Effects of slope, depth, fetch, and sediment organic matter content on the distribution and abundance of mussels (Bivalvia: Unionidae) in a reservoir lake in central Iowa

by

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Signatures have been redacted for privacy

For the Graduate College

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INTRODUCTION

Freshwater mussels are an ecologically important group of organisms that are poorly understood and appear to be falling rapidly to extinction. Mussels may be the most endangered of all animal groups with over 70 percent of mussel species threatened or endangered (Williams *et al.*, 1993). More than seven percent of mussel species may already be extinct.

There are several possible causes for the dramatic declines in observed mussel abundance and distributions. Human activities impact mussel habitats in several ways. Erosion due to agricultural practices and logging can cause increased siltation which can cover and suffocate mussel beds (Coker *et al.*, 1922; Hart, 1993; Mehlhop & Vaughn, 1994). Agricultural run-off introduces fertilizers, herbicides, and insecticides that may contribute to declines in mussel abundances (Strayer, 1980). Industrial effluents introduce toxic chemicals to waters in which mussels occur. Industrial toxins may cause mussel die-offs and decreased mussel productivity (Cvancara, 1970; Fleming, Augspurger & Alderman, 1995). It is thought that mussels may be extremely long lived. If this is true, populations of mussels may be experiencing delayed die-offs due to their advanced ages and previous inability to reproduce. This may be compounded by poor water quality which may inhibit reproduction (Mehlhop & Vaughn, 1994).

Mussels are sensitive indicators of water quality. They can therefore be used to detect many types of pollutants and toxins (Hickey & Martin, 1995). Although sensitive, they can survive to bioaccumulate minute traces of some toxins that may be otherwise undetectable in a water source. Mussels can bioaccumulate both metals and pesticides (Keller & Zam, 1991; Keller, 1993). Other pollutants that may negatively affect mussel abundances include fertilizers, sewage, and silt (Keller, 1993). Mussels have been found useful for monitoring streams for the presence of pollutants (Tessier *et al.*, 1984; Hinch *et al.*, 1986; Jenner, de Zwart & Kramer, 1991). Mussels have also been used to monitor point and non-point source effluents (Foster & Bates, 1978; Herve, 1991; Fent & Hunn, 1995). Freshwater mussels are sensitive permanent residents of aquatic systems and are useful tools in efforts to monitor water quality.

Mussels were an important resource to prehistoric and historic cultures. They were utilized by indigenous cultures as a food source (Parmalee & Klippel, 1974; Stoltman, 1983; Lightfoot, Cerrato & Wallace, 1993). Mussel shell was used as temper in pottery (Stoltman, 1983; Roosevelt *et al*., 1991), as various tools such as spoons, hoes, and scrapers (Gradwohl, 1982; Stoltman, 1983), to shell corn (Gradwohl, 1982), and were fashioned into beads and other jewelry (Stoltman, 1983; Yerkes, 1983; Seymour, 1988). Mussels have been economically important to Caucasian cultures because they were the source of freshwater pearls (Kunz, 1893), and the root of the button industry (Coker, 1921; O'Hara, 1980). Freshwater mussels have been an important resource to humans throughout history.

Mussels continue to be economically important. Freshwater mussels are an important source of natural and cultured pearls (Lopinot, 1967; Thiel & Fritz, 1993) and buttons. From 1989 through 1990 over 14 million pounds of mussels were harvested from the Mississippi and Illinois rivers, valued at greater than $9 million (Thiel & Fritz, 1993). Freshwater mussels continue to be a vital economic resource.

In spite of the ecological, economic and historic importance of freshwater mussels, little is known about their basic ecology. Many aspects of mussel existence are unknown, such as life spans, growth rates, feeding habits, food preferences, habitat requirements and preferences, and spatial and geographic distributions (Salmon & Green, 1983; Strayer *et al*., 1994). In addition, endemic freshwater mussels have complex life histories. They have an obligate parasitic larval stage that requires the presence of a fish host in order to survive. The larvae of different species of mussels require different species of fish hosts in order to develop. This may compound their difficulties since mussels may not be able to adapt to habitat changes within their current geographic distributions. Changes such as lack of host fish, lack of suitable nursery bed sites due to siltation, and changes in water quality could all influence mussel abundance.

Introduced exotic species may exacerbate these problems. Species such as *Dreissena* and *Corbicula* have a free swimming larval stage that does not require a fish host. This life history strategy allows exotic mussel species to proliferate in areas where endemic species are currently distributed, as well as in areas of habitat that is marginal or poor habitat for native freshwater mussels. The complexity of endemic freshwater mussels' life histories as well as the effects of competition from non-native species underscores the need for knowledge of their basic ecology. It is currently poorly understood which aspects of their environment are most important to their growth and survival. Suitability of mussel habitat can vary widely between and among species (Parmalee, 1967; Clarke, 1981). Factors thought to influence mussel distribution are therefore numerous and varied.

If mussels are to be protected, it is necessary to know what factors influence their distribution and abundance in aquatic ecosystems. Detailed knowledge of mussel distributions might allow an understanding of factors influencing them and permit efficient monitoring of changes in abundance. Factors influencing distributions and abundance of mature mussels are among the most rudimentary data required for remediation efforts. Population dynamics of individual populations cannot be understood without information on their distribution, abundance, growth, and reproductive rates. Once a population is located and its distribution recorded, size and frequency data can be obtained and efficiently monitored in subsequent years. Population dynamics can then be determined from these data and population changes can be documented.

Research and documentation of spatial and geographical mussel distributions could create opportunities to monitor water quality using knowledge of mussel distributions. Mussels have been shown to be useful tools in monitoring water quality (Hayton *et al.*, 1990; Jenner, de Zwart & Kramer, 1991). With data on distribution of mussels, water quality monitoring can take place utilizing areas where mussels are present. In addition, mussels could be relocated to areas where they can survive in order to monitor water quality in areas where mussels are absent (Hayton *et al.*, 1990).

Knowledge of factors influencing mussel distributions could allow their efficient location, improving conservation efforts. Once populations are located and the factors determining distributions and preferred habitat characteristics are known, efforts can be made to conserve them. Species whose habitat characteristics are unknown may fall to extinction undetected, without any possibility of efforts to conserve their populations. It is therefore necessary to determine present distributions of existing mussel populations since anything we learn about them may help in conservation efforts. Conservation may include efforts to prevent erosion and thereby siltation, improving water quality, protection of known populations through classification and listing in accordance with the Endangered Species Act (ESA), and actual relocation of mussels from damaged or polluted habitat to areas of more suitable habitat.

Many factors may influence mussel distributions. Some factors such as climate and water chemistry operate on a large scale while other characteristics such as physical and biological conditions may influence mussel distribution within ecosystems. Chemical factors include pH, alkalinity, food, oxygen, and nutrients. Mussels have been shown to be rare in waters with $pH<6$ (Hunter, 1964). This is thought to be due to mussels' inability to form shell in low pH waters. Alkalinity may be one of the most important factors influencing mussel abundance (Hunter, 1964; Green, 1980). Rooke & Mackie (1984) suggest that mussels are more abundant in waters with alkalinity greater than $0.41 mg \cdot L^{-1}$ (Rooke & Mackie, 1984). This is thought to be due to the importance of calcium in their shell structure. Mussels are filter feeders, therefore they feed on algae and detritus suspended in the water column (Hunter, 1964; Hinch *et al.*, 1986). Food availability is thought to have a positive effect on mussel abundance (Coker *et al.*, 1922; Wilbur & Owen, 1964; Hinch *et al.*, 1986). Mussels may be most abundant in eutrophic lakes (Hunter, 1964) indicating the influence of nutrient availability. Highly eutrophic systems may negatively effect mussel abundance, however, due to lack of oxygen and high turbidity (Cvancara, 1970).

Temperature may also influence mussel distributions. Temperature generally is thought to have a positive effect on abundance (Wilbur & Owen 1964). It has been suggested that low temperatures cause decreased growth (Chamberlain, 1930; Cvancara & Freeman, 1978). Coker *et al.*(1922) suggested that freshwater mussels move to deeper waters as winter approaches which would indicate a negative impact of low temperature on mussel abundance.

The distribution of mussels within an ecosystem is thought to be influenced by physical factors that ultimately impact their ability to collect food or stay firmly anchored in the substrate. Wave action and current can positively influence mussel distribution by increasing the amount of food available in the water column (Hinch *et al.*, 1986). Wave action can dislodge mussels, however, and water current can cause substrate instability, therefore mussel distribution may be negatively affected by extreme wave exposure (Coker *et al.*, 1922; Ghent *et al.*, 1978). Wave energy is greater in shallow water and in areas of greater fetch (Håkanson & Jansson, 1983). Therefore, it is expected that shallow depth and high fetch will negatively affect mussel abundance. In addition, mussels may be swept away during periods of high wave action (Coker *et al.*, 1922). Ghent *et al.* (1978) found that thin shelled mussels such as *Anodonta* were often swept away by wave action in shallow water. High turbidity often associated with turbulence could also limit mussel distribution (Cvancara, 1970).

The influence of depth on mussel abundance is controversial in the published literature. Stern (1983) suggests that mussels are least abundant at greater depth but only because current velocity and substrate type vary along a depth gradient. Matteson (1948) stated that depth and abundance are negatively correlated but controlled by temperature. Negus (1966) suggested that interaction between depth and temperature limits *Anodonta* and *Unio* abundance. Green (1980) and Strayer *et al.* (1981) show a parabolic relationship between *Anodonta grandis* and *Elliptio complanata* abundance, respectively, and depth with a maximum abundance at 2-3 meters. The literature suggests that depth alone may not limit mussel abundance. There are several suggestions for interaction effects between depth and other physical variables. Water depth can influence food availability, sediment composition and sediment stability. In very deep waters, sediments are made up of fine particulate organic matter into which mussels can sink and in which oxygen is rapidly depleted. Therefore, we might expect mussel abundance to be greatest at intermediate depth where suspended planktonic food is abundant yet sediments are stable enough to offer a secure substrate.

The effect of bottom slope on mussel abundance is less controversial. A logical assumption would be if slope were too great, mussels would be unable to affix themselves to the substrate. This assumption is supported by Ghent *et al.* (1978) who found that when slope was too severe, *Anodonta grandis* were not able to anchor themselves into the substrate and slid down into unfavorable habitat. Green (1980) found a negative linear effect of slope on *Anodonta grandis* abundance. Strayer *et al.* (1981) also suggested that slope had a negative effect on *Elliptio complanata* abundance.

Although substrate composition is thought to be important, many mussel species seem to inhabit differing substrate so no systematic effect of substrate type on mussel distribution has been discerned (Murray & Leonard, 1962; Parmalee, 1967). Mussels have been found in a wide variety of substrate types, from fine sand to coarse gravel and even mud (Parmalee, 1967; Clarke, 1981). Single species are not necessarily restricted to a single substrate type (Parmalee, 1967). Research has suggested both positive and negative effects of mud on different species' distributions (Coker *et al.*, 1922; Strayer, 1981; Hinch *et al.*, 1986; Cvancara & Freeman, 1978). The literature also suggests varied effects of sand and gravel substrates on the distribution of mussels (Baker, 1928; Cvancara, 1970; Harman, 1972; Haukioja & Hakala, 1974; Stern, 1983). The influence of substrate composition on mussel distribution and abundance is controversial (Kat, 1982). It is possible that substrate composition may interact with other physical variables which may cause some confusion in the literature. Interactions may occur between substrate and fetch, current, turbulence. In shallow water, for example, wave action can be extreme (Håkanson & Jansson, 1983) leading to coarse and impenetrable substrate, enhancing the danger of being dislodged by turbulence. Coker *et al.* (1922) suggest that it is difficult to interpret mussels' substrate affinity because of interactions between substrate type and current velocity and other physical variables. Cvancara (1970) and Stern (1983) both observed that mussels were absent from shifting substrates. Mussels can apparently exist in almost any type of substrate if other physical variables are favorable for survival (Cvancara, 1970). Substrate composition, in concert with other variables, may have an important influence on mussel distribution and abundance.

This study took advantage of an unique research opportunity to determine the factors influencing mussel distribution in a reservoir lake in central Iowa. The level of Big Creek Lake was lowered more than 6 m in the autumn of 1995 to allow shoreline armoring and construction of silt dikes and jetties. This allowed us to efficiently locate and sample mussel populations and determine their physical habitat. We thus were able to test the influence of water depth, maximum effective fetch, bottom slope, and substrate characteristics on mussel abundance across the entire lake.

METHODS

This project was carried out on Big Creek Lake, a reservoir in northwestern Polk County, Iowa (Fig. 1). The dam is located at latitude 41° 47' 30" N. and longitude 93° 43' 45" W. The reservoir has a surface area of 351 ha. The Big Creek Reservoir is an integral part of the Saylorville Reservoir complex and is located approximately 0.5 km east of the main reservoir and approximately 3 km northeast of the Saylorville Dam. In autumn of 1995 the water level of Big Creek Lake was drawn down > 6 m allowing the spatial distribution of stranded mussels to be determined at several sites of differing conditions.

A stratified random experimental design was used. The lake was divided from upstream to downstream into three arbitrary sections of equal length: the upper, middle, and lower portions. This was done in order to distribute sampling effort evenly throughout all portions of the lake. Next, a preliminary survey was carried out by walking the shore of the lake estimating mussel densities by eye. Potential sample sites were placed into one of three arbitrary strata: areas of high, medium, or low mussel density. This information was used to make sure that sampling sites spanned as wide a range as possible of mussel densities. Sites were also chosen considering depth and slope in order to include a wide range of sampling conditions. A stake was placed at the normal zero depth water line on the shore nearest to each of the twenty-seven sites in order to mark the location of each site and indicate where the autolevel (Fig. 2) would be placed. Density stratum and lake section were noted on each stake. Sites were selected to include nine sites from each lake division, three sampling sites in each mussel density stratum in each lake section. At each site, a 15 meter by 15 meter grid was set up on an arbitrary center. The grid was oriented with one edge parallel to the shoreline. Two 50 m tape measures and pin flags were used to measure and mark the corners of the site and the corners of each quadrat within each site. Nine, five meter by five meter quadrats were sampled from each site. A total of 243-25 m^2 quadrats were thus sampled exhaustively for mussels.

All mussel shells were collected from the surface of each of the nine quadrats at each of the twenty-seven sites. A substrate core sample, approximately fifteen centimeters in diameter, was taken to a depth of approximately ten centimeters at the center of each quadrat

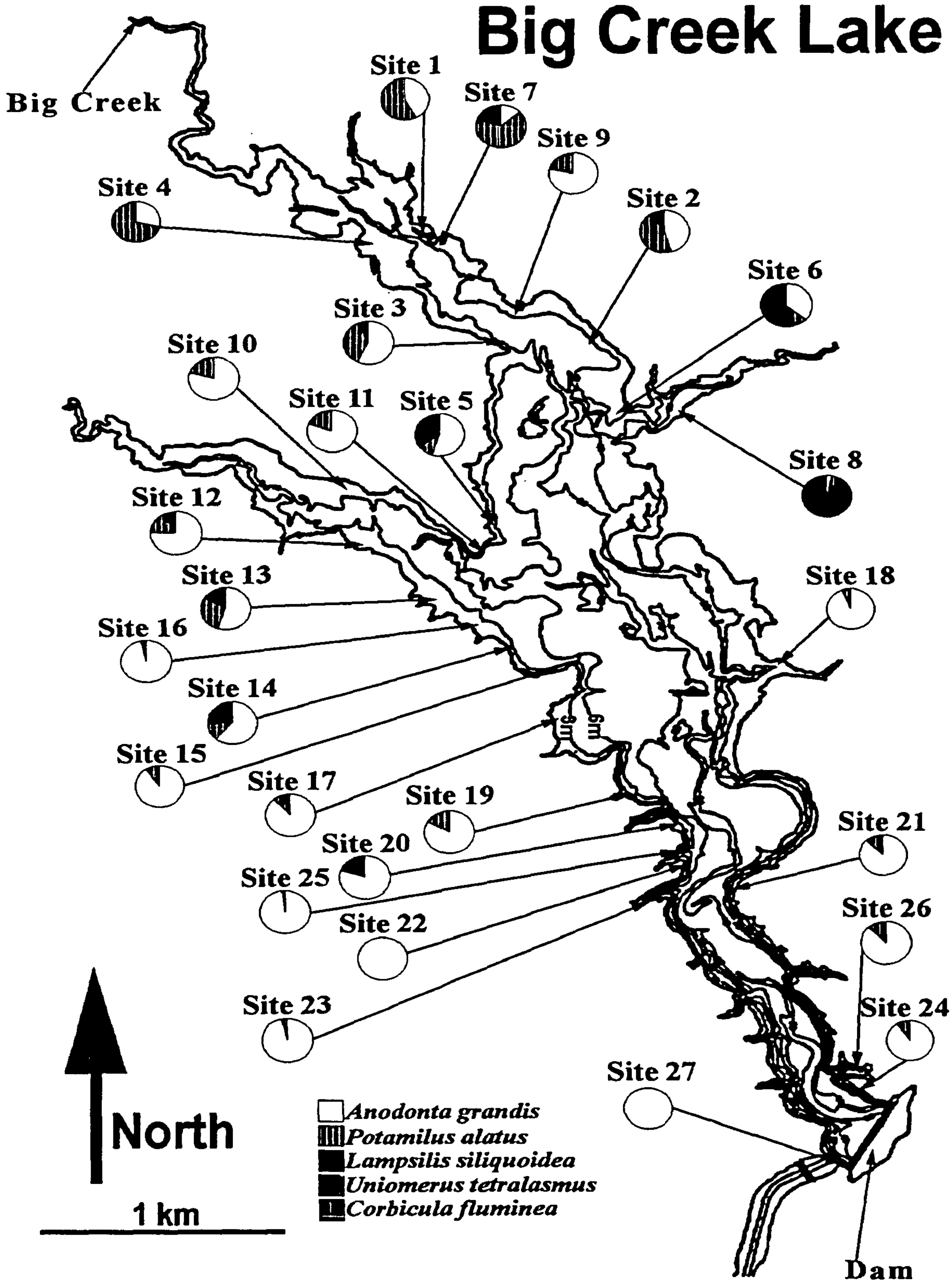


Fig. 1 Location of twenty-seven sample sites at Big Creek Lake, Iowa. Each pie chart represents the proportion of each species of mussel shell found at each site.

with a golf hole cutter. Normal water depth estimates were obtained relative to the normal shoreline using an autolevel and stadia rod. The autolevel was positioned on the shoreline perpendicular to each site. Sixteen normal water depth values were recorded at each of the sixteen corners within each grid (Fig. 2). Slope was calculated geometrically for each quadrat within each site using the quadrat dimensions and depth measurements made at each corner of each quadrat.

The number of mussels previously living at each site was estimated from the number of whole shells found. We counted whole shells which still contained decaying soft tissue. This was to avoid adding long-dead shell to the estimate of mussel abundance. Shells were identified to species and counted. Identifications were confirmed using several taxonomic keys (Baker, 1928; Burch, 1973; Clarke, 1981; Cummings & Mayer, 1992). Shells were paired with their opposing valve if possible to avoid counting individual mussels twice.

Sediment organic matter in substrate samples taken from each of the 243 quadrats was determined by mass loss on ignition (Downing & Rath, 1988). Each substrate sample was mixed by hand within each sample bag until it was homogeneous throughout. Three subsamples were then taken from each sample bag, massed wet, dried for 24 hours at 70° C to constant mass and massed again. The dry samples were then ignited in a muffle furnace for six hours at 500° C, then allowed to cool to room temperature in a dessicator. The cooling process took approximately 2.5 hours. The samples were then massed to determine organic matter loss. The mean mass loss was determined for each set of substrate subsamples. The percent loss was then determined to estimate organic content of each sample. Percent loss was calculated as loss on ignition divided by the dry mass of each sample.

Because we felt that fetch would be a viable predictor of turbulence at each site, we estimated the maximum effective fetch. Effective fetch gives a measure of the free water surface over which wind may generate wave action (Håkanson & Jansson, 1983). Effective fetch accounts for multiple wind directions. Maximum effective fetch was determined for each site according to Håkanson & Jansson (1983). Each site was plotted onto a map of Big Creek Lake. The open water distances from the sampling site to the opposite shore were measured in fifteen different directions. A center line, designated as zero degrees, was

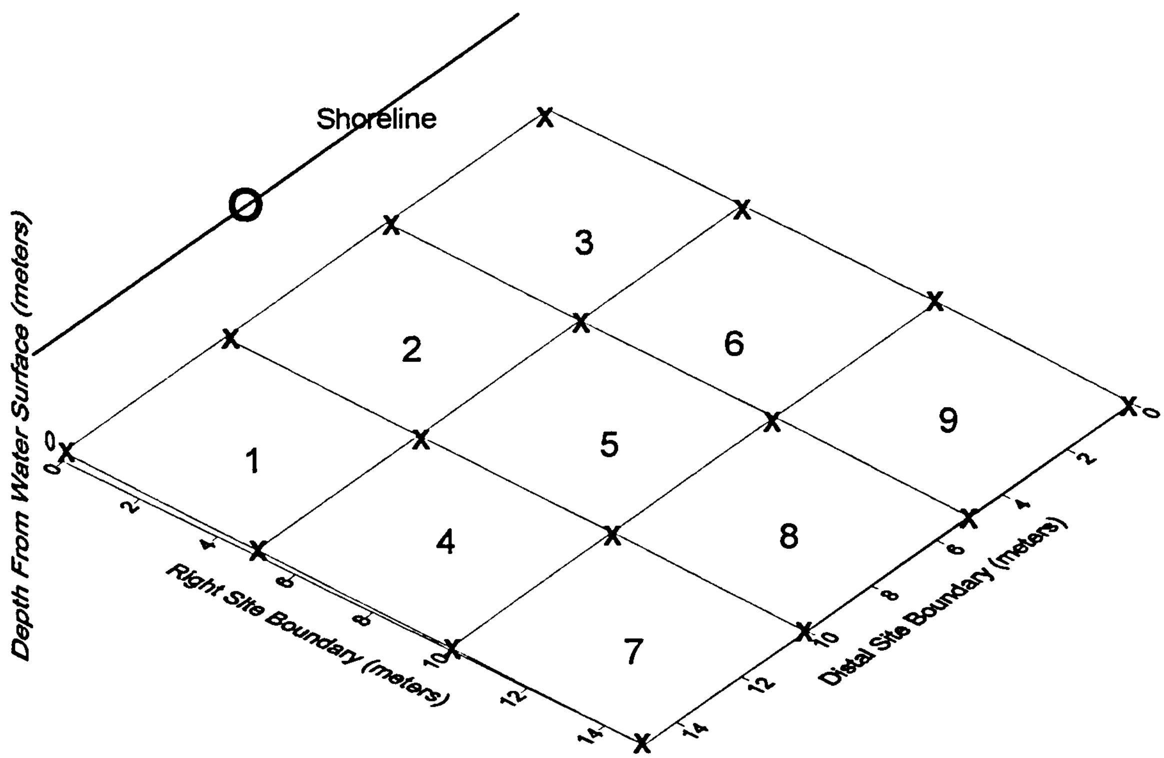


Fig. 2 General layout of sampling grid at each site. Quadrats are numbered 1-9 and mark the locations from which each substrate core sample was taken at the center of each quadrat.Depth measurements were taken with autolevel and stadia rod at each of the corners marked X. The O marks the location of the autolevel.

positioned on the site and angled in the direction of the greatest distance of open water surface. On either side of the center line, seven distances to shore were measured at six degree intervals. These distance values were then used to calculate maximum effective fetch (L_f; km) for each site. The L_f value was calculated from the formula:

$$L_f = ((\Sigma x_i \cdot \cos \gamma_i) / \Sigma \cos \gamma_i)(s')), \quad (1)$$

where $\Sigma \cos \gamma_i = 13.5$, a constant; x_i = open water distance; s' = the map scale constant (Håkanson & Jansson, 1983).

Before statistical analysis, the number of mussels found in each quadrat was transformed using a square root transformation. This transformation was used in order to stabilize the variance among the sample means (Downing & Downing, 1992). A few quadrats were deemed to present mussel numbers unrepresentative of natural mussel densities and were thus withdrawn from the analyses. Site 27 contained 265 *Anodonta grandis* shells. 233 of these were collected from the first row of quadrats. It was apparent that the shells had been deposited by wind and wave action and therefore were not representative of actual densities. For that reason, abundance data from these three quadrats were removed from the analysis. In addition, abundance data from quadrat three at site 26 was removed because the shells were found in a midden pile. It appeared that they had been scavenged by a small mammal such as a raccoon. For that reason, the shells were not representative of actual densities and were not analyzed here. These were the only sites at which the actual distribution of the mussels appeared altered from the natural state.

Bivariate relationships between the abundance of mussel species and site characteristics were sought using correlation analysis (Green, 1979). Multiple regression analysis using backwards elimination variable selection (Hocking, 1985) was used to determine the multivariate influences of site characteristics on mussel abundance. Thirteen candidate variables were included in the initial multivariate regression model. These were slope, depth, sediment organic matter content, fetch, the squares of slope, depth, and sediment organic matter content, and the following interaction terms: slope by depth, slope by fetch, slope by sediment organic matter content, depth by fetch, depth by sediment organic matter content, and fetch by sediment organic matter content. The squares of slope, depth and sediment organic matter content were included in the regression to determine whether parabolic relationships existed with mussel abundance. The interaction terms in the analysis were included to test for relationships between mussel abundance and combinations of environmental characteristics. The initial regression model was therefore:

$$A = b_0 + b_1Z + b_2Z^2 + b_3S + b_4S^2 + b_5C + b_6C^2 + b_7F + b_8SZ + b_9SC + b_{10}SF + b_{11}ZC + b_{12}ZF + b_{13}CF \quad (2)$$

where A = square-root transformed abundance, Z = water depth, S = slope, C = sediment organic matter content, and b_0-b_{13} are fitted regression coefficients. The initial regression was fitted for each species, eliminating insignificant (P>0.05) variables stepwise beginning with the variable explaining the least variance in mussel abundance (Hocking, 1985).

Because multivariate relationships are difficult to interpret, three-dimensional response surface figures were used to examine the form of the complex, multidimensional equations. Surface contour graphs were created, using Surfer® for Windows, to illustrate the resulting relationships based on the final regression equations fitted for the abundance of each species. Abundance contours were plotted based on regression predictions made from each final regression equation for each of the mussel species encountered (Appendix B). These figures were used to interpret and illustrate the complex multivariate relationships between mussel abundance and environmental characteristics.

RESULTS

Mussels

Five species of mussels were found in Big Creek Lake (Table 2). From most abundant to least abundant they were: *Anodonta grandis, Potamilus alatus, Lampsilis siliquoidea, Uniomerus tetralasmus,* and *Corbicula fluminea*. These are all species normally found in Iowa's lakes and rivers (Frest, 1987) with the exception of *Corbicula* which is a recently introduced exotic species (Counts, 1986). *Anodonta* outnumbered *Potamilus* by almost three to one. *Potamilus* and *Lampsilis* abundances were approximately equal ($t = 0.50$, $P>0.5$). Greater than 88 percent of *Potamilus* and *Lampsilis* were found in the upstream portion of the lake. More than 70 percent of *Uniomerus* and 100 percent of *Corbicula* were found in the middle section of the lake.

The spatial distributions of the three most abundant species; *Anodonta, Potamilus,* and *Lampsilis*; overlapped throughout the lake (Fig. 1). *Anodonta* was the most prevalent species as it made up almost 60 percent of the mussels found (Table 3), and was the only species that was found at every site (Table 2). The highest mean site density of *Anodonta* (0.68 / m^2) was found at site 17, while the highest individual quadrat density of 1.1 / m^2 was found at site 16. The greatest density of *Potamilus alatus*, in a single quadrat, (1.6 / m^2) was found at site seven. The highest mean site density of *Potamilus* (0.72 / m^2) was also recorded at site seven. Site eight contained the highest individual quadrat abundance of *Lampsilis* (0.88 / m^2), as well as the highest mean site density of *Lampsilis* (0.63 / m^2). The majority of *Lampsilis* (>96%) were collected from the upstream section of the lake. Few *Uniomerus* (41) and only a very few *Corbicula* (6) were found.

Environment

All correlations among environmental characteristics were weak (Appendix E), therefore interpretation of correlations between environment and mussel abundance should be unconfounded by collinearities. Surfaces maps were made of each of the 27 sites to explore bottom contours (Appendix A). Depth of the sites ranged from 0.09 m to 5.76 m (Table 1). The maximum pre-draw-down water depth was recorded at site 19, which also had the highest average depth (5.44 m) of all 27 sites. Site 19 is in the lower section of the lake near

Table 1 Average values of physical variables for 27 sampling sites at Big Creek Lake, Iowa. Data were collected during November and December of 1995. Z = water depth; S = slope; F = maximum effective fetch; C = sediment organic matter content estimated as loss on ignition."Quadrat" refers to a 5 m by 5 m sampling unit.

