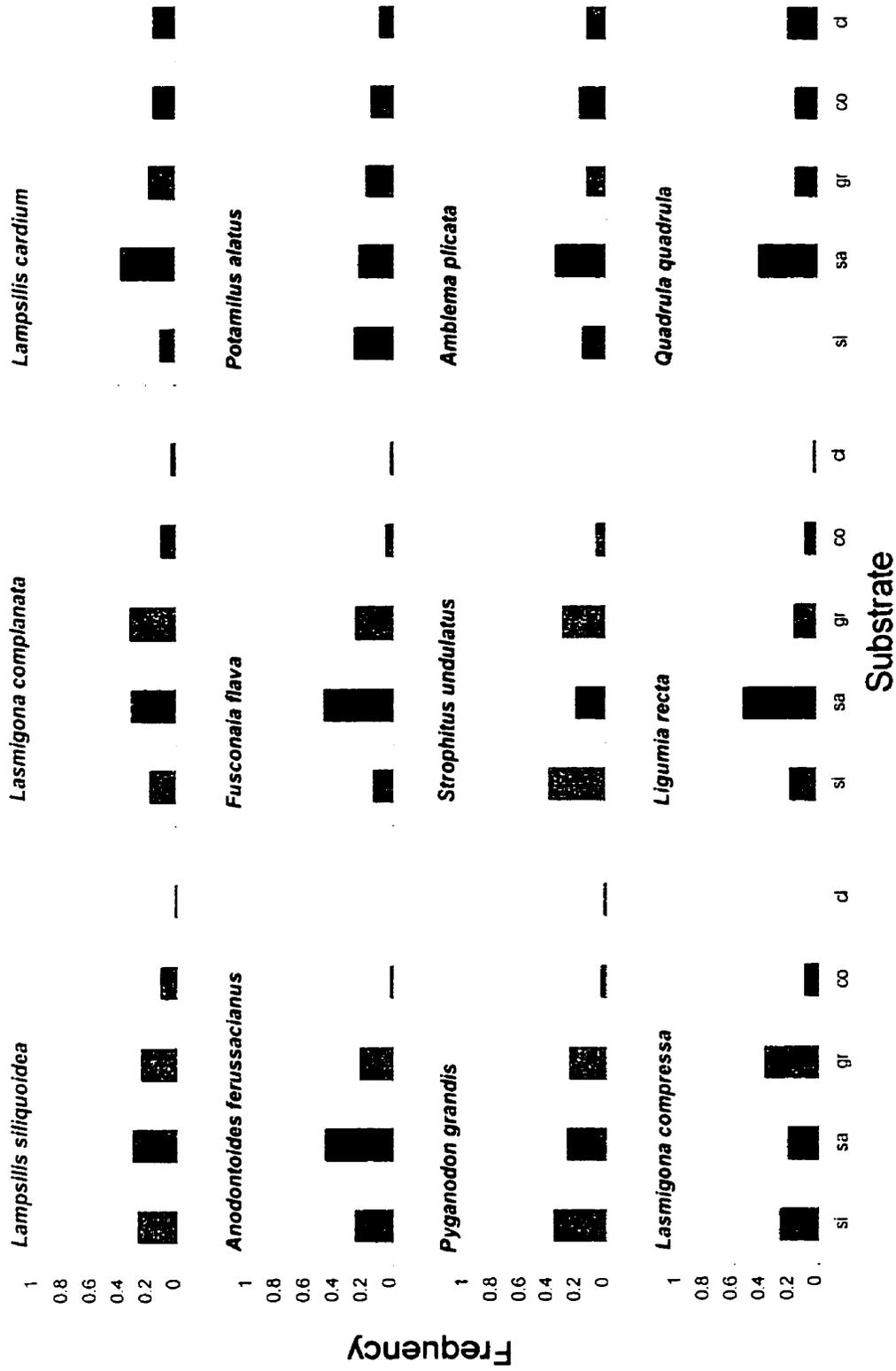


Figure 9. Observed substrates that mussel species utilized in the Assiniboine River drainage. Substrate frequencies are expressed as the proportion of cumulative Total Substrate Score for that species (see text for details). si = silt; sa = sand; gr = gravel; co = cobble; cl = clay.

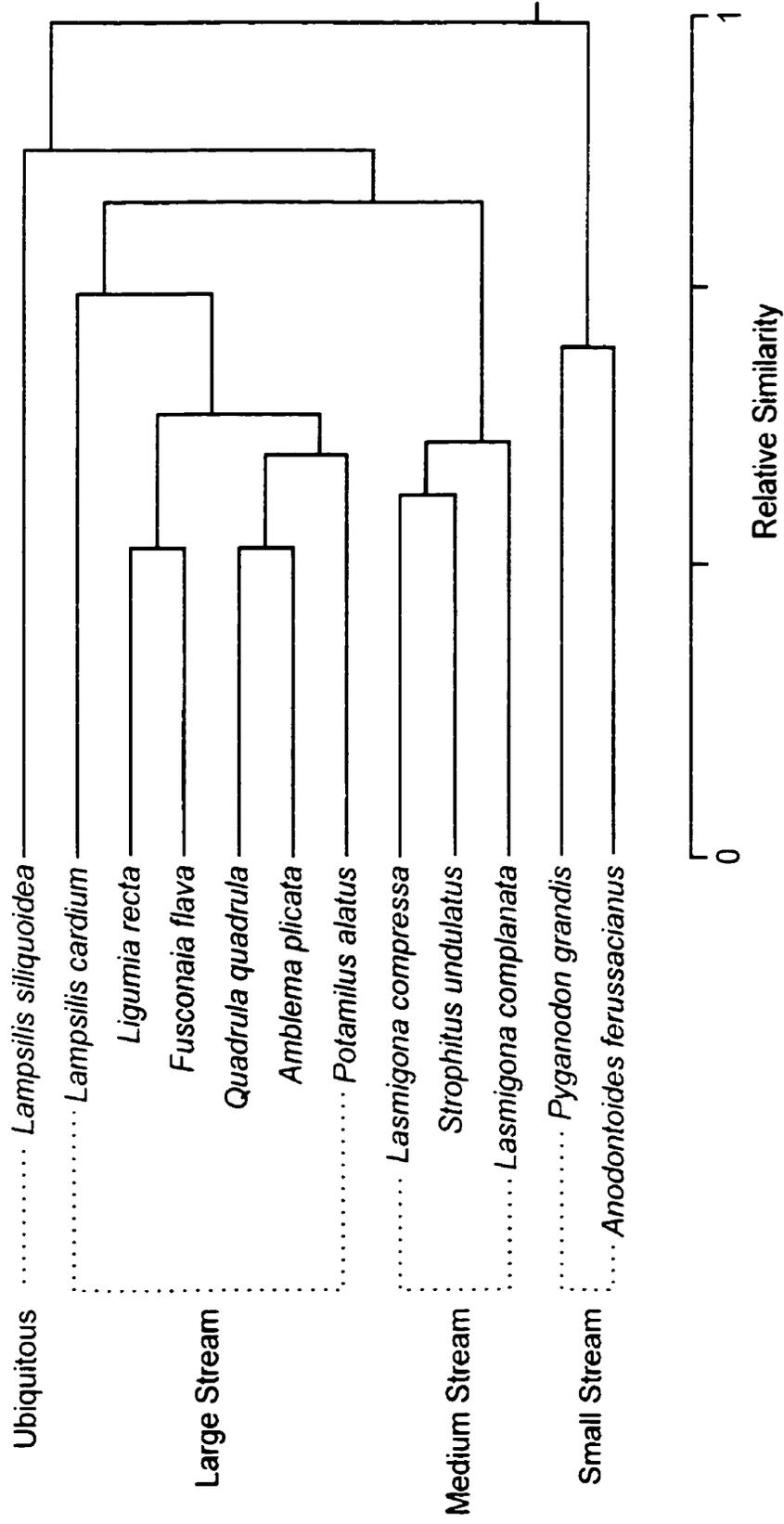


Figure 10. Dendrogram of freshwater mussel associations in the Assiniboine River drainage in Manitoba resulting from cluster analysis of the presence or absence of living mussels (Wards method, Euclidean distance).

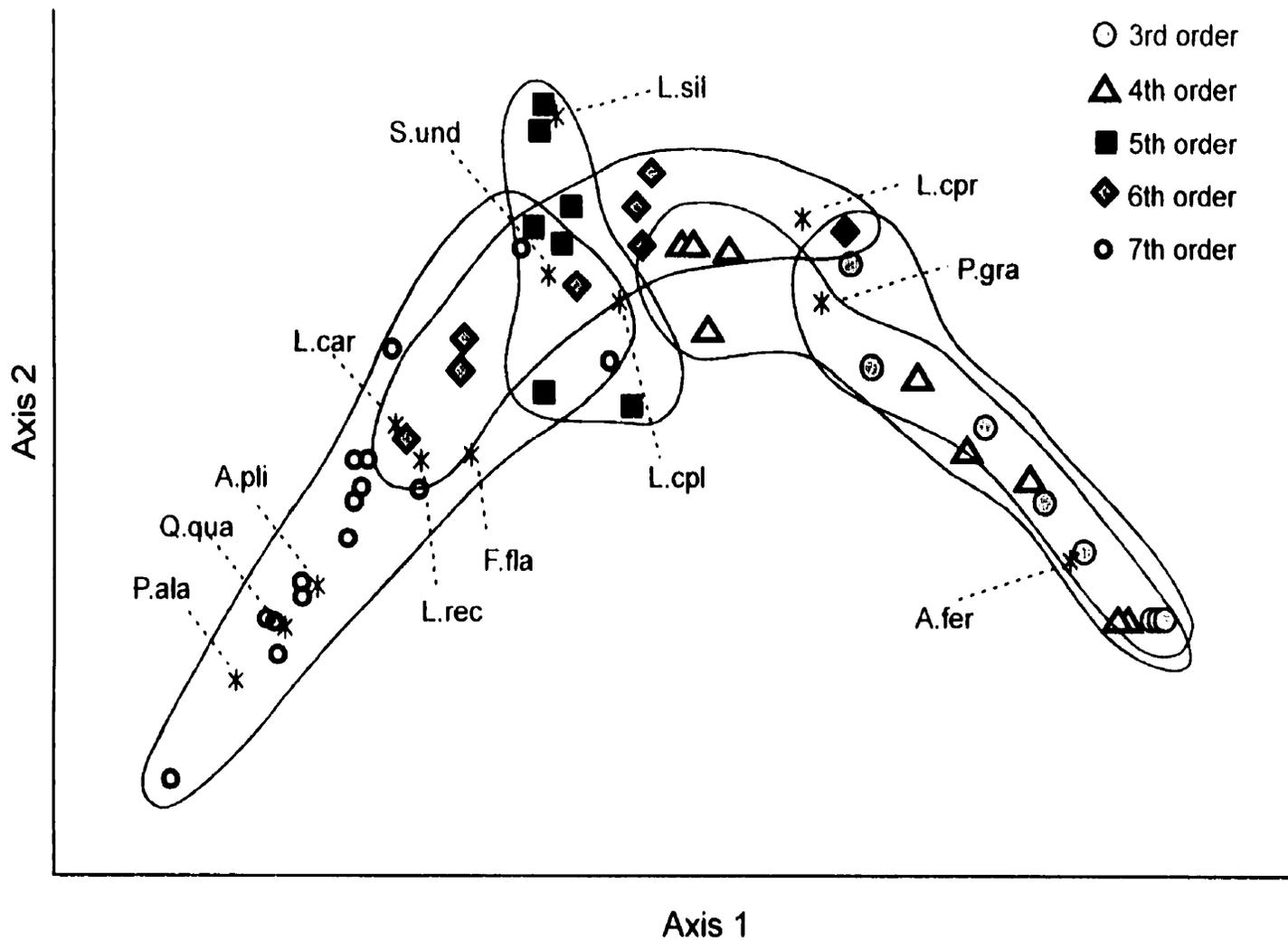


Figure 11. Distribution of sites and species of living freshwater mussels collected from the Assiniboine River drainage as defined by correspondence analysis. The two axes account for 39.5% of the variance in the data. Enclosed curves contain all sites of a given stream order. See Table 1 for abbreviations used for species.

Table 3. Mussel community diversity at sites of different stream orders in the Assiniboine River drainage in Manitoba.

Variable	Order				
	3rd	4th	5th	6th	7th
Number of sites	8	9	7	8	15
No. of mussels collected	112	97	90	138	79
Species richness	3	6	8	9	10
Shannon's index of diversity (H)	0.67	1.34	1.51	1.82	1.91

8), with widths over 12 meters, and on predominately sand and gravel substrates (Figure 9). The specimens of *F. flava* collected ranged from 18.6 to 90.4 mm in length (mean=53.3±12.6 SD, N=33), 14.9 to 67.0 mm in height (mean=40.6±9.2 SD), and 7.8 to 39.1 mm in width (mean=22.0±6.0 SD). The youngest individual collected was 1 year old, and the oldest was 11 (mean=6±2, N=29).

Amblema plicata (three ridge)

Amblema plicata accounted for 4.3% of the mussels collected in this survey. *A. plicata* was collected alive in two streams: the Assiniboine and Souris Rivers. Empty valves were collected from the Little Saskatchewan River. Most (86.4 %) specimens of *A. plicata* collected were found in the Assiniboine River, and accounted for 24.1% of the total mussels collected from this stream. Live specimens of *A. plicata* were found on all types of substrates (Figure 9) and in streams over 40 meters in width. The *A. plicata* collected ranged from 58.2 to 140.0 mm in length (mean=112.15±23.47 SD, N=22), 42.2 to 97.4 mm in height (mean=81.1±16.3 SD), and 24.0 to 59.3 mm in width (mean=46.7±10.3 SD). The ages for individuals of this species could not be determined using the external growth method.

Quadrula quadrula (maple leaf)

Quadrula quadrula accounted for 1.2 % of the total mussels collected in this survey, and was found only in the Assiniboine River. It was found most commonly on sand and clay substrates, and never was found in silt (Figure 9). The specimens of *Q. quadrula* collected ranged from 34.0 mm to 113.5 mm in length (mean=82.3±30.7 SD, N=6), 27.6 to 82.3 mm in height (mean=64.3±20.6

SD), and 14.3 to 46.5 mm in width (mean=37.2±13.1 SD). The ages of individuals of this species could not be determined using the external growth method.

Lasmigona complanata (white heelsplitter)

Lasmigona complanata comprised 7.2% of the mussels collected in this survey. It was most common in the Souris River, representing 21.1% of total mussels found in that stream. Specimens of this species were found in streams of orders four to seven (Figure 8), and with widths over 4.5 meters. Specimens of *L. complanata* were found most commonly on sand and gravel substrates (Figure 9). The specimens of *L. complanata* collected ranged from 11.8 to 167.0 mm in length (mean=81.2±32.7 SD, N=22), 11.0 to 107.2 mm in height (mean=61.4±20.4 SD), and 4.6 to 65.0 mm in width (mean=26.4±12.3 SD). The youngest individual collected was 1 year old, and the oldest was 12 years old (mean=7±4, N=14).

Lasmigona compressa (creek heelsplitter)

Only four live specimens of *L. compressa* were collected in this survey. Live individuals were collected from three streams, but empty valves were collected from three others (Table 2). Specimens were found at fourth and fifth order sites with stream widths of 4.5 to 20.8 meters. Specimens of *L. compressa* were found on silt, sand, gravel, and cobble substrates (Figure 9). The individuals collected ranged from 73.3 to 80.1 mm in length (mean=75.2±3.3 SD, N=4), 39.6 to 46.1 mm in height (mean=42.7±2.6 SD), and 19.4 to 21.0 mm in

width (mean=19.8±0.8 SD). Only one individual could be aged, and it was 5 years old.

Anodontooides ferussacianus (cylindrical papershell)

Anodontooides ferussacianus was the second most abundant species collected in this survey, comprising 21.5% of the total living individuals. Fifty three percent of the individuals collected were from the Cypress River, a fourth order stream. Specimens of *A. ferussacianus* accounted for 83% of the mussels collected from the Cypress River, and 94.1% from the East Shell River. Evidence of *A. ferussacianus* was found in 13 streams, and live specimens were collected from eight. It was mainly collected from third or fourth order sites (Figures 8 and 11), but was found in the Souris River, a sixth order stream. Specimens of *A. ferussacianus* were primarily found on sand substrates (Figure 9) in streams that were from 2.4 to 40 meters in width. The individuals collected ranged from 15.1 to 76.3 mm in length (mean=45.4±14.35 SD, N=112), 9.3 to 39.5 mm in height (mean=24.6±7.4 SD), and 4.1 to 28.8 mm in width (mean=15.0±5.8 SD). The oldest *A. ferussacianus* collected was 7 years old (range 0-7, mean=3±2 SD, N=110).

Pyganodon grandis (giant floater)

Pyganodon grandis was the third most abundant mussel species found in this survey, accounting for 16.8% of the total live mussels collected. It had the widest distribution of all the mussels found in the Assiniboine River drainage: evidence of *P. grandis* was found in 18 of the streams sampled, and live individuals were collected from 13 streams. Specimens of *P. grandis* occurred in

streams with widths over 4.5 meters and orders three to seven, but was most common at sites with orders of three to five (Figure 8). They were found on all types of substrates but were found most often on silt, sand, and gravel (Figure 9). The specimens of *P. grandis* collected ranged from 21.2 to 117.1 mm in length (mean=80.3±19.3 SD, N=94), 12.2 to 80.1 mm in height (mean=44.5±11.3 SD), and 6.1 to 61.4 mm in width (mean=27.5±8.3 SD). The youngest individual collected was 1 year old, and the oldest was 13 (mean=6±3, N=75).

Strophitus undulatus (creeper)

Strophitus undulatus comprised 2.9% of the total living individuals collected in this study. Live individuals of *S. undulatus* were found in four streams in the study area, and was most common in the Shell River, where it comprised 10% of the mussels collected from that stream. They were found at sites with stream orders five to seven (Figure 8), and over ten meters in width. This mussel was found most commonly on silt, sand, and gravel substrates (Figure 9). It was found rarely on cobble, and never on clay. The specimens of *S. undulatus* collected ranged from 35.9 to 87.2 mm in length (mean=61.0±18.9 SD, N=5), 22.9 to 47.0 mm in height (mean=33.6±9.3 SD), and 11.4 to 31.1 mm in width (mean=20.7±7.1 SD), and ranged in age from 5 to 10 years (mean=7±3 SD, N=3).

Potamilus alatus (pink heelsplitter)

Potamilus alatus comprised 4.3% of the living mussels collected in this survey. Specimens were found only in the Assiniboine River, where at 28.9% it was the most common species found. Specimens of *P. alatus* were found on all

types of substrates, but occurred most commonly on silt and sand (Figure 9). The specimens of *P. alatus* collected ranged from 71.6 to 142.0 mm in length (mean=119.0±16.7 SD, N=22), 74.0 to 125.4 mm in height (mean=101.8±12.3 SD), and 24.9 to 51.7 mm in width (mean=41.9±5.3 SD). No individuals of this species were aged.

Ligumia recta (black sandshell)

Ligumia recta comprised 2.7% of the living mussels collected in this study. It was found in rivers with stream orders of five to seven (Figure 8). Specimens were found on all substrates, but were most common on sand (Figure 9). The specimens of *L. recta* collected ranged from 76.8 to 147.2 mm in length (mean=114.4±20.4 SD, N=14), 35.3 to 67.5 mm in height (mean=52.4±9.5 SD), and 19.1 to 44.0 mm in width (mean=32.1±7.5 SD). The youngest age recorded was 7 year old, and the oldest was 13 (mean=10±2 SD, N=7).

Lampsilis siliquoidea (fat mucket)

Lampsilis siliquoidea was the most abundant species encountered during this study, comprising 25.6% of the total mussels sampled. *L. siliquoidea* had a wide distribution in the study area; evidence of this species was found in 14 streams, and live specimens were collected from nine (Table 2). Proportionately, specimens of *L. siliquoidea* were most common in the Little Saskatchewan River, where they comprised 58.6% of the live mussels collected. All seven Souris River sites yielded specimens of *L. siliquoidea*. Specimens were found at sites with stream orders three to five (Figure 8), and on all types of substrates, but predominately on silt, sand, and gravel (Figure 9). The specimens of *L.*

siliquoidea collected ranged from 11.1 to 125.4 mm in length (mean=77.3±21.2 SD, N=134), 10.5 to 77.4 mm in height (mean=46.0±11.3 SD), and 5.0 to 55.7 mm in width (mean=28.0±9.3 SD). The youngest age recorded was 3 year old, and the oldest was 21 (mean=9±4 SD, N=72).

Lampsilis cardium (plain pocketbook)

Lampsilis cardium accounted for 6.4% of the live mussels encountered in this study. Live specimens were collected alive from 5 streams, and empty valves were collected from two others (Table 2). Proportionally, specimens of this species were most numerous in the Little Saskatchewan River, where they accounted for 17.1% of the mussels collected. Live specimens were found in streams that had stream orders of five and larger (Figure 8), and with widths greater than 12 meters. Specimens of *L. cardium* occurred on all substrates, but were most common on sand (Figure 9). Measurements ranged from 51.4 to 130.3 mm in length (mean=87.63±18.9 SD, N=34), 33.2 to 88.6 mm in height (mean=60.9±14.0 SD), and 19.5 to 59.0 mm in width (mean=36.8±9.9 SD). The 13 live *L. cardium* that were aged ranged from 5 to 11 years old (mean=8±2 SD).

Discussion

Species Accounts

Twelve species of freshwater mussels were found in the Assiniboine River drainage in Manitoba. The following account of each species is intended to provide the reader with information about their distribution, habitat preferences,

and maximum size attained by specimens found in this study compared to those reported by Clarke (1981).

Fusconaia flava (Wabash pigtoe)

Fusconaia flava occurs in the Ohio-Mississippi River System, the Great Lakes-St. Lawrence River system in the United States and southern Ontario, and in the Red River, Lake Winnipeg and Nelson River System in Manitoba (Clarke 1981).

In the Assiniboine River drainage, specimens of *F. flava* occurred in small to large streams (Figure 8) and were found most commonly on sand and gravel substrates (Figure 9). In other studies, *F. flava* has been reported from small to large streams, and occasionally from reservoirs and lakes (Clarke 1981, Cvancara 1983, Gordon and Layzer 1989). As in this study, Clarke (1973) and Cvancara (1983) collected *F. flava* from only medium to large rivers (over 12 m wide) in the Canadian Interior Basin and North Dakota. Although *F. flava* usually is reported as having broad habitat tolerances (e.g. Buchanan 1980, Clarke 1973, Gordon and Layzer 1998), some studies support the observation that this species prefers gravel and sand substrates (Oesch 1984, Parmalee and Bogan 1998).

Clarke (1981) reported that in Canada specimens of *F. flava* may grow up to 100 mm long, 70 mm high, and 40 mm wide. Specimens collected from the Assiniboine River drainage reached only 90.4 mm long, 67 mm high, and 39.1 mm wide.

Amblema plicata (threeridge)

Amblema plicata occurs throughout the entire Ohio-Mississippi River system, the Gulf Drainages in Mississippi, Louisiana, and eastern Texas, the Red River and Lake Winnipeg drainage areas, and the Great Lakes-St. Lawrence River drainage (Clarke 1973, Parmalee and Bogan 1998).

In the Assiniboine River drainage, specimens of *A. plicata* occurred in large (sixth and seventh order) streams (Figure 8), and were found on all types of substrates (Figure 9). Other workers found the threeridge in a variety of habitats, from small streams to large rivers, lakes, and in all types of substrates (Parmalee and Bogan 1998). Although Cvancara (1983) and Clarke (1973) found specimens of *A. plicata* in streams over 11 m wide, in this survey they were found only in streams over 40 m wide. Contrary to this study, *A. plicata* has been reported to prefer mixtures of mud, sand, and gravel (Buchanan 1980, Oesch 1984, Parmalee and Bogan 1998).

Clarke (1981) reported that in Canada specimens of *A. plicata* may grow up to 150 mm long, 105 mm high, and 65 mm wide. Specimens collected from the Assiniboine River drainage reached only 140 mm long, 97.4 mm high, and 59.3 mm wide.