	Z (m)	S (m/m)	F (km)	C (%)
Median	2.16	0.06	0.94	2.09
Mean	2.32	0.11	0.96	2.34
Sample Variance	2.18	0.01	0.25	2.31
Quadrat maximum	5.76	0.48	-	6.7
Quadrat minimum	0.09	0.001	-	0.06
Site maximum	5.44	0.31	1.59	5.73
Site minimum	0.16	0.0062	0.08	0.61

Table 2 Density of freshly dead mussels of each species found at each site. Densities are averaged over all nine 25 m^2 quadrats at each site and are expressed as number of mussels per m^2. AG = *Anodonta grandis*; PA = *Potamilus alatus*; LS = *Lampsilis siliquoidea*; UT = *Uniomerus tetralasmus*; CF = *Corbicula fluminea*.

Site	AG	PA	LS	UT	CF
1	0.036	0.049	0	0	0
2	0.022	0.022	0.004	0	0
3	0.036	0.022	0.004	0	0
4	0.036	0.089	0	0	0
5	0.182	0.036	0.080	0.036	0
6	0.089	0.018	0.133	0	0
7	0.147	0.720	0.222	0	0
8	0.022	0.040	0.631	0.004	0
9	0.258	0.067	0	0.004	0
10	0.102	0.027	0	0	0
11	0.036	0.009	0	0	0
12	0.040	0.009	0	0.004	0
13	0.076	0.040	0.018	0	0.004
14	0.204	0.044	0.004	0.076	0.004
15	0.169	0.013	0	0	0.004
16	0.662	0.013	0	0.009	0
17	0.680	0.040	0	0.040	0.009
18	0.204	0.009	0	0	0.004
19	0.044	0.009	0	0	0
20	0.053	0	0.013	0	0
21	0.031	0.004	0	0	0
22	0.138	0	0	0	0
23	0.129	0.004	0	0.009	0
24	0.040	0.004	0	0	0
25	0.218	0	0.004	0	0
26	0.098	0.013	0	0	0
27	0.142	0	0	0	0

Table 3 Densities of each species represented at Big Creek Lake, November and December 1995. Means are average number of each species per m^2. Each mean was calculated among all 239 quadrats. Variances were calculated as population variances about the mean density of each species. Maximum refers to the maximum density of individuals per m^2 found in a single 25 m^2 quadrat. Total is the total number of each species found at all 27 sample sites.

Species	Mean	Variance	Maximum	Total
Anodonta	0.2	5.3	1.1	876
Potamilus	0.05	0.7	1.6	293
Lampsilis	0.04	0.5	0.88	251
Uniomerus	0.007	0.02	0.16	41
Corbicula	0.0008	0.001	0.08	6

the dam. The shallowest depth was found at site one, where the average depth 0.16 m was recorded. Site one was located in the upper section at the northern tip of the lake, near the creek entrance. There was a general increasing gradient in site depths from the upstream reaches of the lake to downstream sites. This phenomenon is typical of reservoir lakes (Håkanson & Jansson, 1983).

Bottom slopes at various sites varied from 0.001 to 0.48 m/m (Table 1). The maximum slope of an individual quadrat was found at site 11, while the minimum slope for an individual quadrat was found at site 26. The greatest mean slope (0.311) was at site 22 in the lower section of the lake. The lowest mean slope (0.0062) was at site four in the upper part of the lake. There was a general increase in slope from upper section sites to lower section sites, although the correlation is weak ($r^2 = 0.222$, $P < 0.0001$). This is expected since deeper sites and thus greater slopes must occur near the dams in reservoirs.

Sites varied from sheltered to very exposed. The maximum effective fetch was greatest (1.59 km) at site nine and least (0.08 km) at Site 26 (Table 1). Because the lake is widest in the middle section of the lake, the sites on the shore of the middle section and sites two, seven and nine in the upper section of the lake had the greatest maximum effective fetches. The wider section creates greater open water surface over which wind may generate wave action. Because the lake is narrower and more sheltered at the upstream end, the upper section of the lake was generally lower in fetch than the sites in the middle portion of the lake, with the exception of site five, which had a fetch of 1.51 km (fourth highest fetch of all sites). The width of the lake narrows downstream as it approaches the dam, resulting in low maximum effective fetch (<0.56 km) for sites nearest the dam.

Because fetch, slope and depth were highly variable, so too was estimated substrate organic content, which varied from 0.06% to 6.70% (Table 1). Organic sediments tend to accumulate at unexposed sites of low slope, often at greater depths (Håkanson & Jansson, 1983). The maximum substrate organic content estimate (6.7%) was found at site three, but the highest mean organic content (5.73%) was found at site one. These substrates were made up solely of organic mud. The minimum organic content (0.06%) was recorded at site 22. This is comparable to pure silica sand which would contain virtually no organic matter at all.

The lowest mean organic content (0.61%) came from site 21 substrates which were very clean, fine-grained sand. There was a slight tendency for sediment organic matter content to decrease with increasing slope ($r^2 = 0.212$, $P<0.0001$) (Fig. 3). This occurs because organic sediments have a specific gravity close to that of water and therefore cannot accumulate on steep slopes.

The physical variable measurements were generally consistent with what would be expected in a reservoir. This indicates that the draw-down did not greatly modify distributions of habitat characteristics like sediment organic matter content. The upstream reaches of the lake had lower slopes than sites in the lower section due to normal reservoir morphology (Håkanson & Jansson, 1983). The greatest slope was 0.48 and was recorded at site 11 (Fig. 4). Although there was a slight linear correlation between depth and slope ($r^2 = 0.12$; $t = 5.59$; $P < 0.0001$), the distribution appeared to be parabolic (Fig. 4). Slope was frequently low at low depth, indicating littoral shelves in the lake basin. Slope was greatest at intermediate depth (2-4 m) indicating the area of transition between the upper and lower shelf. As is usual in reservoirs (Peterka & Reid, 1969; Cvancara & Freeman, 1978) downstream sites in the lower portion of the lake were generally deepest while sites in the upper portion were shallowest. However, site 11, located in the middle section of the lake, was second deepest of all sites.

One exception to the general consistencies between Big Creek Lake and a "normal" lake was the lack of correlation between depth and sediment organic content ($r^2 = 0.001$; $t = -0.50$; $P = 0.618$; Fig. 5). Deep sites in lakes generally are rich in organic matter while shallow areas are often subject to waves and have sediments containing little organic matter. The sites located in the upper portion of the lake generally had the greatest substrate organic matter content. Site one had the highest mean substrate organic matter content (5.73%) of all sites. This may be due to sediment deposition from the creek inflow. As the creek enters the lake, surface area increases in relatively shallow water which would result in a loss of velocity and cause the silt in the bed load to be deposited on the lake bottom.

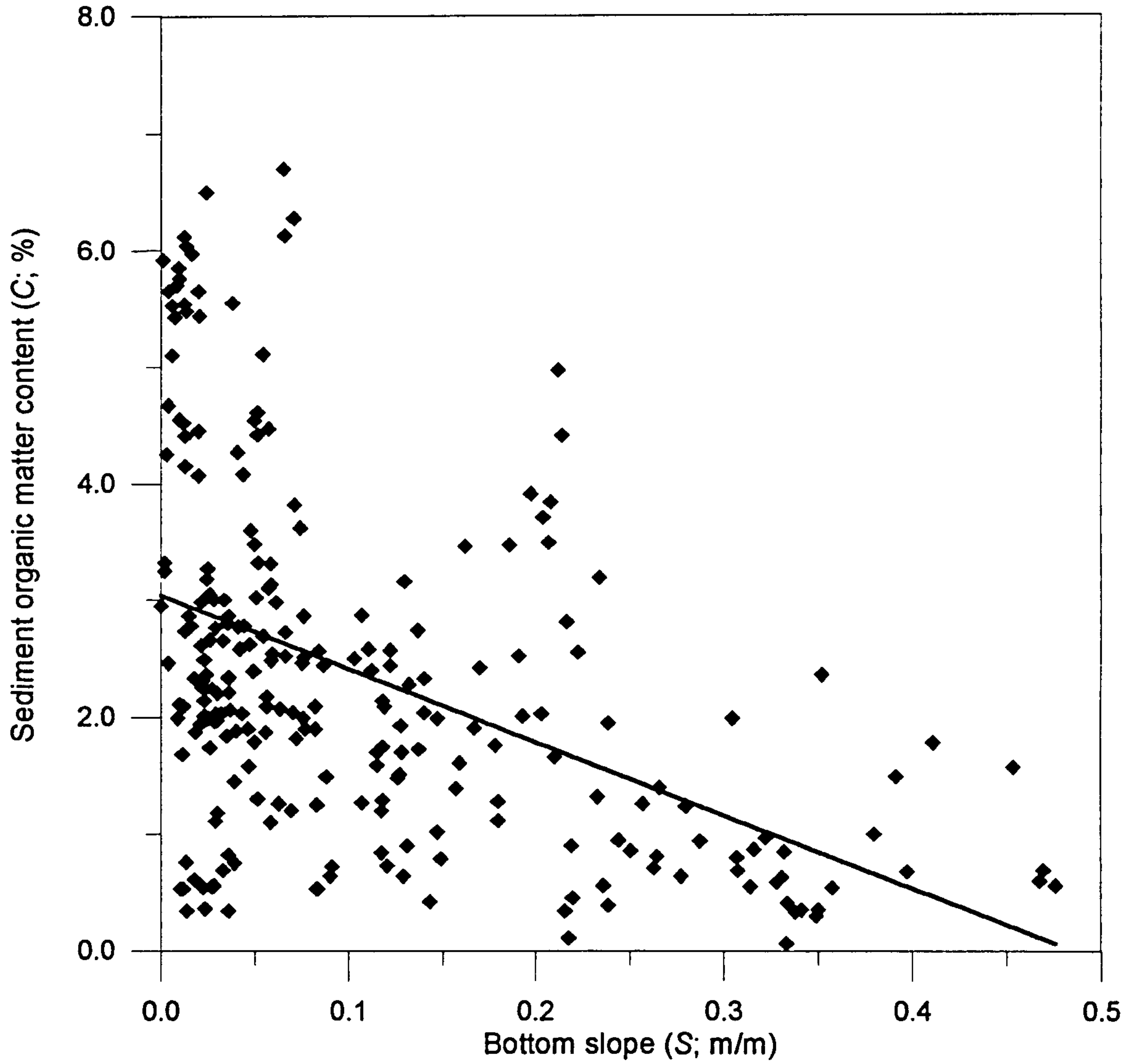


Fig. 3 Relationship between slope and sediment organic matter content found at 27 sites and 243 sampling locations in Big Creek Lake. The line is the least squares regression of the relationship ($r^2 = 0.21$; $P < 0.001$).

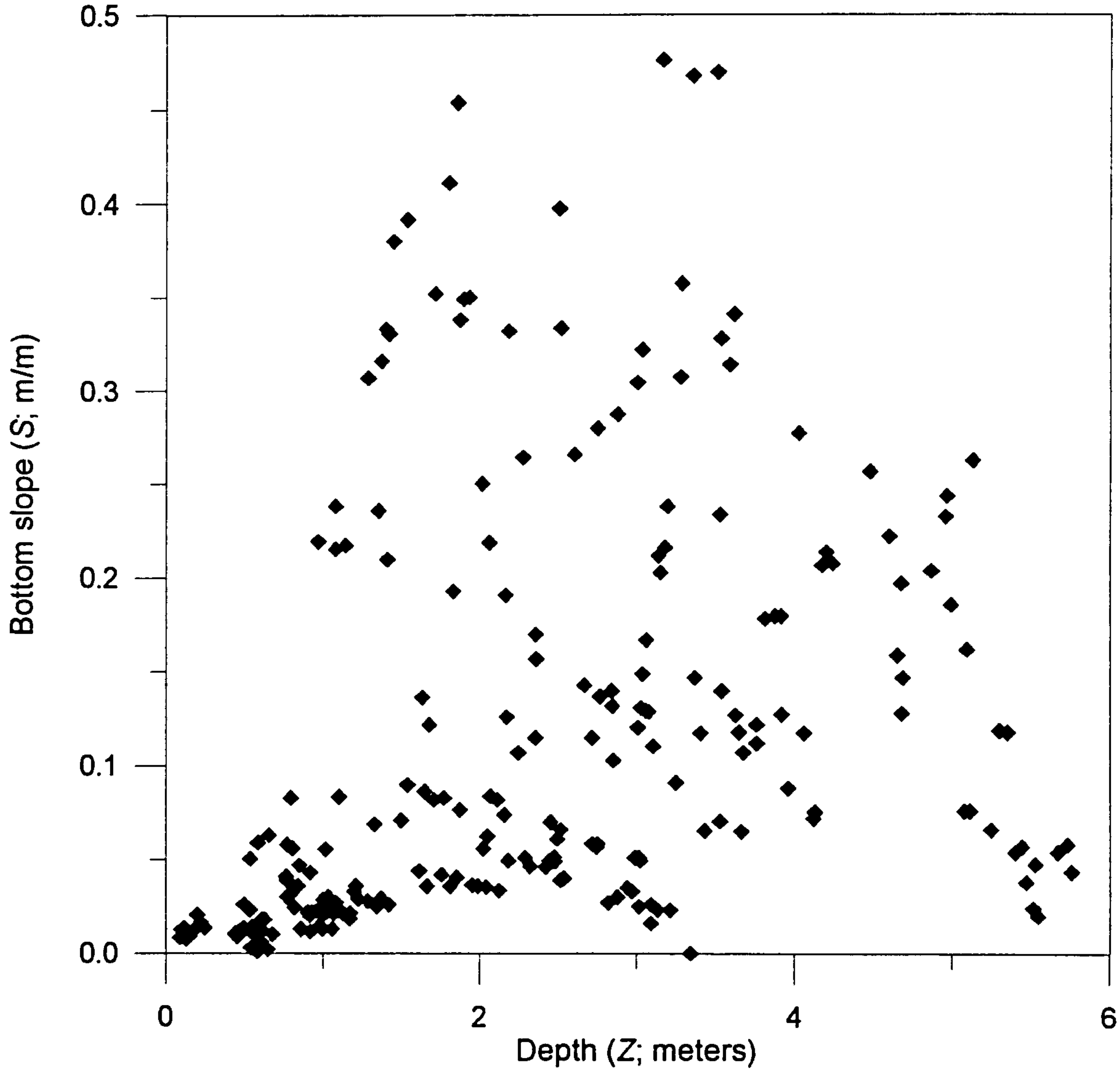


Fig. 4 Relationship between water depth and site slope found at 27 sites and 243 sampling locations in Big Creek Lake ($r^2 = 0.12$; $t = 5.59$; $P < 0.0001$).

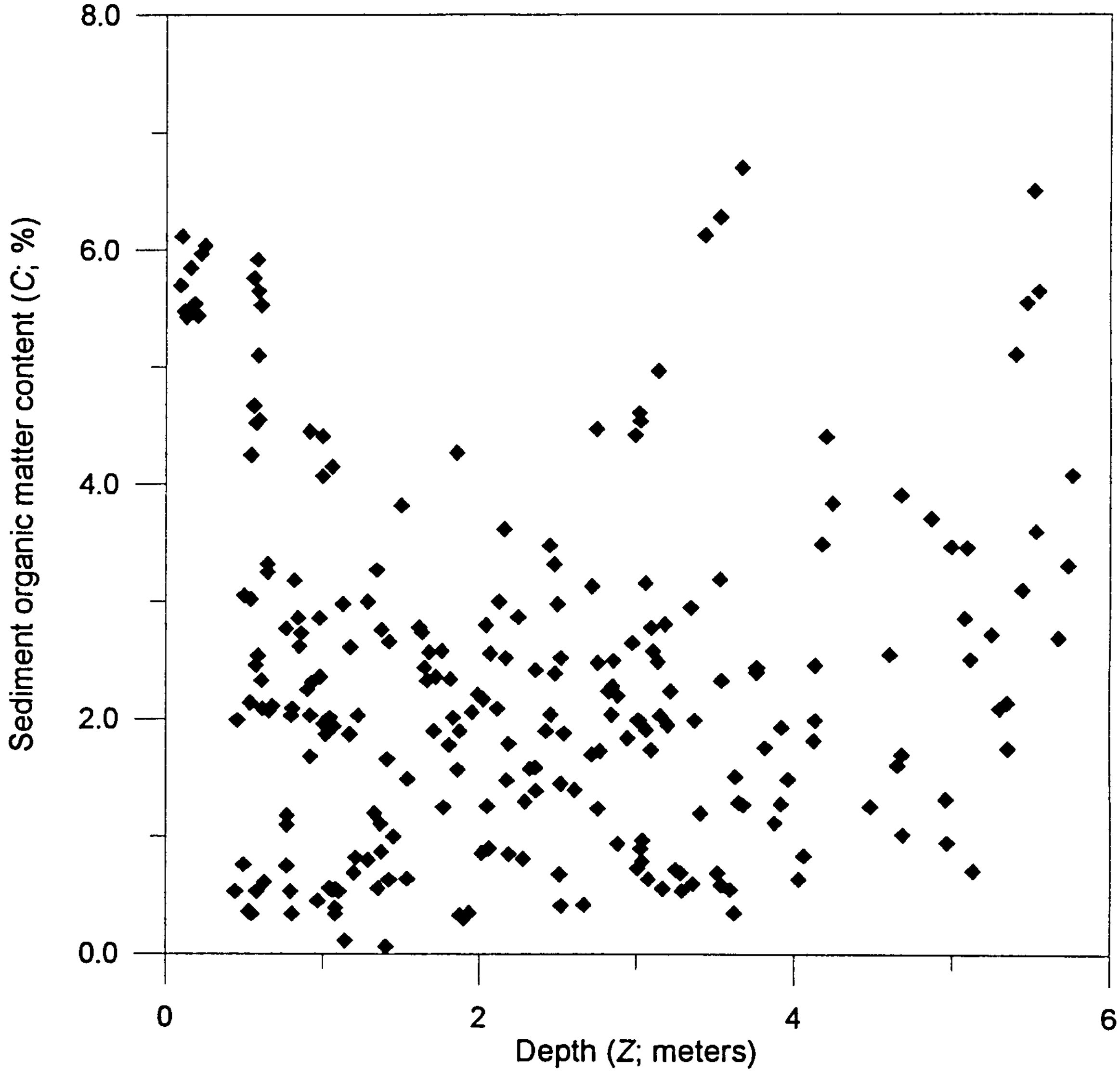


Fig. 5 Relationship between water depth and sediment organic matter content found at 27 sites and 243 sampling units in Big Creek Lake ($r^2 = 0.001$; $t = -0.50$; $P = 0.618$).

Mussel:Environment Relationships

Relationships between mussel abundance and individual environmental characteristics varied among species. The abundance of *A. grandis* was correlated with several site characteristics. *Anodonta* were slightly more abundant at sites with great fetch ($r = 0.2$, $P<0.05$; Table 4) and less dense with increasing substrate organic content (Pearson's $r = -0.237$, $P < 0.0001$) (Table 4). *Anodonta* abundance was not linearly correlated with slope ($P > 0.05$) or depth ($P > 0.05$). Interestingly, maximum *Anodonta* densities appear between depths of one and three meters (Fig. 6).

Potamilus alatus densities were correlated with each environmental characteristic. *Potamilus* abundance decreased with increasing depth ($r = -0.32$, $P<0.0001$; Fig. 7). Greater than 98 percent (288) of the *Potamilus alatus* occurred where water depth was less than 4.2 meters. *Potamilus* were found only in areas where slope was less than 0.25 (Fig. 7). In addition, their abundance declined as slope approached 0.25 (Pearson's $r = -0.351$, $P < 0.0001$). With the exception of site seven, *Potamilus* numbers increased with increasing substrate organic content ($r =0.17$; $P = 0.011$; Table 4). Fetch was weakly correlated with the abundance of *Potamilus* ($r = -0.14$, $P = 0.017$; Table 4).

Lampsilis siliquoidea abundance was influenced by water depth and bottom slope. *Lampsilis* abundance decreased with increasing depth ($r = -0.26$, $P<0.0001$; Fig. 8). All *Lampsilis* were collected at depths of less than four meters, with almost 92 percent (230) found between one and two meters depth. The abundance of *Lampsilis* was also negatively related to slope (Pearson's $r = -0.233$, $P = 0.001$; Table 4). *Lampsilis* were found primarily (>96%, 242 individuals) in low slope areas (<0.21) in the upper section of the lake. Although densities of *Lampsilis* were highest at levels of substrate organic content around two percent, abundance and substrate organic matter were not linearly correlated (Table 4). In contrast to *Anodonta*, *Lampsilis* were less abundant at sites where fetch was great.

The two least abundant species found at Big Creek Lake, *Uniomerus* and *Corbicula*, showed little clear relationship to the environmental characteristics studied here. Densities of *Uniomerus tetralasmus* were greatest at depths between one and three meters, although *Uniomerus* abundance and depth were not significantly correlated ($r = 0.03$, $P = 0.615$; Table

Table 4 Bivariate correlations between each mussel species abundance and environmental characteristic found in 239 sampling locations at 27 sites in Big Creek Lake. *t*-values represent tests to determine whether abundance and environmental characteristic distributions overlap. *P*-values are the probability of each *t*-value being found by chance alone. Each *r* represents correlation between mussel species abundance and the environmental characteristic.

Species	Independent Variables	*t*	*P*	*r*
Anodonta grandis	*Z*	-0.72	0.473	-0.045
	S	-1.17	0.242	-0.077
	F	3.19	0.002	0.200
	C	-3.76	<0.001	-0.245
Potamilus alatus	*Z*	-5.20	<0.001	-0.316
	S	-5.77	<0.001	-0.346
	F	-2.40	0.017	-0.141
	C	2.56	0.011	0.173
Lampsilis siliquoidea	*Z*	-4.31	<0.001	-0.265
	S	-3.52	0.001	-0.224
	F	-3.25	0.001	-0.200
	C	0.15	0.878	0.010
Uniomerus tetralasmus	*Z*	-0.50	0.615	-0.032
	S	-1.29	0.197	-0.084
	F	2.22	0.027	0.141
	C	-1.29	0.200	-0.084

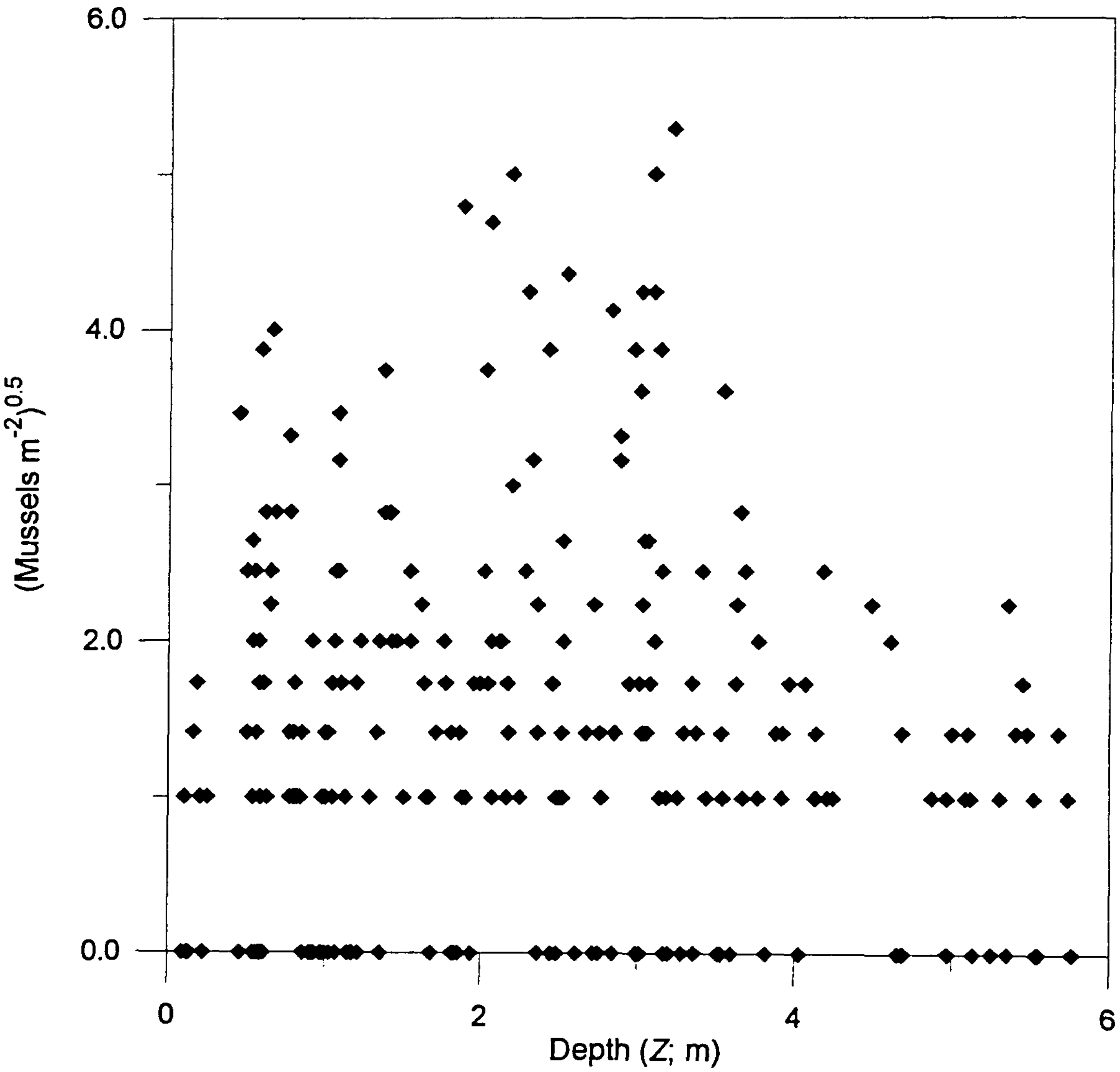


Fig. 6 Relationship between the abundance of *Anodonta grandis* and water depth at 27 sites and 239 sampling locations at Big Creek Lake (r^2 = 0.002; t = -0.72; P = 0.473).

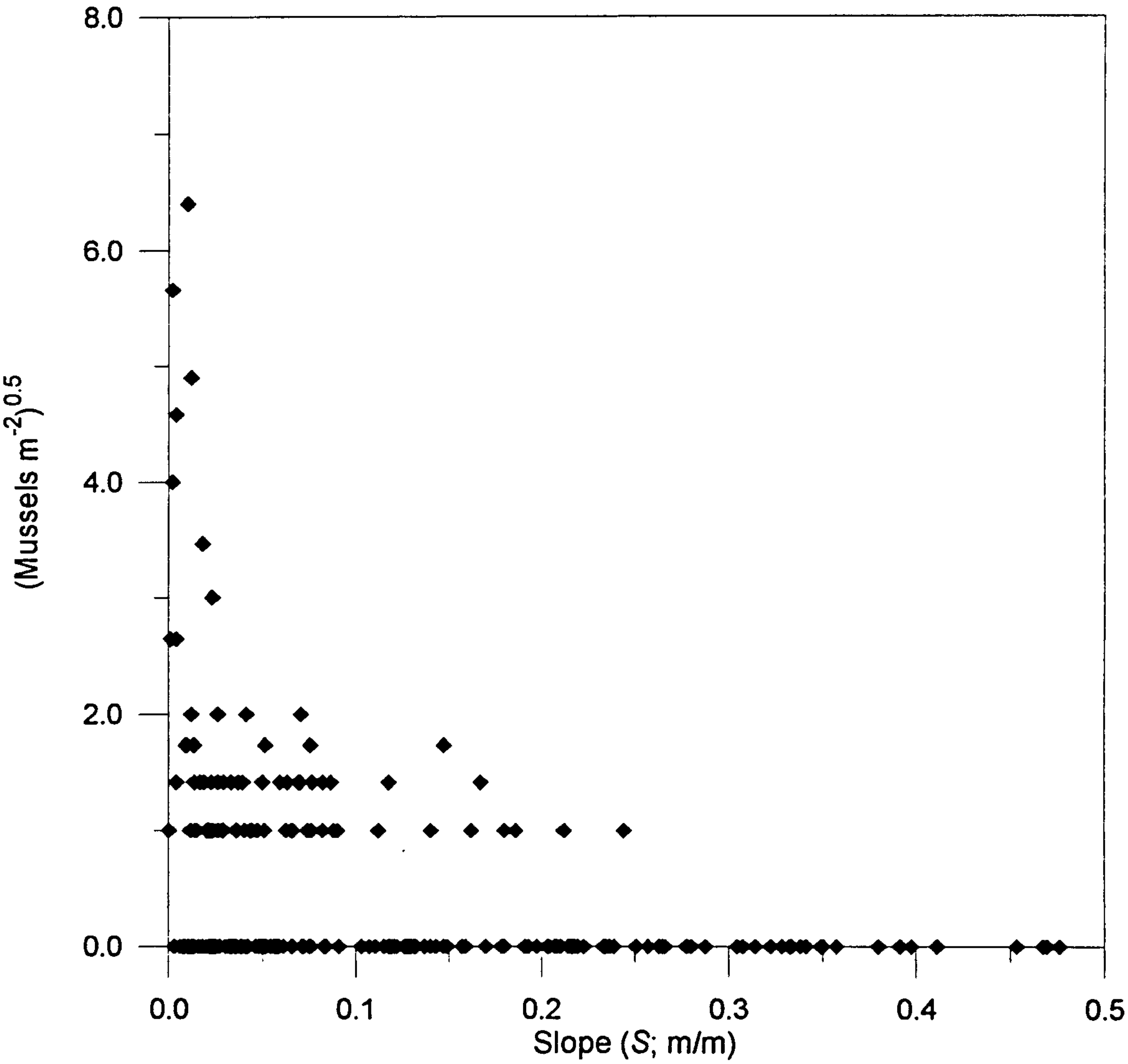


Fig. 7 Relationship between the abundance of *Potamilus alatus* and site slope at 27 sites and 239 sampling locations at Big Creek Lake (r^2 = 0.12; t = -3.091; P < 0.0001).