Quadrula quadrula (maple leaf)

Quadrula quadrula occurs throughout the entire Ohio-Mississippi and Alabama River systems, from Texas and Alabama to Minnesota and Pennsylvania, the Red River system in Manitoba and the United States, and in

the St. Lawrence River system, from Wisconsin to southern Ontario and western New York (Clarke 1973, Buchanan 1980).

In the Assiniboine River drainage, *Q. quadrula* was found only in the Assiniboine River (Figure 8) and was most common on sand and clay substrates (Figure 9). Most authorities consider the maple leaf a large river species (Gordon and Layzer 1989), but it has been known to do well in shallow lakes and reservoirs (Parmalee and Bogan 1998). In North Dakota, Cvancara (1983) only collected living specimens of *Q. quadrula* from the Red River (stream width over 30 m), whereas Clarke (1973) found them in rivers over 12 m wide in the Canadian Interior Basin. Unlike this study, Buchanan (1980) and Oesch (1984) found that specimens of *Q. quadrula* occurred primarily on coarser substrates (gravel to boulder) in Missouri. *Q. quadrula* is usually reported to prefer mud, sand, or fine gravel substrates (Clark 1981, Cummings and Mayer 1992, Parmalee and Bogan 1998). In the Canadian Interior Basin, Clarke (1973, p 33) found specimens of this species in "mud or sand with or without clay, rocks, or gravel".

Clarke (1981) reported that in Canada specimens of *Q. quadrula* may grow up to 125 mm long, 100 mm high, and 50 mm wide. Specimens collected from the Assiniboine River drainage only reached 113.5 mm long, 82.3 mm high, and 46.5 mm wide.

Lasmiogona complanata (white heelsplitter)

Lasmiogona complanata occurs throughout the Ohio- Mississippi River system, the Alabama River system, the Middle Great Lakes-Upper St. Lawrence

River in the United States and southern Ontario, and the Lake Winnipeg-Nelson River drainage basin, from western Ontario to Alberta (Clarke 1973, Parmalee and Bogan 1998).

In the Assiniboine River drainage, specimens of *L. complanata* were found in small to large (fourth to seventh order) streams (Figure 8), and were most common on sand and gravel substrates (Figure 9). Other studies report that the white heelsplitter can be found in a wide variety of habitats, including small to large streams, ponds, lakes, and reservoirs (Cvancara 1983, Parmalee and Bogan 1998). Unlike this study, individuals of this species often are reported to prefer areas of low flow with mud and sand substrates (Buchanan 1980, Clarke 1981, Oesch 1984, Cummings and Mayer 1992, Parmalee and Bogan 1998).

Clarke (1981) reported that in Canada specimens of *L. complanata* may grow up to 190 mm long, 125 mm high, and 65 mm wide. Specimens collected from the Assiniboine River drainage only reached 167 mm long, 107.2 mm high, and 65 mm wide.

Lasmigona compressa (creek heelsplitter)

Lasmigona compressa occurs in the Hudson River drainage in New York, and the Ohio-Mississippi River, Great Lakes-St. Lawrence River, and Hudson Bay drainages from Saskatchewan to Quebec and from Nebraska to West Virginia (Clarke 1973, 1981).

In the Assiniboine River drainage, specimens of *L. compressa* occurred in small to medium sized streams (Figure 8) and were found on silt to cobble substrates (Figure 9). Other studies report that the creek heelsplitter usually

occurs in small to medium rivers, but occasionally may be found in larger rivers or lakes (Clarke 1981, Cvancara 1983, Cummings and Mayer 1992). As in this study, Clarke (1973, 1981) and Cvancara (1981) found specimens of *L. compressa* on silt to cobble substrates.

Clarke (1981) reported that in Canada specimens of *L. compressa* may grow up to 115 mm long, 55 mm high, and 40 mm wide. Specimens collected from the Assiniboine River drainage reached only 80.1 mm long, 46.1 mm high, and 21 mm wide.

Anodontooides ferussacianus (cylindrical papershell)

Anodontooides ferussacianus occurs in the Ohio-Mississippi River, Great Lakes-St. Lawrence and Ottawa River systems, from Montreal, New York, and North Dakota to Colorado and Tennessee, and in the James Bay and Hudson Bay systems, from southeastern Saskatchewan to central Ontario (Clarke 1981, Parmalee and Bogan 1998).

In the Assiniboine River drainage, specimens of *A. ferussacianus* were found primarily on sand substrates (Figure 9) and in smaller (third and fourth order) streams (Figure 8). Specimens also were collected from the Souris River, which is a sixth order stream. The cylindrical papershell typically is considered a small streams species of mussel, but occasionally may be found in larger rivers and lakes (Clarke 1981, Cvancara 1983, Oesch 1984, Parmalee and Bogan 1998). It usually is reported to prefer mud or sand bottoms (Clarke 1973, 1981, Cummings and Mayer 1992, Parmalee and Bogan 1998), but sometimes may be found in gravel and cobble (Buchanan 1980, Gordon and Layzer 1989).

Clarke (1981) reported that in Canada specimens of *A. ferussacianus* may grow up to up to 95 mm long, 40 mm high, and 40 mm wide. Specimens collected from the Assiniboine River drainage reached only 76.3 mm long, 39.5 mm high, and 28.8 mm wide.

Pyganodon grandis (giant floater)

Pyganodon grandis occurs throughout the Mississippi-Missouri River drainage, the Gulf of Mexico drainages in Louisiana and Texas, and in most of the St. Lawrence River, Hudson Bay, and Arctic drainages, from Quebec and northern Alberta northwest to the Mackenzie River Delta (Clarke 1973, 1981).

In the Assiniboine River drainage, specimens of *P. grandis* occurred in small to large rivers (Figure 8) and were found most commonly on silt, sand, and gravel substrates (Figure 9). The giant floater has been reported from small to large streams, lakes, ponds, and reservoirs (Clarke 1981). It occurs in all types of sediments, but mud or mud-gravel generally is considered its preferred substrate (Buchanan 1980, Clarke 1981, Oesch 1984, Cummings and Mayer 1992, Parmalee and Bogan 1998). Cvancara (1983) reported specimens of *P. grandis* primarily were found from small streams in North Dakota, whereas Clarke (1973) collected specimens from rivers 6 to 90 m wide in the Canadian Interior Basin.

Clarke (1981) reported that in Canada specimens of *P. grandis* may grow up to 160 mm long, 100 mm high, and 75 mm wide. Specimens collected from the Assiniboine River drainage reached only 117.1 mm long, 80.1 mm high, and 61.4 mm wide.

Strophitus undulatus (creeper)

Strophitus undulatus is found throughout the Ohio-Mississippi River drainage, from Pennsylvania to Minnesota and central Texas to Tennessee, the Atlantic coast drainage from Nova Scotia to the upper Savannah River System in South Carolina, the entire Great Lakes-St. Lawrence system, and in the Red River and Nelson River systems from Saskatchewan to western Ontario and North Dakota (Clarke 1973, Parmalee and Bogan 1989).

In the Assiniboine River drainage, specimens of *S. undulatus* were found in medium to larger rivers (Figure 8) and were most common on silt, sand, and gravel substrates (Figure 9). The creeper has been reported from a variety of habitats, including small to large rivers and lakes, and in silt to cobble substrates (Buchanan 1980, Cvancara 1983, Parmalee and Bogan 1998). It usually is reported to be most abundant in small to medium sized rivers in mud, sand, or gravel substrates (Clarke 1973, Gordon and Layzer 1989, Parmalee and Bogan 1998).

Clarke (1981) reported that in Canada specimens of *S. undulatus* may grow up to 100 mm long, 55 mm high, and 45 mm wide. Specimens collected from the Assiniboine River drainage reached only 97.2 mm long, 47 mm high, and 31.1 mm wide.

Potamilus alatus (pink heelsplitter)

Potamilus alatus occurs throughout the Mississippi River system, from eastern North Dakota to Pennsylvania, and south to Arkansas, Tennessee and northern Alabama, the Great Lakes-St. Lawrence River system, except Lake

Superior, and in the Red River and Winnipeg River systems in Manitoba (Clarke 1973, Clarke 1983).

In the Assiniboine River drainage, specimens of *P. alatus* were found only in the Assiniboine River (a seventh order stream), and were most common on silt and sand substrates (Figure 9). The pink heelsplitter may be found in a wide range of habitats, including lakes, reservoirs, medium to large rivers, and, on rare occasion, small streams (Cvancara 1983, Gordon and Layzer 1989). Although it may be found in almost any type of substrate (Buchanan 1980, Gordon and Layzer 1989), usually it is reported to prefer mud or sand and gravel in medium to large rivers (Clarke 1973, 1981, Cvancara 1983, Cummings and Mayer 1992, Parmalee and Bogan 1998).

Clarke (1981) reported that in Canada specimens of *P. alatus* may grow up to 150 mm long, 100 mm high, and 55 mm wide. Specimens collected from the Assiniboine River drainage reached only 142 mm long, 125.4 mm high, and 51.7 mm wide.

Ligumia recta (black sandshell)

Ligumia recta occurs throughout the Mississippi River system, from Minnesota to western New York and Pennsylvania southwest to Oklahoma, the Alabama River system in Alabama and Georgia, the Great Lakes-St. Lawrence River system, except Lake Superior, and in the Red River and Winnipeg River systems in Manitoba (Clarke 1973, 1981, Parmalee and Bogan 1998).

In the Assiniboine River drainage, specimens of *L. recta* were collected from medium to large rivers (Figure 8) and was found most commonly on sand

substrates (Figure 9). The black sandshell usually is reported to prefer medium to large rivers, but it also may be found in lakes (Clarke 1981, Cummings and Mayer 1992, Parmalee and Bogan 1998). It is reported to prefer sand or gravel substrates (Clarke 1981, Oesch 1984, Cummings and Mayer 1992, Parmalee and Bogan 1998), and occasionally mud (Clarke 1973, 1981, Gordon and Layzer 1989).

Clarke (1981) reported that in Canada specimens of *L. recta* may grow up to 175 mm long, 75 mm high, and 45 mm wide. Specimens collected from the Assiniboine River drainage reached only 147.2 mm long, 67.5 mm high, and 44 mm wide.

Lampsilis siliquoidea (fat mucket)

Lampsilis siliquoidea occurs throughout the entire Mississippi River basin, except for the Tennessee and Cumberland River drainages, and from western New York to Minnesota, Colorado, and Montana, south to Arkansas. It also is found in the Ottawa River, the St Lawrence River-Great Lakes drainage, the Canadian Interior Basin from Quebec to Alberta, and the Mackenzie River system north to Great Slave Lake (Clarke 1973, Parmalee and Bogan 1998).

In the Assiniboine River drainage, specimens of *L. siliquoidea* were found in small to medium sized rivers (Figure 8) and on all types of substrates, but predominately on silt, sand, and gravel (Figure 9). The fat mucket has been found in all types of habitats, including small to large rivers, lakes, and reservoirs (Clarke 1973, Cvancara 1983). Although it occurs on all types of substrates (including cracks in bedrock) (Gordon and Layzer 1989), specimens of *L.*

siliquoidea have been reported to prefer mud, sand, or gravel (Cummings and Mayer 1992, Parmalee and Bogan 1998). Clarke (1973) found that in the Canadian Interior Basin, specimens of *L. siliquoidea* (*radiata siliquoidea*) were often the only mussel species present at a site, and usually dominated when present.

Clarke (1981) reported that in Canada specimens of *L. siliquoidea* (*radiata siliquoidea*) may grow up to 140 mm long, 70 mm high, and 55 mm wide. Specimens collected from the Assiniboine River drainage reached only 125.4 mm long, 77.4 mm high, and 55.7 mm wide.

Lampsilis cardium (plain pocketbook)

Lampsilis cardium occurs throughout the entire Mississippi River system, ranging from Arkansas and Tennessee north to North Dakota and Wisconsin, and from Kansas east to New York (Cvancara 1983, Parmalee and Bogan 1998). It also occurs throughout the Great Lakes-St. Lawrence system, the Winnipeg, Red, and Nelson River systems in eastern Saskatchewan and Manitoba, and has been introduced into the Potomac River in the Atlantic drainage area (Clarke 1981). See Appendix 1 for more information about the distribution of *L. cardium* in North America.

In the Assiniboine River drainage, specimens of *L. cardium* were collected from medium to large streams (Figure 8), and were found most commonly on sand substrates. The plain pocketbook is considered a large river species (Gordon and Layzer 1989), but it has been reported to occur in lakes and small streams (Cvancara 1983). Specimens of this species may be found on almost

any type of substrate (Buchanan 1980, Clarke 1981), but they have been reported to avoid shifting sands (Oesch 1984) and to "thrive on a stable substrate composed of a high percentage of mud and silt" (Parmalee and Bogan 1998). It is interesting that in this study, many specimens of *L. cardium* collected from the Assiniboine River occurred in sand, and often were the only species present in these substrates (personal observations).

Clarke (1981) reported that in Canada specimens of *L. cardium* (*ventricosa*) may grow up to 155 mm long, 100 mm high, and 75 mm wide. Specimens collected from the Assiniboine River drainage reached only 130.3 mm long, 88.6 mm high, and 59 mm wide.

Zoogeography

The re-invasion of freshwater mussels into the Assiniboine River drainage basin began soon after the retreat of the Wisconsin ice sheet about 11,500 years ago (Clayton 1983). The 12 unionid species found in the Assiniboine River basin probably originated from the Mississippi River basin, entering via a former confluence between the Minnesota (upper Mississippi drainage basin) and Red rivers (Johnson 1980). Pro-glacial lakes and drainage courses would have provided initial migration routes for fish (Stewart and Lindsey 1983) and the mussels that used them as hosts. *Pyganodon grandis* and *L. siliquoidea* probably were the first freshwater mussel species to enter into the Red River drainage: their fossil remains have been found in 11,500-year-old ice-contact deposits in North Dakota (Tuthill 1961, Tuthill et al. 1964). *Lasmigona compressa*, *L. siliquoidea* and *A. ferussacianus* could also have entered the

Hudson Bay drainage from the Great Lakes-St. Lawrence River System via a connection with the Rainy River-Winnipeg River System at Saganaga Lake (Clarke 1973, Johnson 1980). The transfer of new biota (mussels and their host fish) from the upper Mississippi River drainage basin is still possible when the Minnesota and Red Rivers are joined through a connection at Big Stone Lake and Lake Traverse (see Figure 12) during periods of high water (Clarke 1973). *Lasmsgona costata* is known to be tolerant of a wide range of substrates and habitats (Clarke 1981). The presence of *L. costata* in the eastern tributaries of the Red River and the Winnipeg River system, and not the Assiniboine River drainage (Figure 12), may indicate an alternative avenue of dispersal for this species. Outside of the Red and Winnipeg River systems *L. costata* occurs in the Great Lakes-St. Lawrence system, from southern Lake Huron east to the Ottawa River and Lake Champlain, and in the entire Mississippi River system (Clarke 1973). Dispersal of *L. costata* into the Winnipeg River system from the Great Lakes-St. Lawrence system is unlikely since it has not been recorded from the intervening area. Since *L. costata* is known to use cold-water adapted fish species that are in the study area (specifically, northern pike, *Esox lucius* Linnaeus, yellow perch, *Perca flavescens* Mitchill, and walleye, *Stizostedion vitreum* Mitchill) (Hove et al. 1994 in Parmalee and Bogan 1998), the absence of *L. costata* in the Assiniboine River drainage suggests it has indirectly entered the Winnipeg River systems via the upper Mississippi River system.

Stewart and Lindsay (1983) suggest that warm water-adapted fish species could not have survived in a pro-glacial lake and “may have existed in streams

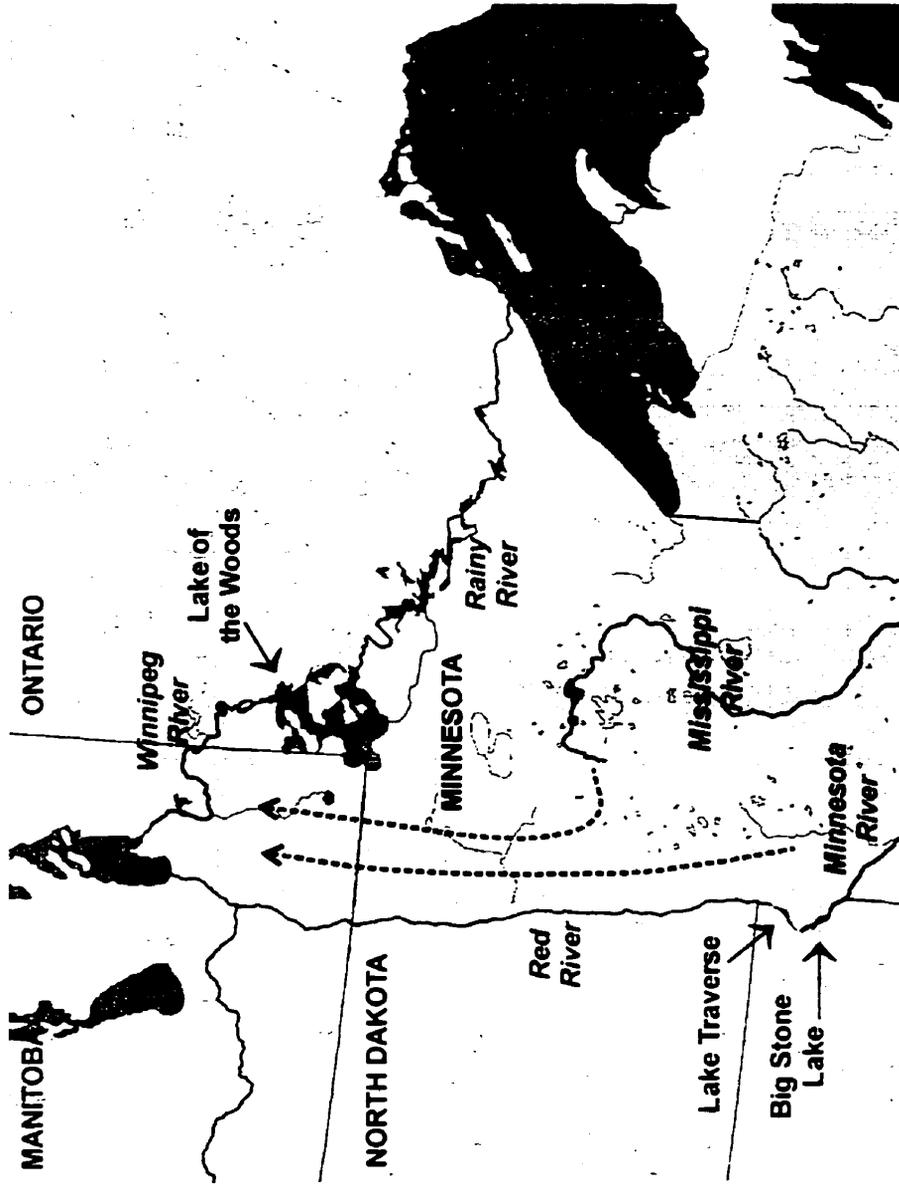


Figure 12. Distribution of *Lasmigona costata* in Manitoba and north central United States. Proposed avenue of northern post-glacial dispersal are represented by dashed lines.

and ponds peripheral to Lake Agassiz" (pp. 416). Since *L. costata* utilizes warm-water adapted fish hosts that are found in the study area (the rockbass, *Ambloplites rupestris* Rafinesque, Smallmouth bass, *Micropterus dolomieu* Lacépède, and brown bullhead, *Ameiurus nebulosus* Lesueur) (Luo 1993 in Parmalee and Bogan 1998), it may have dispersed northward from the upper Mississippi River system into the Winnipeg River system by way of a marshy area of land along the eastern edge of the province (Figure 12). The mudpuppy, *Necturus maculosus* Rafinesque, which has a similar distribution to that of *L. costata* in Manitoba, may have used the same avenue of dispersal (K.W. Stewart personal communication 1997). It is possible that the distribution of the two species is similar because, although it has not been demonstrated, *L. costata* may actually use the mudpuppy as a host. Recent experiments indicate that amphibians may be more important as hosts for freshwater mussels than had been previously thought (Watters and O'Dee 1998).

Species Associations

Many factors are important in determining the distribution and abundance of freshwater mussels in lotic systems. Unfortunately, the effects of any one factor cannot easily be distinguished from another because of the great variation and overlap that exists in microhabitat tolerances of different mussel species (Simpson et al. 1986, Huehner 1987). Consequently, any one factor is of limited use when predicting the occurrence of particular mussel species in running waters (Strayer 1981, Strayer and Ralley 1993).

The substrate preferences of freshwater mussels are poorly understood, but most authorities recognize substrate type as one of the most important factors in the regulation of species distribution and community structure (James 1985, Simpson et al. 1986). In general, freshwater mussels are most successful in stable, sand-gravel mixtures, and are largely absent from substrates with heavy silt loads (McMahon 1991). Cvancara et al. (1976) state that unstable substrate such as rippled sand is the primary factor that restricts mussel distribution in the Red River System of North Dakota. Heavy silting and unstable shifting sands typically bury mussels, and most species cannot extricate themselves once covered deeply (Bailey 1993, Vannote and Minshall 1982). In the Assiniboine River drainage, however, mussels were found most frequently on these silt and sand substrates (Figure 9). This is probably not a function of substrate preference, but because there was simply more of the finer substrates available for mussels to use at each site.

Freshwater mussel distribution is influenced by stream size (Strayer 1993). As a drainage area increases in size, there usually is a corresponding increase in the number of mussel species, with an addition and/or replacement of species in a downstream direction (Warren et al. 1984, McMahon 1991). Mussels in the Assiniboine River drainage follow this general trend (Table 3).

The four freshwater mussel groups resulting from the cluster analysis (Figure 10) can be named after the common stream order preferences that members of each category exhibited in this study occur in the Assiniboine River drainage: (1) one ubiquitous species, *L. siliquoidea*; (2) a large stream category

(*L. cardium* group); (3) a medium stream category (*L. compressa* category); and (4) a small stream category (*P. grandis* and *A. ferussacianus*). Note that the cluster analysis was conducted only on species associations and not habitat variables. *Lampsilis siliquoidea*, the ubiquitous species, was found in all stream orders in the Assiniboine River drainage. *Anodontoidea ferussacianus* and *P. grandis* could be considered small stream (low order) species because they were found predominately in low (third and fourth) order streams. *Lasmigona compressa*, *L. complanata* and *S. undulatus* were all most commonly found in fifth and/or sixth order (medium stream) sites. All the large stream category species occurred most frequently in the Assiniboine River (the only seventh order stream), with the exceptions of *F. flava* and *L. recta*. Stream order occurrences for *F. flava*, *L. recta*, and *L. cardium* (Figure 8) indicate they could be included in the medium stream category.

Membership of a species in any one category should not be considered absolute. The correspondence analysis biplot (Figure 11) indicates there is a gradual transition in species composition between the different stream orders. The position of *A. ferussacianus* in correspondence analysis biplot (Figure 11) indicates, correctly, that it is most common in third order and fourth order streams. *Pyganodon grandis* is more centrally located in the correspondence analysis biplot (Figure 12) because of its high frequency in third, fourth, and fifth order streams. *Fusconaia flava*, *L. recta* and *L. cardium* are found in both medium and large streams (predominately fifth to seventh order sites). The other

large stream category members (*A. plicata*, *Q. quadrula* and *P. alatus*) were found almost exclusively in the Assiniboine River.

Since the stream size preferences of mussels within each of the four categories are similar, stream order may be a useful parameter to predict the general freshwater mussel species composition in streams within the Assiniboine River drainage.

Potential threats to mussels in the Assiniboine River drainage

The decline, extirpation and eventual extinction of 13 species of North American freshwater mussels is tied directly to the degradation and loss of essential habitat and loss of host fish (Bogan 1993, Williams et al. 1993). The habitat degradation observed in the Assiniboine River drainage eventually may lead to severe declines in mussel populations in Manitoba.

Impoundments on the Assiniboine River and its tributaries may deleteriously affect the Province's populations of freshwater mussels. The stable riffle habitats that unionids need to grow and reproduce are those that are most effected by dams (Layzer et al. 1993). Damming alters the fish fauna, substrate composition, water chemistry, dissolved oxygen content, and temperature in the area below impoundments (Bogan 1993). Mussel populations within the impoundment are lost because of siltation and oxygen depletion in the hypolimnion (Layzer et al. 1993). Alterations in water temperature cycles in the impoundment or the areas below them, suppress or induce reproduction at the wrong times, cause abortion of glochidia, and may delay mussel maturation and/or development (Fuller 1974, Layzer et al. 1993). Mussel populations below

impoundments can not tolerate the prolonged and frequent periods of dewatering associated with flood control or yearly maintenance (Layzer et al. 1993). Drawdown of an impoundment also may cause the total loss of whatever mussel populations existed in the reservoir (Samad and Stanley 1986). The construction of fish-ways in dams does allow the re-invasion of mussels into stretches of river that have lost their mussel populations (Smith 1985). Some spillways also support rich faunal assemblages, yet they must have stable substrates, adequate oxygen and nutrient concentrations, and not be choked with macrophytes (Fuller 1974). Shallow and productive impoundments above dams can offer a rich food source to mussel populations that are downstream (Fuller 1974).

River channel modifications of many low order streams in the Assiniboine River drainage also may affect mussel populations. The dredging process of altering waterways for flood control or improved drainage destroys mussel populations. These changes need not be bad for freshwater mussels, as they may quickly repopulate the area if the channel has stable walls and floors, and water flows within the channel are moderate (Fuller 1974). However, channelization usually causes siltation or sand accumulation, which causes declines in mussel numbers (Fuller 1974). Channelization also may create channel adjustments downstream, which may lead to siltation or burial of clam beds (Bogan 1993).

The effects of pollution on mussel populations have been well documented. Pollution from various industries is known to cause the extirpation of the mussel populations of whole rivers (Fuller 1974, Strayer 1980, Bogan

1993). In the Red River Cvangara (1970) found that downstream of a sugar plant at Drayton, North Dakota, a 75% decrease in mussel numbers occurred in less than a year. Untreated sewage effluents enrich local waters; this may increase food production, but typically increases in vegetative growth leads to a reduction in water flow and siltation (Fuller 1974). Agricultural runoff (fertilizers, agricultural chemicals, and topsoil) has similar effects on mussel populations (Strayer 1980).

This study provides some of the first baseline data on species occurrences in this drainage basin. Continued collections in the Assiniboine River drainage will be important to monitor changes in species distributions and to discover the occurrence of new freshwater mussel species, particularly the highly invasive zebra mussel. Agricultural practices must be modified in order to preserve the mussel fauna of small streams within this drainage.

CHAPTER 4 - LIFE HISTORY OF *ANODONTOIDES FERUSSACIANUS* IN THE CYPRESS RIVER, MANITOBA

Introduction

Anodontoides ferussacianus (Subfamily Anodontinae), commonly known as the cylindrical papershell, is a relatively small (up to 7.5 cm long) (Clarke 1973) species of freshwater mussel. Cummings and Mayer (1993) reported it to be "widespread and locally abundant" throughout its range, although it is considered threatened in Iowa (Cummings and Mayer 1993), endangered in Missouri (Oesch 1984), and probably is extirpated in Tennessee (Parmalee and Bogan 1998).

Very little is known of the growth or reproductive cycle of *A. ferussacianus*. Ortmann (1919) and Baker (1928) found that populations of *A. ferussacianus* in Pennsylvania and Wisconsin were bradytictic, with fertilization occurring in August, and the release of glochidia following in May. The blacknose shiner (*Notropis heterolepis* Eigenmann and Eigenmann), bluntnose minnow (*Pimephales notatus* Rafinesque), brook stickleback (*Culea inconstans* Kirtland), common shiner (*Luxilus cornutus* Mitchill), fathead minnow (*Pimephales promelas* Rafinesque), Iowa darter (*Etheostoma exile* Girard), mottled sculpin (*Cottus bairdi* Girard), sea lamprey (*Petromyzon marinus* Linnaeus), white sucker (*Catostomus commersoni* Lacépède) (Watters 1994a), black crappie (*Pomoxis nigromaculatus* Lesueur), spotfin shiner (*Cyprinella spiloptera* Cope) (Hove et al. 1995), largemouth bass (*Micropterus salmoides* Lacépède), and the bluegill

(*Lepomis macrochirus* Rafinesque) (O'Dee and Watters 1998) have been identified as hosts for *A. ferussacianus*. The longevity and age of sexual maturity is unknown for this species. Cvancara (1983, p 36) collected a gravid individual that was "37 mm long with about three rest rings" on its shell. Tevesz et al. (1985) reported an average age of 5.2 for five individuals collected from the Vermilion River, Ohio.

Individuals of *A. ferussacianus* may display a pattern seasonal migration into and out of the sediment. Populations of the freshwater mussel *E. complanata* display non-random vertical migration in both lentic and lotic habitats (Amyot and Downing 1991, 1997, Balfour and Smock 1995). There is a seasonal change from a predominantly epibenthic to an endobenthic existence, burrowing in the fall and coming to the surface in spring or early summer. Juvenile mussels tend to occur exclusively in the sediment year-round, while adults come to the sediment surface as water temperatures increase in the spring, which corresponds to the period of glochidial release (Balfour and Smock 1995). Adult mussels remain epibenthic until water temperatures drop in the fall, when they once again become endobenthic. Movement to the surface by adult females may be necessary for the release of glochidia (Balfour and Smock 1995), and both male and female mussels may need to be epibenthic during the breeding season so that reproduction can occur. It has been suggested that seasonal vertical migration may be a mechanism to avoid predation (Negus 1966; Kondo 1986) or to prevent being swept away during periods of high flow (Balfour and Smock 1995).

The objectives of this study were to (1) to obtain population demographics (such as sex ratio, age, size-class, and growth information), (2) describe the reproductive cycle of *A. ferussacianus*, and (3) to determine if *A. ferussacianus* displays seasonal vertical migrations within the Cypress River.

Methods

Study Area

The study was conducted from May to October 1996 at a site on the Cypress River approximately one km east of the town of St. Alphonse, Manitoba (49°26'30 N, 98°59'47 W). The Cypress River is a fourth-order tributary of the Assiniboine River, and it is a third-order stream at the study area. A population of *A. ferussacianus* was found at this site while conducting the mussel survey in 1995 (Figure 7, site 4). Sediment type at the study area is primarily fine shale. The following fish were collected from within the general area of the sample site in 1995: common shiner (*L. cornutus*), creek chub (*Semotilus atromaculatus* Mitchill), bigmouth shiner (*Notropis dorsalis* Agassiz), fathead minnow (*P. promelas*), blacknose dace (*Rhinichthys atratulus* Hermann), white sucker (*C. commersoni*), johnny darter (*Etheostoma nigrum* Rafinesque), and brook stickleback (*C. inconstans*) (W.G. Franzin, unpublished data). Evidence of predation (partially consumed, fresh-dead mussels) was observed at the study site during the sampling period and in 1995. Fresh tracks in riverbank mud indicated that the predators probably were raccoons.

Mussel Collection and Physical Measurements

Sampling was conducted on 13 days during 1996: May 7, 14, 22, and 28, June 11 and 25, July 24, August 7 and 20, September 7 and 17, and October 5 and 17. A stretch of stream about 1 km long was divided into 13 approximately equal sampling reaches (one for each day sampled). On each date, sampling began by randomly placing four 1 m² quadrats on the stream bottom. Quadrats were placed approximately three meters apart, beginning at the start of the sampling reach and working in an upstream direction. All visible epibenthic individuals (mussels that were visible at the sediment surface) were collected from each quadrat, placed in plastic bags, and put on ice for transport to the laboratory. Endobenthic individuals (mussels below the sediment surface) were then collected from each quadrat by using a hand rake to sift through the sediment to an approximate depth of 30 cm, starting downstream and working upstream.

Depth and velocity readings were taken at each corner and middle of each quadrat. The stream depth and velocity on each sampling date was calculated by taking the average values of all four quadrats. On each sampling date, stream width (width of the wetted channel), water temperature, and a water sample was taken at the beginning of the first sampling reach. Water temperatures and samples were taken at mid-channel prior to sampling. The water sample was packed in ice, brought back to the laboratory, and analyzed for total dissolved phosphorus, dissolved inorganic carbon, dissolved organic carbon, soluble reactive silica, chloride, sulfate, total suspended solids,

conductivity, potassium, calcium, pH, and alkalinity. Additional mussels (both epibenthic and endobenthic) were collected downstream of the sampling site to assess age and reproductive development. Water temperatures were recorded hourly throughout the sampling period with a StowAway™ data logger (Onset Instruments, Pocasset, MA).

To increase the sample size for the assessment of reproduction and growth parameters, additional mussels were collected on July 9. Water samples were not taken on May 7, July 9, or July 24.

Data Collection from Mussel Specimens

In the laboratory the length, width, and height (Figure 5) of each individual collected was measured to the nearest 0.05 mm using digital calipers. Mussels were then pegged open with wooden blocks, fixed in 10% buffered formalin for one week, and stored in 70% ethanol.

Mussel ages first were estimated externally by counting the number of opaque bands on the shell exterior that extended circumferentially from the umbo (i.e. using the external growth method). The external bands were considered annual growth increments, and the number of these rings was referred to as the external age of the mussel. The shells showed distinct external growth rings that were counted easily. The short life span of *A. ferussacianus* in this population prevents crowding of annual rings at the shell margins, as it does in the older individuals of longer-lived species (Neves and Moyer 1988). The internal age of each mussel was determined using a modification of the methods of Balfour and Smock (1988). The right valve of each mussel was embedded in fiberglass liquid

resin, allowed to cure, and then sectioned through the umbo along the axis of maximum growth (Figure 5) using a Buehler Isomet variable speed saw. The exposed valve edge was polished by hand using 1500 grid sandpaper. Shell sections approximately 1 mm thick were then cut, and the polished edge was fastened to a glass slide using epoxy glue. The section was reduced to about 300 μm thick with successively finer sandpaper (down to 1500 grit), leaving a highly polished surface. The sections were viewed using a stereoscope and opaque bands were counted. A band was considered annual only if it started at a discontinuity at the shell margin, and extended uninterrupted from the prismatic layer through to the umbo region. In this study, these true annuli were easily differentiated from false annuli, which were represented by non-continuous bands.

A block of gonad tissue from the central region of the gonadal-visceral mass was dissected from each mussel. The block was then processed through a dehydration series and embedded in paraffin. Serial 8- μm sections were mounted on slides and stained using the Hematoxylin-Eosin method outlined in Humason (1972). The sex of each individual was determined by inspecting the sections using a light microscope, and the presence of glochidia was determined by inspecting marsupial demibranchs with a stereoscope.

Analysis

The Wilcoxon signed rank test was used to compare the differences between external and internal aging techniques.

The calculation of the growth parameters was based on the length at internal age data of both quadrat and additional mussels. The von Bertalanffy (1938) asymptotic growth equation was used to model growth. This equation has been found suitable for describing growth of freshwater mussels (Haukioja and Hakala 1979, Bauer 1997). The von Bertalanffy growth equation is expressed as:

$$L_t = L_{\infty} (1 - e^{-k(t-t_0)})$$

where, L_t denotes shell length at time t , L_{∞} is theoretical maximum shell length, K is the growth constant, T_0 is the hypothetical age when shell length is 0, and t is the age of the mussel. Growth parameters (k , L_{∞} , and t_0) were computed by the least-squares method (Tomlinson and Abramson 1961).

Stage of reproductive development was assigned according to a scheme modified from Holland-Bartels and Kammer (1989):

Stage 1: Indicates that gonad tissue was undifferentiated, and it is not possible to determine the sex of the individual.

Stage 2: Males had well-differentiated gonads, with spermatogonia or spermatids present. Females had acini that contained small ovocytes and nutritive tissue, and some larger ova may have been present.

Stage 3: Males had closely packed acini, and the lumina were filled with tightly packed spermatogonia, spermatids, and

spermatozoa. Females had acini closely associated with the lumina, which were filled with mature ova.

Stages for the occurrence of glochidia in marsupia were assigned according to a scheme modified from Holland-Bartels and Kammer (1989):

Stage 1: Evidence of the recent release of glochidia, which was based on a pad-like, but clear and empty marsupia.

Stage 2: Individuals had no embryos or glochidia present in the marsupia.

Stage 3: Embryos or mature glochidia were present in the marsupia.

A Pearson product correlation analysis was used to explore the correlation between the frequency of epibenthic individuals and each physical and chemical parameter measured.

Results

One hundred and twenty-six mussels were collected from the quadrats, and an additional sixty-four mussels were collected for calculating growth curves and determining reproductive patterns. Measurements for all mussels collected are found in Appendix 6. Out of the 52 quadrats sampled, 63.5% yielded no mussels. In the quadrats that yielded mussels, densities ranged from 1 to 12 individuals/m². The overall mean density of mussels for the study site was 2.4 individuals/m².

Ageing and growth

Of the 190 mussels collected, 182 were aged by thin-sectioning and counting internal bands. Internal ages could not be determined for eight mussels because their valves were broken during the ageing process. Assuming that the internal ageing is a more accurate technique of age determination (Neves and Moyer 1988), the Wilcoxon signed ranks test showed that external aging technique tended to overestimate the age of a mussel ($T = -4.082$, $df = 182$, $p < 0.0005$). The ages of 19 individuals were overestimated by 1 year, and the age of 1 individual was overestimated by 2 years. The age of only one individual was underestimated (by one year). The likelihood of overestimating a mussel's age using the external growth method increased with the age of the mussel. The ages of 6% of the one year olds, 14.3% of the two year olds, and 42.9% of the three to five year olds were overestimated.

Specimens of *A. ferussacianus* collected from the quadrats ranged from young of the year (YOY) to five years in age (Figure 13), with 1-year-olds forming the major year class. Few three to five year old mussels were collected. YOY individuals were not collected from quadrats until October, although the additional collections yielded three young of the year mussels on August 26.

Mussels ranged from 10.4 to 80 mm in length. The von Bertalanffy growth curve derived by the least squares method, using data from all the internally aged mussels, is shown in Figure 14. This population of *A. ferussacianus* showed asymptotic growth. One and two year old mussels grew quickly, but growth of older individuals decreased rapidly with age. The

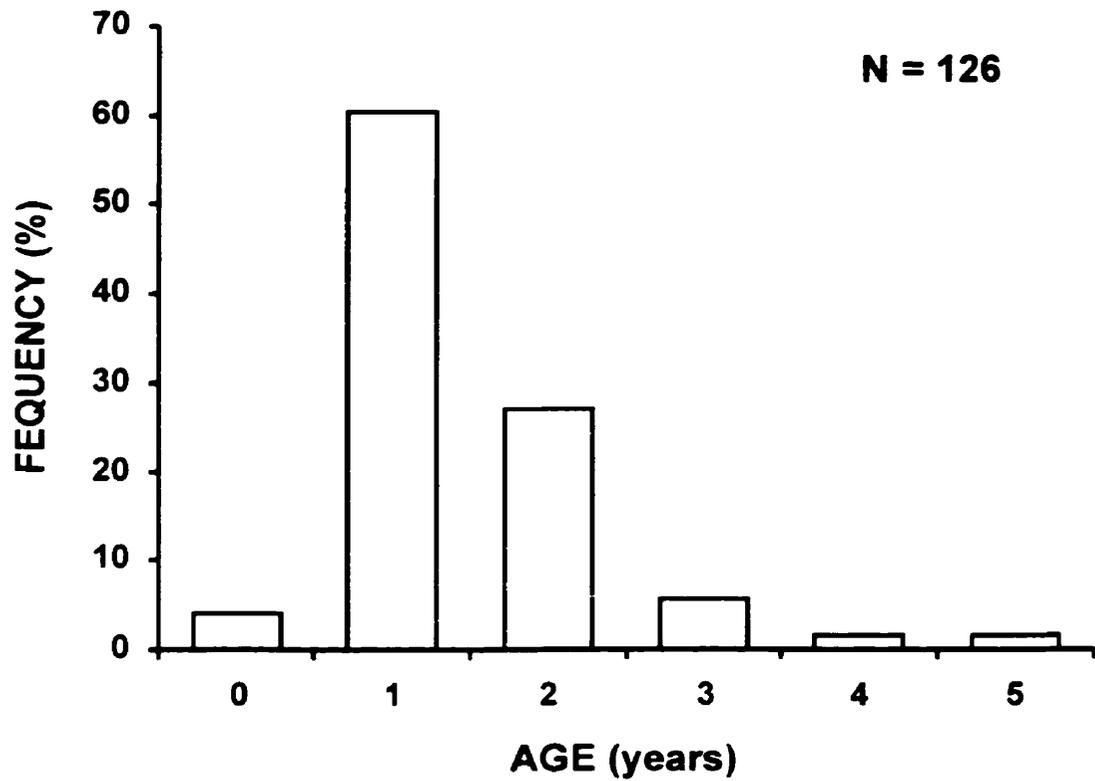


Figure 13. Age structure of the *Anodontoides ferussacianus* collected from quadrats in the Cypress River in 1996.

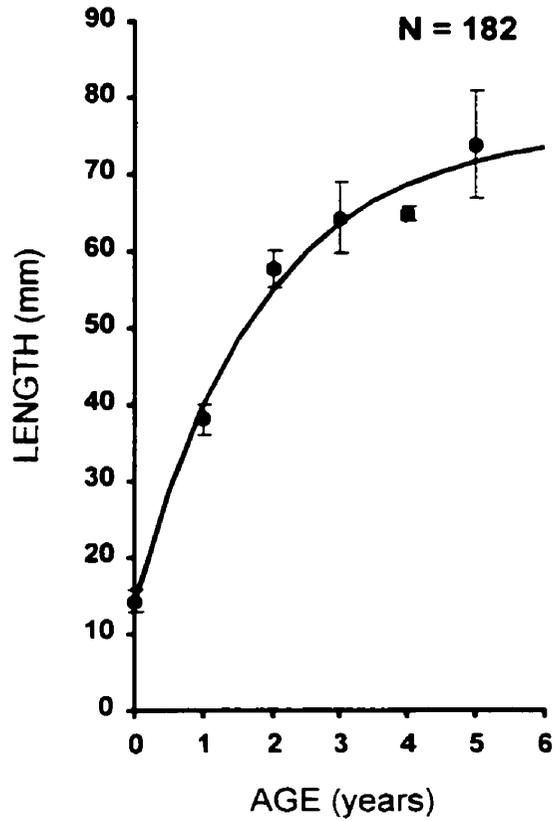


Figure 14. Mean total lengths and von Bertalanffy growth curve of *Anodontoides ferussacianus* collected from the Cypress River in 1996. Vertical bars indicate 95% confidence intervals of the mean

maximum theoretical length calculated by the least squares method was 75.63 mm, t_0 was calculated as -0.30, and k as 0.55.

Seasonal growth in length is shown in Figure 15. Seasonal growth can be seen clearly in year 1 mussels (Figure 15B). The most rapid growth occurred during June, July and August. By the second year of growth (Figure 15C) there was a large variability in lengths among individuals, but the pattern of seasonal growth is still discernable. The lack of the three to five year old individuals (Figure 15D - F) made interpretations of seasonal growth difficult for these age classes. The internal ages for the unsectioned quadrat mussels (four individuals) were estimated by comparing their lengths to the von Bertalanffy growth curve (Figure 14).

Age of sexual maturity, sex ratio, and hermaphroditism

Gonadal sections from 183 specimens of *A. ferussacianus* were examined. All year 0 individuals were in stage 1 of gonad development. Sexual maturity occurred at one year of age. Only four (3.5%) of the year 1 individuals were not sexually mature (stage 1), and three (2.6%) were hermaphroditic. The gonadal section of one hermaphroditic individual had predominately (>95%) male tissue, and two had predominately female tissue (Figure 16). No hermaphroditic or sexually immature individuals were found in the older year classes. Of the 169 sexually mature individuals (including the male and female hermaphrodites), 53% were females and 47% were male, which is not statistically different from a 1:1 sex ratio ($\chi^2 = 0.48$, $df = 1$, $p = < 0.05$).

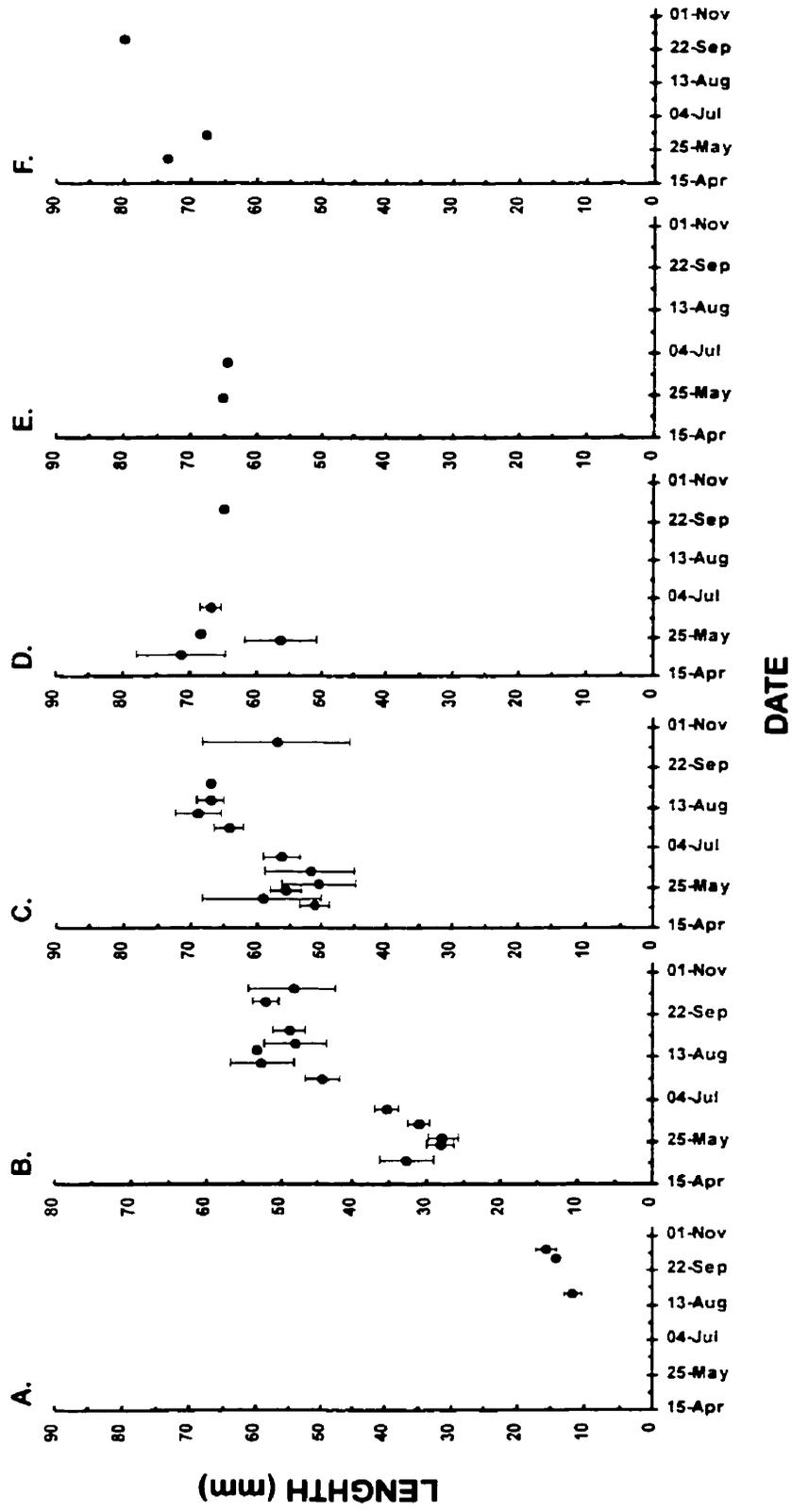


Figure 15. Seasonal growth of *Anodontoidea ferussacianus* collected from the Cypress River in 1996. A. YOY individuals (N = 10); B. Year 1 individuals (N = 116); C. Year 2 individuals (N = 42); D. Year 3 individuals (N = 9); E. Year 4 individuals (N = 2); and F. Year 5 individuals (N = 3). Vertical bars represent 95% confidence intervals of mean lengths. Points without error bars represent measurements of single individuals.

Figure 16. Sections of gonads from hermaphroditic specimens of *Anodontoides ferussacianus* collected from the Cypress River in 1996. A. Stage 3 male hermaphrodite showing a small amount of female tissue (arrow). B. Stage 2 female hermaphrodite showing a small amount of male tissue (arrow). The bar represents 200 μm .