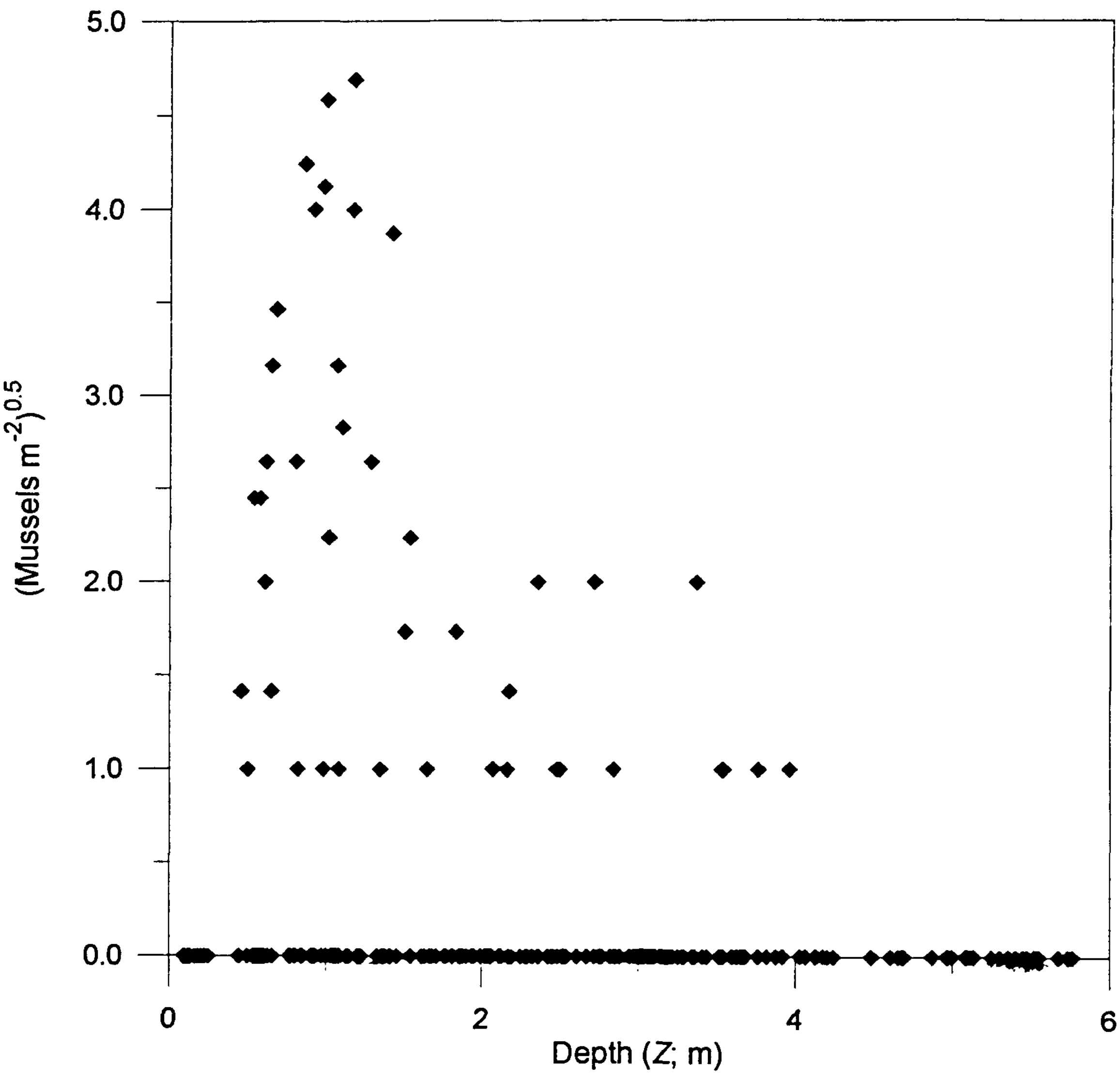


Fig. 8 Relationship between the abundance of *Lampsilis siliquoidea* and water depth at 27 sites and 239 sampling locations in Big Creek Lake ($r^2 = 0.07$; $t = -4.31$; $P < 0.0001$).

4). *Uniomerus* was never found at depths greater than four meters, at sites where slope was greater than 0.2, or in substrates that contained greater than four percent organic matter. There was a slight positive relationship (Pearson's $r = 0.143$, $P = 0.027$) between abundance and fetch (Table 4). Since only six *Corbicula fluminea* were collected, little can be said about factors influencing their distribution. Generally, *Corbicula* were found at areas of high fetch (>1.32 km), depth between zero and four meters, slope less than 0.11, and substrate organic matter content less than four percent.

It is clear from Table 4 and Figs. 3-8 that mussel densities were correlated with several site characteristics in Big Creek Lake. This is substantiated by multivariate analysis. When analyzed by multiple regression, *Anodonta grandis* abundance showed a negative relationship with bottom slope and sediment organic content but was positively related to fetch and most abundant at intermediate depth. Variables that accounted for significant ($P < 0.05$) variation in *Anodonta* abundance were depth, the square of depth, slope, fetch, the interaction of slope and fetch and the interaction of sediment organic matter and fetch (Table 5):

$$A_{AG} = 0.211 + (0.613Z) - (0.110Z^2) + (3.41S) + (1.51F) - (6.95SF) - (0.208CF) \qquad (3)$$

where A_{AG} is *Anodonta grandis* abundance, Z is depth in meters, S is bottom slope in m/m, F is maximum effective fetch in km and C is sediment organic matter content in percent.

Lampsilis siliquoidea abundance was negatively correlated with slope, depth and fetch. *Lampsilis* abundance was greatest at intermediate levels of sediment organic matter content. The variables that accounted for significant ($P < 0.05$) variation in *Lampsilis* abundance were depth, slope, the square of sediment organic matter content, fetch , the interaction of slope and fetch, the interaction of depth and sediment organic matter, the interaction of depth and fetch, and the interaction of sediment organic matter content and fetch (Table 6):

$$A_{LS} = 2.96 - (0.567Z) - (6.03S) - (0.0681C^2) - (1.97F) + (5.18SF) + (0.0679ZC) + (0.245ZF) + (0.160CF) \qquad (4)$$

Potamilus alatus abundance decreased with slope, depth, and fetch (Table 7). Sediment organic matter content was uncorrelated with *Potamilus* abundance. The variables

Table 5 Results of regression analyses examining the statistitical influence of independent variables on the number of *Anodonta grandis* found in each of the 239-25 m^2 quadrats (eq. 3). Standard deviations are given for each coefficient in eq. (3). Partial *t*-values test the hypothesis that coefficients are zero and *P*-values represent the probability that this *t*-value could be obtained by chance. (*s* (the estimated standard deviation about the regression line) = 1.08, $R^2 = 0.234$)

Analysis of variance

Source	*df*	SS	MS	*F*	*P*
Regression	6	82.527	13.755	11.79	<0.001
Error	232	270.650	1.167		
Total	238	353.177			

Partial Effects

Predictor	StDev	*t*	*P*
Constant	0.247	0.85	0.394
Z	0.200	3.07	0.002
Z^2	0.034	-3.23	0.001
S	1.43	2.38	0.018
F	0.238	6.35	<0.001
SF	1.35	-5.15	<0.001
CF	0.056	-3.72	<0.001

Table 6 Results of regression analyses examining the statistitical influence of independent variables on the number of *Lampsilis siliquoidea* found in each of the 239-25 m^2 quadrats (eq. 4). Standard deviations are given for each coefficient in eq. (4). Partial *t*-values test the hypothesis that coefficients are zero and *P*-values represent the probability that this *t*-value could be obtained by chance. ($s = 0.806$, $R^2 = 0.311$)

Analysis of variance

Source	*df*	SS	MS	*F*	*P*
Regression	8	67.429	8.429	12.96	<0.001
Error	230	149.571	0.650		
Total	238	217.000			

Partial Effects

Predictor	StDev	*t*	*P*
Constant	0.276	10.76	<0.001
Z	0.112	-5.06	<0.001
S	1.139	-5.03	<0.001
C^2	0.011	-6.42	<0.001
F	0.280	-7.04	<0.001
SF	1.149	4.50	<0.001
ZC	0.024	2.81	0.005
ZF	0.081	3.01	0.003
CF	0.075	2.14	0.034

that accounted for significant ($P < 0.05$) variation in *Potamilus* abundance were depth, slope and fetch (Table 7):

$$A_{PA} = 1.62 - (0.115Z) - (5.21S) - (0.557F) + (2.96SF) \quad (5)$$

Through multivariate analyses, *Anodonta grandis* and *Lampsilis siliquoidea* abundances were found to be influenced by water depth, bottom slope, sediment organic matter content and maximum effective fetch. Abundances of *Potamilus alatus* were correlated with water depth, bottom slope and maximum effective fetch.

Table 7 Results of regression analyses examining the statistitical influence of independent variables on the number of *Potamilus alatus* found in each of the 239-25 m^2 quadrats (eq. 5). Standard deviations are given for each coefficient in eq. (5). Partial t-values test the hypothesis that coefficients are zero and P-values represent the probability that this t-value could be obtained by chance. ($s = 0.861$, $R^2 = 0.211$)

Analysis of variance

Source	*df*	SS	MS	*F*	*P*
Regression	4	46.423	11.606	15.65	<0.001
Error	234	173.540	0.742		
Total	238	219.964			

Partial Effects

Predictor	StDev	*t*	*P*
Constant	0.171	9.49	<0.001
Z	0.042	-2.77	0.006
S	1.084	-4.81	<0.001
F	0.159	-3.50	0.001
SF	1.052	2.81	0.005

DISCUSSION

Although each of the three most abundant species co-occur throughout the lake, they reach their peak abundance in different locales. *Anodonta* dominates the densities at virtually every site, and is particularly abundant in the lower part of the lake while *Potamilus* and *Lampsilis* were most abundant in the upper lake (Fig. 1). *Lampsilis* was most abundant in an inlet that enters the lake on the upper northeast side (Fig. 1).

Anodonta grandis were distributed throughout the lake (Fig. 1), however, they were most abundant in the downstream reaches. This agrees with other research which has found *Anodonta* to be distributed widely with an affinity for deep areas with high organic content (Cvancara & Freeman, 1978; Ghent *et al.*, 1978). *Anodonta* may be able to colonize and survive in habitat that would be considered marginal for other species. *Anodonta* may have higher mobility in mud than other species (Hinch *et al.*, 1978; Stern, 1983). Research has shown that some species' mobility may be impaired by mud, however, mussels with inflated shells, such as *Anodonta*, can inhabit muddy substrates (Hinch *et al.*, 1978; Stern, 1983).

The mussels found at Big Creek Lake were found in a wide range of habitats. Assuming abundance as an indicator of optimal habitat, *Anodonta grandis'* optimal habitat appeared to be at a depth of around three meters (Fig. 9), with slope of less than 0.15 m/m (Fig. 10), at fetch of greater than one kilometer (Fig. 11), and in substrate containing less than 3.5% organic matter (Fig. 12). *Anodonta* were found at intermediate depth and substrate organic matter content, low slope and high fetch. These characteristics may be important to *Anodonta* abundance for several reasons. Turbulence caused by high fetch at low depth may cause mussels to become unstable or dislodged from their substrate, therefore, at intermediate depth, mussels may be able to remain firmly anchored to the substrate. As effects of wave action decrease with increasing depth, deposition of previously suspended sediments occurs which could bury or suffocate mussels. This may be why *Anodonta* were distributed in substrates with intermediate organic matter content at intermediate depth (Fig. 12). *Anodonta* abundance may be dependent on high fetch to increase turbulence and therefore suspend food particles in the water column.

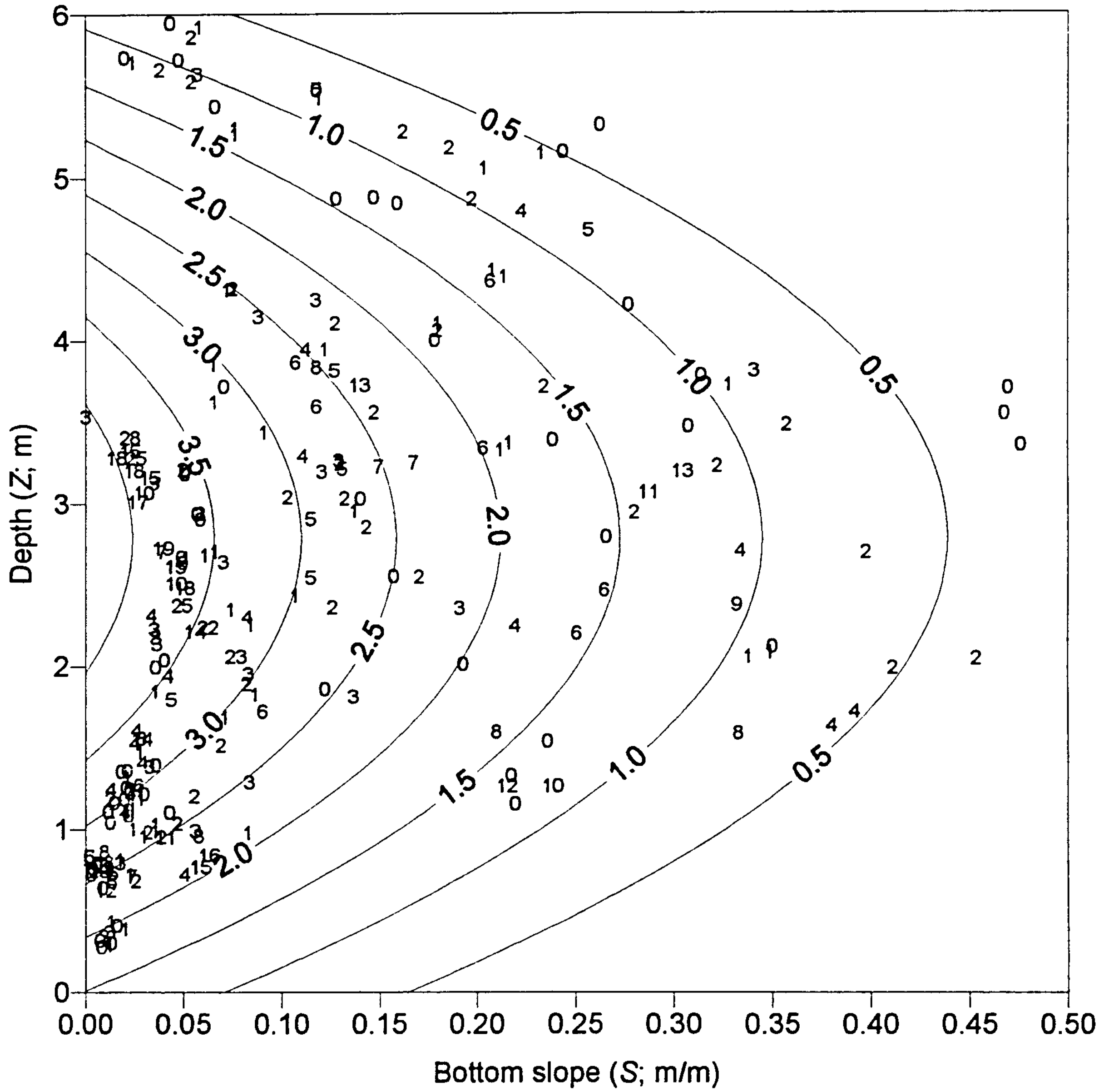


Fig. 9 Mussel densities predicted from eq. 3 plotted as a function of slope and depth. Contours are predicted *Anodonta grandis* abundance in a 25 m^2 quadrat. Predictions were made assuming average values of F (0.939 km) and C (2.09%). Posted numbers show actual *Anodonta* density observations in the 239 sampled quadrats to illustrate concordance with predicted trends.

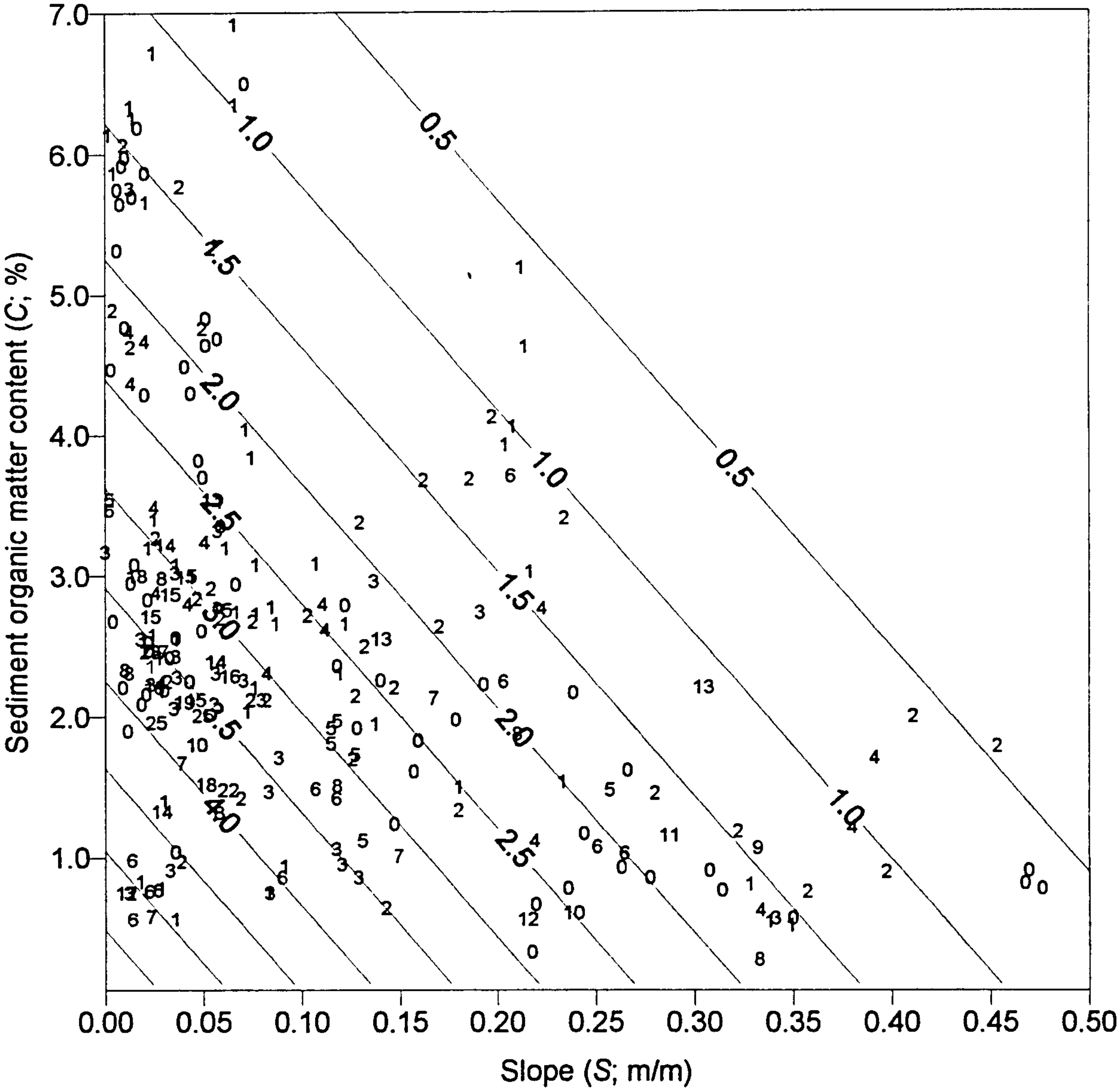


Fig. 10 Mussel densities predicted from eq. 3 plotted as a function of slope and sediment organic matter content. Contours are predicted *Anodonta grandis* abundance in a 25 m^2 quadrat. Predictions were made assuming average values of F (0.939 km) and Z (2.16 m). Posted numbers show actual *Anodonta* density observations in the 239 sampled quadrats to illustrate concordance with predicted trends.

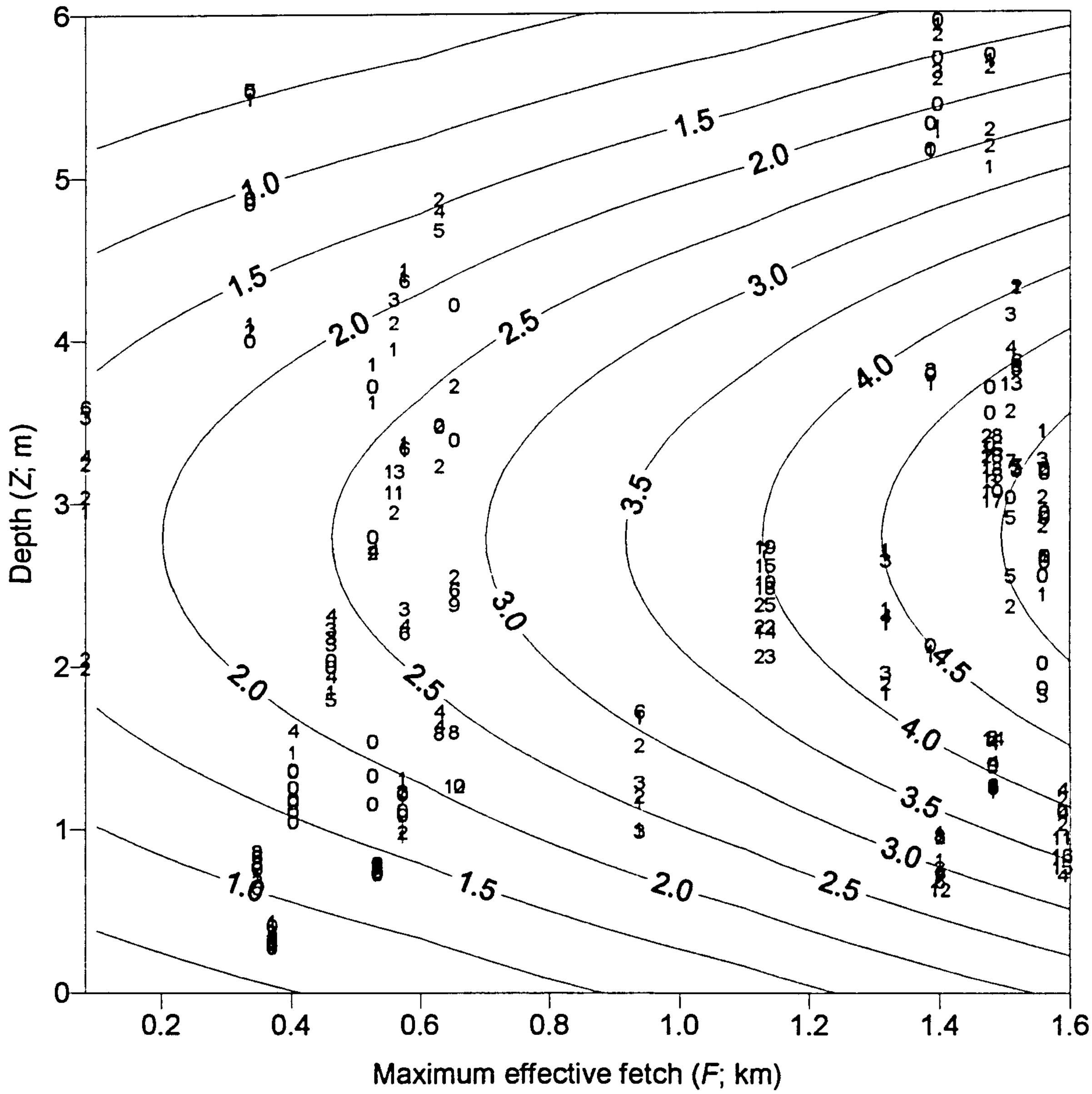


Fig. 11 Mussel densities predicted from eq. 3 plotted as a function of depth and maximum effective fetch. Contours are predicted *Anodonta grandis* abundance in a 25 m² quadrat. Predictions were made assuming average values of *S* (0.063) and *C* (2.09%). Posted numbers show actual *Anodonta* density observations in the 239 sampled quadrats to illustrate concordance with predicted trends.

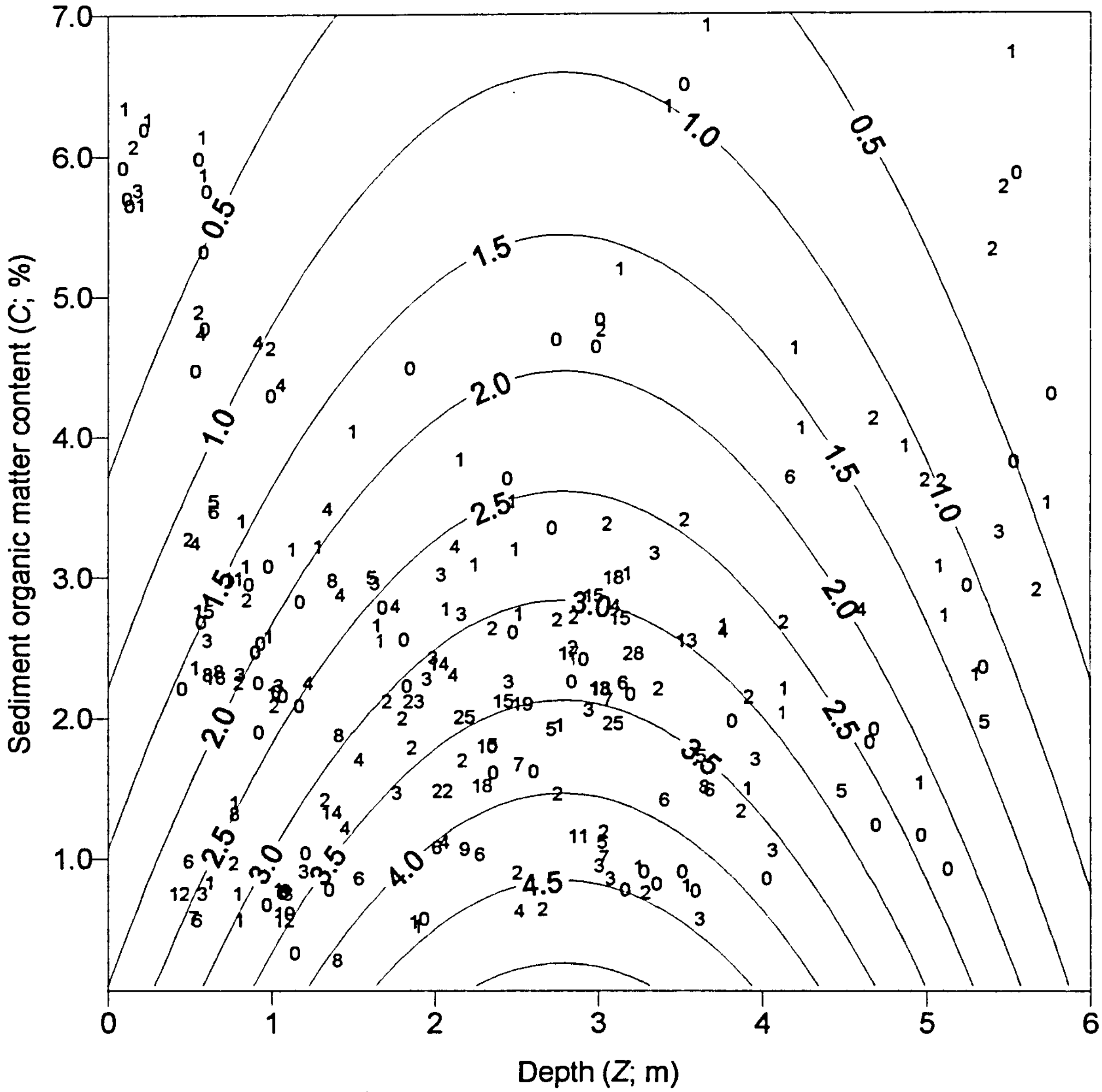


Fig. 12 Mussel densities predicted from eq. 3 plotted as a function of depth and sediment organic matter content. Contours are predicted *Anodonta grandis* abundance in a 25 m^2 quadrat. Predictions were made assuming average values of S (0.063) and F (0.939 km). Posted numbers show actual *Anodonta* density observations in the 239 sampled quadrats to illustrate concordance with predicted trends.