Reproductive cycle

Figure 17 shows the stages of gonad development of mature specimens of *A. ferussacianus* throughout the sampling period. Males were in stage 2 development (Figure 18A) from May until early June. Male gonad maturation and active spermatogenesis (stage 3, Figure 18B) was first observed in late June and persisted until late August (Figure 17). Active spermatogenesis seemed to have begun about a week after water temperatures had risen to about 22°C¹ (Figure 19). Stage 3 development in females (Figure 20B) was first observed in June, when water temperatures reached 22°C, and persisted until early August (Figure 17). From mid-August to September females displayed stage 2 gonad development (Figure 20A). Stage 3 development was again observed in some females from mid-September until the end of the sampling period. No one year-old females had mature glochidia in their marsupia at the beginning of the sampling period (Figure 21A). Evidence of recent release of glochidia was observed in two year and older females until the end of May, although two females were still found brooding mature glochidia in June (Figure 21B). No females had glochidia in their marsupia in July. Embryos were again observed in the marsupia in early August (Figure 21B), which coincides with the end of female oogenesis (Figure 17B). The marsupia of one 1 year-old female did not contain embryos in September (Figure 21A).

¹ Unfortunately, the temperature data logger was lost after the 1996 field. However, there seems to be a good correlation between the water temperatures collected on each sampling date and hourly water temperatures recorded for the Cypress River in 1995. The 1995 temperature data in Figure 19 has been provided for comparative purposes.

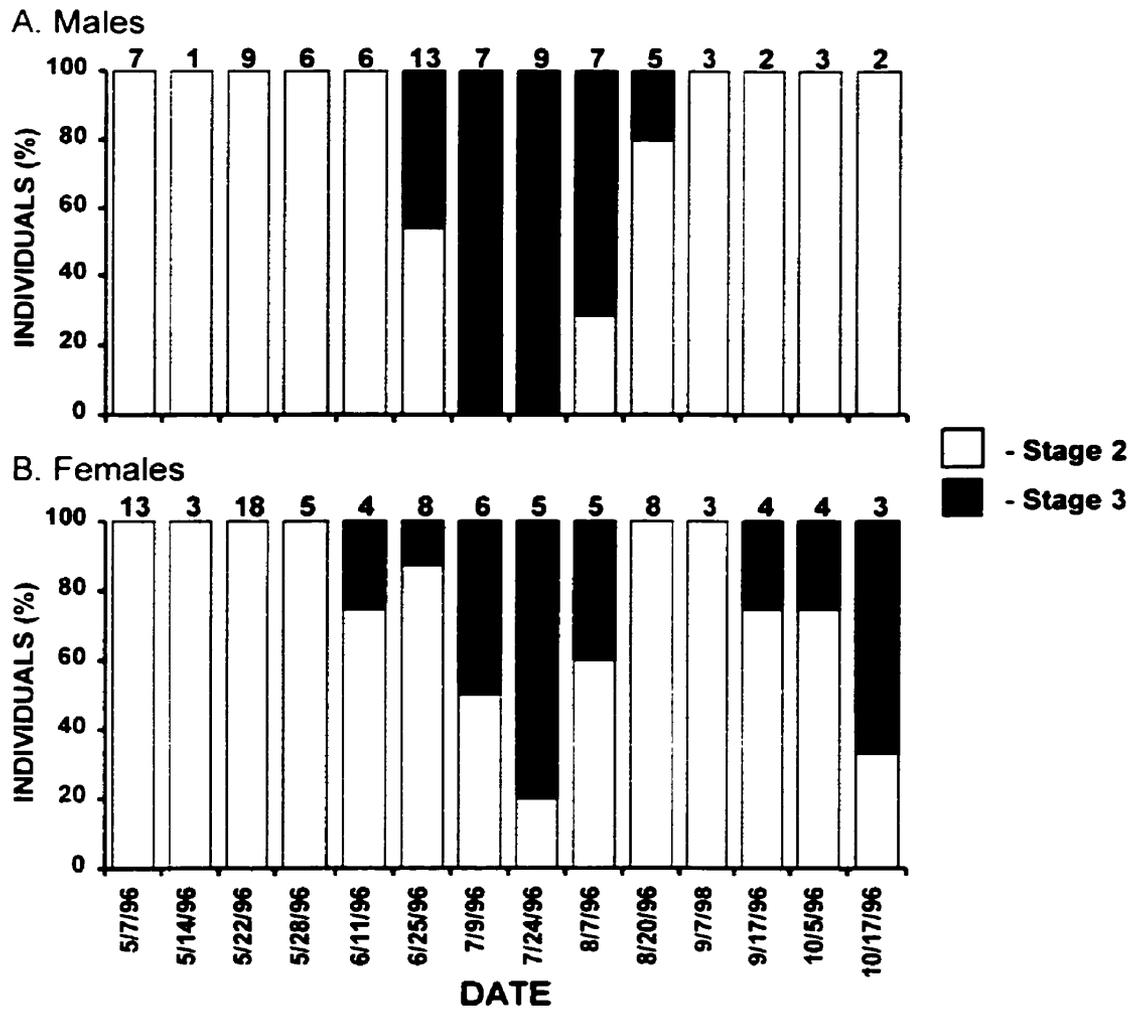


Figure 17. Seasonal changes in the proportion of gonad stages in mature male (A) and female (B) specimens of *Anodontooides ferussacianus* collected from the Cypress River in 1996. Numbers indicate number of individuals contributing to each observation. Stage 2 = males with spermatogonia or spermatids present; females with acini that contain small ovocytes, nutritive tissue, and perhaps some ova. Stage 3 = males with closely packed acini, and lumina filled with tightly spaced spermatogonia, spermatids, and spermatozoa; females with acini closely associated with the lumina, which are filled with mature ova.

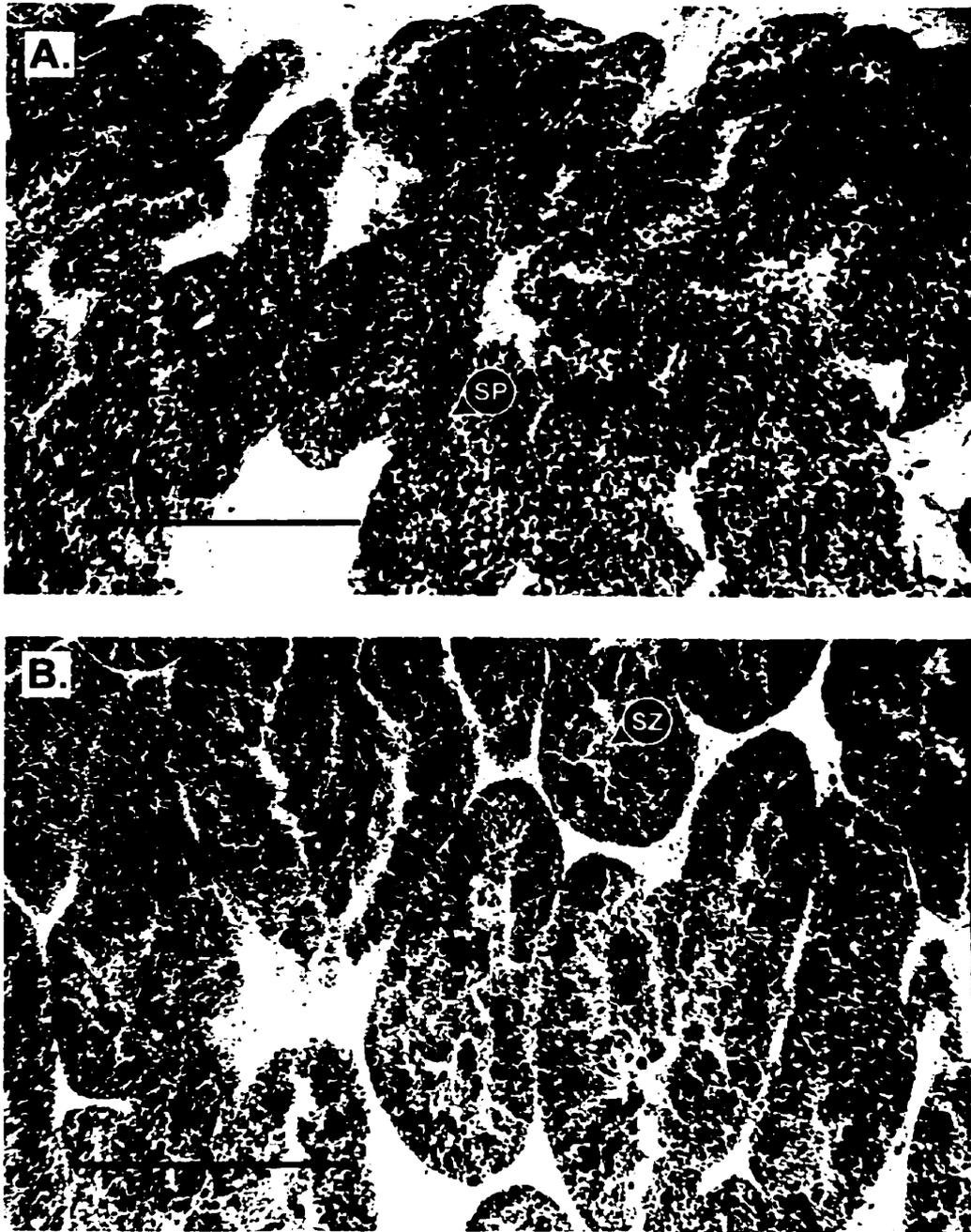


Figure 18. Stages of testis development in male *Anodontoides ferussacianus* collected from the Cypress River in 1996. A. Stage 2 male with spermatozoa and larger spermatids (SP). B. Stage 3 male with spermatozoa (SZ). The bar represents 200 μm .

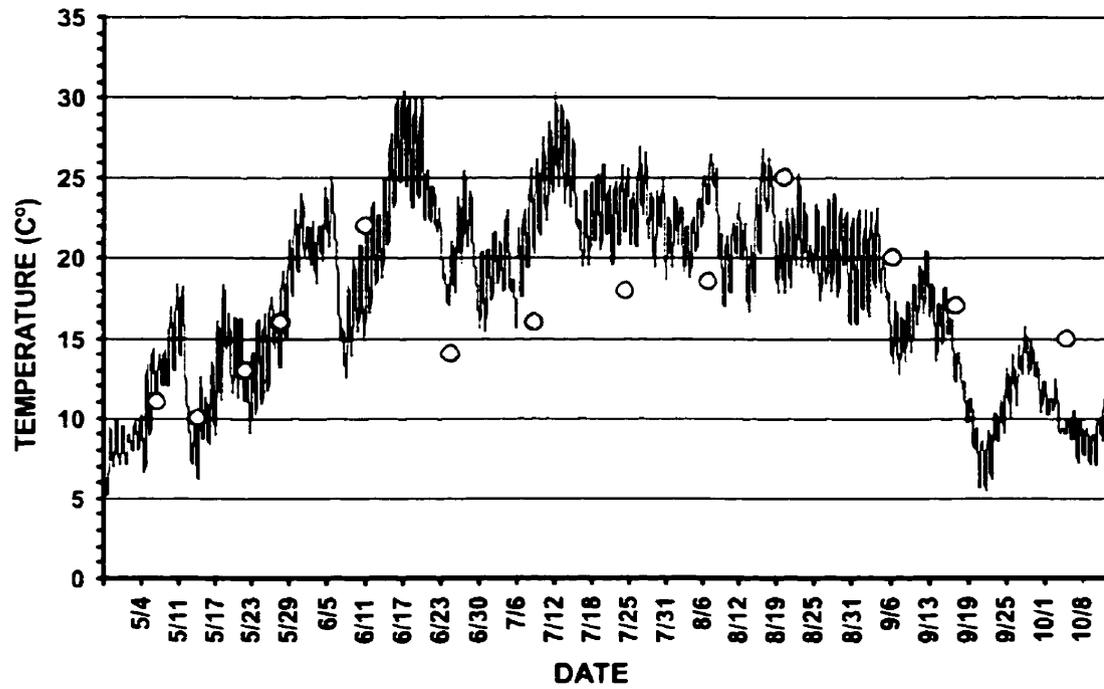


Figure 19. Water temperatures for the Cypress River. The solid line shows hourly readings taken in 1995, and the open circles represents the readings taken during the 1996 study period.

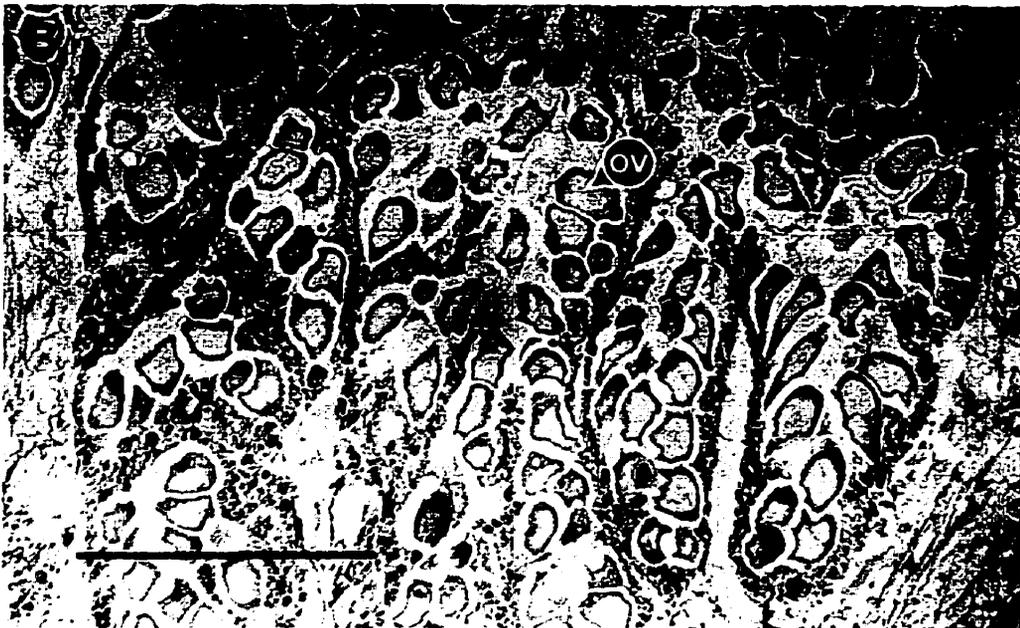
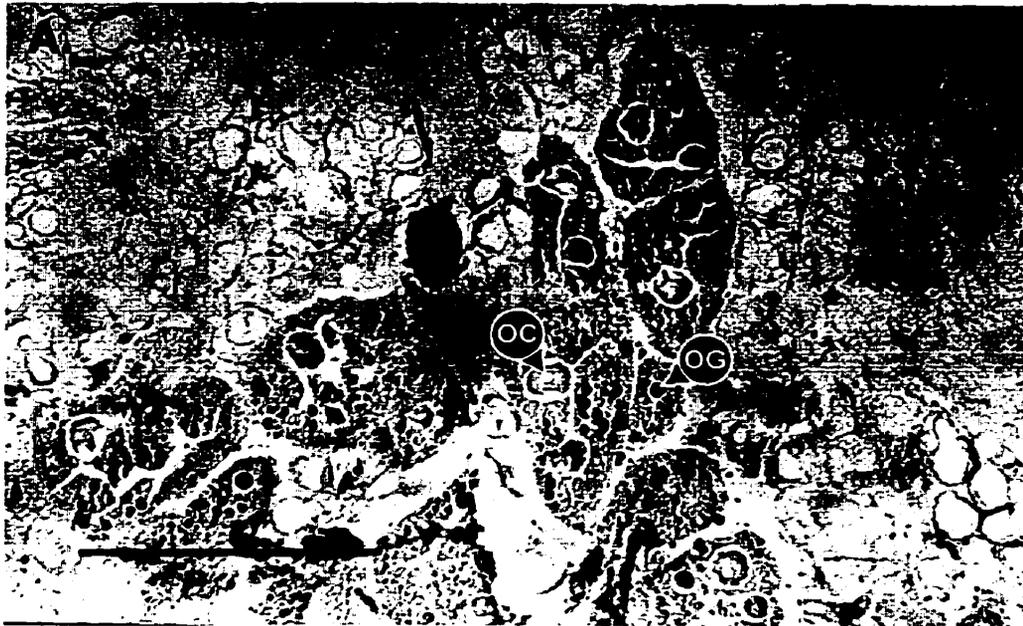


Figure 20. Stages of ovary development in female *Anodontoides ferussacianus* collected from the Cypress River in 1996. A. Stage 2 female with developing oogonia (OG) and oocysts (OC). B. Stage 3 female showing many developed ova (OV). The bar represents 200 μm .

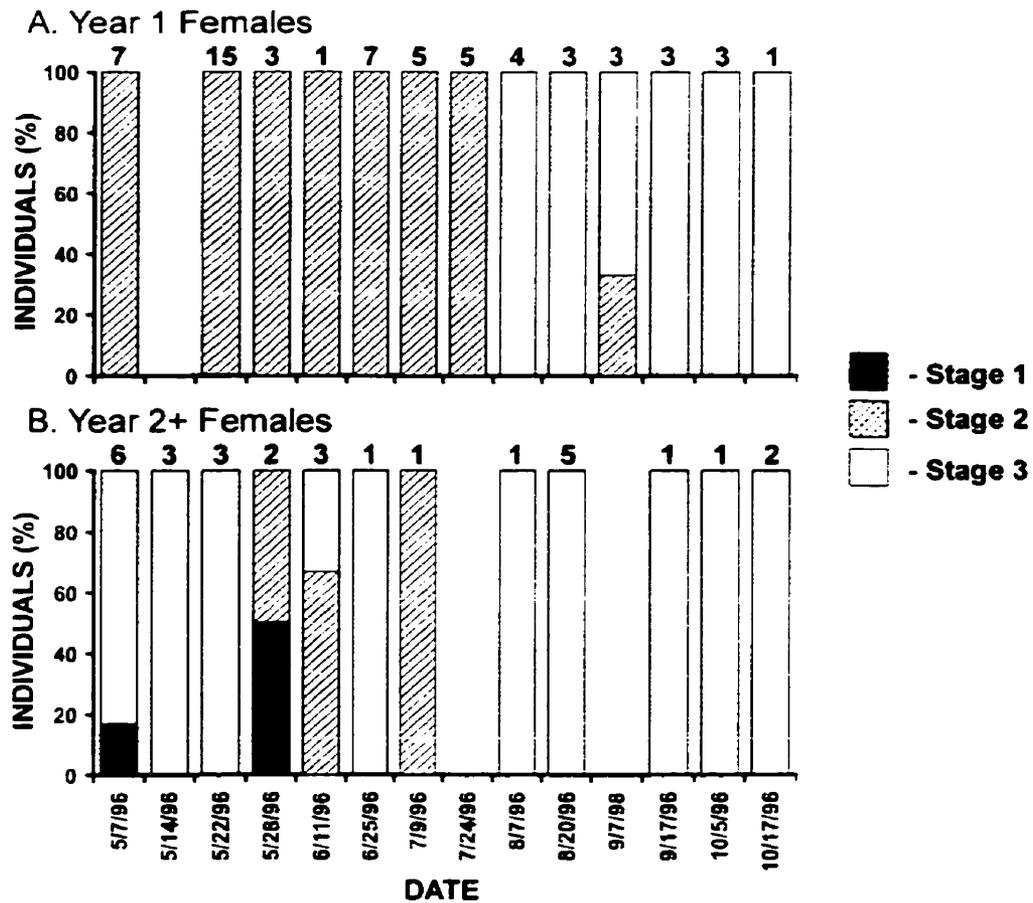


Figure 21. Seasonal changes in the proportion of marsupial stages in (A) Year 1 and (B) Year 2+ female specimens of *Anodontoides ferussacianus* collected from the Cypress River in 1996. Numbers indicate number of individuals contributing to each observation. Stage 1 = evidence of the recent release of glochidia; Stage 2 = no embryos or glochidia present; Stage 3 = embryos or mature glochidia present.

Benthic Distributions

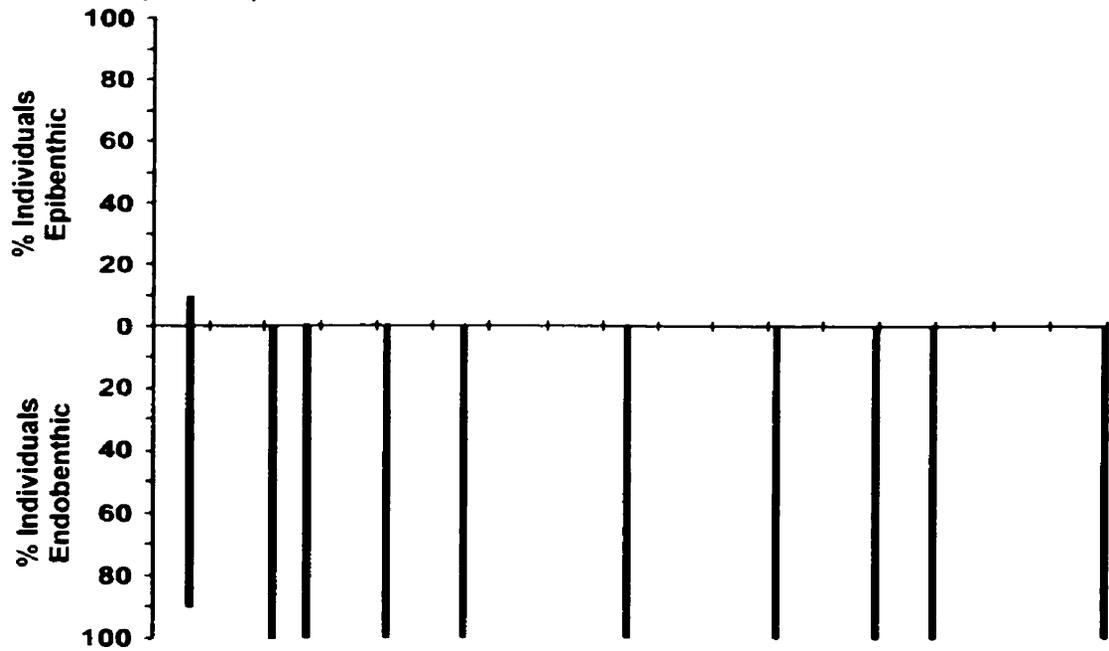
The percentage of mussels that were epibenthic varied throughout the sampling period (Figure 22). Only one epibenthic 1 year-old mussel was collected (early May) (Figure 22A). Most of the older individuals were found at the sediment surface until late June (June 25th), after which the mussels moved down into the sediment, becoming endobenthic (Figure 22B). Values of the chemical and physical parameters measured in the Cypress River over the sampling period are provided in Appendix 7. Several physical parameters measured were significantly correlated with the frequency of epibenthic individuals (Table 4, Figure 23). Levels of dissolved inorganic carbon and soluble reactive silica were most correlated ($r = -0.96$, $p < 0.001$) with the frequency of epibenthic individuals (Table 4). There were differences between the frequency of male and female epibenthic individuals (Figure 24). The last epibenthic female was observed on May 28 (Figure 24A), and active oogenesis (females in stage 3 development) was first observed soon afterwards (Figure 17A). The last epibenthic male was observed on June 25 (Figure 24B), the same date that active spermatogenesis was first observed (Figure 17B).

Discussion

Density

The densities of *A. ferussacianus* sampled from the Cypress River (mean of 2.4 /m², ranging from 0 to 12/m²) are similar to those reported from other

A. Year 1 (N = 76)



B. Year 2+ (N = 45)

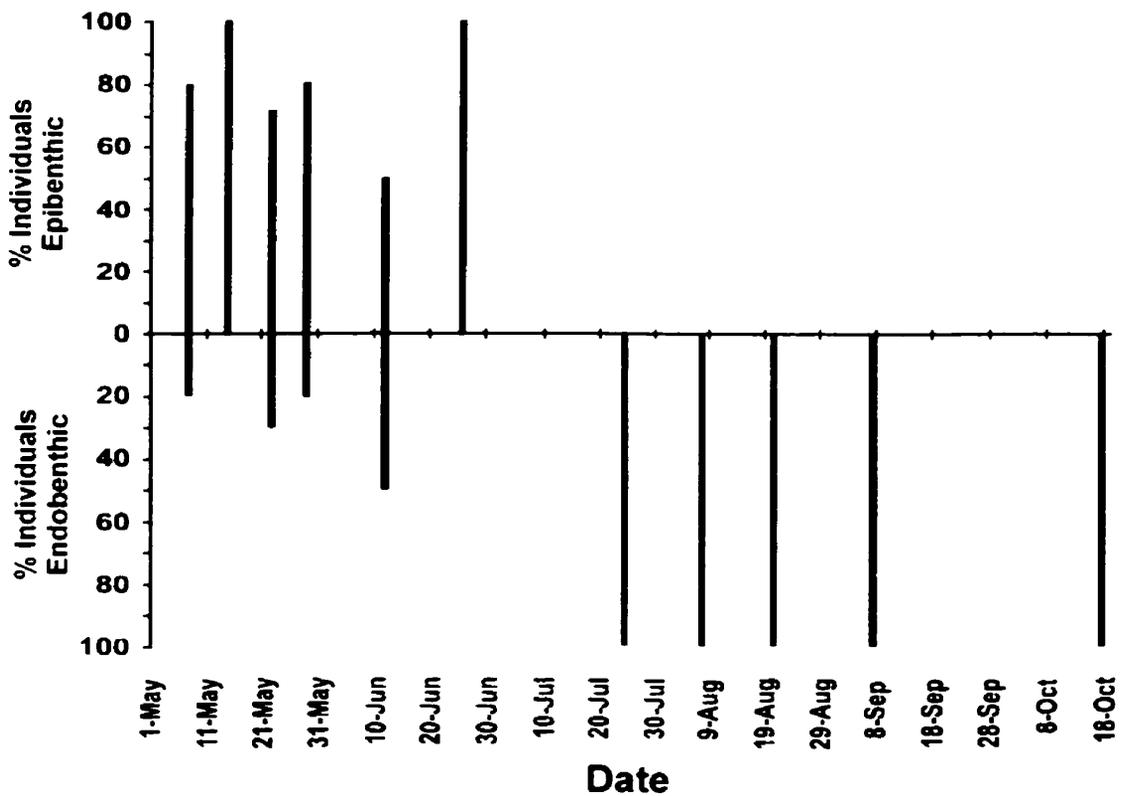


Figure 22. The percentage of Year 1 (A) and Year 2+ (B) specimens of *Anodontoides ferussacianus* occurring epi- and endobenthic in the Cypress River during the 1996 sampling period.

Table 4. Pearson product moment coefficient of correlations (r) between the occurrence of epibenthic individuals (% frequency) and the chemical and physical variables measured in the Cypress River.

	r
Dissolved Inorganic Carbon ($\mu\text{m/l}$)	- 0.96***
Soluble Reactive Silica (mg/l)	- 0.96***
Alkalinity (ueq/l)	- 0.92***
pH	- 0.89**
Stream Width (m)	0.88**
Sulfate (mg/l)	0.87**
Conductivity ($\mu\text{S/cm}$)	- 0.85**
Dissolved Organic Carbon ($\mu\text{m/l}$)	0.83**
Chloride (mg/l)	- 0.81**
Mean Depth (cm)	0.78*
Potassium (mpg/l)	0.58
Mean Velocity (m/s)	0.52
Total Dissolved Phosphorus ($\mu\text{g/l}$)	0.43
Calcium (mg/l)	0.32
Temperature ($^{\circ}\text{C}$)	- 0.31
Total Suspended Solids (mg/l)	0.24

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

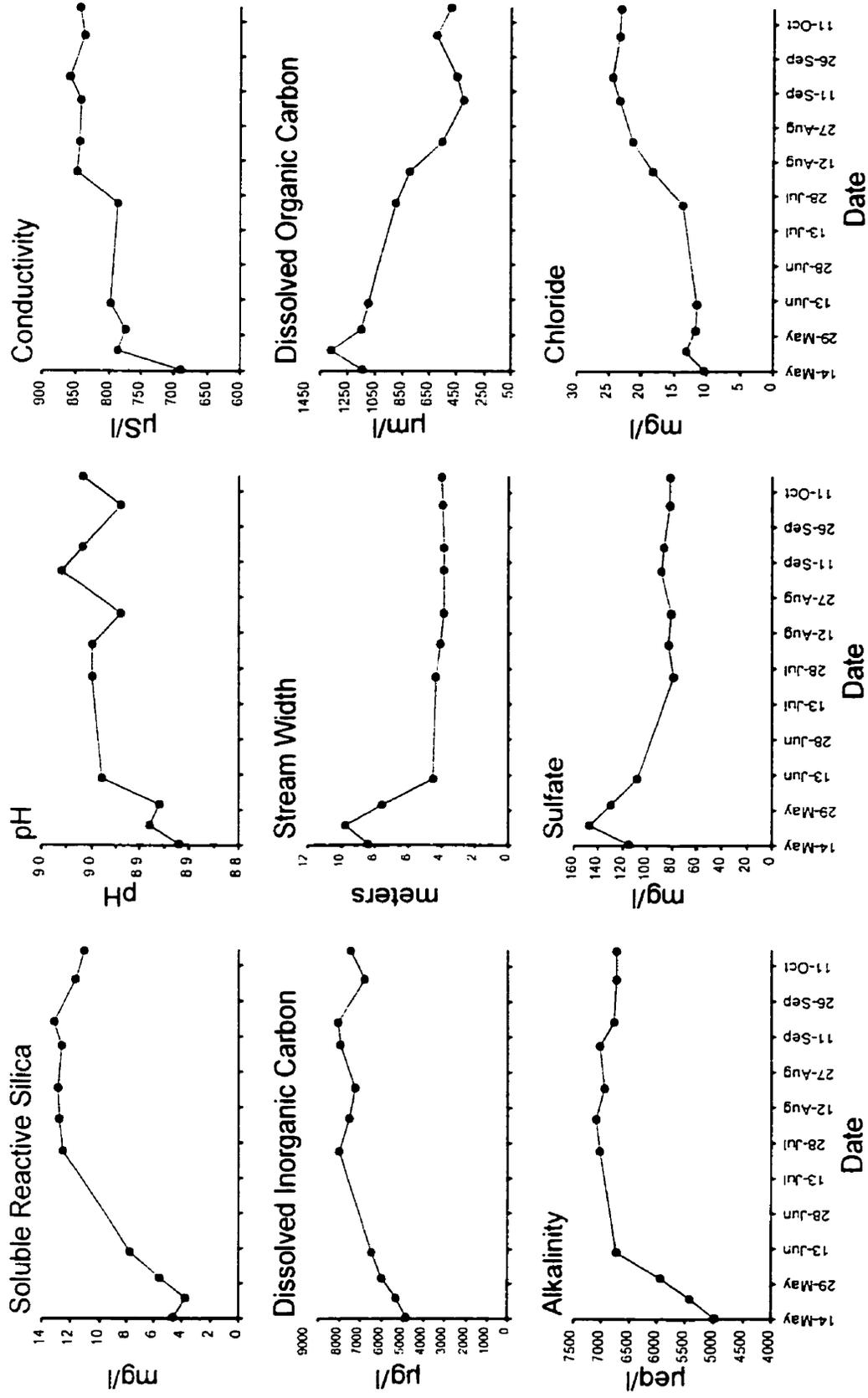
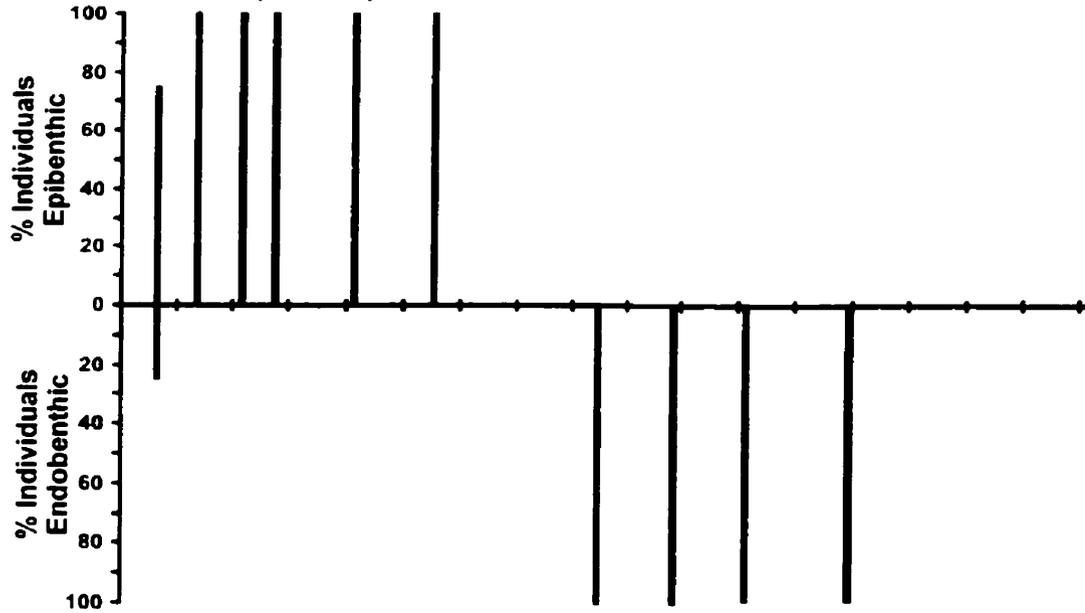


Figure 23. Chemical and physical data from the Cypress River during the 1996 sampling period.

A. Year 2+ Males (N = 21)



B. Year 2+ Females (N = 24)

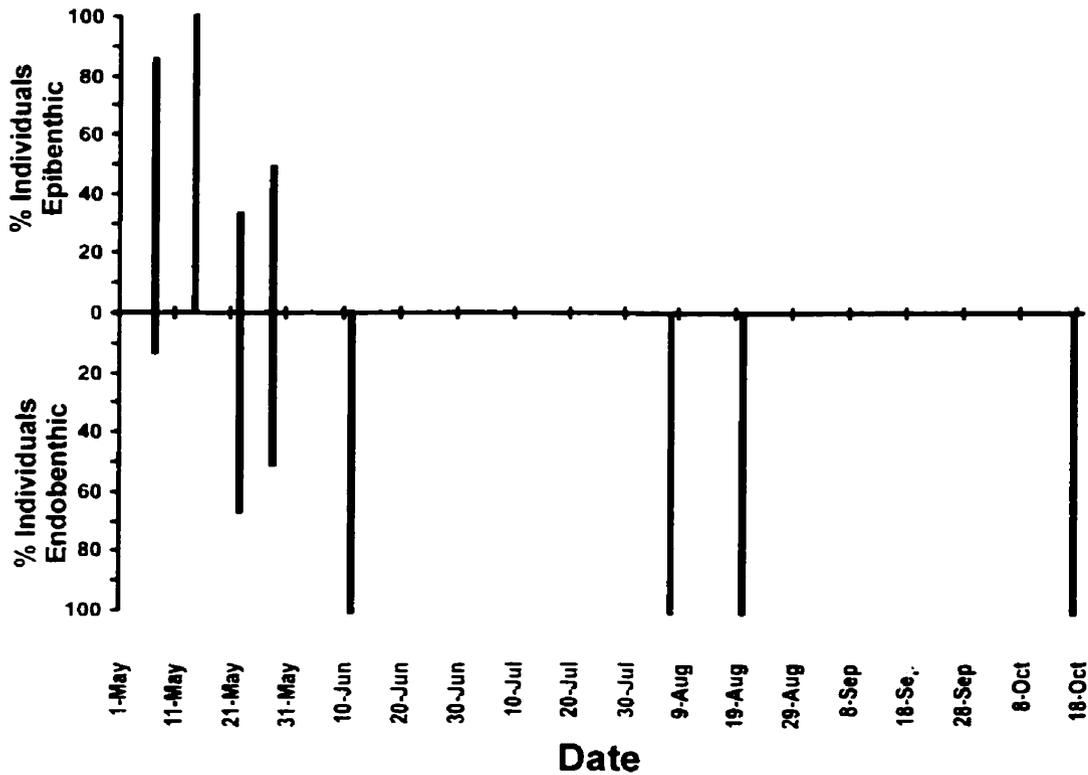


Figure 24. The percentage of Year 2+ male (A) and female (B) specimens of *Anodontoides ferussacianus* occurring epi- and endobenthic in the Cypress River during the 1996 sampling period.

studies of freshwater mussels in lotic systems. For example, Balfour and Smock (1995), in a study of *E. complanata* in a small headwater stream, found mean densities of 2.5/m². Mussel densities in small streams are usually less than 1/m², and rarely exceed 15/m² (Strayer 1981).

Ageing and growth

As discussed previously (Chapter 2, pages 20-21), it is generally accepted that the external growth rings of temperate freshwater mussels are annual in nature, with some studies indicating that ages derived by the external growth method are unreliable, particularly in older individuals (Haukioja and Hakala 1978, Neves and Moyer 1988, Metcalfe-Smith and Green 1992, Michaelson and Neves 1995, Veinott and Cornett 1996). Counting the internal bands in thin-sections is believed to be a more accurate estimate of age (Neves and Moyer 1988). In the present study, more external rings were counted than internal bands, and the likelihood of overestimating an individual's age increased as the mussel got older. Overestimates were probably due to some disturbance rings being included in the external annuli count. Although *A. ferussacianus* is not long-lived (up to 5 years in the study area), these results suggest that caution should be used when counting external bands to estimate the age of individuals of this species. Nevertheless, in this situation the count of external bands was 88.5% accurate when compared the count of internal bands. This accuracy would be suitable in many circumstances.

The age structure of *A. ferussacianus* in the Cypress River is not similar to that reported for other freshwater mussels in lakes and rivers. Other studies

indicate that younger individuals usually comprise a very small proportion of the total population, and that the predominant year classes are intermediate in age (Negus 1966, Strayer et al. 1981, Dudgeon and Morton 1983, James 1985, Hanson et al. 1988, Huebner et al. 1990, Balfour and Smock 1995, Jokela and Mutikainen 1995, Müller and Patzner 1996). In this study, year 1 mussels comprised over 60% of the mussels collected (Figure 13). This indicates either that there was extremely low recruitment in previous years (perhaps due to adverse environmental conditions), or there was size specific mortality. Probably this population of *A. ferussacianus* has high annual recruitment but also experiences high mortality due to raccoon predation. It has been demonstrated that muskrats (*Ondatra* sp.) select larger mussels as their prey in both lakes (Convey et al. 1989, Hanson et al. 1989) and rivers (Jokela and Mutikainen 1995, Tyrell and Hornbach 1998). Although muskrats prefer larger prey, in locations where larger individuals are not available they will consume smaller mussels (Tyrell and Hornbach 1998). Selective predation of larger mussels by raccoons may influence the population structure of *A. ferussacianus* in the Cypress River. Because age 1 mussels remained almost exclusively endobenthic (Figure 22), this year class may be protected from predation. When older mussels are epibenthic (from May to the end of June, Figure 22), they could be disproportionately vulnerable and selectively preyed upon, leading to the observed age class distribution (Figure 13).

Although the life span of *A. ferussacianus* is unknown, the maximum age of individuals collected from the Cypress River (5 years) is less than that

observed in other populations found in this study. In the East Shell River (site 35, Appendix 2), the maximum age recorded was 7 years, and the 16 individuals collected had a mean age of 5.6 (± 0.81 SD). Most other members of the subfamily Anodontinae usually live to 9-14 years (Heard 1975), and only specimens of *A. imbecillis* from Lake Erie has been reported rarely to exceed 5 years of age (Heard 1975).

The growth rate of this population of *A. ferussacianus* is similar to other species of Anodontinae in lotic systems (i.e. Negus 1966, Balfour and Smock 1995). Individuals in this population approximated the maximum lengths reported by Clarke (1981) (80mm compared to 95 mm). The growth rate of specimens of *A. ferussacianus* decreased considerably after reached sexual maturity at age 1, which is similar to observations of other freshwater mussels (e.g. Isely 1914, Grier 1922, Howard 1922, Chamberlain 1931, St. John 1974, Hanson et al. 1988, Nalepa and Gauvin 1988, Gordon and Layzer 1989, Jirka and Neves 1992, Woody and Holland-Bartels 1993).

Age of sexual maturity, sex ratio, and hermaphroditism

The age of sexual maturity displayed by specimens of *A. ferussacianus* in the Cypress River (age 1) is the lowest recorded for any unionid. Previously, *P. grandis* showed the youngest age of sexual maturity, with some populations reproducing at two years of age (Heard 1975).

Although the incidence of hermaphroditism is most common in members of the subfamily Anodontinae, the low prevalence of hermaphroditic individuals found in this study (3 of 183 mussels examined) is typical of other dioecious

freshwater mussel populations (Heard 1975). The hermaphroditic specimens of *A. ferussacianus* had gonads composed predominately of tissue of only one sex. Hermaphroditism is thought to be an adaptation to increase the probably of fertilization in environments where there is restricted contact with suitable mates (Ghiselin 1969). For example, hermaphroditism generally is more prevalent in bodies of standing water than in running waters (Heard 1975). In lakes there are large expanses of habitat that are unsuitable for mussels, and the transfer of sperm occurs only over short distances because of the lack of water currents.

Reproductive cycle

This study supports observations of Ortmann (1919) and Baker (1928) that *A. ferussacianus* is a bradytictic (long-term) brooder. Fertilization of ova occurs in late July and early August, the eggs are held in marsupia over winter, and the release of mature glochidia begins in May (Figure 17).

Mature males and females demonstrated some gonadal activity from May to October. Both sexes displayed greatest gonad activity during the warmest months of the year, but this period was slightly asynchronous between males and females. Oogenesis commenced soon after water temperatures reached their summer levels in mid June, and was completed by early August (Figures 17 and 19). Spermatogenesis occurred from late June to late August (Figure 17), thus overlapping the period when the females are most likely to be receptive to fertilization. Seasonal temperature changes often are referred to as being important in the timing of spawning in freshwater mussels (Holland-Bartels and Kammer 1989, Bruenderman and Neves 1993). The second period of oogenesis

from late September to late October (Figure 17) can not be readily explained, particularly since a second period of spermatogenesis was not observed. After fertilization of the eggs in August, constant warm temperatures may have been conducive to the resumption of oogenesis in late September and October. Long periods of high temperatures may be responsible for the extended breeding seasons and repetitive breeding cycles that are typical of some tropical freshwater mussels (Dudgeon and Morton 1983, Jones et al. 1986). Glochidia were beginning to form in the marsupia by August, and continued to develop until late October (Figure 21). The cue for the release of glochidia in early May probably was the increasing water temperatures in the spring. Ortmann (1919) and Baker (1923) suggest that release of glochidia occurs from May to June, but in this study there were still glochidia in marsupia at the end of July (Figure 21). This is the most northern population of *A. ferrussacianus* that has been studied. It is possible that lower spring temperatures at higher latitudes delay glochidial release. By the end of first week of August all glochidia had been expelled from marsupia.

The glochidia of *A. ferrussacianus* in Cypress River may use the brook stickleback, common shiner, fathead minnow, and white sucker as hosts. Although juveniles were collected in late August, it is unknown when the metamorphosed mussels first drop off their hosts.

Benthic distributions

One year-old *A. ferrussacianus* were almost exclusively endobenthic year-round (Figure 22). Older *A. ferrussacianus* (> 2 years of age) displayed a distinct

pattern of seasonal vertical migration in the Cypress River. Both male and female mussels occurred at the sediment surface from May until June, after which they burrowed into the sediment and remained endobenthic until late October (Figure 22). Balfour and Smock (1995) describe a similar situation where individuals of *E. complanata* were exclusively endobenthic until they reached the age of 3, after which time they began to display seasonal vertical migration. The age of sexual maturity of individuals of *E. complanata* is not known, but probably is later than for those of *A. ferussacianus*. However, the vertical migration displayed by individuals of *A. ferussacianus* in this study that displayed by individuals of *E. complanata* in lakes (Amyot and Downing 1997) and rivers (Balfour and Smock 1995). In both cases mussels gradually came to the surface during the spring, remained epibenthic for the entire summer, and then abruptly became endobenthic again in the fall.

Balfour and Smock (1995) found that none of the physical, chemical, or hydraulic parameters they measured (water temperature, pH, velocity, discharge, depth, width, conductivity, or organic matter content) were correlated with the abundance of riverine specimens of *E. complanata* at the sediment surface. They speculated that burrowing into the sediment might be a mechanism to prevent predation or being swept away during periods of high flow. Amyot and Downing (1997) found that the vertical distribution of a lacustrine population of *E. complanata* was most strongly correlated with water temperatures. They speculated that vertical migration may be an adaptation which enhances survival during adverse conditions, or a method that could "allow mussels to live at

temperatures closer to that of the groundwater”, and thus avoid freezing in shallow waters during extremely cold winters. Burrowing into the sediment also may be beneficial as a method of avoiding predation (e.g. from aquatic mammals) (Negus 1966), and being epibenthic may be necessary in order for the successful release of glochidia (Balfour and Smock 1995).

Since individuals of *A. ferussacianus* were endobenthic during the period of fertilization, it would seem that it is unnecessary for them to be epibenthic for the transfer of sperm. However, it is possible that there is a diel pattern of movement. Changes in light intensity, which are detected by photoreceptor cells on the mantle and siphon edges (McMahon 1991), may play a significant role in controlling unionid behavior and diurnal rhythms. Englund and Heino (1994) discovered that specimens of *Anodonta antina* exhibited rhythmic, diurnal valve movements. Although it has not been studied, endobenthic individuals may come to the surface to breed or feed at night to avoid visual predators.

Female mussels may be epibenthic and risk predation in order to release glochidia. Since the one-year-old females were not gravid, they may have been able to remain epibenthic throughout the year. Year 2+ female mussels seemed to be epibenthic during the period corresponding to glochidial release (Figures 21 and 24). Once they have released their glochidia they would then be able to migrate back into the sediments, which may explain why some year 2+ females were found to be endobenthic during May and June (Figure 24). However, it is not clear why year 2+ males were epibenthic during May and June. Since the

males do not need to release glochidia, there should be no need to risk predation and be epibenthic during this period.

In this study, mussel abundance at the surface was significantly correlated with numerous factors (Table 4), and migration into the sediment seemed to coincide with the onset of peak summer temperatures and active gametogenesis. These factors seem to be correlated to the transition from runoff to groundwater input into Cypress River (Figure 23). I propose that specimens of *A. ferussacianus* are epibenthic during the spring and early summer because of high water velocities, and the presence of epibenthic individuals was not a behavioral response. The last epibenthic individual was found on June 30. The chemical and physical parameters correlated with mussel abundance at the sediment surface seem to reach summer levels (Figure 23, Appendix 7) around the same date. Year 2+ mussels became endobenthic (Figure 22) at the end of June as well. Furthermore, water velocities and stream widths decrease, and water temperatures reached summer levels at the same time. Because of the unstable substrate (fine, loose shale) and their large size, Year 2+ mussels may not be able to remain buried in the sediment during high water flows in May and June. Because of their small size, Year 1 individuals may be able stay buried during these months. The only epibenthic Year 1 individual was collected at peak flows in the spring. In temperate freshwater mussels, gametogenesis typically occurs during the warmest months of the year (Jones et al. 1986). It may be only coincidental that gametogenesis coincides with mussels becoming endobenthic in June.

CHAPTER 5 – CONCLUSIONS

1) Twelve species of freshwater mussels occur in the Assiniboine River drainage in Manitoba. These are the Wabash pigtoe (*Fusconaia flava*), threeridge (*Amblema plicata*), maple leaf (*Quadrula quadrula*), white heelsplitter (*Lasmigona complanata*), creek heelsplitter (*Lasmigona compressa*), cylindrical papershell (*Anodontoidea ferussacianus*), giant floater (*Pyganodon grandis*), creeper (*Strophitus undulatus*), pink heelsplitter (*Potamilus alatus*), black sandshell (*Ligumia recta*), fat mucket (*Lampsilis siliquoidea*), and the plain pocketbook (*Lampsilis cardium*).

2) The fluted shell, *Lasmigona costata*, was not found in the Assiniboine River drainage in Manitoba, but does occur in the Winnipeg River system. It may and may have dispersed this river system from the upper Mississippi River system by way of a marshy area of land along the eastern edge of the province.

3) The analysis of freshwater mussel species associations shows four groups of species that can be associated with the stream size preferences that members have in common. Stream order is useful in predicting the general composition of the freshwater mussel assemblages in streams within the Assiniboine River drainage.

4) The lack of freshwater mussels at a large number of small stream sites was probably due to the destruction of mussel habitat caused by allowing cattle access to streams, channelization of streams for flood control, and the creation of dugouts.