The majority of *Lampsilis* found were distributed in the upper section of the lake. Site eight contained the highest density of *Lampsilis* (Fig. 1). The site was located in a shallow finger of the lake into which a small stream flowed. It may be an area of exceptional habitat for *Lampsilis*. It is an area of low fetch, intermediate organic content, low slope, and shallow depth, all of which appear to favorably affect *Lampsilis* abundance. *Lampsilis siliquoidea* was most abundant at slope less than 0.10 m/m (Fig. 13), depths less than 1.5 m (Fig. 14), in areas of low fetch (< 0.4 km) (Fig. 15), and in substrate containing between one and three percent organic matter (Fig. 16). Generally, *Lampsilis* were found in calm, flat, intermediate depth areas where substrate organic matter content was not too high. Low fetch in shallow water may result in increased deposition due to decreased turbulence. This may also explain why they are abundant in substrates with intermediate organic matter content. The process of deposition may provide *Lampsilis* with a food source. High turbidity at low depth and low slope may provide *Lampsilis* a planktonic food source. *Lampsilis* abundance may depend on stable substrate which results from low fetch and low slope. Relatively calm areas with low slope may result in less variable temperature which could affect *Lampsilis* abundance. At shallow depth oxygen must be sufficient to allow the persistence of *Lampsilis*.

Like *Anodonta*, *Potamilus* was also distributed throughout the lake (Fig. 1), however, *Potamilus* was most abundant in the upstream part of the lake. *Potamilus* occurred in much lower densities than *Anodonta*. Substrate organic matter content had little influence on *Potamilus* abundance agreeing with previous descriptions of *Potamilus* habitat preference (Clarke, 1981; Cummings & Mayer, 1995). *Potamilus alatus* occurred in areas with a broad range of depths (0.3-5 m), but only at low slope (<0.01 m/m) and low fetch (<0.8 km). A very weak correlation was found between *Potamilus* abundance and sediment organic matter content ($r^2 = 0.02$, $t = 2.56$, $P = 0.011$; Table 7). *Potamilus* existed in areas of varying depth at low slope and fetch. Those found at low depth may have used plankton as a food resource. *Potamilus* found at high depth may have depended upon detritus material for food. Levels of oxygen must be relatively consistent between depths in order to support *Potamilus* abundance. Temperature may be less variable at high depth as well as at low depth with low fetch. Therefore, stable temperature may affect *Potamilus* abundance. Their abundance may

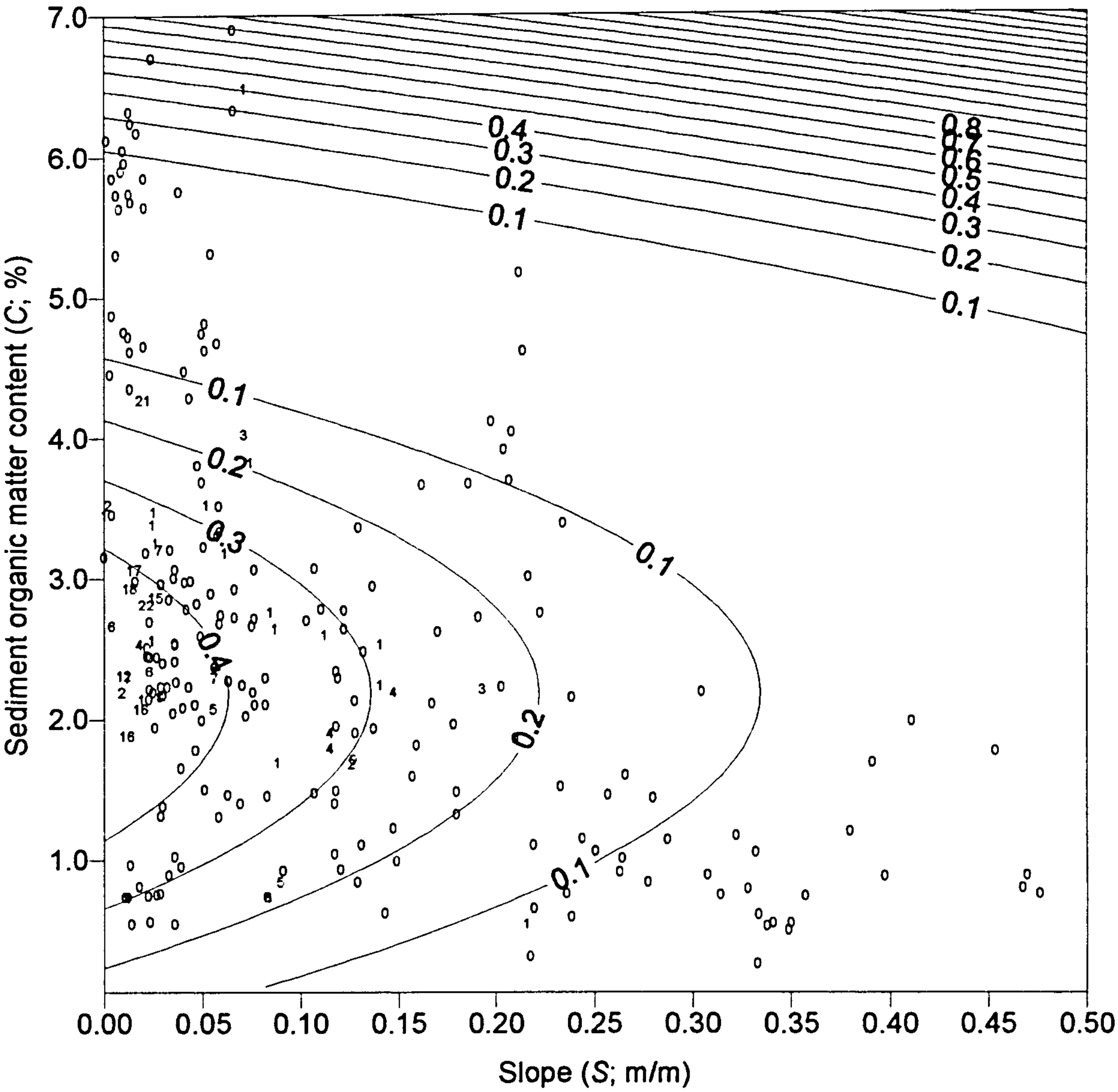


Fig. 13 Mussel densities predicted from eq. 4 plotted as a function of slope and sediment organic matter content. Contours are predicted *Lampsilis siliquoidea* abundance in a 25 m^2 quadrat. Predictions were made assuming average values of Z (2.16 m) and F (0.939 km). Posted numbers show actual *Lampsilis* density observations in the 239 sampled quadrats to illustrate concordance with predicted trends.

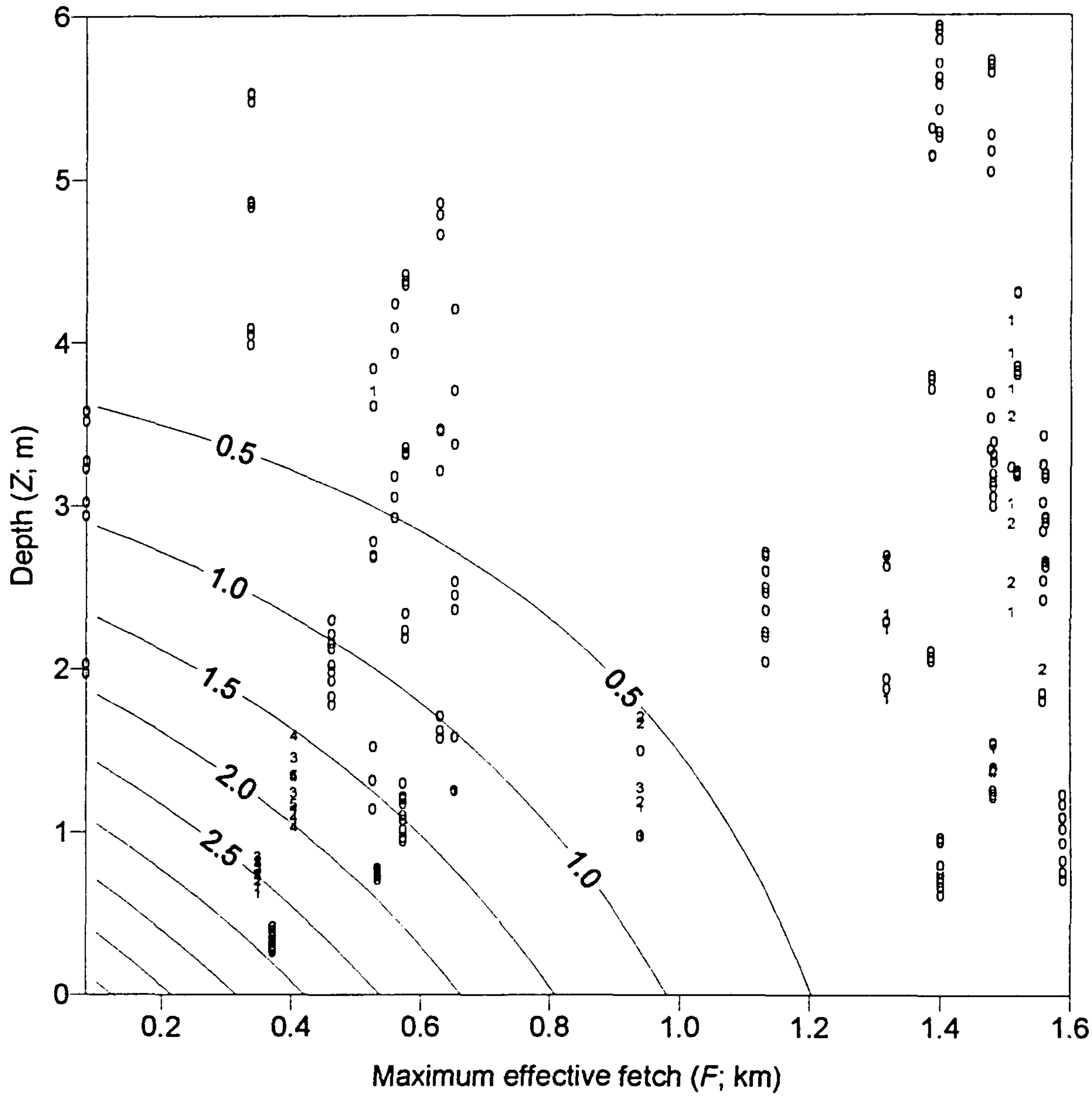


Fig. 14 Mussel densities predicted from eq. 4 plotted as a function of depth and maximum effective fetch. Contours are predicted *Lampsilis siliquoidea* abundance in a 25 m^2 quadrat. Predictions were made assuming average values of S (0.063) and C (2.09%). Posted numbers show actual *Lampsilis* density observations in the 239 sampled quadrats to illustrate concordance with predicted trends.

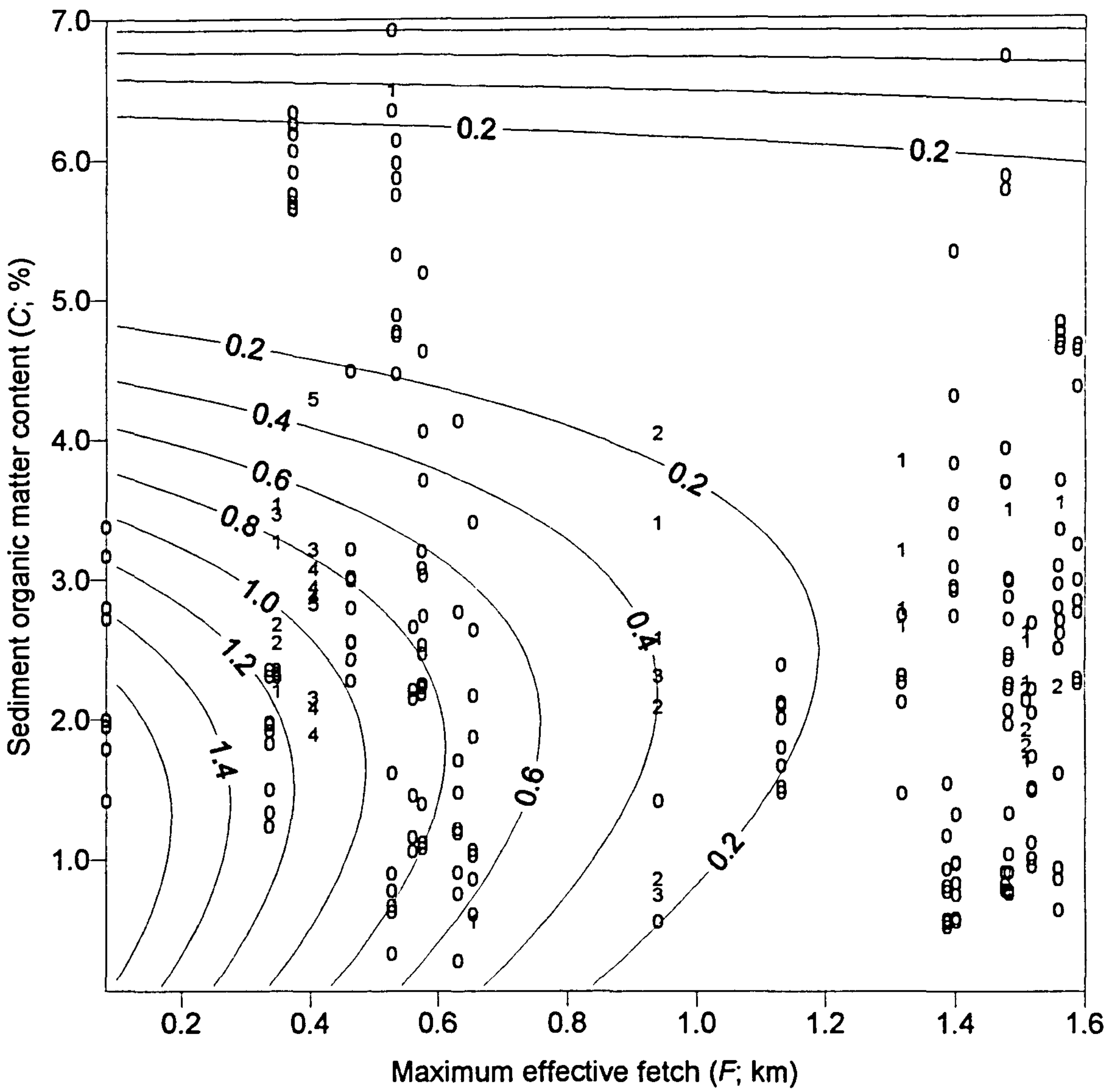


Fig. 15 Mussel densities predicted from eq. 4 plotted as a function of fetch and sediment organic content. Contours are predicted *Lampsilis siliquoidea* abundance in a 25 m^2 quadrat. Predictions were made assuming average values of S (0.063) and Z (2.16 m). Posted numbers show actual *Lampsilis* density observations in the 239 sampled quadrats to illustrate concordance with predicted trends.

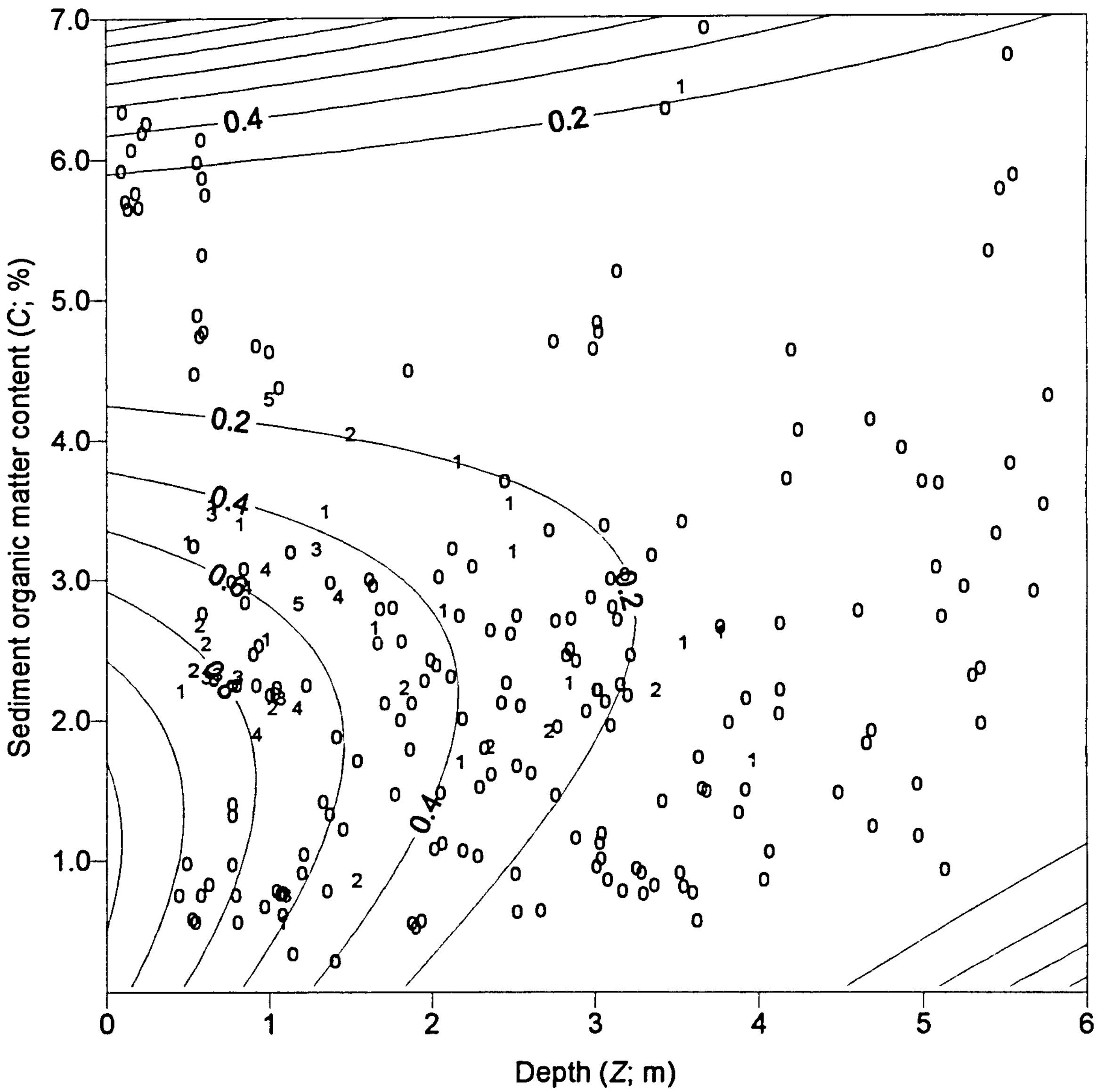


Fig. 16 Mussel densities predicted from eq. 4 plotted as a function of depth and sediment organic content. Contours are predicted *Lampsilis siliquoidea* abundance in a 25 m^2 quadrat. Predictions were made assuming average values of S (0.063) and F (0.939 km). Posted numbers show actual *Lampsilis* density observations in the 239 sampled quadrats to illustrate concordance with predicted trends.

be negatively affected by high turbulence which could explain why *Potamilus* were found in areas of low fetch where turbulence would be minimal. *Potamilus* were found in a variety of substrates which suggests that abundance is not dependent upon substrate type. *Potamilus* abundance may be affected by low fetch and slope because of increased substrate stability and the mussels' ability to anchor themselves to the substrate.

Mussel densities found at Big Creek Lake were low (*cf.* Downing & Downing, 1992) but appeared to be consistent with those in other water bodies. Densities of *Anodonta* and *Lampsilis* were similar to those found by Cvancara & Freeman (1978) in a typical reservoir lake. They found *Anodonta grandis* at mean density 0.27 m^{-2} and *Lampsilis siliquoidea* at mean density 0.05 m^{-2}. In Big Creek Lake, the mean density of *Anodonta grandis* was 0.20 m^{-2} and the mean density of *Lampsilis siliquoidea* was 0.04 m^{-2}.

The results obtained in this study indicate the influence of several environmental factors on abundance of *Anodonta*, *Potamilus* and *Lampsilis*. These results suggest the negative impact that environmental characteristics may have on mussel abundance such as high slope and high depth. In particular, sediment organic matter content may change rapidly through time (Mehlhop & Vaughn, 1994). High levels of organic matter content indicate substrates that may be unsuitable for species such as *Anodonta grandis* and *Uniomerus tetralasmus* (Table 4). Increased organic matter deposition may occur as a result of increased sediment erosion from agricultural fields. This could affect each species of freshwater mussel found in Big Creek Lake. Increased siltation may bury and suffocate mussel beds (Coker *et al.*, 1922; Hart, 1993; Mehlhop & Vaughn, 1994).

Understanding the factors that affect freshwater mussel distribution may make it possible to efficiently conserve remaining populations. Populations that are located through studies to determine mussel distributions can be documented and monitored in order to determine the status of each population, whether it is growing, stable, or declining. A population that is declining may benefit from efforts to conserve or maintain that population. Abundances of all species found in Big Creek Lake were found to be influenced by maximum effective fetch.

Determining actual mussel abundance and distribution could aid in effective management of economically important mussel populations. As mussel populations are discovered, general abundance could be monitored. In addition, their basic population ecology (i.e. their fecundity, growth and mortality rates) may then be determined. Harvest of healthy populations of economically valuable, non-threatened freshwater mussels could be effectively regulated using this information.

The results of this study agree with previous studies with one exception. Abundance of *Anodonta grandis* was found to be negatively affected by increasing substrate organic matter content (Table 4). This result stands in contrast to Cvancara & Freeman (1978) and Ghent *et al.* (1978) who suggested that abundance of *Anodonta grandis* was positively correlated with substrate organic matter content. This may be due to natural variability in *Anodonta* distribution as a result of their apparent ability to inhabit a variety of substrates.

This study may provide clues about why the literature has been confused regarding the influences of these factors on freshwater mussel abundances. The resulting low r-values (< 0.35) from the regressions may indicate that environmental characteristics in addition to water depth, bottom slope, sediment organic matter content, and maximum effective fetch determines mussel abundance and distribution. It is known that the impounding of rivers usually negatively affects Unionid mussel abundances (Cvancara and Freeman 1978). However, reasons for this phenomenon are not clearly understood. This is because of the large number of factors that may affect mussel abundance and distribution. These include biological variables, climatic factors, physical characteristics, and the impact of various human activities. The upper section of the lake was the shallowest, had the lowest slope and the highest substrate organic content. This is consistent with the expected morphology of a reservoir lake (Cvancara & Freeman, 1978; Håkanson & Jansson, 1983), shallow with gradually sloped basin near the head of the lake and deep with steep sloped banks near the lake impoundment. Sediment deposition is relatively high with low water flow and shallow depth. In addition, maximum effective fetch was lowest in the upper section of the lake which means that there would be is less wave action to suspend sediment in the water.

Although mussel populations varied greatly at each site, bottom slope, water depth, maximum effective fetch, and substrate organic matter content were each shown to affect abundance of *Anodonta, Potamilus,* and *Lampsilis* to some degree. Individual effects of each of these factors were weak (Tables 4-7). It is probable that there are other variables that we did not measure that affect mussel abundance.

Unionid mussel populations cannot persist without the presence of host fish. Unionids have an obligate parasitic larval stage that requires the presence of a fish host in order to survive. Lack of host fish in an area where mussels were distributed would cause a low mussel abundance due to marginal reproduction. The larvae of different species of mussels require different species of fish hosts in order to develop. *Anodonta* fish hosts include yellow perch (*Perca flavenscens*) and bluegill (*Lepomis macrochirus*). *Lampsilis* hosts include yellow perch (*Perca flavenscens*), bluegill (*Lepomis macrochirus*), smallmouth bass (*Micropterus dolomieui*), and largemouth bass (*Micropterus salmoides*). The fish host for *Potamilus* is the freshwater drum (*Aplodinotus grunniens*).

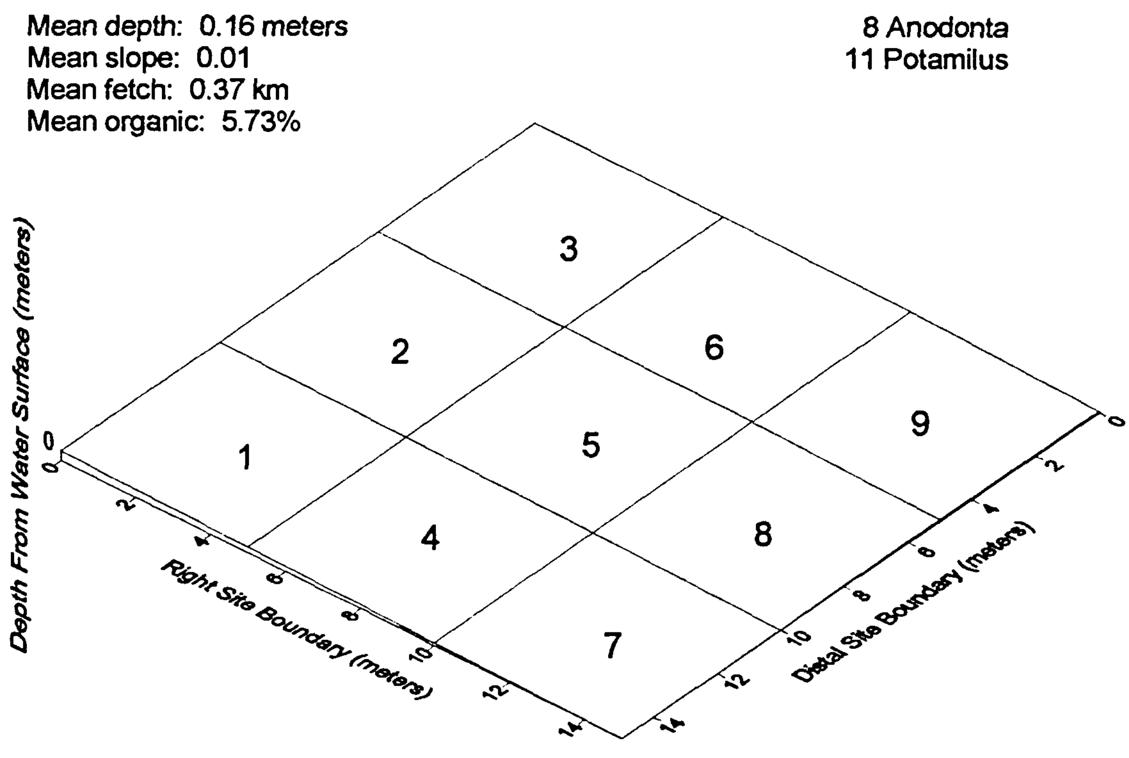
Anodonta, Lampsilis and *Potamilus* have Bradytictic breeding seasons. This means that they have long breeding seasons. These mussels retain developing glochidial larvae in their gills through the year, except the summer months. *Uniomerus* hosts and breeding season are unknown. *Corbicula* have no need of a fish host as they have veliger (free swimming) larvae which are not parasitic. They are capable of breeding any time the water temperature exceeds 19°C (Britton & Morton, 1979).