5) Specimens of *A. ferussacianus* in the Cypress River had a mean density of 2.5 mussels/m², and ranged from 0 to 12 mussels/m². Similar densities have been in other studies of freshwater mussels in lotic systems.

6) Young (Year 1) individuals comprise a large proportion of the *A. ferussacianus* in Cypress River. This age structure is atypical of other freshwater mussel populations and may be due selective predation of older year classes by raccoons. This predation may be responsible for the extremely short longevity (maximum age 5 years) displayed by this population.

7) The growth rate of the *A. ferussacianus* in the Cypress River is similar to the growth rates of other riverine populations of freshwater mussels.

8) The age of first maturity of *A. ferussacianus* in the Cypress River (Age 1+) is the lowest recorded for any species of freshwater mussel.

9) The *A. ferussacianus* in the Cypress River are bradyctictic. Fertilization of ova occurs in August, the eggs over-winter in the marsupia, and the release of mature glochidia occurs from May until June. Male and females displayed continuous gonadal activity. The timing of oogenesis and spermatogenesis was slightly asynchronous. Oogenesis occurred from late June to early August, and spermatogenesis occurred from late June to late August.

10) The *A. ferussacianus* in the Cypress River displayed a distinct pattern of vertical migration. Most male and female mussels occurred at the sediment surface in the spring and abruptly became endobenthic in late June. Year one individuals were almost exclusively endobenthic throughout the year. The

occurrence of *A. ferussacianus* at the sediment surface may not be behavioral, but rather may be a consequence of high water velocities.

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Appendix 1. A note on freshwater mussel classification.

The classification of members of the bivalve family Unionidae is complex and unstable. Early collectors described virtually every specimen collected from different geographic areas as new species, yet these specific designations often reflected only intraspecific or ecophenotypic variation of shells (Watters 1994b, Lydeard and Roe 1998). Recent systematic and genetic investigations (Heard and Guckert 1970, Davis and Fuller 1981, Kat 1983b, Davis 1984, Hoeh 1990, Lydeard et al. 1996, Roe and Lydeard 1997) have clarified some of the relationships between the various groups within the Unionidae. However, these studies have led to the reinstatement of many earlier names, further complicating freshwater mussel nomenclature. In an attempt collate recent studies the American Fisheries Society recently published a revised compilation of common and scientific names for molluscs (including freshwater mussels) in the United States and Canada (Turgeon et al. 1998). The classification of mussels for this study has been standardized to this nomenclature.

Of concern during this study has been the specific designation of the plain pocketbook, *Lampsilis cardium*. Clarke (1973) lists the pocketbook, *Lampsilis ovata*, as being found in Assiniboine River and adjacent Red River drainages. *Lampsilis ovata* has been given many names that represent numerous environmental variants, and Johnson (1970) gives a comprehensive list of synonymies for *L. ovata*. Some malacologists have used *Lampsilis ovata ventricosa* to differentiate environmental variants in shell shape of *L. ovata* (e.g.

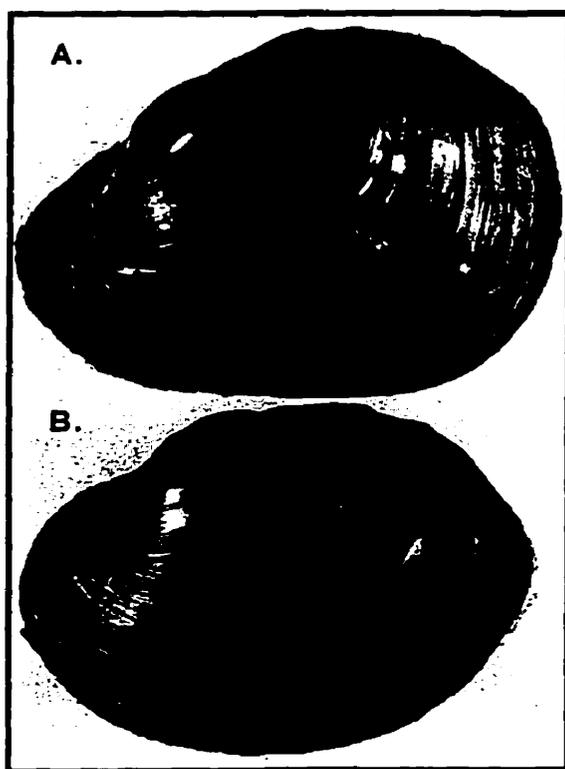
Burch 1973). Clarke (1981, page 346) wrote "Recent work at the Ohio State University Museum of Zoology has shown that *L. ventricosa* and *L. ovata* (Say, 1917) are biologically distinct species. The Canadian mussel formerly called *Lampsilis ovata ventricosa* should therefore be called *Lampsilis ventricosa*." The "recent work" that Clarke refers to is that of Putman (1971) (K.S. Cummings, personal communication), who bases the difference between the two species as that of shell morphology. The name, *L. cardium* (Rafinesque 1920), has since been given priority over *L. ventricosa* (Barnes 1823) (K.S. Cumming, personal communication).

In the mid-west United States, *L. ovata* is restricted to southern Illinois and Indiana (the Ohio River system) (Cummings and Mayer 1992, K.S. Cummings, personal communication), although Strayer and Jirka (1997) found forms that are similar to *L. ovata* in the Allegheny River in New York. *L. ovata* is sympatric with *L. cardium*, whose distribution ranges from Arkansas and Tennessee north to Minnesota and Wisconsin, and from Kansas east to New York (Parmalee and Bogan 1998, Strayer and Jirka 1997). These distributions are based solely on differences in the morphological characteristics of the two species (K.S. Cummings, personal communication). Williams et al. (1993), erroneously list *L. ovata* (and not *L. cardium*) as being in Saskatchewan, Manitoba, Ontario and Quebec in Canada (K.S. Cummings, personal communication).

Preliminary results of a comparative genetic study of *L. ovata* and *L. cardium* at the University of Vermont indicate that there are not enough differences between the two species to warrant the assignment of separate taxa

(J.E. Marsden, personal communication). If further genetic studies support these preliminary results, the name *L. ovata* (Say 1817) would have priority over *L. cardium*.

For the purposes of this study *L. cardium* and *L. ovata* have been recognized as separate species (Putman 1971, Clarke 1981, Cummings and Mayer 1992, Turgeon et al. 1998), and *L. cardium* is considered to be the species that is found in Manitoba. A comparison of the shell shape of *L. ovata* and *L. cardium* described and illustrated in Cummings and Mayer (1992), the specimens from Manitoba are similar to *L. cardium*.



Lampsilis cardium, (A) female and (B) male from the Assiniboine River near St. Francois-Xavier, Manitoba (this study).

Appendix 2: Species and physical data for mussels collected from the Assiniboine River drainage in Manitoba.

LOCATION	N LAT. W LONG.	DATE	ORD	W(m)	SUBSTRATE	D(cm)	SPECIES	N
1. Cypress River, 5 mi N of Holland and 3 mi W of PTH 34	49°39'	5/4/96	4		silt/fine shale	75	<i>Lasmigona complanata</i>	1
	98°55'				silt/fine shale	75	<i>Lasmigona compressa</i>	1
					silt/fine shale	75	<i>Anodontooides ferussacianus</i>	5
					silt/fine shale	75	<i>Pyganodon grandis</i>	3
2. Cypress River, 1 mi E of Cypress River and 1 mi S of PTH 2	49°32'	5/4/95	3		shale	75	<i>Lasmigona complanata</i>	EV
	99°06'						<i>Anodontooides ferussacianus</i>	13
3. Cypress River, St. Alphonse	49°26'	5/11/95	3		fine shale	15	<i>Lasmigona compressa</i>	EV
	98°59'						<i>Anodontooides ferussacianus</i>	12
4. Cypress River, 1.5 mi N and 1 mi W of St. Alphonse	49°27'	5/11/95	3		silt/sand	50	<i>Anodontooides ferussacianus</i>	24
	98°01'						<i>Pyganodon grandis</i>	EV
5. Cypress River, 6 mi W of Holland and 6 mi N of PTH 2	49°35'	5/11/95	3		mud	75	<i>Anodontooides ferussacianus</i>	5
	99°01'				cobble	75	<i>Pyganodon grandis</i>	7
							<i>Lampsilis siliquoidea</i>	EV
6. Souris River, PR 345 (9 mi E of Bede)	49°23'	5/18/95	6				<i>Lasmigona complanata</i>	EV
	100°45'						<i>Pyganodon grandis</i>	EV
							<i>Lampsilis siliquoidea</i>	EV
7. Souris River, Bunclody	49°32'	5/18/95	6		shale/cobble	100	<i>Lasmigona complanata</i>	1
	100°03'				shale/cobble	100	<i>Lampsilis siliquoidea</i>	5
8. Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)	49°37'	5/18/95	6		cobble/gravel/silt	100	<i>Fusconaia flava</i>	25
	99°35'				cobble/gravel/silt	100	<i>Ambleria plicata</i>	3
					cobble/gravel/silt	100	<i>Lasmigona complanata</i>	14
					cobble/gravel/silt	100	<i>Anodontooides ferussacianus</i>	2
					cobble/gravel/silt	100	<i>Pyganodon grandis</i>	4
					cobble/gravel/silt	100	<i>Strophitus undulatus</i>	1
					cobble/gravel/silt	100	<i>Ligumia recta</i>	2
					cobble/gravel/silt	100	<i>Lampsilis siliquoidea</i>	6
				cobble/gravel/silt	100	<i>Lampsilis cardium</i>	6	
9. Souris River, PTH 2 (1 mi S and 1.5 mi E of Wawanesa)	49°34'	6/28/95	5	20.8	silt	75	<i>Pyganodon grandis</i>	9
	99°43'				silt	75	<i>Lampsilis siliquoidea</i>	8

Appendix 2: Continued

LOCATION	N LAT. W LONG.	DATE	ORD	W(m)	SUBSTRATE	D(cm)	SPECIES	N
10. Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)	49°37' 99°35'	6/29/95	6		gravel/sand	50	<i>Fusconaia flava</i>	1
					sand	20	<i>Lasimigona complanata</i>	6
					gravel/sand	50	<i>Lasimigona compressa</i>	1
					sand	20	<i>Anodontoides ferussacianus</i>	4
							<i>Pyganodon grandis</i>	EV
							<i>Strophitus undulatus</i>	EV
					sand	20	<i>Ligumia recta</i>	2
					sand	20	<i>Lampsilis siliquoides</i>	8
					sand	20	<i>Lampsilis cardium</i>	1

11. Assiniboine River, Hwy 1	49°53' 97°30'	7/12/95	7		silty sand	150	<i>Fusconaia flava</i>	1
					silty sand	150	<i>Amblema plicata</i>	9
					silty sand	150	<i>Potamilius alatus</i>	16
							<i>Ligumia recta</i>	2
					silty sand	150	<i>Lampsilis siliquoides</i>	3

12. Little Saskatchewan River, 1 mi S and 3 mi W of Rapid City	50°06' 100°07'	7/19/95	5		cobble	20	<i>Lasimigona complanata</i>	1
					sand	52	<i>Lasimigona compressa</i>	2
					sand	52	<i>Pyganodon grandis</i>	2
					sand	52	<i>Strophitus undulatus</i>	1
					cobble	20	<i>Lampsilis siliquoides</i>	22

13. Little Saskatchewan River, 4 mi S and 2 mi E of Carnegie	49°54' 100°08'	7/20/95	5		cobble/sand	50	<i>Fusconaia flava</i>	1
					cobble/sand	50	<i>Lampsilis siliquoides</i>	2
					cobble/sand	50	<i>Lampsilis cardium</i>	1

14. Qu'Appelle River, 1 mi W of St.Lazare	50°27' 101°25'	7/26/95			sand	50	<i>Ligumia recta</i>	2
						50	<i>Lampsilis siliquoides</i>	11
						50	<i>Lampsilis cardium</i>	2

15. Assiniboine River, river km 154	49°56' 98°17'	8/9/95	7		cobble/sand	135	<i>Fusconaia flava</i>	1
					cobble/sand	135	<i>Quadrula quadrula</i>	1
					gravel/sand/clay	100	<i>Potamilius alatus</i>	1
							<i>Lampsilis cardium</i>	EV

16. Assiniboine River, river km 140	49°57' 98°09'	8/11/95	7		silt/sand	193	<i>Potamilius alatus</i>	1

Appendix 2: Continued

LOCATION	N LAT W LONG.	DATE	ORD	W(m)	SUBSTRATE	D(cm)	SPECIES	N
17. Assiniboine River, river km 115	50°01' 97°59'	8/11/95	7		sand	88	<i>Lampsilis cardium</i>	1
18. Assiniboine River, river km 109	46°39' 99°06'	8/12/95	7				<i>Lampsilis cardium</i>	EV
19. Assiniboine River, river km 73	49°59' 97°41'	8/12/95	7		sand gravel/sand sand/cobble	95 128 88	<i>Fusconaia flava</i> <i>Quadrula quadrula</i> <i>Ambiema plicata</i> <i>Strophitus undulatus</i> <i>Ligumia recta</i>	1 1 3 EV EV
20. Assiniboine River, river km 47	49°54' 97°32'	8/13/95	7		clay/cobble/sand clay/cobble/sand	160 160	<i>Quadrula quadrula</i> <i>Lasmigona complanata</i> <i>Ligumia recta</i>	1 1 EV
21. Assiniboine River, river km 28	49°52' 97°25'	8/13/95	7		cobble/gravel cobble/gravel cobble/gravel	161 175 193	<i>Ambiema plicata</i> <i>Potamilius alatus</i> <i>Lampsilis siliquoides</i> <i>Lampsilis cardium</i>	EV 1 2 1
22. Assiniboine River, river km 15	49°51' 97°16'	8/17/95	7		clay/cobble silt/debris	190 136	<i>Ambiema plicata</i> <i>Potamilius alatus</i> <i>Lampsilis siliquoides</i> <i>Lampsilis cardium</i>	EV 1 EV 1
23. Assiniboine River, river km 157	49°57' 98°19'	9/15/95	7		gravel/sand clay/gravel/sand	145 115	<i>Pyganodon grandis</i> <i>Lampsilis cardium</i>	1 1
24. Assiniboine River, river km 84	50°00' 97°46'	9/16/95	7		sand/clay/silt	120	<i>Lampsilis siliquoides</i> <i>Lampsilis cardium</i>	EV 1
25. Assiniboine River, river km 77		9/17/95	7		sand/cobble/clay sand/cobble/clay sand/cobble/clay	140 140 140	<i>Ambiema plicata</i> <i>Quadrula quadrula</i> <i>Ligumia recta</i>	1 1 1

Appendix 2: Continued

LOCATION	N LAT W LONG	DATE	ORD	W(m)	SUBSTRATE	D(cm)	SPECIES	N
26. Assiniboine River, river km 64	49°57' 97°38'	9/17/95	7		sand/cobble/clay	140	<i>Lampsilis siliquoidea</i>	1
					sand/cobble/clay	140	<i>Lampsilis cardium</i>	3
							<i>Fusconaia flava</i>	EV
							<i>Amblerma plicata</i>	EV
							<i>Quadrula quadrula</i>	EV
							<i>Lasrnigona compressa</i>	EV
							<i>Lampsilis siliquoidea</i>	EV
							<i>Lampsilis cardium</i>	EV
27. Assiniboine River, river km 57	49°55' 97°35'	9/17/95	7		cobble/clay	93	<i>Fusconaia flava</i>	EV
							<i>Amblerma plicata</i>	3
28. Assiniboine River, river km 45	49°53' 97°30'	9/17/95	7		cobble/clay	93	<i>Lampsilis siliquoidea</i>	2
					cobble/clay	93	<i>Lampsilis cardium</i>	1
29. Assiniboine River, river km 32	49°51' 97°27'	9/18/95	7		sand/clay	240	<i>Potamilius alatus</i>	EV
30. Assiniboine River, river km 23	49°52' 97°22'	9/18/95	7		sand/clay	105	<i>Quadrula quadrula</i>	2
					sand/clay	105	<i>Amblerma plicata</i>	2
							<i>Lampsilis siliquoidea</i>	EV
					sand/clay	82	<i>Lampsilis cardium</i>	1
31. Assiniboine River, river km 18	49°52' 97°22'	9/18/95	7		cobble/sand	99	<i>Amblerma plicata</i>	1
					gravel/sand	208	<i>Potamilius alatus</i>	1
					sand/cobble	108	<i>Potamilius alatus</i>	1
					sand/cobble	108	<i>Lampsilis siliquoidea</i>	1
							<i>Lampsilis cardium</i>	EV
32. Shell River, PTH 83 (1 mi N and 2 mi E of Inglis)	50°57' 101°18'	7/3/96	5	18.4	cobble/gravel/sand	148	<i>Amblerma plicata</i>	EV
					gravel/cobble	87	<i>Lasrnigona complanata</i>	2
					gravel/cobble	87	<i>Strophitus undulatus</i>	1
							<i>Potamilius alatus</i>	EV
							<i>Lampsilis cardium</i>	1
					silt/gravel	51	<i>Lasrnigona complanata</i>	1
					silt/gravel	51	<i>Pyganodon grandis</i>	1

Appendix 2: Continued

LOCATION	N LAT W LONG	DATE	ORD	W(m)	SUBSTRATE	D(cm)	SPECIES	N
33. Shell River, PTH 5 (1 mi N of Shevlin)	51°11' 101°15'	7/3/96	5	23.3	silt/gravel silt/gravel silt/gravel	51 51 51	<i>Strophitus undulatus</i> <i>Lampsilis siliquoidea</i> <i>Lampsilis cardium</i>	EV 3 1
34. Boggy Creek, 6 mi W and 3 mi N of Roblin	51°16' 101°29'	7/3/96		8.5	sand/silt	68	<i>Lasmigona complanata</i> <i>Pyganodon grandis</i>	EV 1
35. East Shell River, PR 366 (6 mi N of PR 367 and 7 mi S of PR 271)	51°41' 100°39'	7/4/96	3		sand/silt sand/silt	68 68	<i>Strophitus undulatus</i> <i>Lampsilis siliquoidea</i>	2 2
36. Shell River, PR 367 (6 mi E and 2.5 mi N of Boggy Creek)	51°36' 101°15'	7/3/96		8.5			<i>Pyganodon grandis</i>	EV
37. Silver Creek, 1.5 mi E and 2.5 S of Gambler	50°33' 101°22'	7/5/96	4	4.1	silt silt		<i>Anodontooides ferussacianus</i> <i>Pyganodon grandis</i>	16 1
38. Birdtail River, PR 477 (3 mi S and 4 mi W of Birtle)	50°22' 101°08'	7/4/96	5	9.8	gravel/cobble/silt	42	<i>Lasmigona complanata</i> <i>Lasmigona compressa</i>	EV 1
39. Birdtail River, PTH 16 (1 mi N and 1.5 mi W of Solsgrith)	50°33' 101°22'	7/5/96	4	4.1	gravel/cobble/silt gravel/silt/sand	42 34	<i>Anodontooides ferussacianus</i> <i>Pyganodon grandis</i>	EV 4
40. Birdtail River, 1 mi N and 1 mi E of Mears	50°22' 101°08'	7/5/96	4	20.8			<i>Fusconeia flava</i> <i>Pyganodon grandis</i> <i>Lampsilis cardium</i>	EV EV EV
41. Birdtail River, PR 359 (7 mi W of Vista)	50°30' 100°57'	7/5/96	4	13.6	shale/silt shale/silt	52 52	<i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	5 2
	50°50' 100°42'	7/6/96	3				<i>Anodontooides ferussacianus</i> <i>Pyganodon grandis</i>	EV EV
	50°37' 100°52'	7/6/96	4	15	silt/shale/gravel	46	<i>Lasmigona complanata</i> <i>Pyganodon grandis</i> <i>Strophitus undulatus</i> <i>Lampsilis siliquoidea</i>	EV 3 EV 4

Appendix 2: Continued

LOCATION	N LAT. W LONG.	DATE	ORD	W(m)	SUBSTRATE	D(cm)	SPECIES	N
42. Golden Creek, 1 mi S and 1 mi E of Glenloch	50°05' 100°57'	7/8/96	4	6.5			<i>Anodontoides ferussacianus</i>	EV
43. Little Saskatchewan River, PR 354 (3 mi S of Elphinstone)	50°28' 100°19'	7/8/96	4	17.5			<i>Lasmigona complanata</i> <i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	EV EV EV
44. Little Saskatchewan River, 1.2 mi NW of Grand Valley Prov. Rec. Park	49°52' 100°06'	7/9/96	5	16.6	sand/gravel	42	<i>Fusconaia flava</i> <i>Amblema plicata</i> <i>Lasmigona complanata</i> <i>Ligumia recta</i> <i>Lampsilis siliquoidea</i> <i>Lampsilis cardium</i>	1 EV EV 5 2 11
45. Little Saskatchewan River, 1 mi S of Rivers	50°01' 100°14'	7/9/96	5	9.1			<i>Ligumia recta</i> <i>Lampsilis siliquoidea</i>	EV EV
46. Little Saskatchewan River, 1 mi S and 3 mi W of Rapid City	50°06' 100°07'	7/9/96	5	22.8	silt/cobble	31	<i>Lasmigona complanata</i> <i>Pyganodon grandis</i> <i>Strophitus undulatus</i> <i>Lampsilis siliquoidea</i>	EV 4 EV 16
47. Rolling River, 7.5 mi S and 2 mi W of Erikson	50°23' 99°57'	7/10/96	5	11			<i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	EV EV
48. Rolling River, 3.5 mi N of Erickson	50°32' 99°54'	7/10/96	5	10.5	silt silt		<i>Anodontoides ferussacianus</i> <i>Pyganodon grandis</i>	1 1
49. Rolling River, PR 263 (1 mi N and .5 mi W of Scandinavia)	50°32' 99°45'	7/10/96	4	10.1	silt silt		<i>Anodontoides ferussacianus</i> <i>Pyganodon grandis</i>	5 2
50. Whirlpool River, PTH 19	50°43' 99°50'	7/30/96	4	9.1	gravel/silt/sand gravel/silt/sand	55 55	<i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	10 11
51. Jackfish Creek, 5 mi N and 4 mi E of Lake Audy	50°47' 100°08'	7/31/96	3	9.1	gravel/silt/sand gravel/silt/sand	27 27	<i>Anodontoides ferussacianus</i> <i>Pyganodon grandis</i>	4 1
52. Whirlpool River, Whirlpool Lake	50°42' 99°48'	7/31/96	3	7.7	gravel/sand	52	<i>Pyganodon grandis</i>	21

Appendix 2: Continued

LOCATION	N LAT. W LONG.	DATE	ORD	W(m)	SUBSTRATE	D(cm)	SPECIES	N
53. Clear Creek, 1 mi E of Crawford Park	50°50' 100°05'	8/1/96	3	16.7			<i>Pyganodon grandis</i>	EV
54. Clear Creek, PR 354 (1.5 mi S and 1 mi W of Lake Audy)	50°41' 100°09'	8/1/96	3	6.5	sand/gravel/silt sand/gravel/silt sand/gravel/silt	34 34 34	<i>Anodontoides ferussacianus</i> <i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	2 5 1
55. Pipestone Creek, 4 mi N of Reston	49°37' 101°05'	8/12/96		10.5			<i>Anodontoides ferussacianus</i> <i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	EV EV EV
56. Pipestone Creek, 1.5 mi W of Kola	49°50' 101°23'	8/12/96		14.6	sand	58	<i>Lasimona complanata</i> <i>Anodontoides ferussacianus</i> <i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	EV 2 EV EV
57. Gainsborough Creek, 3 mi W and 1.5 mi N of Lyleton	49°04' 101°14'	8/13/96					<i>Anodontoides ferussacianus</i> <i>Pyganodon grandis</i>	EV EV
58. Antler River, 2 mi S and 2 mi E of Lyleton	49°01' 101°08'	8/13/96		8.1			<i>Lasimona complanata</i> <i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	EV EV EV
59. Medora Creek, 1 mi E and 1 mi N of Napinka	49°20' 100°49'	8/13/96	3	4.3			<i>Pyganodon grandis</i>	EV
60. Souris River, 2 mi N and 1.5 mi W of Lauder		8/13/96	6	36	silt/sand		<i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	EV 10
61. Souris River, Bunclody	49°32' 100°03'	8/14/96	6	48.3	shale shale shale		<i>Lasimona complanata</i> <i>Pyganodon grandis</i> <i>Strophitus undulatus</i> <i>Lampsilis siliquoidea</i>	4 EV 1 5
62. Pipestone Creek, Cromer	49°44' 101°14'	8/15/96		13.6	sand/silt/gravel sand/silt/gravel sand/silt/gravel	55 55 55	<i>Lasimona complanata</i> <i>Anodontoides ferussacianus</i> <i>Pyganodon grandis</i> <i>Lampsilis siliquoidea</i>	1 11 4 EV

Appendix 2: Continued

LOCATION	N LAT. W LONG.	DATE	ORD	W(m)	SUBSTRATE	D(cm)	SPECIES	N
63. Oak Creek, 1 mi S and 2 mi E of Treesbank	49°37' 99°34'	8/22/96	4	5.5	sand	26	<i>Fusconata flava</i>	2
					sand	26	<i>Lasmigona complanata</i>	2
					sand	26	<i>Anodontooides ferussacianus</i>	2
					sand	26	<i>Pyganodon grandis</i>	8
					sand	26	<i>Lampsilis silquidea</i>	9
							<i>Lampsilis cardium</i>	EV

ORD = stream order; W = stream width; D = depth; N = number of individuals; EV = empty valves

Appendix 3. Locations from which mussel species were collected in this survey.

SPECIES	LOCATION
<i>Fusconara flava</i>	Assiniboine River, Hwy 1
	Assiniboine River, river km 57
	Assiniboine River, river km 64
	Assiniboine River, river km 73
	Assiniboine River, river km 154
	Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)
	Souris River, PTH 2 (1 mi S and 1.5 mi E of Wawanesa)
	Little Saskatchewan River, 1.2 mi NW of Grand Valley Prov Rec Park
	Little Saskatchewan River, 4 mi S and 2 mi E of Carnegie
	Birdtail River, PR 477 (3 mi S and 4 mi W of Birtle)
	Oak Creek, 1 mi S and 2 mi E of Treesbank
<i>Amblyma plicata</i>	Assiniboine River, Hwy 1
	Assiniboine River, river km 15
	Assiniboine River, river km 18
	Assiniboine River, river km 23
	Assiniboine River, river km 28
	Assiniboine River, river km 32
	Assiniboine River, river km 73
	Assiniboine River, river km 77
	Assiniboine River, river km 57
	Assiniboine River, river km 64
Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)	
Little Saskatchewan River, 1.2 mi NW of Grand Valley Prov Rec Park	
<i>Quadrula quadrula</i>	Assiniboine River, river km 32
	Assiniboine River, river km 47
	Assiniboine River, river km 73
	Assiniboine River, river km 64
	Assiniboine River, river km 77
	Assiniboine River, river km 154
<i>Lasmigona complanata</i>	Assiniboine River, river km 47
	Assiniboine River, river km 18
	Souris River, PR 345 (9 mi E of Bede)
	Souris River, Bunclody
	Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)
	Little Saskatchewan River, 1 mi S and 3 mi W of Rapid City
	Little Saskatchewan River, PR 354 (3 mi S of Elphinstone)
	Little Saskatchewan River, 1.2 mi NW of Grand Valley Prov. Rec. Park
	Shell River, PTH 83 (1 mi N and 2 mi E of Inglis)
	Shell River, PTH 5 (1 mi N of Shevlin)
	Shell River, PR 367 (6 mi E and 2.5 mi N of Boggy Creek)
	Birdtail River, PR 359 (7 mi W of Vista)
	Pipestone Creek, 1.5 mi W of Kola
	Pipestone Creek, Cromer
Antler River, 2 mi S and 2 mi E of Lyleton	
Oak Creek, 1 mi S and 2 mi E of Treesbank	
Cypress River, 5 mi N of Holland and 3 mi W of PTH 34	
Cypress River, 1 mi W of Cypress River and 1 mi S of PTH 2	
<i>Lasmigona compressa</i>	Assiniboine River, river km 64
	Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)
	Little Saskatchewan River, 1 mi S and 3 mi W of Rapid City
	Shell River, PR 367 (6 mi E and 2.5 mi N of Boggy Creek)
	Cypress River, 5 mi N of Holland and 3 mi W of PTH 34
	Cypress River, St. Alphonse
<i>Anodontoides ferussacianus</i>	Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)
	Rolling River, 3.5 mi N of Erickson
	Rolling River, PTH 263 (1 mi N and .5 mi W of Scandinavia)
	Birdtail River, 1 mi N and 1 mi E of Mears
	Shell River, PR 367 (6 mi E and 2.5 mi N of Boggy Creek)
	East Shell River, PR 366 (6 mi N of PR 367 and 7 mi S of PR 271)
	Golden Creek, 1 mi S and 1 mi E of Glenlochar
	Silver Creek, 1.5 mi E and 2.5 S of Gambler

Appendix 3: Continued

SPECIES	LOCATION
	Clear Creek, PR 354 (1.5 mi S and 1 mi W of Lake Audy)
	Jackfish Creek, 5 mi N and 4 mi E of Lake Audy
	Pipestone Creek, 4 mi N of Reston
	Pipestone Creek, 1.5 mi W of Kola
	Pipestone Creek, Cromer
	Gainsborough Creek, 3 mi W and 1.5 mi N of Lyleton
	Oak Creek, 1 mi S and 2 mi E of Treesbank
	Cypress River, 5 mi N of Holland and 3 mi W of PTH 34
	Cypress River, 1 mi W of Cypress River and 1 mi S of PTH 2
	Cypress River, St. Alphonse
	Cypress River, 1.5 mi N and 1 mi W of St. Alphonse
	Cypress River, 6 mi E of Holland and 6 mi N of PTH 2
<i>Pyganodon grandis</i>	Assiniboine River, river km 157
	Souris River, PR 345 (9 mi E of Bede)
	Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)
	Souris River, PTH 2 (1 mi S and 1.5 mi E of Wawanesa)
	Souris River, 2 mi N and 1.5 mi W of Lauder
	Souris River, Bunclody
	Little Saskatchewan River, 1 mi S and 3 mi W of Rapid City
	Little Saskatchewan River, PR 354 (3 mi S of Elphinstone)
	Shell River, PTH 83 (1 mi N and 2 mi E of Inglis)
	Shell River, PTH 5 (1 mi N of Shevlin)
	Shell River, PR 367 (6 mi E and 2.5 mi N of Boggy Creek)
	East Shell River, PR 366 (6 mi N of PR 367 and 7 mi S of PR 271)
	Birdtail River, PR 477 (3 mi S and 4 mi W of Birtle)
	Birdtail River, PTH 16 (1 mi N and 1.5 mi W of Solsgirth)
	Birdtail River, 1 mi N and 1 mi E of Mears
	Birdtail River, PR 359 (7 mi W of Vista)
	Silver Creek, 1.5 mi E and 2.5 S of Gambler
	Rolling River, 7.5 mi S and 2 mi W of Erikson
	Rolling River, 3.5 mi N of Erickson
	Rolling River, PTH 263 (1 mi N and .5 mi W of Scandinavia)
	Pipestone Creek, 4 mi N of Reston
	Pipestone Creek, 1.5 mi W of Kola
	Pipestone Creek, Cromer
	Gainsborough Creek, 3 mi W and 1.5 mi N of Lyleton
	Antler River, 2 mi S and 2 mi E of Lyleton
	Medora Creek, 1 mi E and 1 mi N of Napinka
	Boggy Creek, 6 mi W and 3 mi N of Roblin
	Whirlpool River, PTH 19
	Whirlpool River, Whirlpool Lake
	Clear Creek, 1 mi E of Crawford Park
	Clear Creek, PR 354 (1.5 mi S and 1 mi W of Lake Audy)
	Jackfish Creek, 5 mi N and 4 mi E of Lake Audy
	Oak Creek, 1 mi S and 2 mi E of Treesbank
	Cypress River, 5 mi N of Holland and 3 mi W of PTH 34
	Cypress River, 1.5 mi N and 1 mi W of St. Alphonse
	Cypress River, 6 mi E of Holland and 6 mi N of PTH 2
<i>Strophitus undulatus</i>	Assiniboine River, river km 18
	Assiniboine River, river km 73
	Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)
	Souris River, Bunclody
	Little Saskatchewan River, 1 mi S and 3 mi W of Rapid City
	Shell River, PTH 83 (1 mi N and 2 mi E of Inglis)
	Shell River, PTH 5 (1 mi N of Shevlin)
	Birdtail River, PR 359 (7 mi W of Vista)
<i>Potamilus alatus</i>	Assiniboine River, Hwy 1
	Assiniboine River, river km 15
	Assiniboine River, river km 18
	Assiniboine River, river km 23
	Assiniboine River, river km 28
	Assiniboine River, river km 45
	Assiniboine River, river km 140
	Assiniboine River, river km 154

Appendix 3: Continued

SPECIES	LOCATION
<i>Ligumia recta</i>	Assiniboine River, Hwy 1
	Assiniboine River, river km 47
	Assiniboine River, river km 73
	Assiniboine River, river km 77
	Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)
	Little Saskatchewan River, 1.2 mi NW of Grand Valley Prov Rec Park
	Little Saskatchewan River, 1 mi S of Rivers
	Qu'Appelle River, 1 mi W of St.Lazare
<i>Lampsilis siliquoidea</i>	Assiniboine River, Hwy 1
	Assiniboine River, river km 15
	Assiniboine River, river km 23
	Assiniboine River, river km 28
	Assiniboine River, river km 32
	Assiniboine River, river km 57
	Assiniboine River, river km 64
	Assiniboine River, river km 77
	Assiniboine River, river km 73
	Assiniboine River, river km 84
	Souris River, PR 345 (9 mi E of Bede)
	Souris River, Bunclody
	Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)
	Souris River, PTH 2 (1 mi S and 1.5 mi E of Wawanesa)
	Souris River, 2 mi N and 1.5 mi W of Lauder
	Little Saskatchewan River, PR 354 (3 mi S of Elphinstone)
	Little Saskatchewan River, 1.2 mi NW of Grand Valley Prov. Rec. Park
	Little Saskatchewan River, 1 mi S of Rivers
	Little Saskatchewan River, 1 mi S and 3 mi W of Rapid City
	Little Saskatchewan River, 4 mi S and 2 mi E of Carnegie
	Qu'Appelle River, 1 mi W of St.Lazare
	Shell River, PTH 83 (1 mi N and 2 mi E of Inglis)
	Shell River, PTH 5 (1 mi N of Shevlin)
	Birdtail River, PTH 16 (1 mi N and 1.5 mi W of Solsgirth)
	Birdtail River, PR 359 (7 mi W of Vista)
	Rolling River, 7.5 mi S and 2 mi W of Erikson
	Whirlpool River, PTH 19
Jackfish Creek, 5 mi N and 4 mi E of Lake Audy	
Clear Creek, PR 354 (1.5 mi S and 1 mi W of Lake Audy)	
Antler River, 2 mi S and 2 mi E of Lyleton	
Pipestone Creek, 4 mi N of Reston	
Pipestone Creek, 1.5 mi W of Kola	
Pipestone Creek, Cromer	
Oak Creek, 1 mi S and 2 mi E of Treesbank	
Cypress River, 6 mi E of Holland and 6 mi N of PTH 2	
<i>Lampsilis ovata</i>	Assiniboine River, river km 18
	Assiniboine River, river km 15
	Assiniboine River, river km 23
	Assiniboine River, river km 28
	Assiniboine River, river km 32
	Assiniboine River, river km 57
	Assiniboine River, river km 64
	Assiniboine River, river km 73
	Assiniboine River, river km 77
	Assiniboine River, river km 84
	Assiniboine River, river km 109
	Assiniboine River, river km 115
	Assiniboine River, river km 154
	Assiniboine River, river km 157
	Souris River, PR 340 (.5 mi E and .5 mi S of Treesbank)
	Little Saskatchewan River, 1.2 mi NW of Grand Valley Prov Rec Park
	Little Saskatchewan River, 4 mi S and 2 mi E of Carnegie
	Shell River, PTH 83 (1 mi N and 2 mi E of Inglis)
Birdtail River, PR 477 (3 mi S and 4 mi W of Birtle)	
Qu'Appelle River, 1 mi W of St.Lazare	
Oak Creek, 1 mi S and 2 mi E of Treesbank	

Appendix 4. Distribution maps freshwater mussels collected from the 1995 and 1996 surveys of the Assiniboine River Drainage in Manitoba.

Amblema plicata

- - live occurrences
- - empty valves only

LAKE

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Quadrula quadrula

- - live occurrences
- - empty valves only

LAKE

MANITOBA



Lasmigona compressa

- - live occurrences
- - empty valves only

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LAKE

MANITOBA

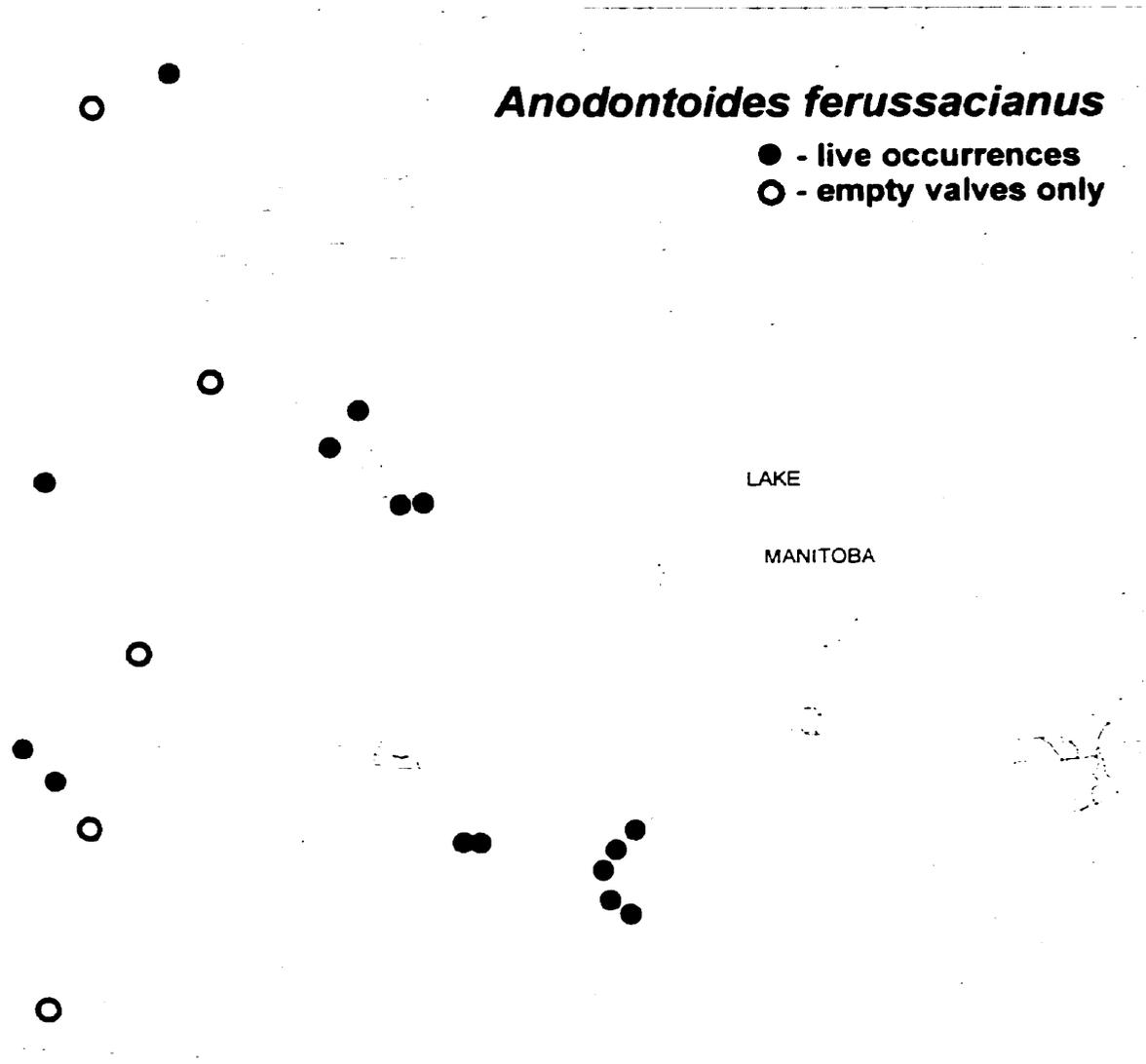
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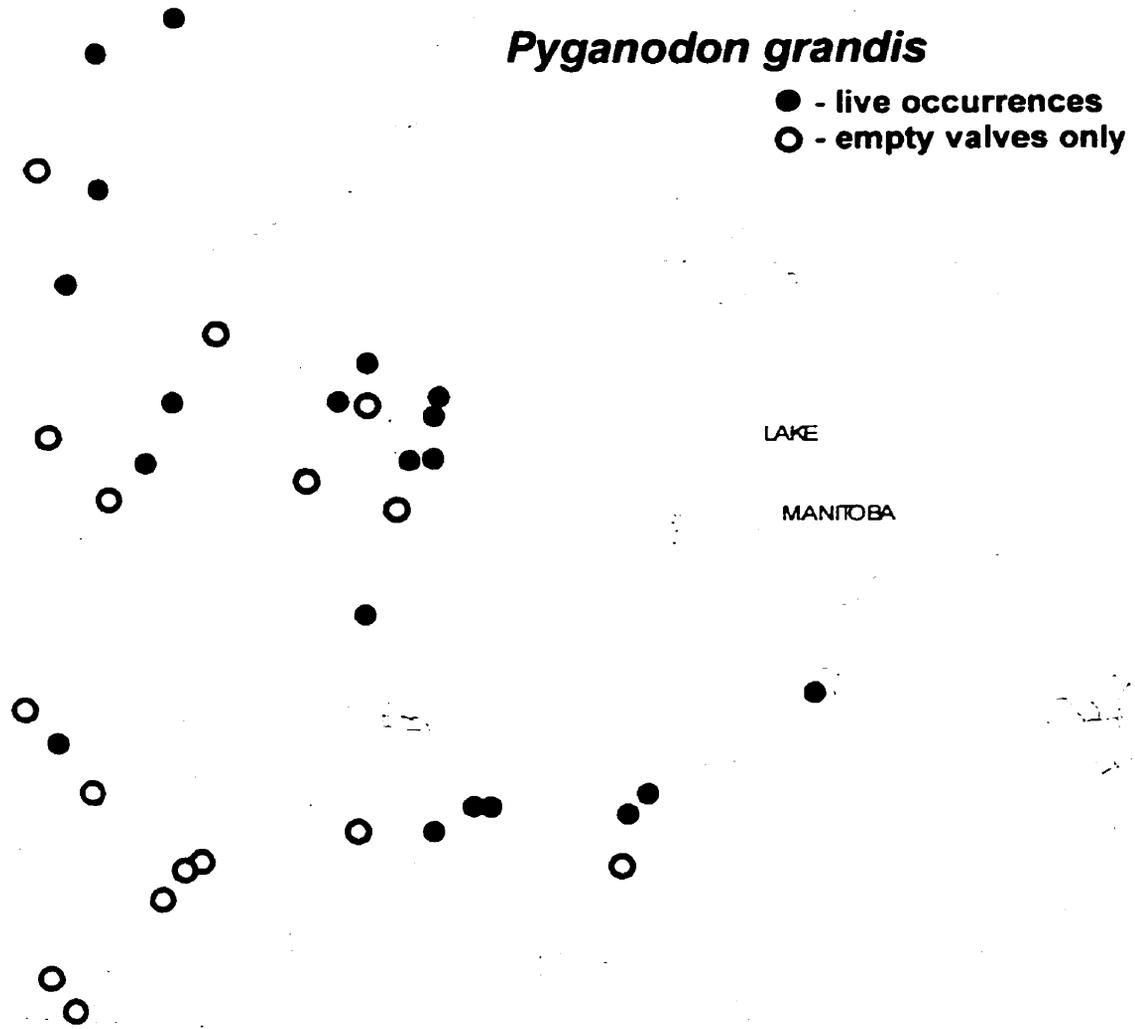
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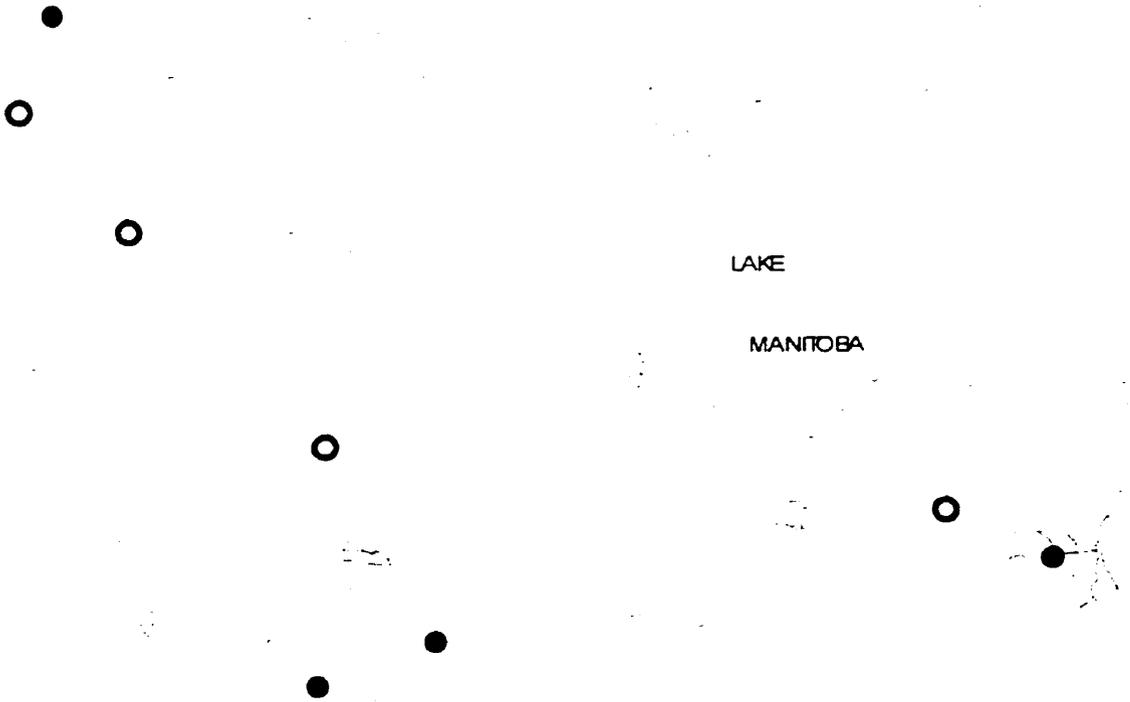
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Strophitus undulatus

- - live occurrences
- - empty valves only



Potamilus alatus

- - live occurrences
- - empty valves only

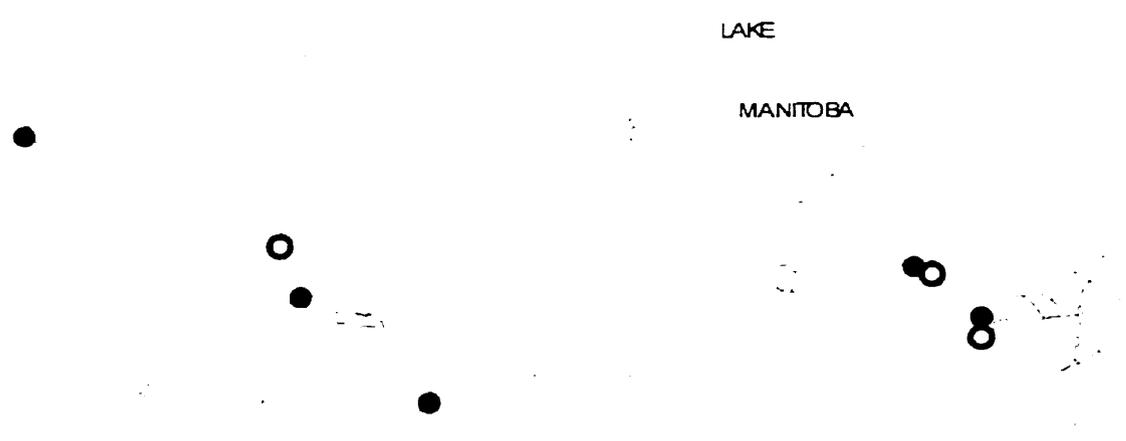
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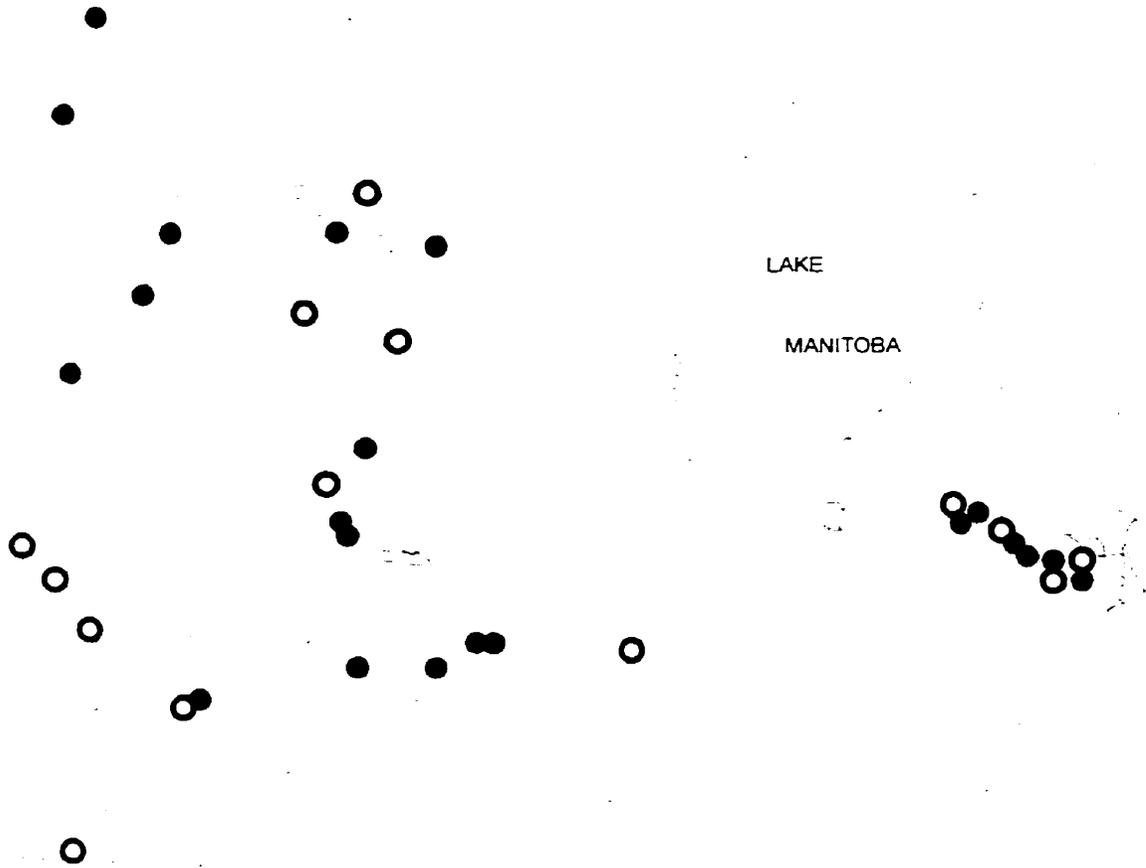
Ligumia recta

- - live occurrences
- - empty valves only



Lampsilis siliquoidea

- - live occurrences
- - empty valves only



Lampsilis cardium

- - live occurrences
- - empty valves only

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Appendix 5. Previous records of freshwater mussels for the Assiniboine River drainage in Manitoba.