Freshwater mussels are thought to be disappearing rapidly due principally to habitat destruction (Bogan, 1993). This research has shown that Unionid mussels in Big Creek Lake have specific, divergent habitat requirements. In general, they need stable substrates and moderate levels of turbulence. Turbulence is presumably necessary to provide food, oxygen and to prevent siltation of mussel beds. *Anodonta grandis* were most abundant in substrates with less than 4.0% sediment organic matter content, in areas with low bottom slope (<0.15 m/m), at intermediate depth (1-3 m) and high effective fetch (>1 km). *Lampsilis siliquoidea* were most abundant in substrates with 2-3% sediment organic matter content, at low slope (<0.21 m/m), and at one to two meters depth. *Potamilus alatus* were most abundant at slopes of < 0.25 m/m and at depths of < 4 m. Alteration of these habitat characteristics may cause mussel abundance to decline.

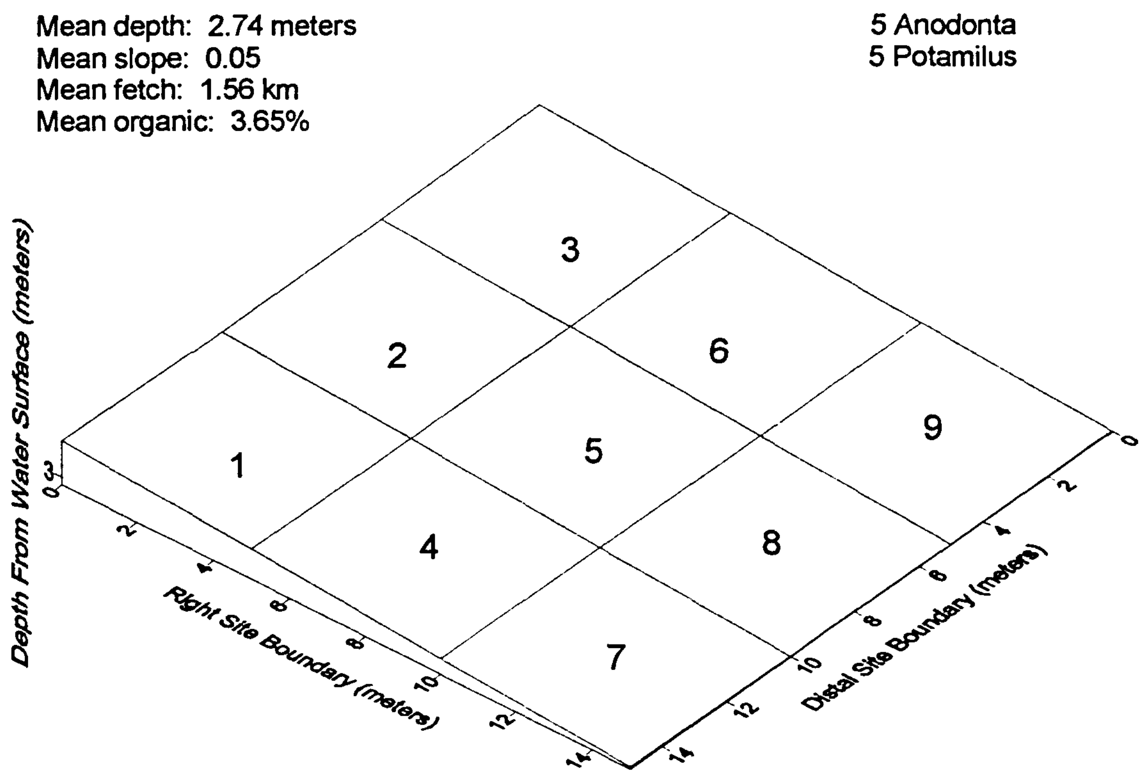
Mussels can be very sensitive to habitat changes. The optimal habitat characteristics implied in this study therefore indicate that habitat changes may negatively affect species abundances. Fish communities, substrate organic matter content, benthic macroinvertebrate assemblages, water chemistry, dissolved oxygen, and water temperature can all be altered by habitat modification (Bogan, 1993). For example, dredging, channel modification, and riparian management schemes can alter lake basin morphometry, increasing or decreasing bottom slopes, and altering depth profiles. In fact, construction of bulkheads, revetments, groins, breakwaters, and jetties are frequently applied methods that attempt to directly manipulate depth, slope and sediment mobility (Dept. of Army, 1984). Increased slope would negatively affect abundance of *A. grandis*, *P. alatus*, and *L. siliquoidea* which were found in Big Creek Lake. Decreased slopes could encourage increased siltation which would negatively affect mussel abundance. Decreased water level, for extended periods of time, might cause mussel die-offs at lower depths. Decreased water level may also result in mussel habitat loss. Siltation is common in agricultural landscapes. Increased siltation may bury and suffocate mussel beds (Coker *et al.*, 1922; Hart, 1993; Mehlhop & Vaughn, 1994). Increased siltation and primary production from nutrient loading in agricultural landscapes could increase sediment organic matter content which may negatively affect *Anodonta grandis* in Big Creek Lake. Modifications of the lake to enhance recreational fishing, such as the addition of submerged structure, may cover mussel beds, result in decreased turbulence, and cause increased siltation, all of which may negatively impact mussel abundances. This study suggests that alteration of mussels' physical habitat must be done with extreme caution if these important components of aquatic biodiversity are to be preserved.

APPENDIX A. SITE SURFACE MAPS

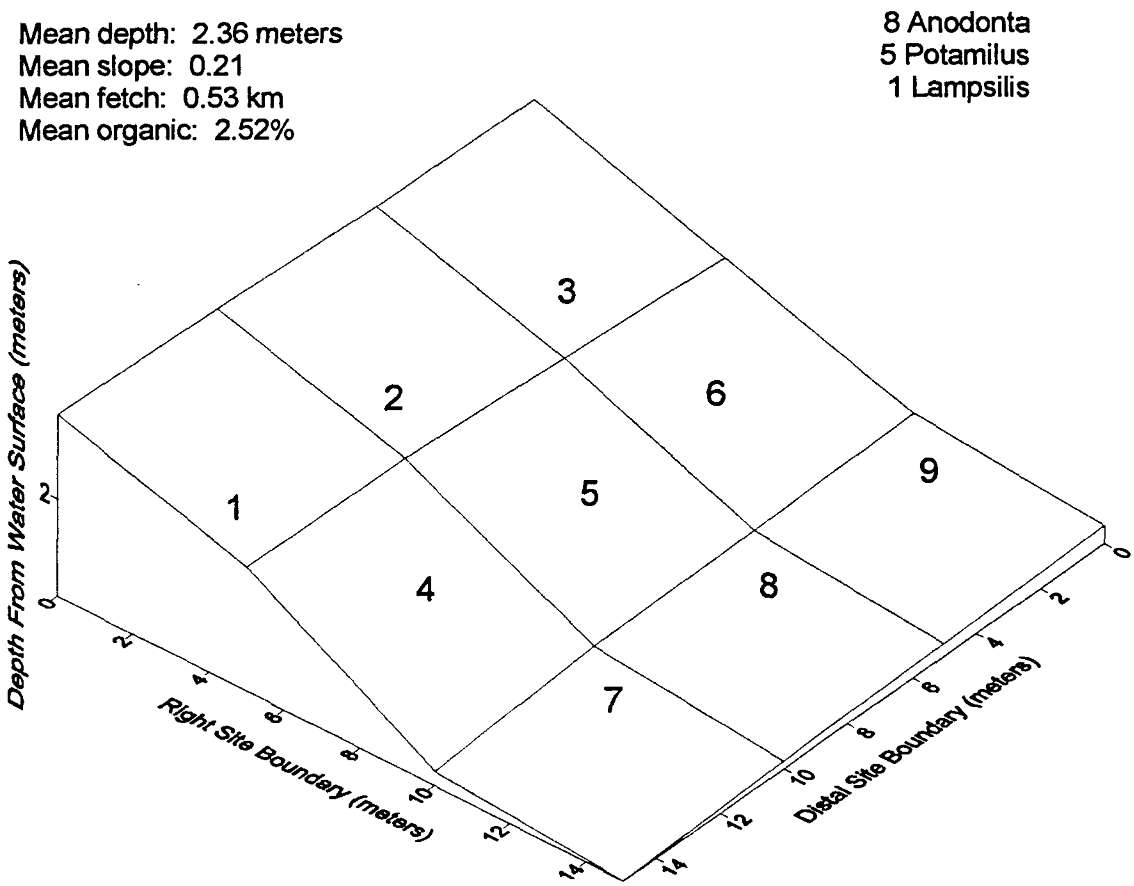
Three-dimensional surface maps for each of the twenty-seven sample sites at Big Creek Lake. These maps visually illustrate bottom contours found at each site. The average slope, depth, fetch, and sediment organic matter content found at each site are listed at the upper left of each map. Actual abundances of each species found at each site are listed at the upper right of each map.



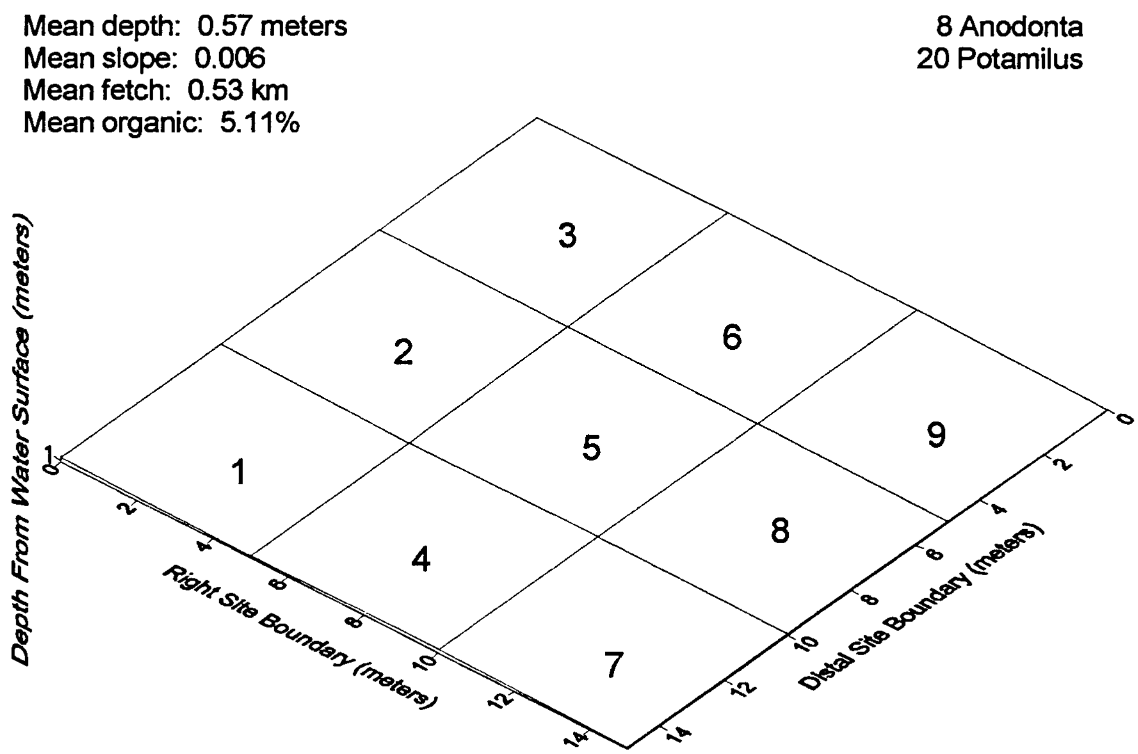
Site 1
(quadrats numbered 1-9)



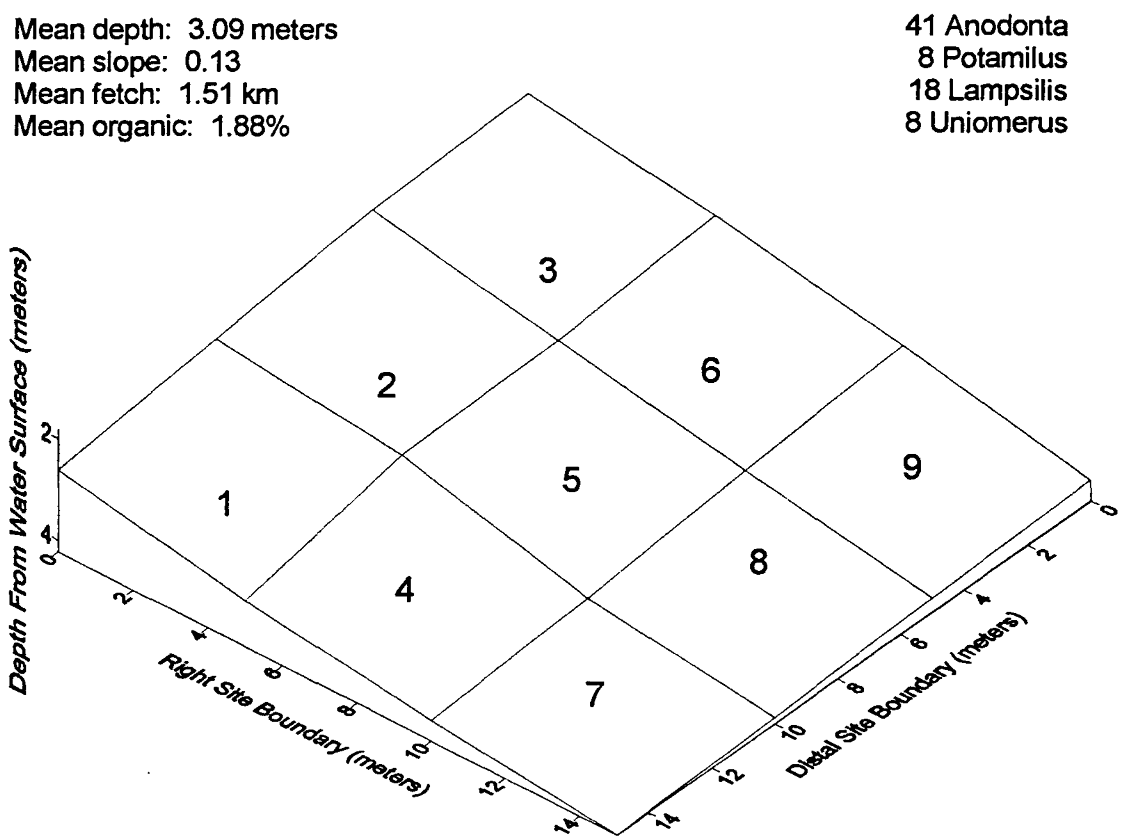
Site 2
(quadrats numbered 1-9)



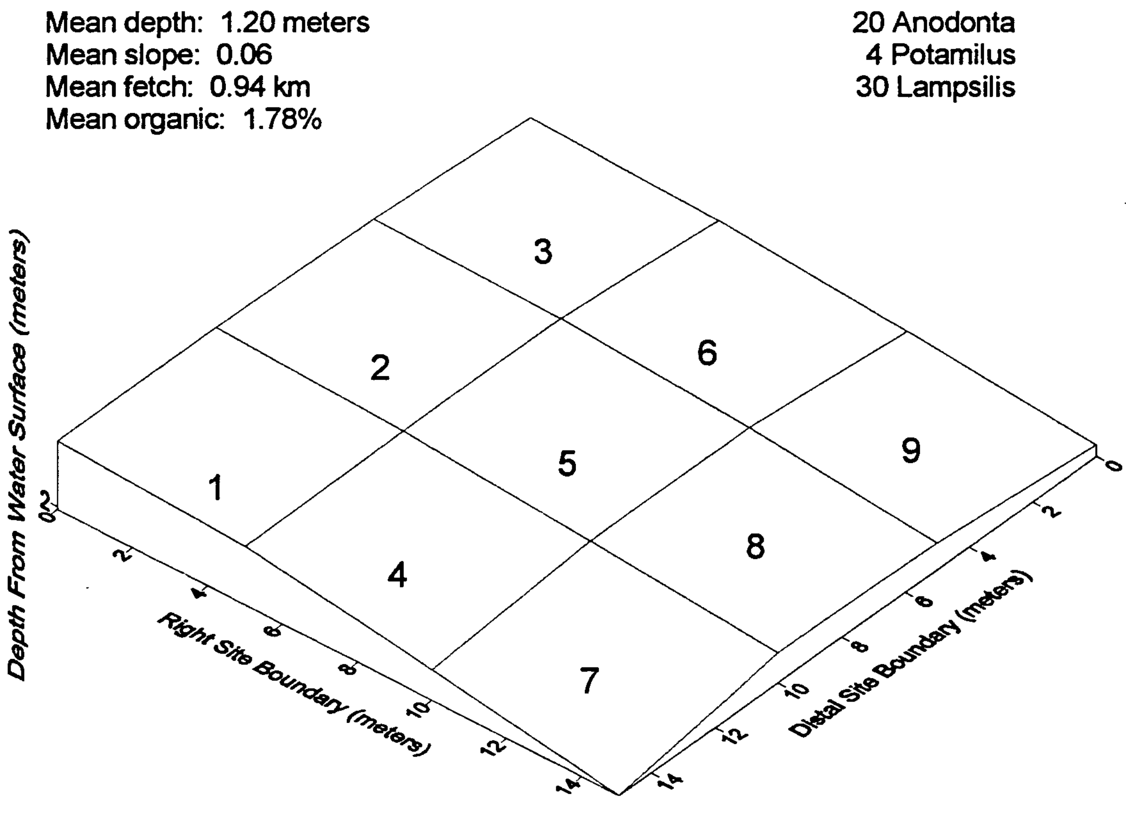
Site 3
(quadrats numbered 1-9)



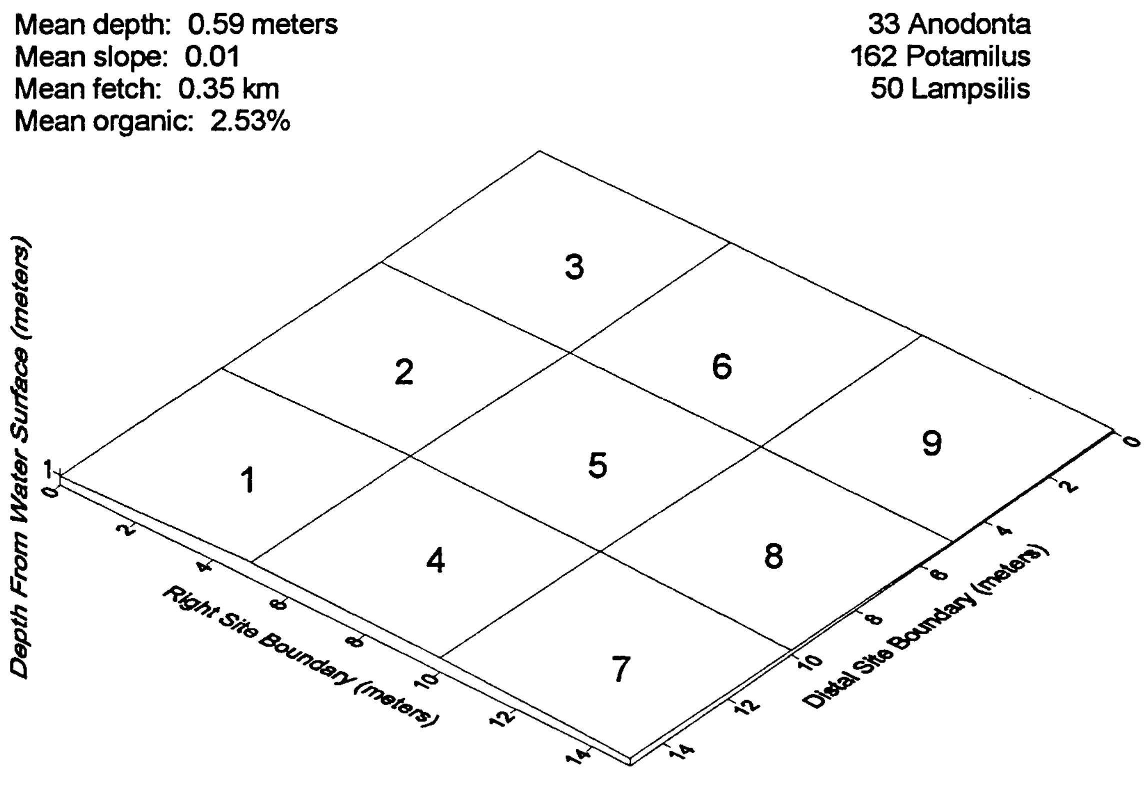
Site 4
(quadrats numbered 1-9)



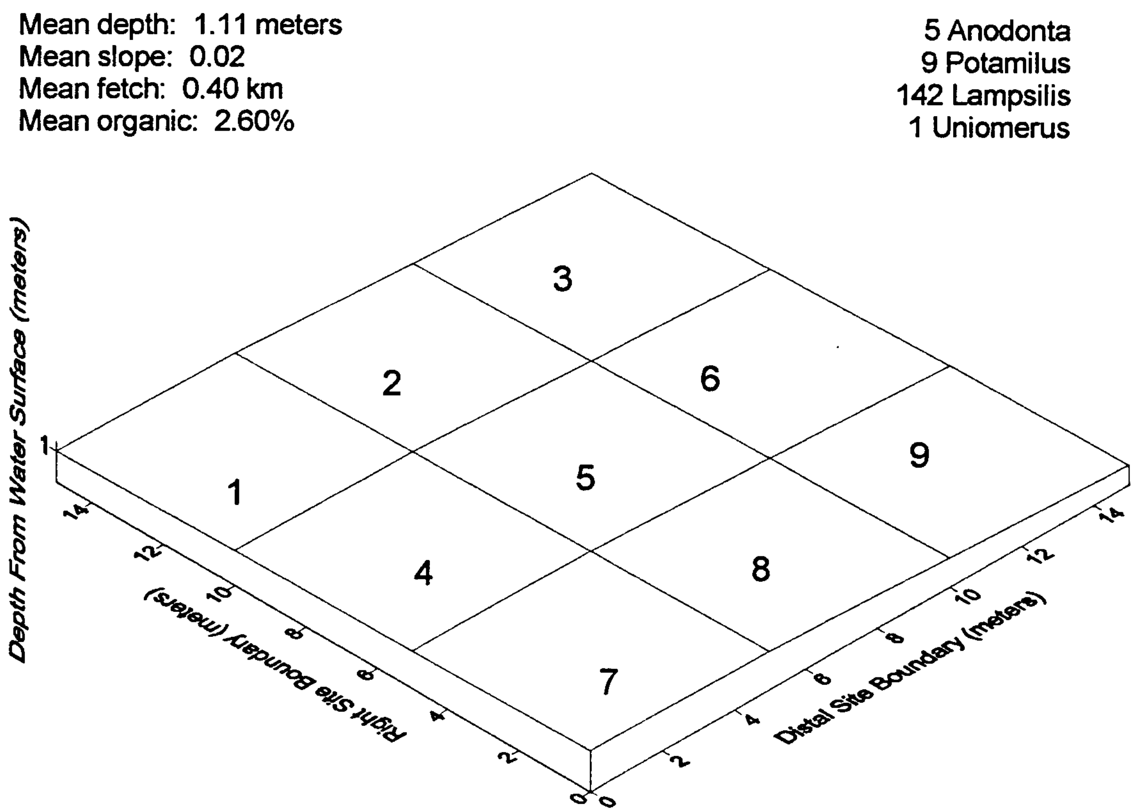
Site 5
(quadrats numbered 1-9)



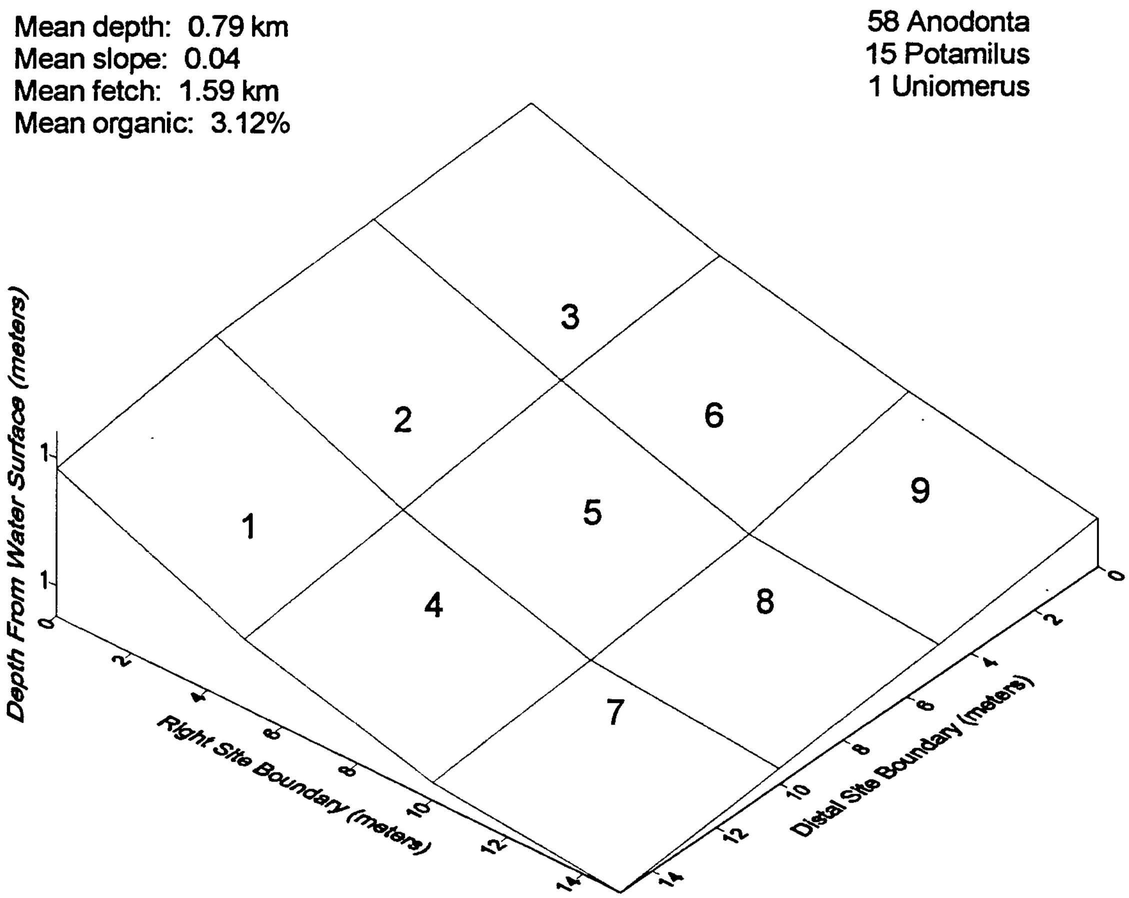
Site 6
(quadrats numbered 1-9)



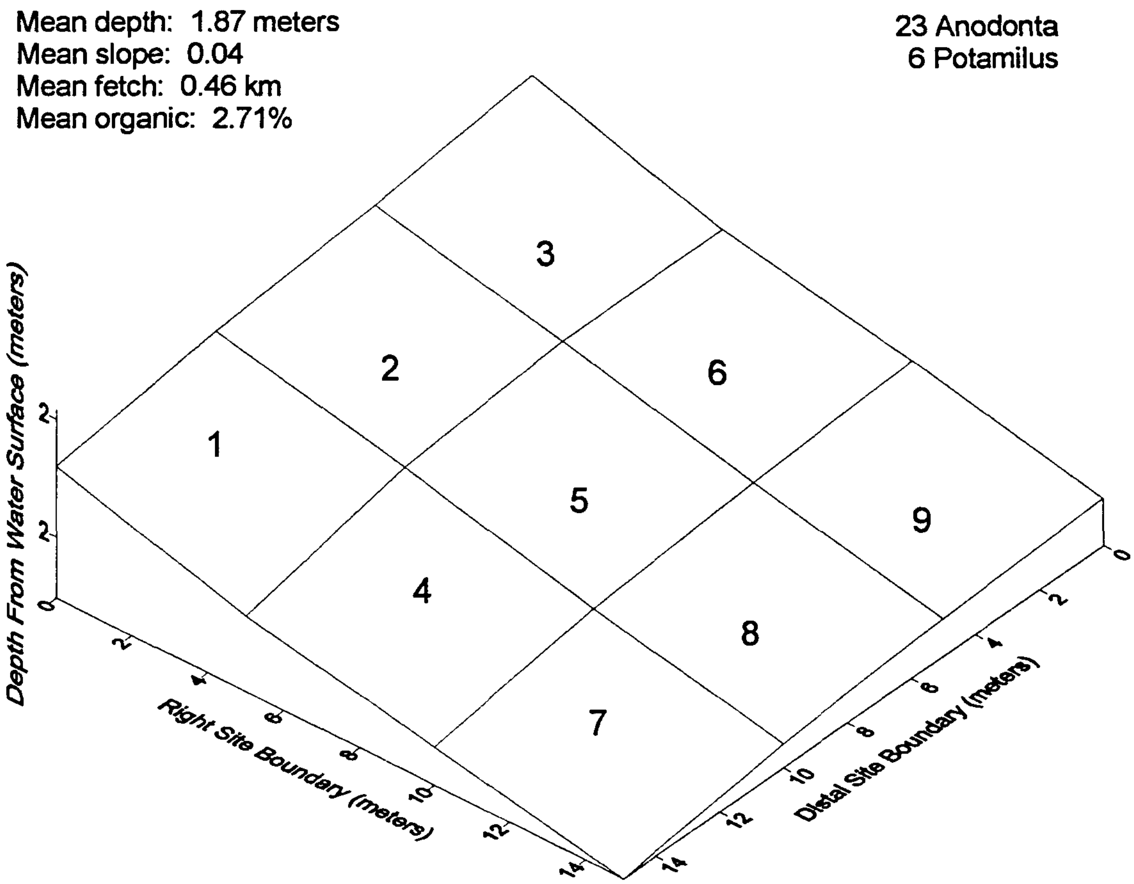
Site 7
(quadrats numbered 1-9)



Site 8
(quadrats numbered 1-9)



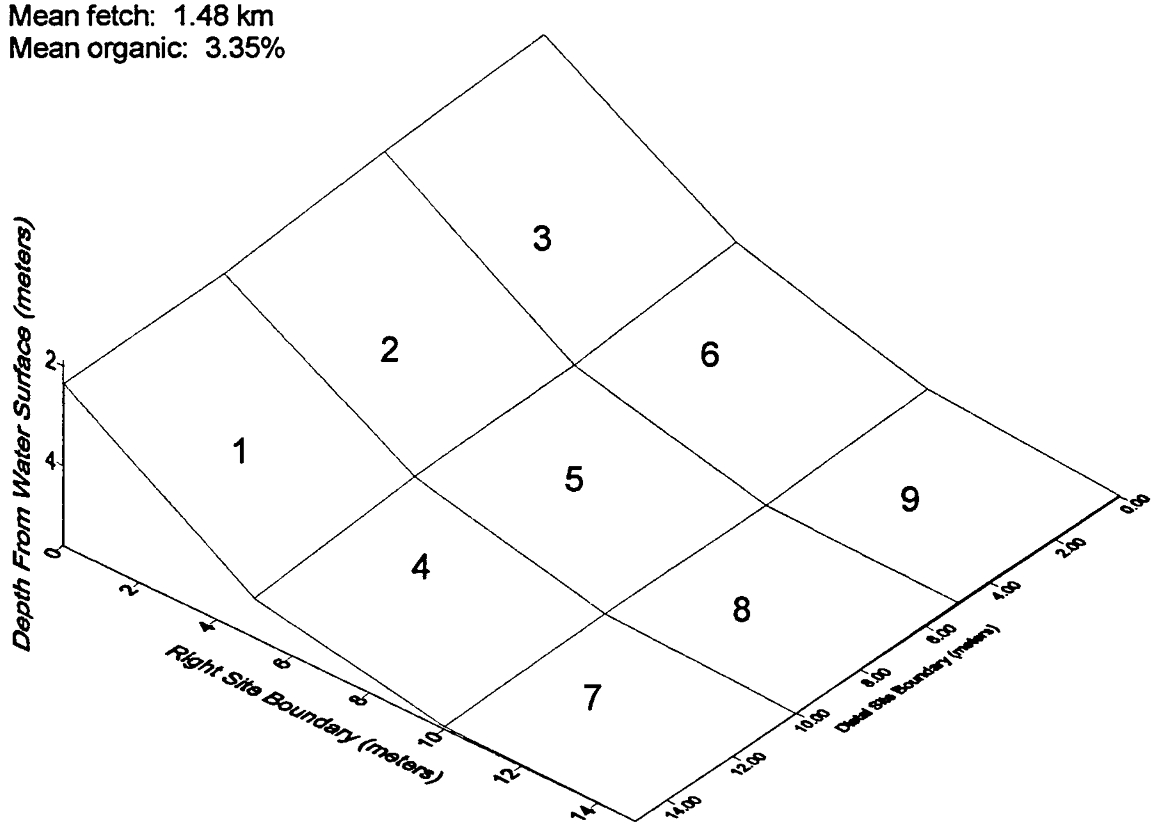
Site 9
(quadrats numbered 1-9)



Site 10
(quadrats numbered 1-9)

Mean depth: 4.43 meters
Mean slope: 0.22
Mean fetch: 1.48 km
Mean organic: 3.35%

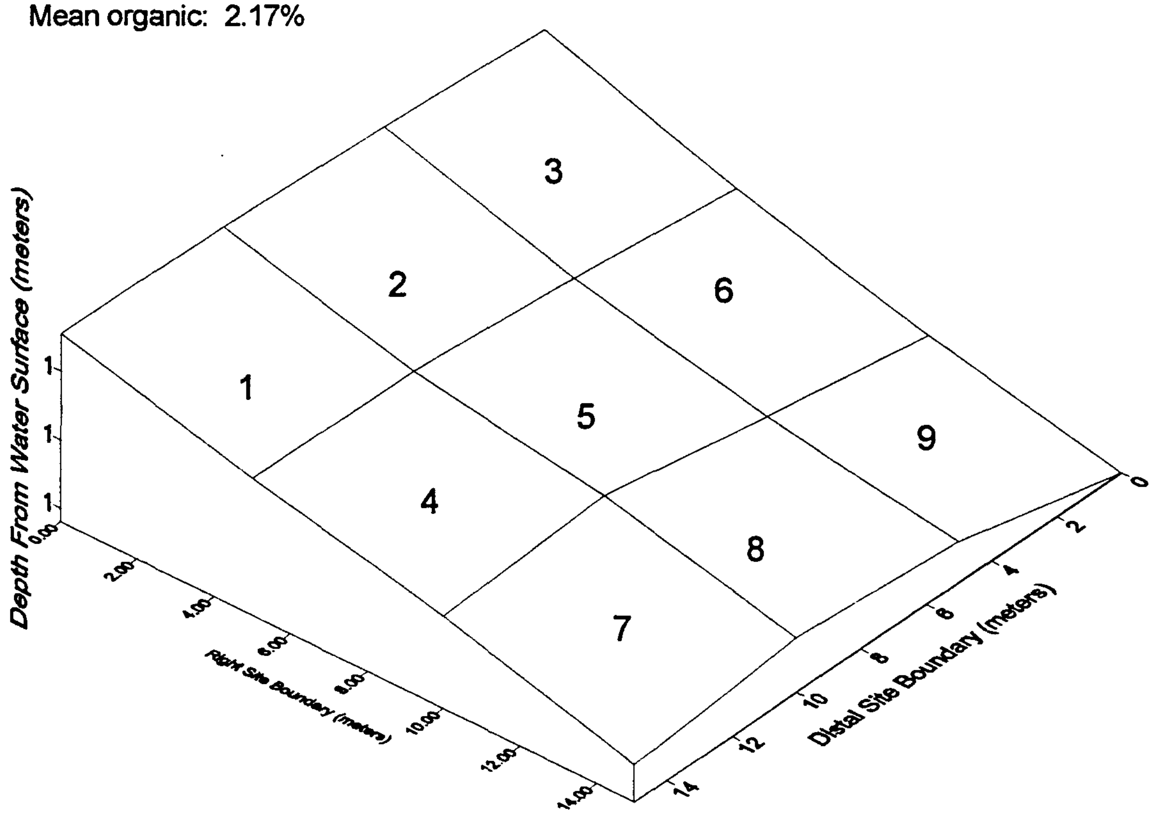
8 Anodonta
2 Potamilus



Site 11
(quadrats numbered 1-9)

Mean depth: 0.94 meters
Mean slope: 0.28
Mean fetch: 0.57 km
Mean organic: 2.17%

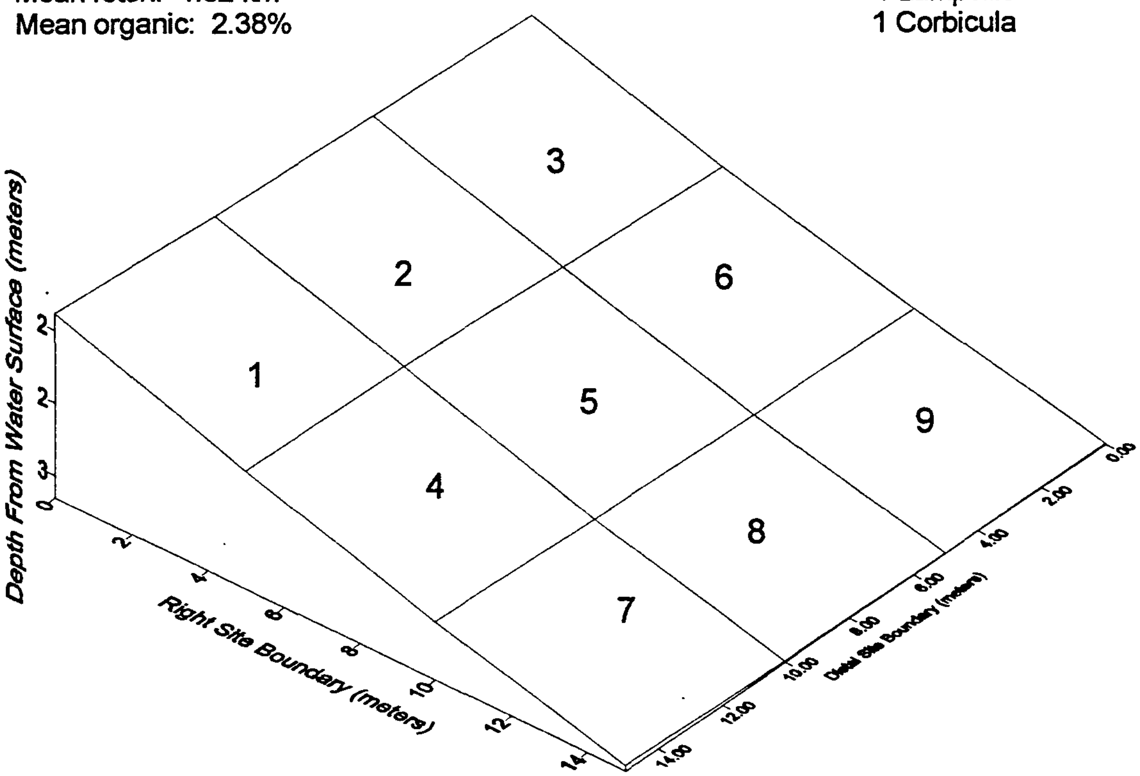
9 Anodonta
2 Potamilus
1 Uniomerus



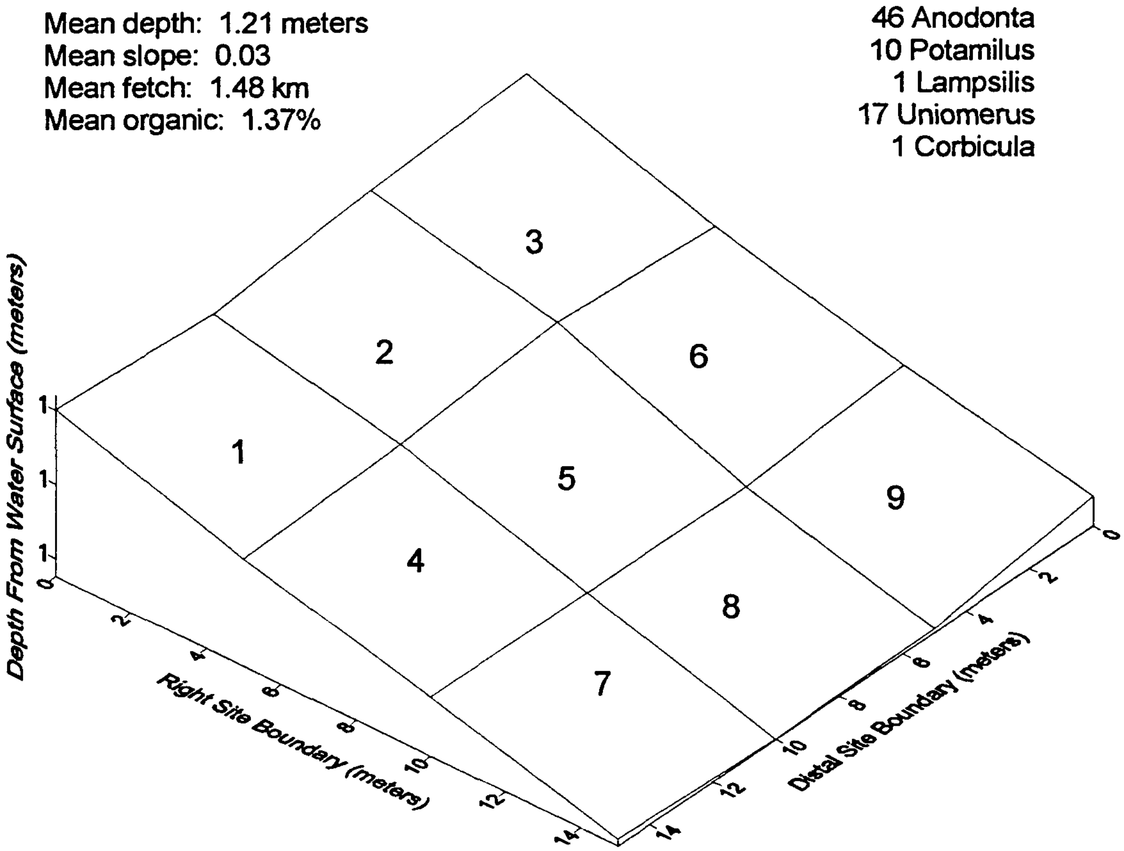
Site 12
(quadrats numbered 1-9)

Mean depth: 2.09 meters
Mean slope: 0.08
Mean fetch: 1.32 km
Mean organic: 2.38%

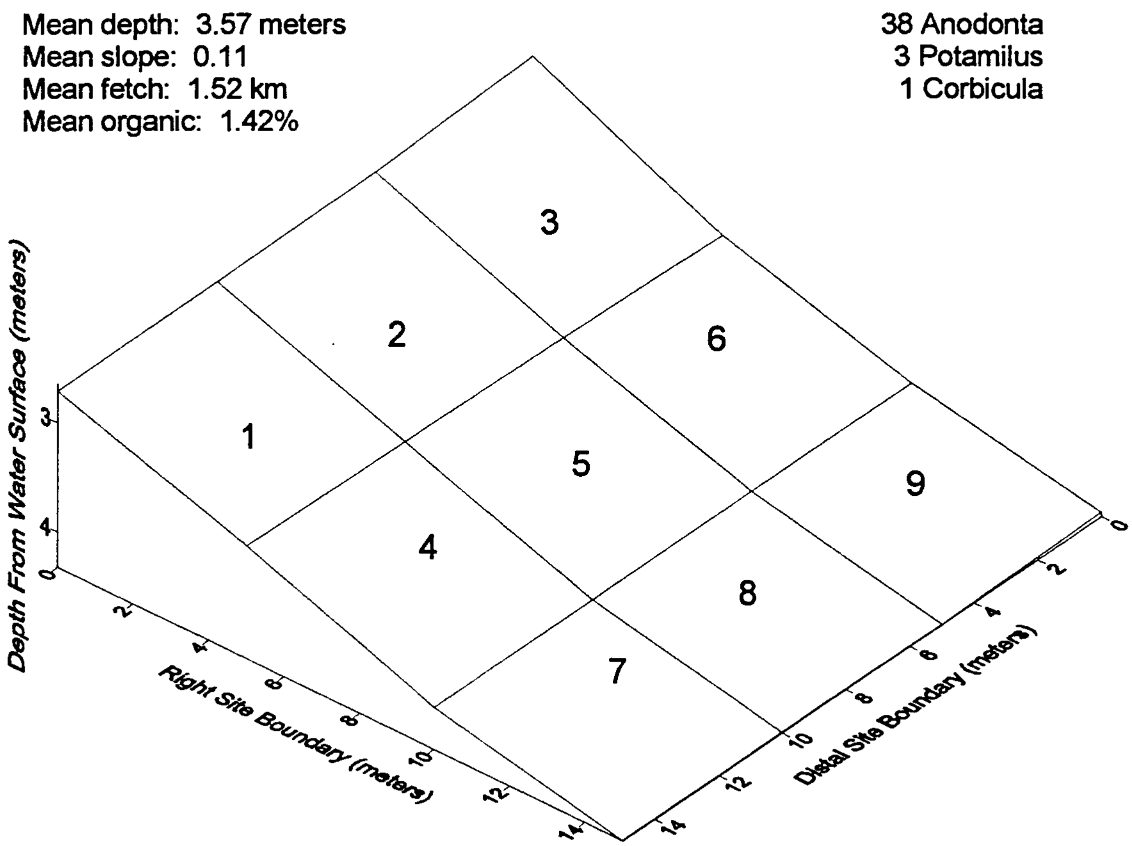
17 Anodonta
9 Potamilus
4 Lampsilis
1 Corbicula



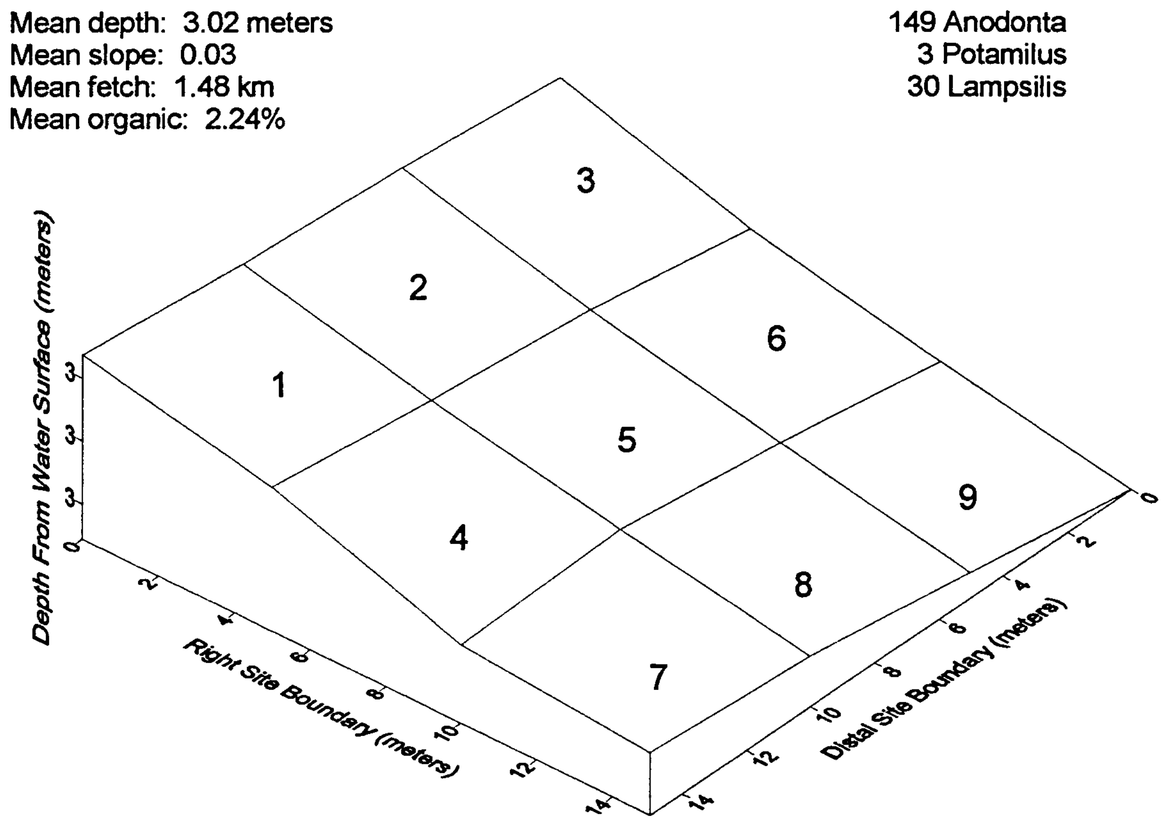
Site 13
(quadrats numbered 1-9)



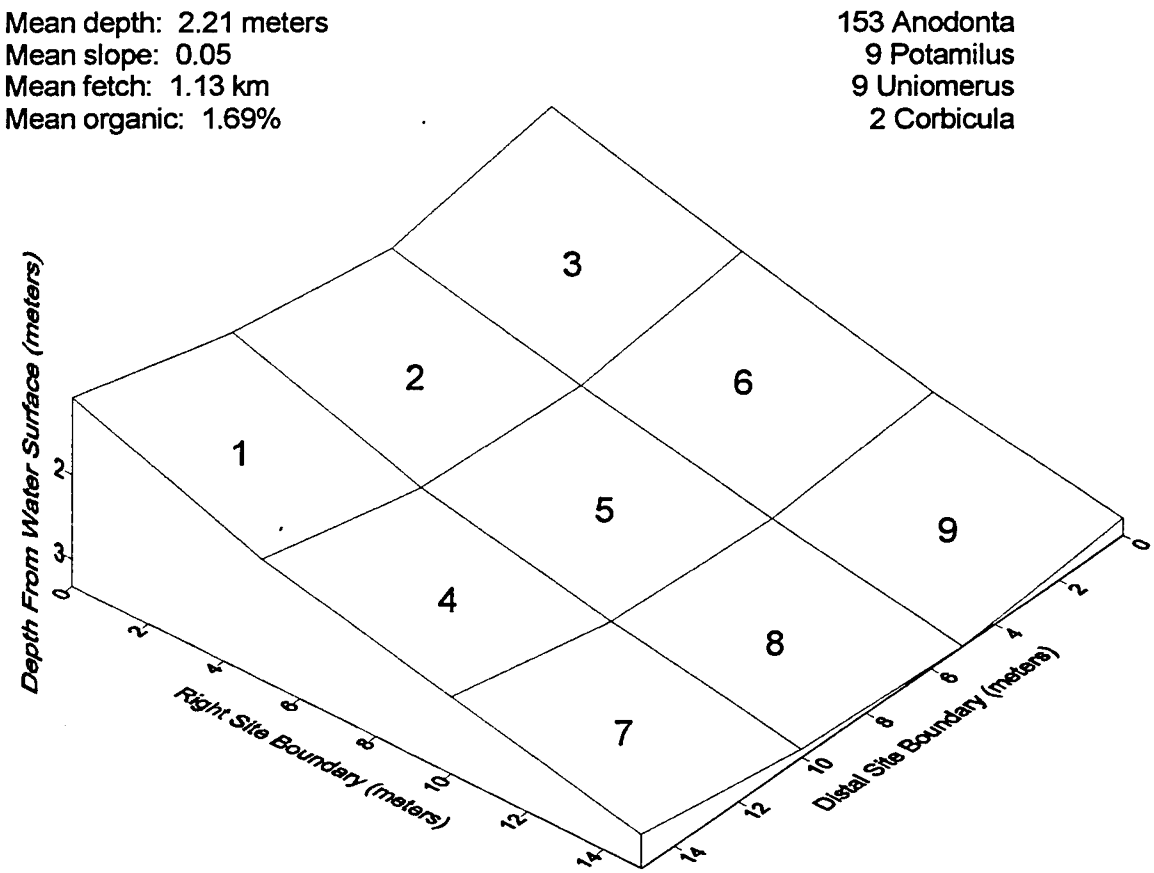
Site 14
(quadrats numbered 1-9)



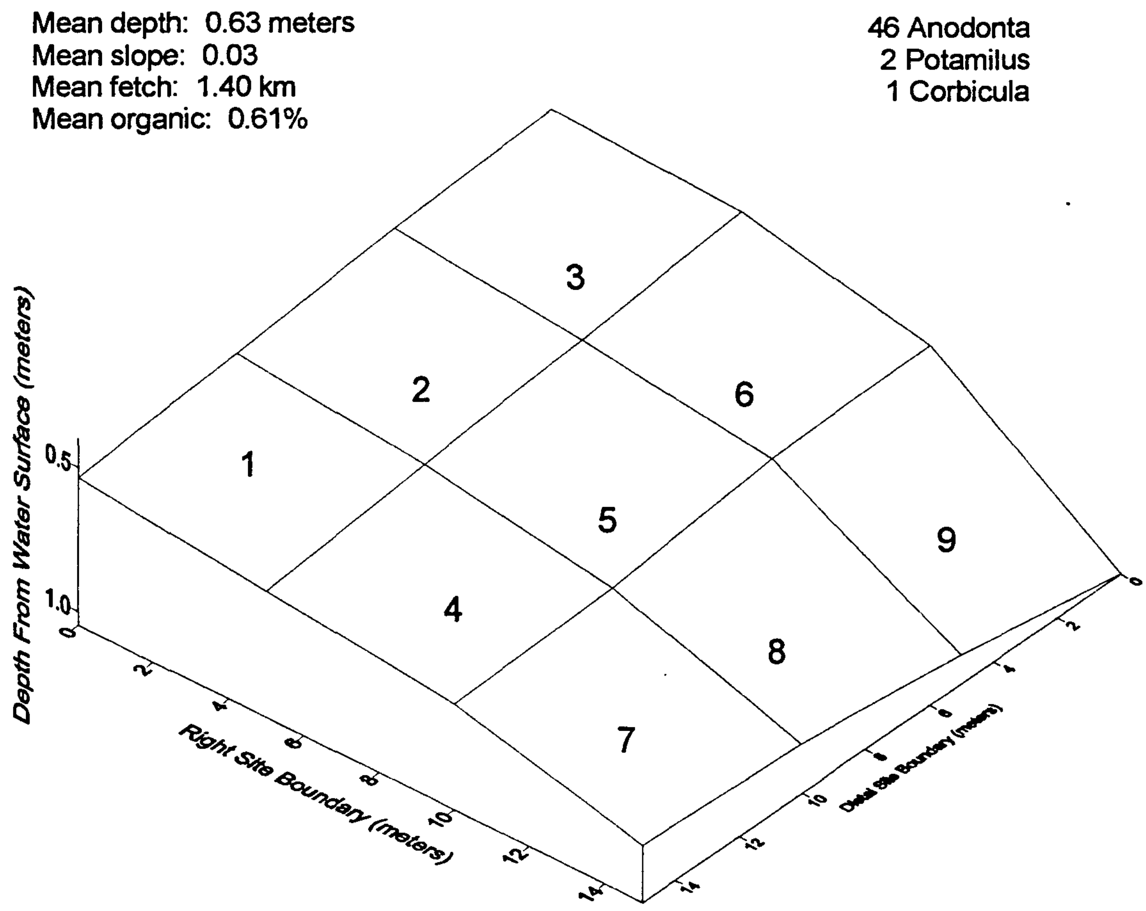
Site 15
(quadrats numbered 1-9)



Site 16
(quadrats numbered 1-9)



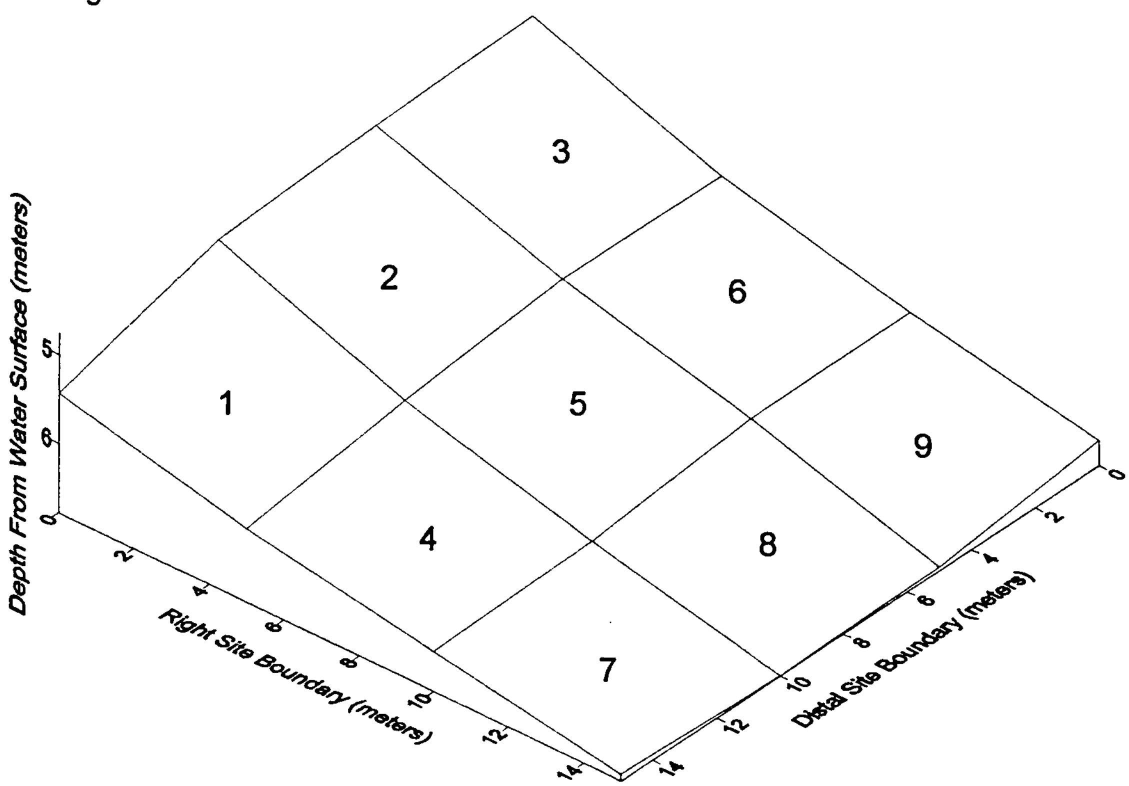
Site 17
(quadrats numbered 1-9)