SPECIES	LOCATION	COLLECTION
<i>Fusconaia flava</i>	Assiniboine River west of Winnipeg (Headingley)	Pip 1995
	Assiniboine River from PR 241 upstream to PTH 1	Scaife and Janusz 1992
	Assiniboine River west Winnipeg	Clarke 1973
	Assiniboine River 8 miles west of Winnipeg	Clarke 1973
	Assiniboine River 12 miles northwest of St. Francis Xavier	Clarke 1973
	Souris River	Mozley 1938 (see Clarke 1973)
<i>Amblema plicata</i>	Assiniboine River west of Winnipeg (Headingley)	Pip 1995
	Assiniboine River from PR 241 upstream to PTH 1	Scaife and Janusz 1992
	Assiniboine River west Winnipeg	Clarke 1973
	Assiniboine River 8 miles west of Winnipeg	Clarke 1973
	Assiniboine River 12 miles northwest of St. Francis Xavier	Clarke 1973
	Assiniboine River at Millwood	Tyrell 1889 (see Clarke 1973)
<i>Quadrula quadrula</i>	Assiniboine River west of Winnipeg (Headingley)	Pip 1995
	Assiniboine River from PR 241 upstream to PTH 1	Scaife and Janusz 1992
	Assiniboine River at west Winnipeg	Clarke 1973
	Assiniboine River 8 miles west of Winnipeg	Clarke 1973
<i>Lasmigona complanata</i>	Assiniboine River from PR 241 upstream to PTH 1	Scaife and Janusz 1992
	Assiniboine River west Winnipeg	Clarke 1973
	Assiniboine River 12 miles northwest of St. Francis Xavier	Clarke 1973
	Assiniboine River at Millwood	Tyrell 1889 (see Clarke 1973)
	"Upper" Assiniboine River	Bell 1984 (see Whiteaves 1895)
	Shell River 6 miles east of Roblin	Clarke 1973
	Shell River 8 miles east of Roblin	Clarke 1973
	Shell River 9 miles north-northwest of Roblin	Clarke 1973
	Little Saskatchewan River 11 miles north-northeast of Elphinstone	Clarke 1973
	Little Saskatchewan River 10 miles north-northwest of Minnedosa	Clarke 1973
	Souris River at Souris	Seiwyn 1882 (see Clarke 1973)
<i>Lasmigona compressa</i>	Shell River 6 miles east of Roblin	Clarke 1973
	Shell River 8 miles east of Roblin	Clarke 1973
<i>Anodontoides ferussacianus</i>	Souris River .5 miles northeast of Souris	Clarke 1973
<i>Pyganodon grandis</i>	Assiniboine River west of Winnipeg (Headingley)	Pip 1995
	Assiniboine River west Winnipeg	Clarke 1973
	Little Saskatchewan River 11 miles north-northeast of Elphinstone	Clarke 1973
	Little Saskatchewan River 10 miles north-northwest of Minnedosa	Clarke 1973
	Clear Lake 4 miles and 8 miles North of Wasagaming	Clarke 1973
	Shell River 6 miles east-southeast of Roblin	Clarke 1973
	Shell River 8 miles east of Roblin	Clarke 1973
Shell River 9 miles north-northwest of Roblin	Clarke 1973	
<i>Strophitus undulatus</i>	Assiniboine River west Winnipeg	Clarke 1973
	Assiniboine River 12 miles northwest of St. Francis Xavier	Clarke 1973
	Birdtail Creek near Birtle	Mozley 1938 (see Clarke 1973)
	Shell River 6 miles east of Roblin	Clarke 1973
	Shell River 8 miles east of Roblin	Clarke 1973
	Shell River 9 miles north-northwest of Roblin	Clarke 1973
<i>Potamilus alatus</i>	Assiniboine River west of Winnipeg (Headingley)	Pip 1995
	Assiniboine River from PR 241 upstream to PTH 1	Scaife and Janusz 1992

Appendix 5: Continued

SPECIES	LOCATION	COLLECTION
<i>Ligumia recta</i>	Assiniboine River west Winnipeg	Clarke 1973
	Assiniboine River 12 miles northwest of St. Francis Xavier	Clarke 1973
	Assiniboine at Millwood	Tyrell 1888 (see Clarke 1973)
	Assiniboine River west of Winnipeg (Headingley)	Pip 1995
	Assiniboine River from PR 241 upstream to PTH 1	Scaife and Janusz 1992
<i>Lampsilis siliquoidea</i>	Numerous Records	
<i>Lampsilis cardium</i>	Assiniboine River west of Winnipeg (Headingley)	Pip 1995
	Assiniboine River from PR 241 upstream to PTH 1	Scaife and Janusz 1992
	Assiniboine River west Winnipeg	Clarke 1973
	Assiniboine River 8 miles west of Winnipeg	Clarke 1973
	Assiniboine River 12 miles northwest of St. Francis Xavier	Clarke 1973
	Assiniboine at Millwood	Tyrell 1888 (see Clarke 1973)
	Shell River 6 miles east of Roblin	Clarke 1973
Shell River 9 miles north-northwest of Roblin	Clarke 1973	

Appendix 6. Measurements for specimens of *Anodontoides ferussacianus* collected from the Cypress River in 1996. ns = not sectioned.

Date	Location	#	Length	Height	Width	Ext. Age	Int. Age	Sex	Gonad Score	Glochidia Score
5/7/96	Endo 1	1	48.35	26.35	17.95	2	1	m	3	-
		2	33.15	19.5	11.25	1	1	f	3	2
		3	32	19.4	10.85	1	1	f	3	2
		4	32.25	18.1	10.2	1	1	f	3	2
		5	31.8	18	10.65	1	1	f	3	2
5/7/96	Endo 3	1	57.85	31.2	19.95	2	2	f	3	1
		2	51.5	27.75	17.3	2	2	m	3	-
		3	29	17	9.05	1	1	m	3	-
		4	29.2	16.85	8.7	1	1	f	3	2
		5	27.95	16.4	9	1	1	f	3	2
5/7/96	Endo 4	1	31	17.65	9.6	1	1	f	3	2
5/7/96	Epi 1	1	50.8	28.8	17.75	2	2	m	3	-
5/7/96	Epi 2	1	53.2	28.95	18.45	2	2	f	3	3
5/7/96	Epi 3	1	74.7	40	27.55	4	3	f	3	3
		2	68	34.4	25.4	3	3	ns	ns	3
		3	52.55	28.25	19.75	2	2	f	3	3
		4	49.4	27.1	14.4	2	2	m	3	-
		5	31.4	18.6	9.8	1	1	m	3	-
5/7/96	Epi 4	1	51.55	28.55	17.55	2	2	f	3	3
		2	45.65	24.7	16.65	2	2	m	3	-
		3	46.9	26.3	16.1	2	2	f	3	3
5/14/96	Epi 4	1	73.6	40.65	27.6	6	5	m	3	-
		2	68.5	35.35	28.2	3	2	f	3	3
		3	54.15	28.05	19.9	2	2	f	3	3
5/14/96	Epi 3	1	54.8	27.6	19.5	2	2	f	3	3
5/22/96	Epi 1	1	59.6	32.85	20	2	3	m	3	-
5/22/96	Epi 2	1	58	31.1	19.9	2	2	m	3	-
5/22/96	Epi 3	1	55.2	28.65	20.4	2	2	f	3	3
5/22/96	Epi 4	1	65.25	35	25.1	5	4	m	3	-
		2	58.45	31.55	19.85	3	3	m	3	-
5/22/96	Endo 1	1	53.9	27.8	19.85	2	2	f	3	3
		2	29.35	16.65	9.65	1	1	f	3	2
		3	28.95	17.2	8.95	1	1	f	3	2
		4	24.7	14.3	7.2	1	1	-	1	-
		5	24.5	15	8.1	1	1	f	2	2
		6	18.65	11.8	6.05	1	1	f	2	2
5/22/96	Endo 2	1	50.8	28.8	17.95	3	3	f	3	3
		2	32.9	18.6	10.9	1	1	f	3	2
		3	30.45	17.8	9.6	1	1	f	3	2
		4	29.9	17.3	9.4	1	1	f	3	2
		5	28.85	16.9	8.65	1	1	m	3	-
		6	28	16.45	9.05	1	1	f	3	2
		7	23.25	13.5	7.35	1	1	m	3	-
		8	21.9	13.6	7.55	1	1	f	3	2
		9	20.8	12.45	7.7	2	1	f	3	2
		10	17.6	10.6	5.45	1	1	-	1	-
5/22/96	Endo 3	1	28.6	16.5	8.3	1	1	f	3	2
5/22/96	Endo 4	1	31	18.1	10.3	1	1	f	3	2
		2	29.1	17.55	9.5	1	1	f	3	2

Appendix 6: Continued

Date	Location	#	Length	Height	Width	Ext. Age	Int. Age	Sex	Gonad Score	Glochidia Score
		3	26.5	16.4	8.2	1	1	m	3	-
		4	27.25	16.1	8.75	1	1	m	3	-
		5	24.65	14.45	7.6	1	1	f	3	2
		6	22.4	13.4	6.5	1	1	m	3	-
		7	23.2	13.95	7.6	1	1	f	3	2

5/28/96	Epi 1	1	66.65	35.05	23.7	3	NS	f	3	1
5/28/96	Epi 2	1	54.4	29.1	19.45	2	2	m	3	-
		2	52.25	28.8	18.25	2	2	m	3	-
5/28/96	Epi 4	1	68.35	36.15	25	3	3	m	3	-
5/28/96	Endo 1	1	44.65	24.8	15.7	3	2	f	3	2
		2	31.45	18.65	9.25	1	NS	m	3	-
		3	27.3	16.2	8.6	1	1	f	3	2
5/28/96	Endo 2	1	29.85	7.55	9.2	1	1	m	3	-
5/28/96	Endo 4	1	28.35	16.5	9.9	1	1	f	3	2
		2	28.35	16.75	9.05	1	1	m	3	-
		3	29.8	17.05	9.9	1	1	f	3	2
		4	23.1	13.55	7.05	1	1	-	1	-

6/11/96	Epi 1	1	67.7	36.5	24.3	5	5	m	3	-
6/11/96	Endo 1	1	55.85	30.3	20.85	2	2	f	4	2
		2	30.5	18.85	10.65	1	1	m	3	-
6/11/96	Endo 3	1	30.4	17.3	9.55	1	1	f	3	2
6/11/96	Misc Endo	1	28.7	16.9	9.2	1	1	m	3	-
		2	31.9	18.85	10.7	1	1	m	3	-
		3	33	20.1	11.55	1	1	m	3	-
		4	41.2	23.8	15	2	2	f	3	2
		5	54.9	29.4	18.15	2	2	m	3	-
		6	55.5	29.65	20.85	2	2	f	3	3

6/25/96	Epi 1	1	64.4	35.75	25.05	5	4	m	4	-
6/25/96	Misc Epi	1	66.1	37	23.5	4	3	m	4	-
		2	67.7	36.25	23.1	4	3	m	4	-
6/25/96	Endo 2	1	40.85	23.05	13.75	1	1	m	3	-
		2	35	20.1	12.6	1	1	m	3	-
6/25/96	Endo 3	1	40.1	22.9	13.35	1	1	f	3	2
		2	38.75	22.75	13.05	1	1	m	4	-
		3	41.5	24.4	12	1	1	m	3	-
		4	36.4	21.55	11.9	1	1	m	3	-
		5	35.25	20.3	11.8	1	1	m	3	-
		6	33.95	19.6	11.4	1	1	m	3	-
		7	35.15	20.2	11.3	1	1	f	3	2
		8	30.95	17.5	9.9	1	1	f	3	2
		9	30.75	17	9.9	1	1	f	3	2
		10	31.5	18.45	9.55	1	1	m	3	-
		11	32.65	16.95	10.75	1	1	f	3	2
		12	27.85	12.05		1	1	-	1	-
6/25/96	Endo 4	1	40.75	22.55	13.95	1	1	f	3	2
		2	37.4	21.35	13	1	1	f	3	2
6/25/96	Misc Endo	1	59.2	31.65	21.05	2	2	m	4	-
		2	57.55	29.85	21.8	2	2	f	4	3
		3	52.55	29	18.85	2	2	m	4	-
		4	38	21.6	13.5	1	1	ns	ns	ns
		5	37.15	21.7	13.1	1	1	ns	ns	ns

Appendix 6: Continued

Date	Location	#	Length	Height	Width	Ext. Age	Int. Age	Sex	Gonad Score	Glochidia Score
7/9/96	Misc Endo	1	63.8	33.9	24.65	2	NS	f	4	2
		2	55.7	29.8	18.5	2	2	m	4	-
		3	40.7	22.2	14.45	1	1	f	3	2
		4	40.15	23.4	13.1	1	NS	m	4	-
		5	38.75	22.2	13.8	1	NS	f	4	2
		6	38.05	22.1	13	1	1	m	4	-
		7	36.7	21.1	11.9	1	1	m	4	-
		8	37.35	21.1	12.85	1	1	f	4	2
		9	35.4	19.75	10.2	1	1	m	4	-
		10	32.65	18.8	11.05	1	1	m	4	-
		11	32.75	18.6	10.3	1	1	F/m	3	2
		12	30.05	16.65	9.6	1	1	f	3	2
		13	26.35	15	14.5	1	1	m	4	-
7/24/96	Endo 1	1	63.75	36.25	24.5	2	2	m	4	-
		2	61.9	32.65	23.9	3	2	ns	ns	3
		3	67.55	35.25	25.1	2	2	ns	ns	3
		4	64.1	35.3	23.6	2	2	m	4	-
		5	52.7	29.3	18.25	1	1	ns	ns	ns
		6	50.6	27.85	17.1	1	1	f	4	2
		7	48.4	26.5	16.4	1	1	m	4	-
		8	45.9	24.35	16.2	1	1	m	4	-
		9	44	24.45	15.3	1	1	m	4	-
		10	41.4	23.25	15.1	1	1	f	4	2
		11	42	24	13.6	1	1	m	4	-
		12	39.25	22.9	13.1	1	1	m	4	-
7/24/96	Misc Endo	1	45.8	25.8	16.55	1	1	f	4	2
		2	45.85	26.3	16.55	1	1	m	4	
		3	42.1	24	14.7	1	1	f	4	2
		4	37.5	22.05	12.3	1	1	f	3	2
7/24/96	Endo 3	1	39.1	22.05	12.25	2	1	m	4	-
8/7/96	Endo 2	1	70.7	36.75	27.4	2	2	f	3	3
8/7/96	Endo 4	1	67.15	35.55	23	2	2	m	3	-
8/7/96	Misc Endo	1	63.7	33.75	23.65	2	1	m	3	-
		2	63.75	34	23.15	2	1	m	4	-
		3	56.7	30.55	20.75	2	1	m	4	-
		4	52.9	27.7	18.8	2	1	f	3	3
		5	50.15	29.2	17.8	1	1	f	4	3
		6	46.85	26	16.3	1	1	m	4	-
		7	48.85	28.15	17.05	1	1	m	4	-
		8	49.55	27.25	17.9	1	1	F/m	4	3
		9	49.7	28.1	16.1	1	1	M/f	4	-
		10	42.65	22.7	14.25	1	1	f	3	3
8/20/96	Endo 1	1	69.5	34.2	25.1	2	2	f	3	3
8/20/96	Endo 3	1	70.1	35	26.3	3	2	f	3	3
		2	67.75	34.6	26.05	2	2	f	3	3
		3	65.05	34.55	22.8	2	NS	m	3	-
		4	65	33.8	28.05	2	2	f	3	3
		5	67.15	34.05	26	2	2	f	3	3
		6	63.2	32.5	22.85	2	2	m	3	-
		7	53.1	27.8	19.55	1	1	f	3	3
8/20/96	Endo 4	1	53.35	29.2	19.4	1	1	ns	ns	3
8/26/96	Misc Endo	1	53.75	29	19.35	1	1	f	3	3

Appendix 6: Continued

Date	Location	#	Length	Height	Width	Ext. Age	Int. Age	Sex	Gonad Score	Glochidia Score
		2	51.75	29.05	19.1	1	1	m	4	-
		3	47.8	27.85	15.5	1	1	m	3	-
		4	42.25	22.65	14.45	1	1	f	3	3
		5	44.05	24.1	15.85	1	1	m	3	-
		6	12.2	7.65	3.55	0	0	-	1	-
		7	10.4	6.45	3.1	0	0	-	1	-
		8	12.5	7.6	3.4	0	0	-	1	-

9/7/96	Endo 1	1	50.75	28.4	16.25	1	1	m	3	-
		2	50.45	27.05	18.4	1	1	f	3	3
9/7/96	Endo 3	1	66.95	36.05	24.15	2	2	m	3	-
		2	53.85	28.9	19.3	1	1	f	3	3
		3	45.55	25	15.2	1	1	f	3	2
		4	42.55	23.05	14.3	1	1	m	3	-

9/17/96	Endo 2	1	54.85	31	18.1	1	NS	m	3	-
9/17/96	Misc Endo	1	65.6	39.95	26.55	3	NS	f	4	3
		2	50.95	22.9	18.3	1	1	f	3	3
		3	49.7	26.2	18.5	1	1	f	3	3
		4	47.7	26.6	15.95	1	1	f	3	3
9/17/96	Misc Epi	1	47.55	25.9	15.7	1	1	m	3	-

10/5/96	Endo 3	1	14.15	7.9	3.55	0	0	-	1	-
10/5/96	Misc Endo	1	65	37.25	24.95	5	3	m	3	-
		2	50.15	27.55	17.45	1	1	m	3	-
		3	53	28.4	19.8	1	1	f	3	3
		4	49.65	26.7	16.7	1	1	m	3	-
		5	54.05	28.5	19.8	1	1	f	3	3
		6	53	29.4	18.4	1	1	f	3	3
10/5/96	Misc Epi	1	80	40.05	29.6	5	5	f	4	3

10/17/96	Endo 1	1	51.3	26.85	19.15	1	1	f	4	3
		2	45.2	25.4	14.55	1	1	m	3	-
10/17/96	Endo 2	1	53.05	28.5	20.4	3	2	f	3	3
		2	15.45	9.4	4.3	0	0	-	1	-
		3	12.3	7.55	3.5	0	0	-	1	-
10/17/96	Endo 3	1	15.5	10.25	4.45	0	0	-	1	-
		2	17.5	10.8	5.7	0	0	-	1	-
10/17/96	Misc Endo	1	68.45	36.95	25.5	3	2	f	4	3
		2	49.4	27.55	16.25	2	2	m	3	-
		3	17.3	9.9	4.8	0	0	-	1	-
		4	15.6	9.6	4.65	0	0	-	1	-

Appendix 7. Physical and chemical data for the Cypress River during the 1996 sampling period. Mean depth and velocities are averages of sampling quadrats.

	5/14/96	5/22/96	5/28/96	6/11/96	7/24/96	8/7/96	8/20/96	9/7/96	9/17/96	10/5/96	10/17/96
Temperature (°C)	10	13	16	22	18	18.5	25	20	17	15	5
Stream Width (m)	8.4	9.75	7.55	4.5	4.4	4.1	3.9	3.85	3.9	3.95	4.05
Mean Depth (cm)*	27.325	37.05	46.45	31.2	16.675	25.25	20.45	17.475	17.075	20.825	17.525
Mean Velocity (m/s)*	4.305	15.499	9.0205	5.1565	10.4295	1.604	0.87395	0.93695	0	0	0
Total Dissolved Phosphorus (µg/l)	0	266	196	205	0	115	0	106	0	0	0
Dissolved Inorganic Carbon (µm/l)	4850	5350	6000	6450	8000	7500	7250	7950	8050	6800	7450
Dissolved Organic Carbon (µm/l)	1140	1370	1150	1100	900	800	560	400	450	600	500
Soluble Reactive Silica (mg/l)	4.680	3.740	5.600	7.710	12.500	12.800	12.900	12.600	13.100	11.700	11.100
Chloride (mg/l)	10.30	13.00	11.60	11.40	13.60	18.20	21.40	23.30	24.50	23.40	23.10
Sulphate (mg/l)	114.40	147.00	129.10	107.50	78.30	82.10	80.70	88.00	86.00	81.20	81.20
Total Suspended Solids (mg/l)	5	8	9	20	11	7	3	5	4	8	3
Conductivity (µS/cm)	690	786	774	797	786	848	846	843	860	838	846
Potassium (mpg/l)	7.14	8.00	8.05	7.60	7.50	7.20	6.95	6.70	6.90	6.18	5.88
Calcium (mg/l)	89.00	102.00	108.00	110.00	101.00	90.60	91.80	91.00	93.20	95.70	97.20
pH	8.86	8.89	8.88	8.94	8.95	8.95	8.92	8.98	8.96	8.92	8.96
Alkalinity (ueq/l)	4980	5425	5932	6723	7030	7098	6940	7034	6768	6730	6730

* Depths and velocities are mean values calculated from all values for quadrats on each sampling date.