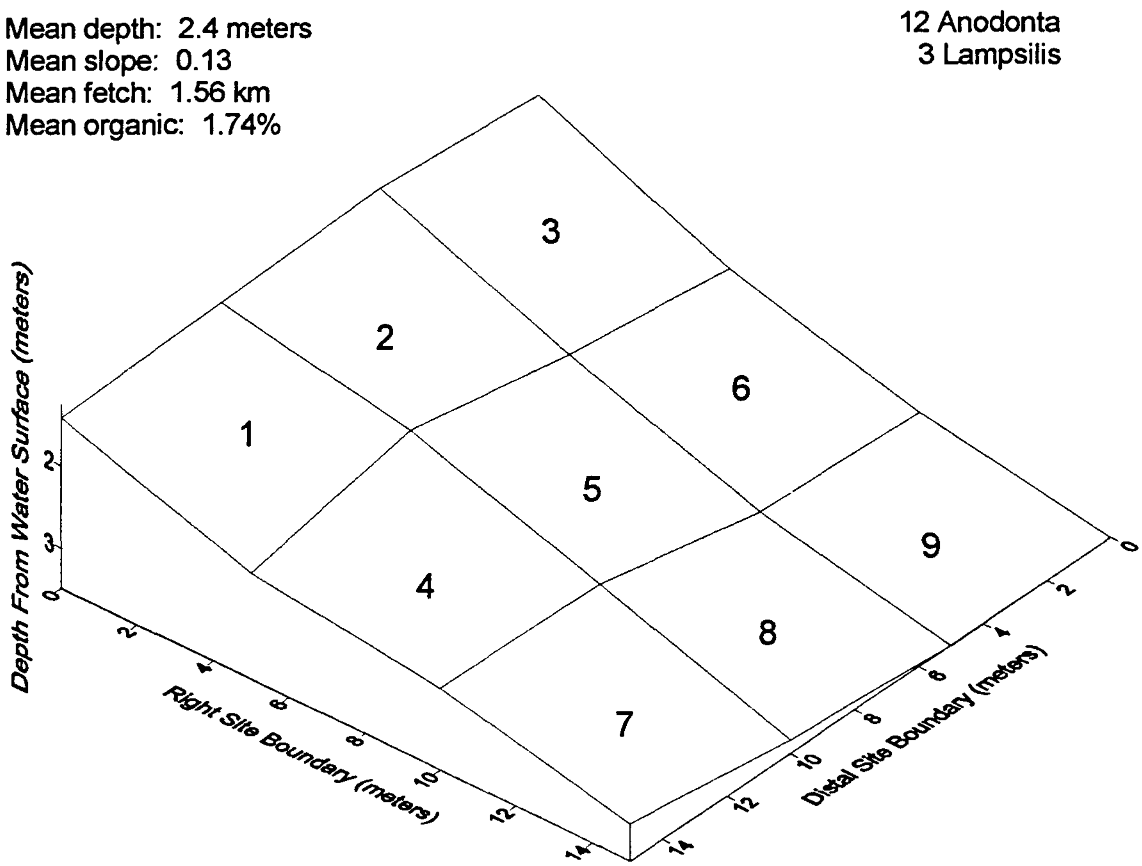
Site 18
(quadrats numbered 1-9)

Mean depth: 5.44 meters
Mean slope: 0.06
Mean fetch: 1.40 km
Mean organic: 3.33%

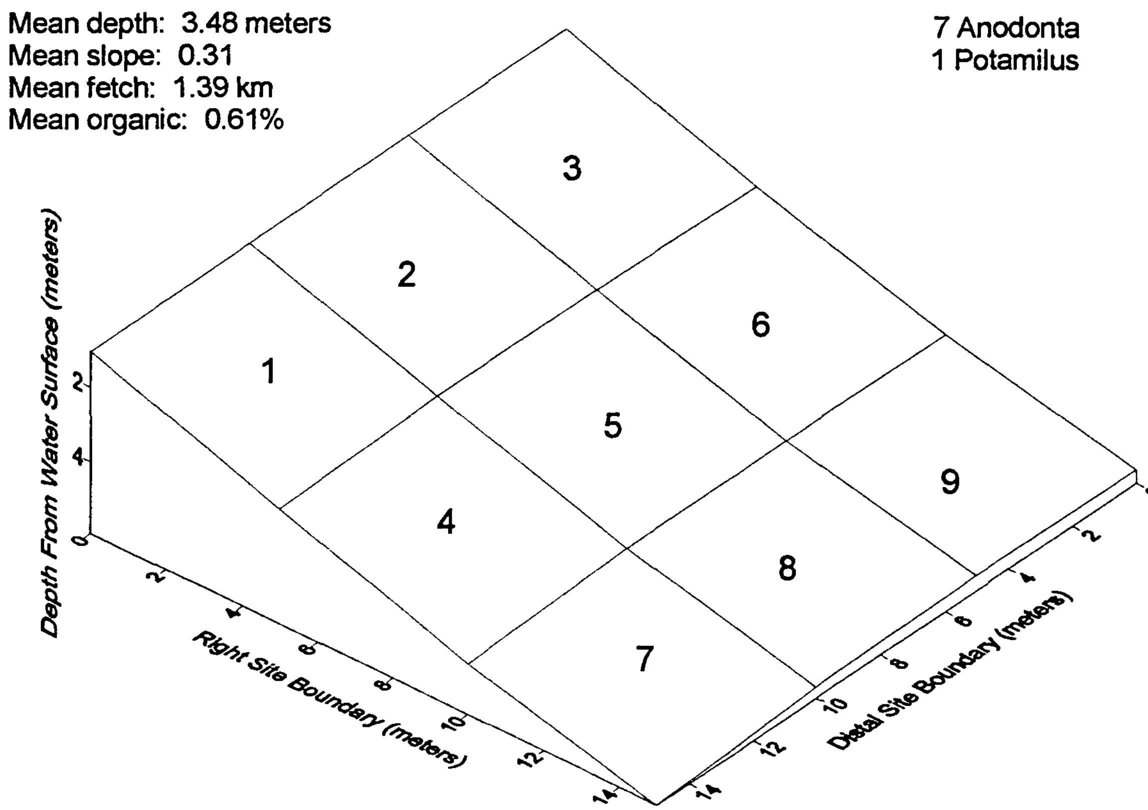
10 Anodonta
2 Potamilus



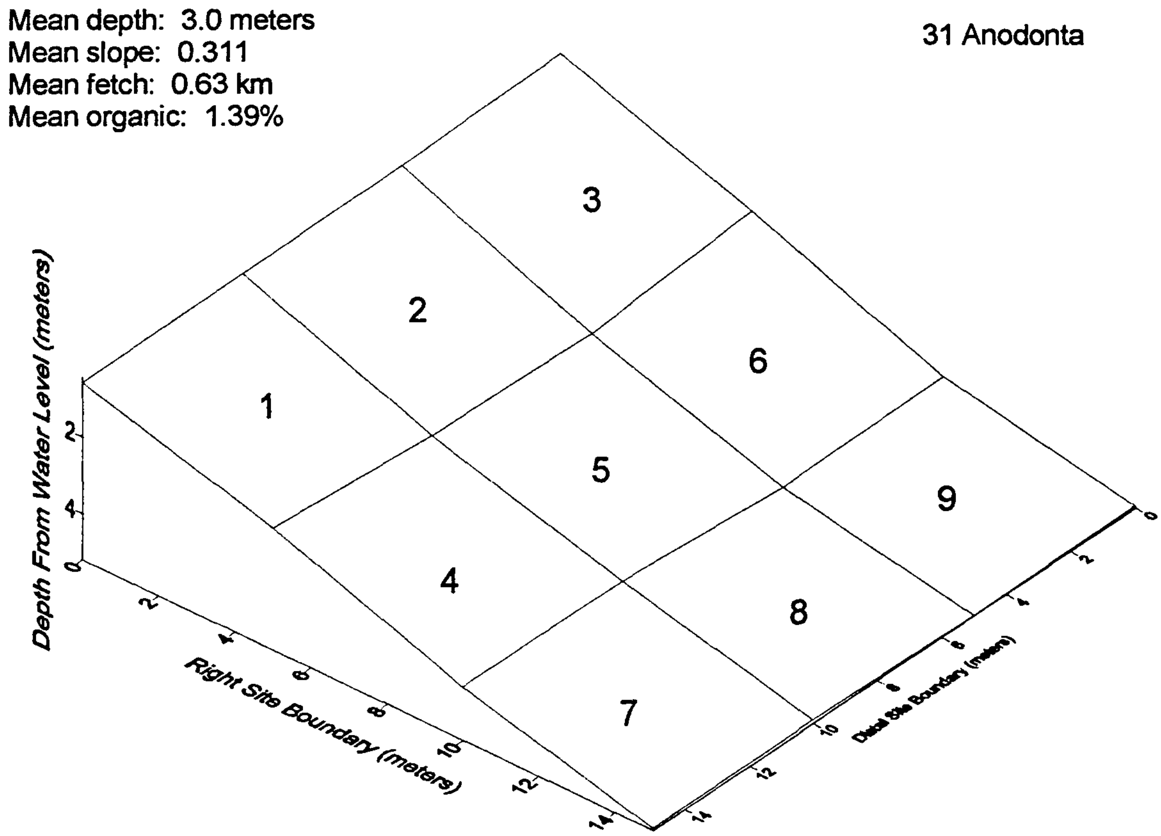
Site 19
(quadrats numbered 1-9)



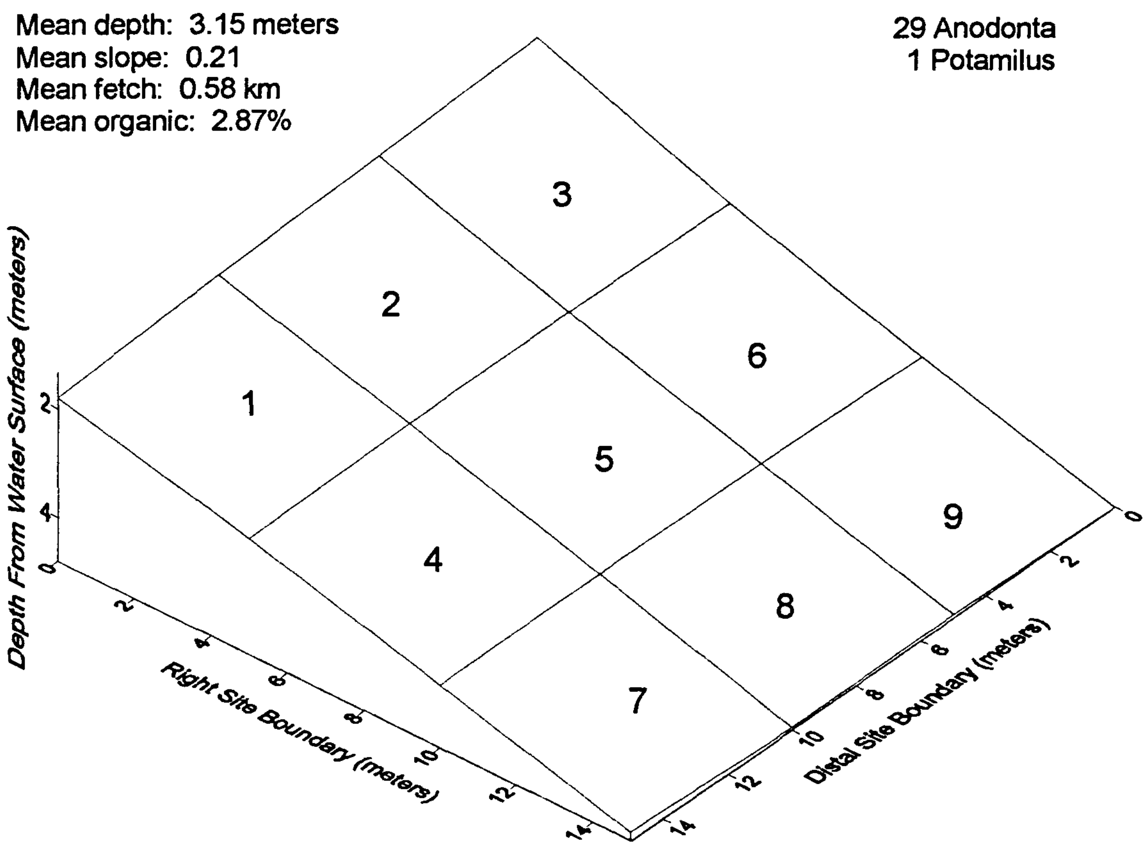
Site 20
(quadrats numbered 1-9)



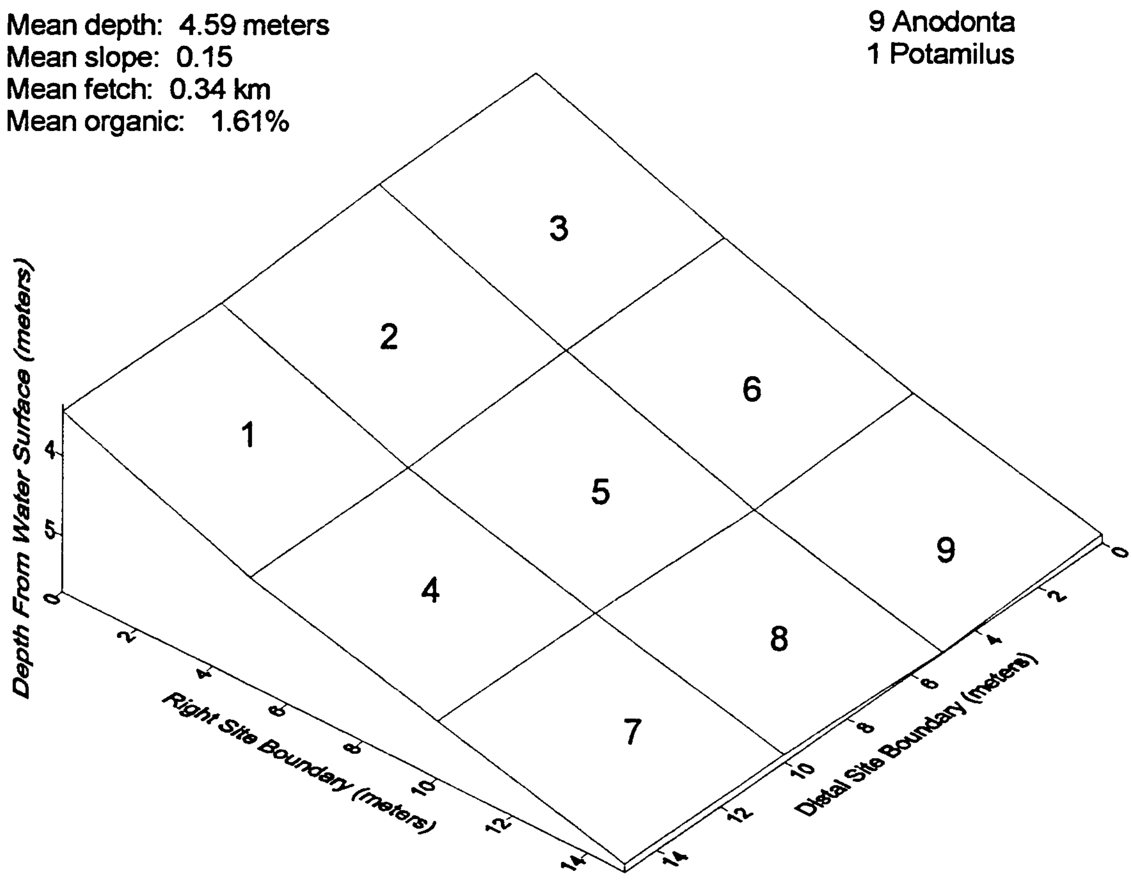
Site 21
(quadrats numbered 1-9)



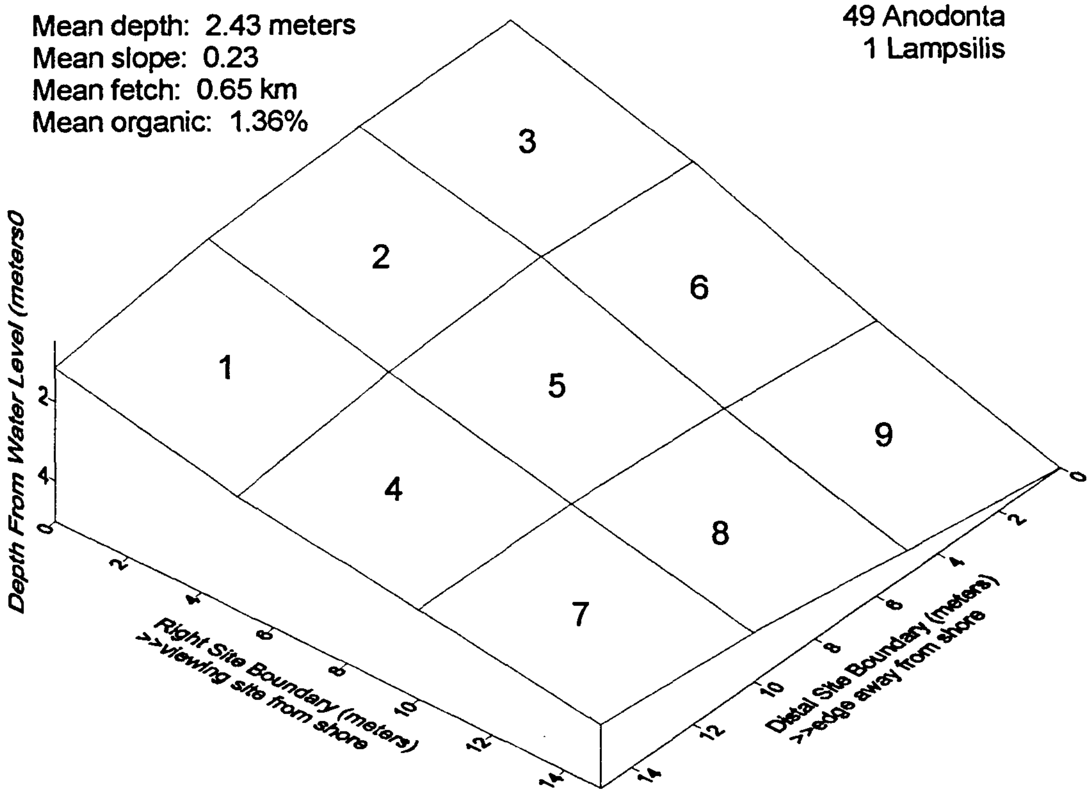
Site 22
(quadrats numbered 1-9)



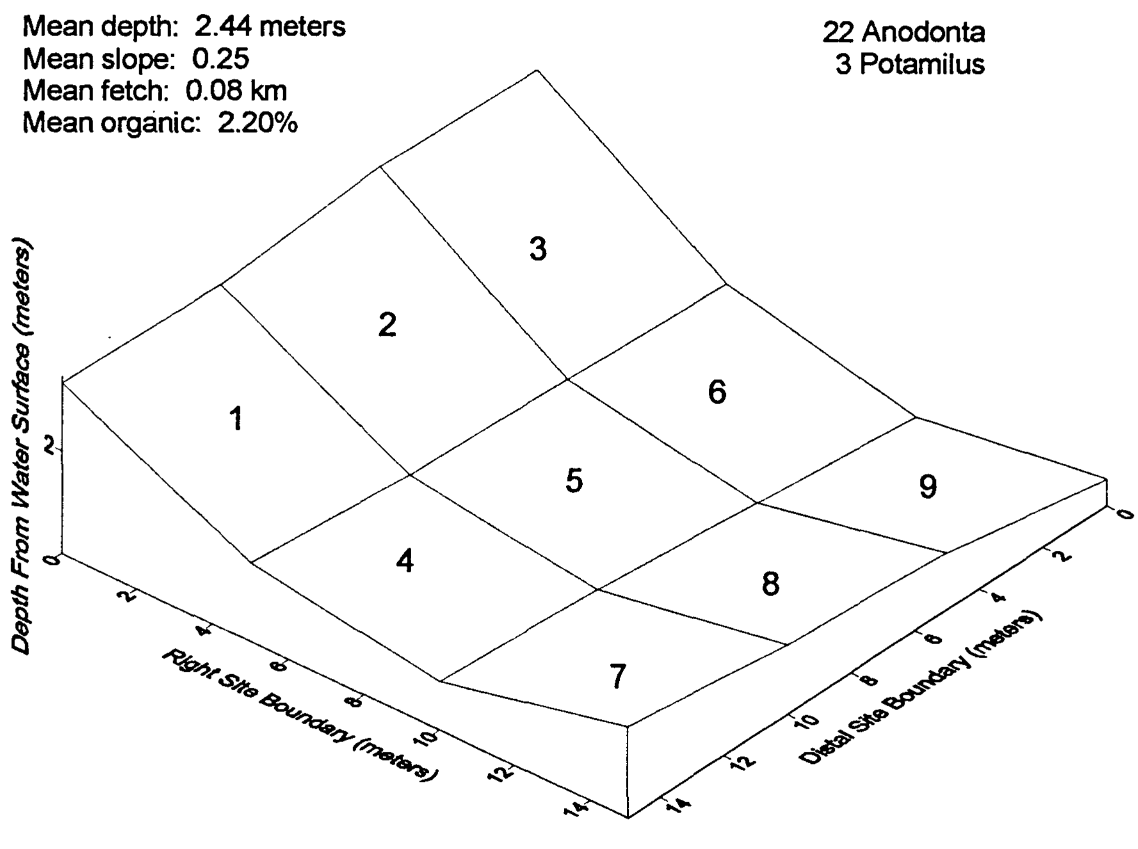
Site 23
(quadrats numbered 1-9)



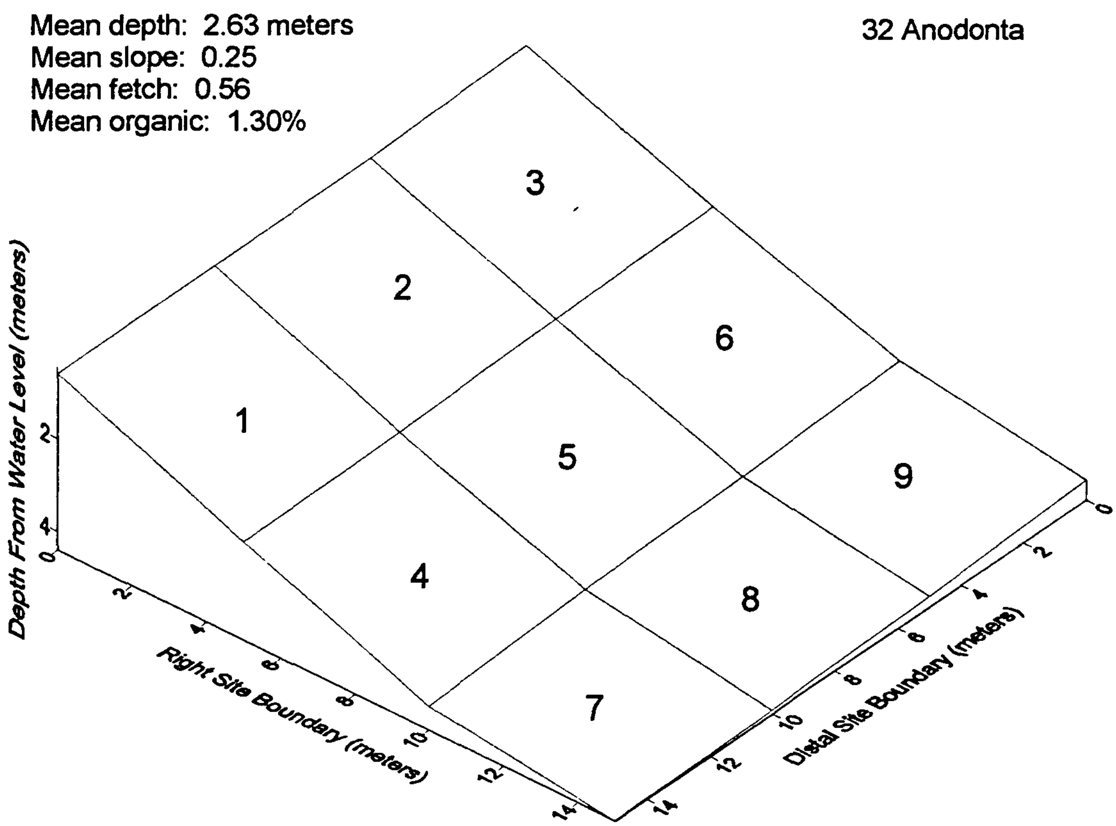
Site 24
(quadrats numbered 1-9)



Site 25
(quadrats numbered 1-9)



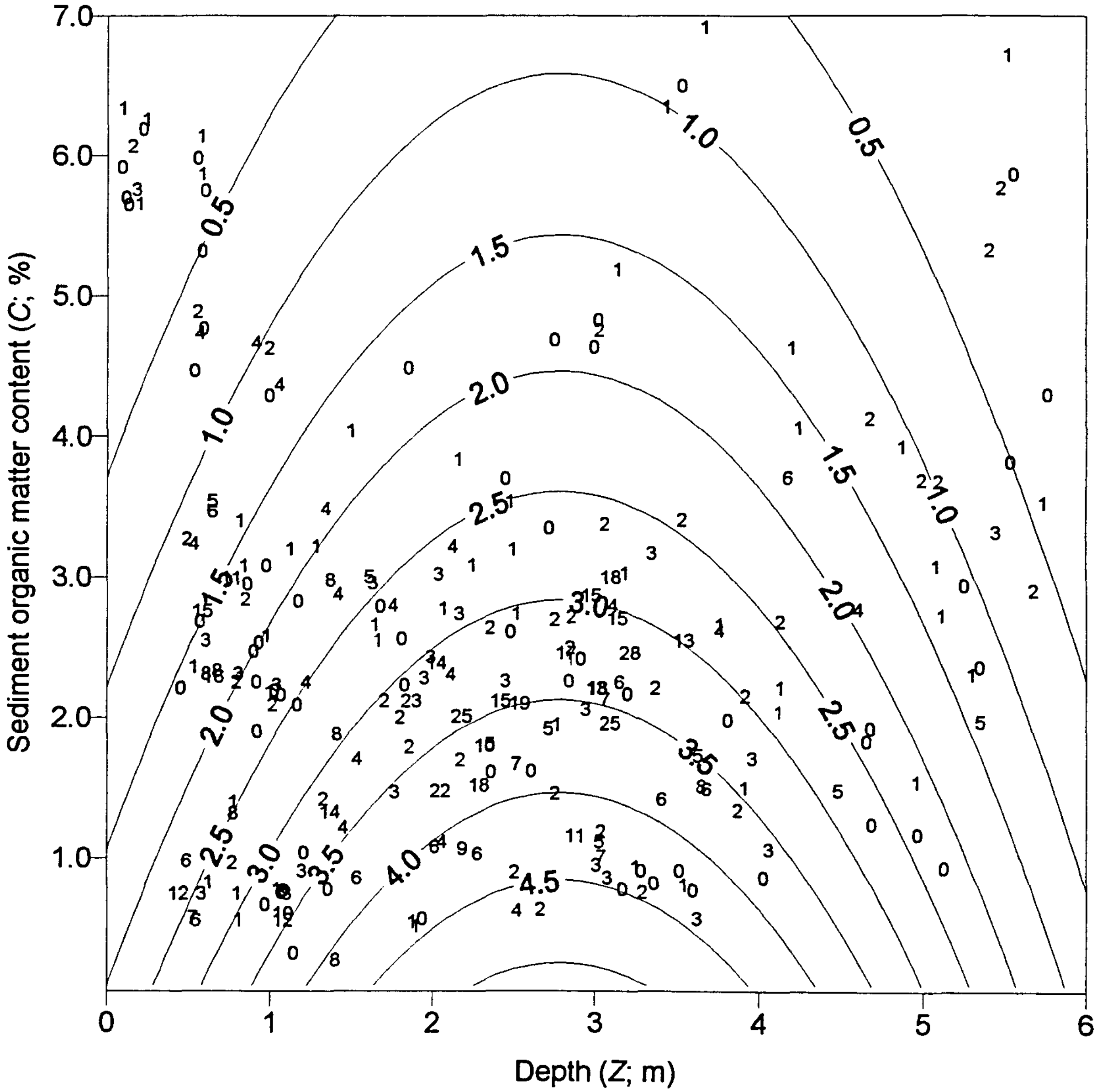
Site 26
(quadrats numbered 1-9)

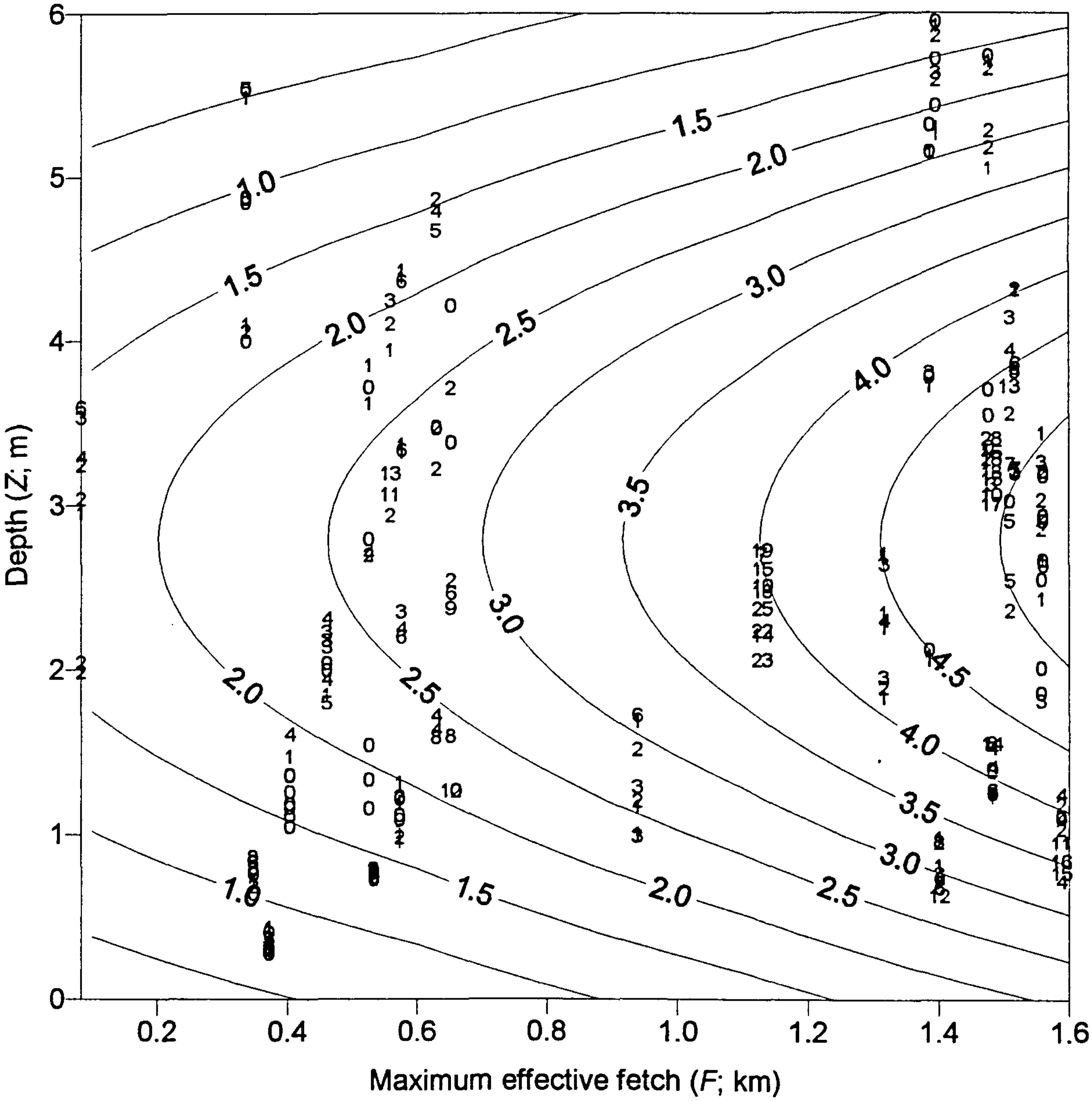


Site 27
(quadrats numbered 1-9)

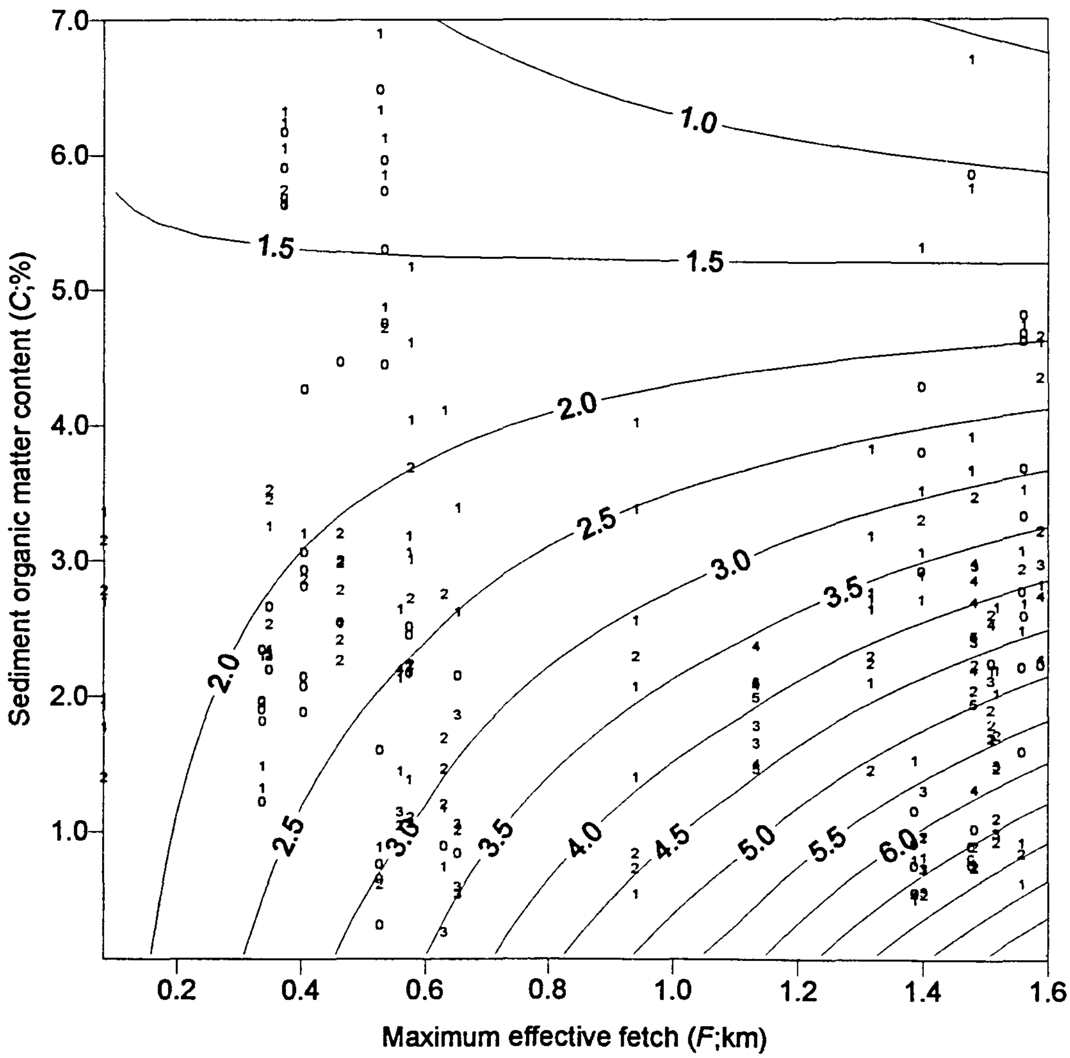
APPENDIX B. MULTIVARIATE MUSSEL DENSITY GRAPHS

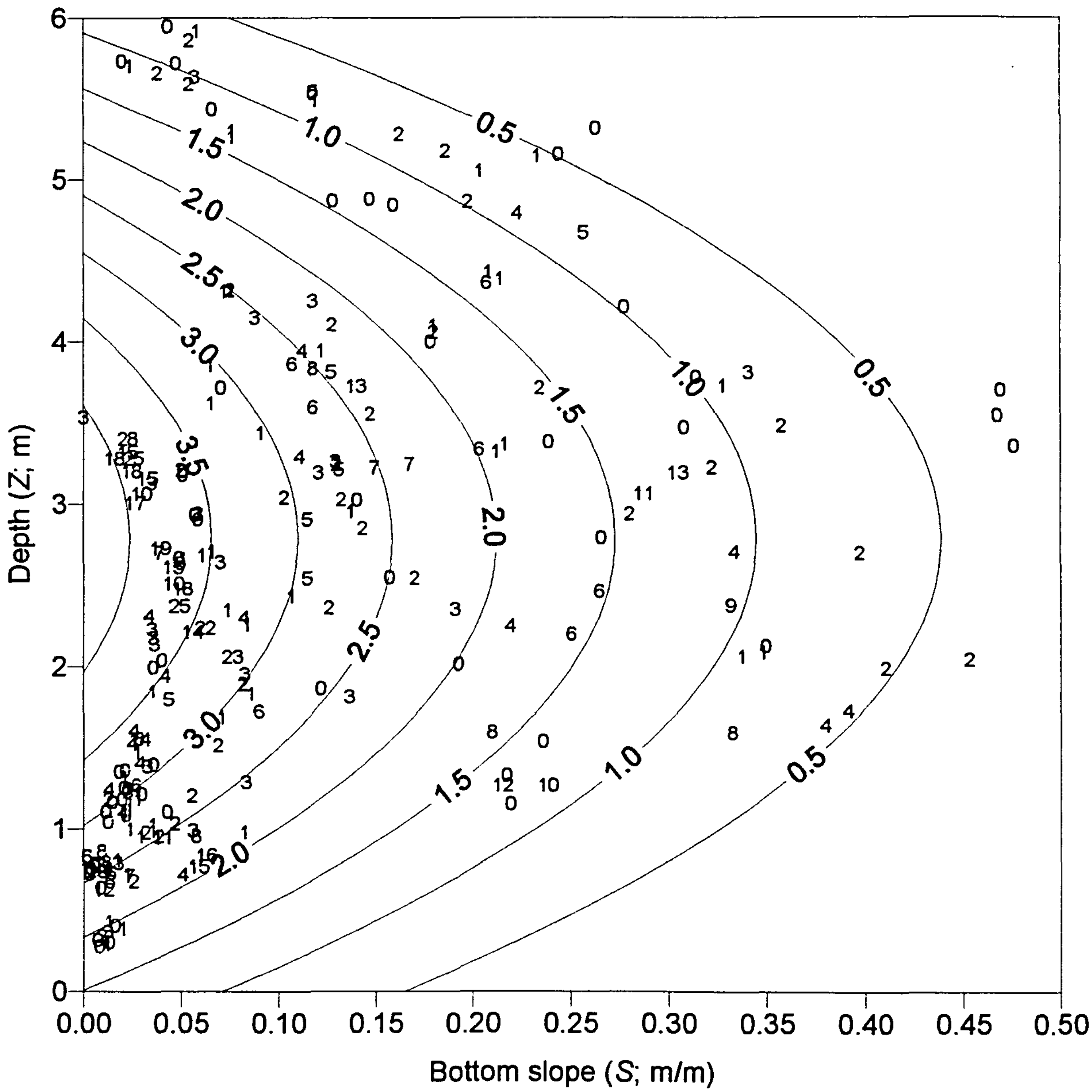
These graphs represent mussel densities predicted from eq. (3) for *Anodonta grandis*, from eq. (4) for *Lampsilis siliquoidea*, and from eq. (5) for *Potamilus alatus*. Contours are predicted mussel abundance in a 25 m^2 quadrat. Pages 75 through 80 are predictions for *A. grandis*. Pages 81 through 86 are predictions for *L. siliquoidea*. Pages 87 through 89 are predictions for *P. alatus*. Posted numbers show actual species density observations in the 239 sampled quadrats at Big Creek Lake to illustrate concordance with predicted trends. On pages 75 and 81, predictions were made assuming average values of *S* (0.063 m/m) and *F* (0.939 km). On pages 76, 82, and 87, predictions were made assuming average values of *S* (0.063 m/m) and *C* (2.09%). Predictions were made assuming average values of *S* (0.063 m/m) and *Z* (2.16 m) on pages 77 and 83. Predictions on pages 78, 84, and 88 were made assuming average values of *F* (0.939) and *C* (2.09%). On pages 79, 85, and 89, predictions were made assuming average values of *Z* (2.16 m) and *C* (2.09%). Lastly, predictions were made assuming average values of *Z* (2.16 m) and *F* (0.939 km) on pages 80 and 86.

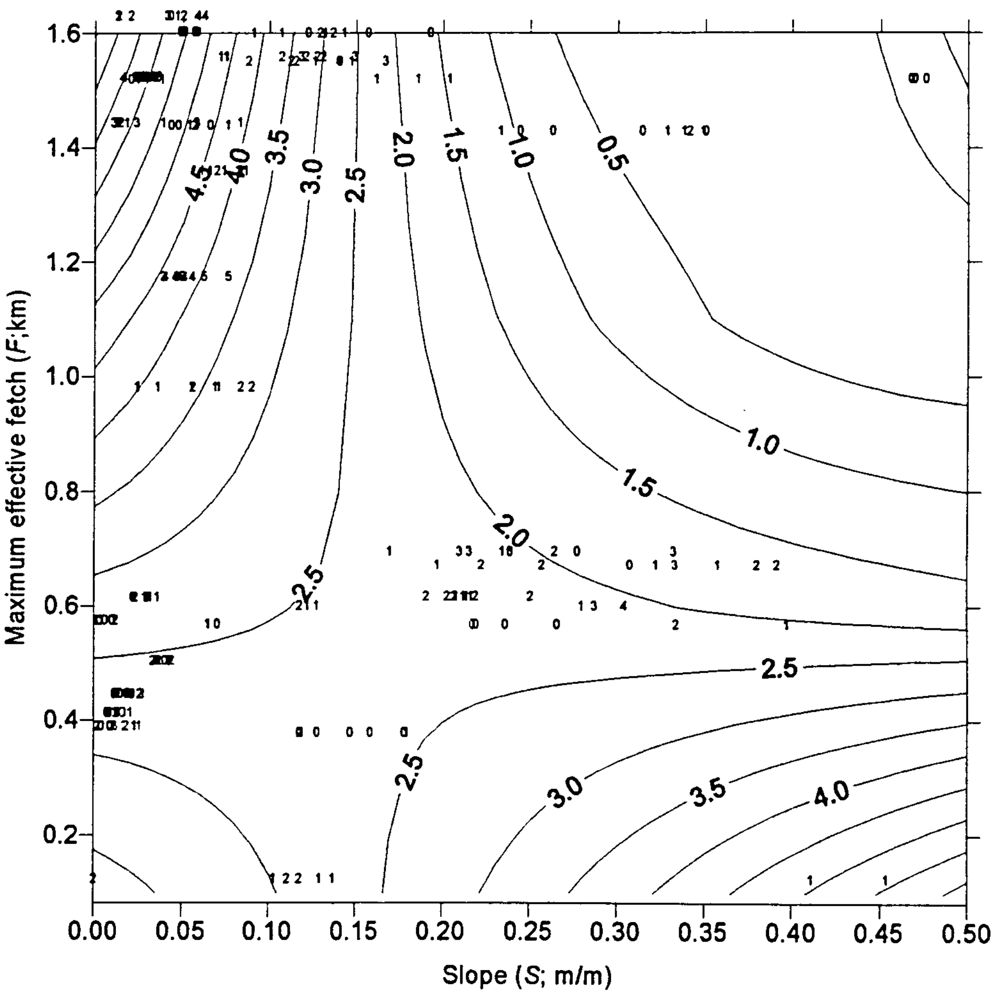

Sediment organic matter content (C; %)
Depth (Z; m)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5



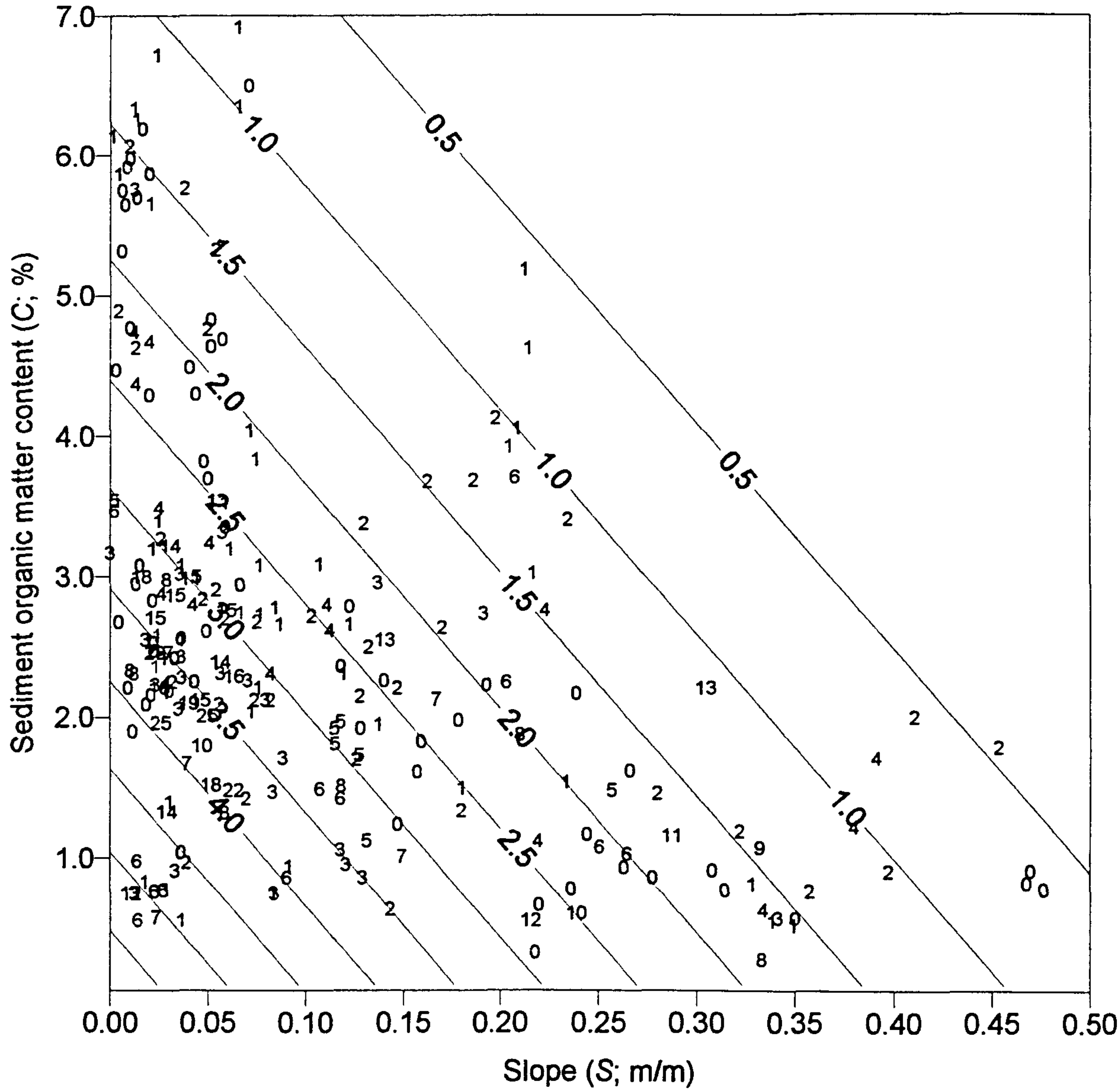
Depth (Z; m)
Maximum effective fetch (F; km)
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

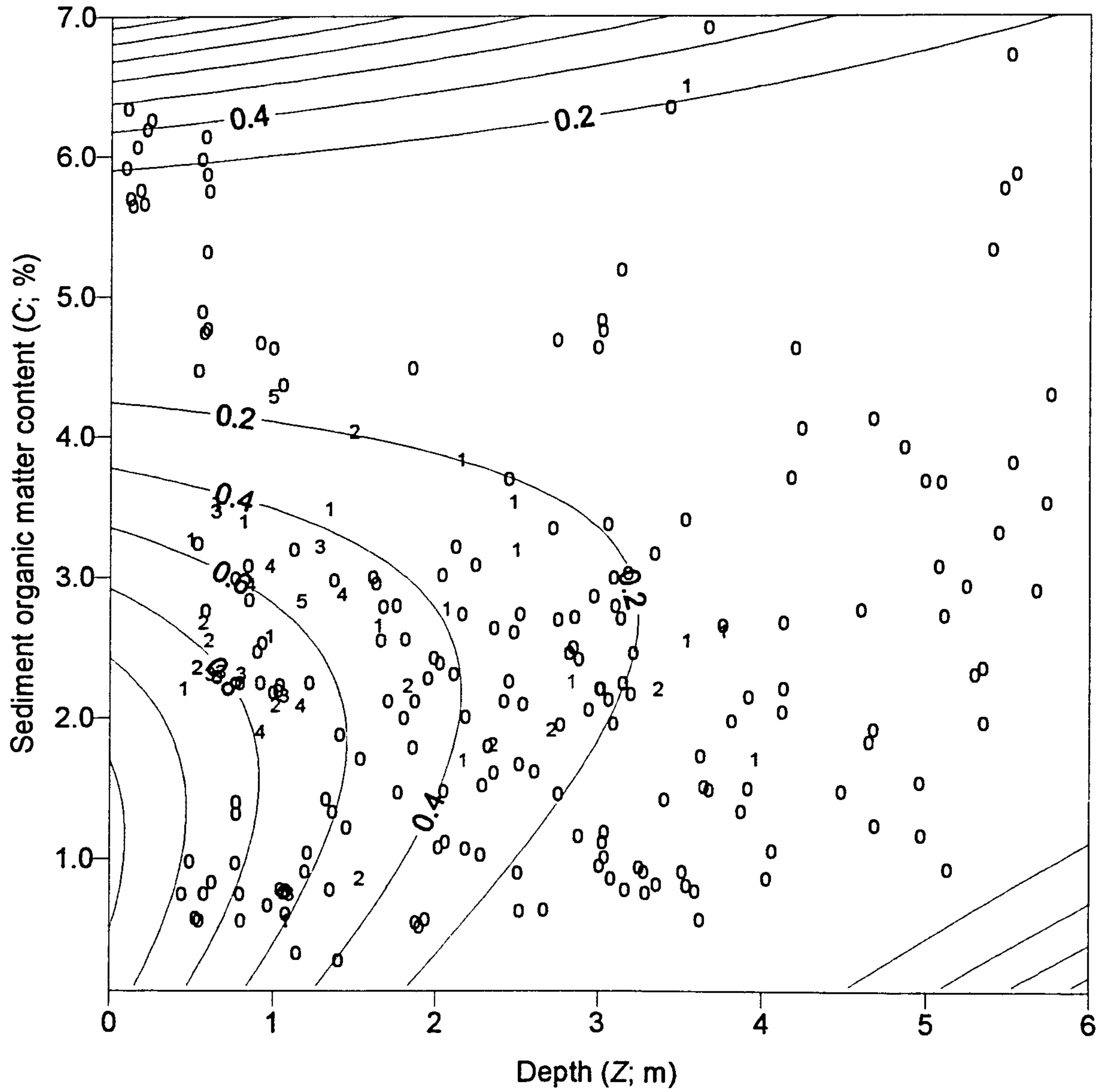

Sediment organic matter content (C;%)
Maximum effective fetch (F;km)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.0
1.5
1.5
2.0
2.0
2.5
2.5
3.0
3.0
3.5
3.5
4.0
4.5
5.0
5.5
6.0

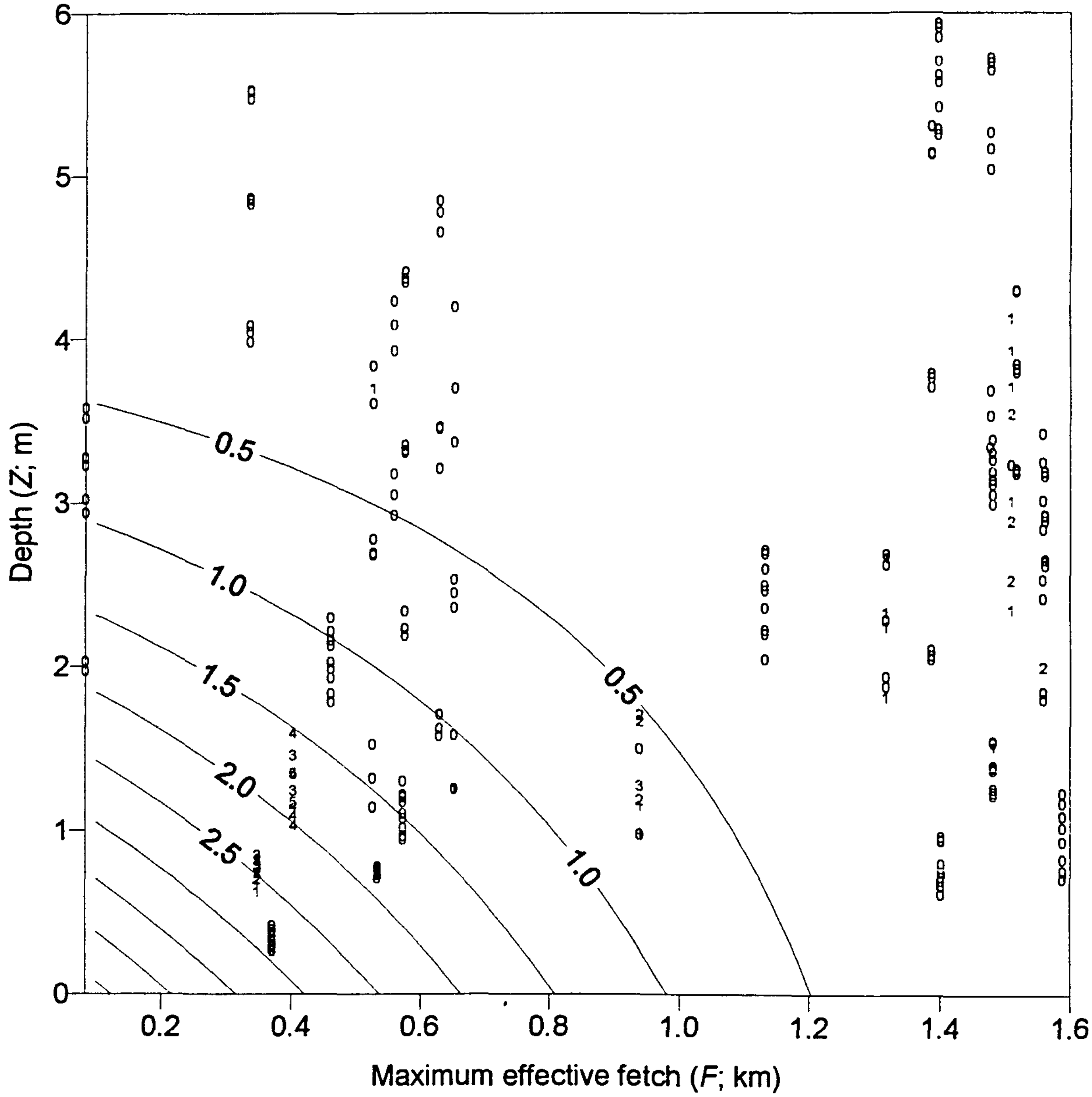

Depth (Z; m)
Bottom slope (S; m/m)
0
1
2
3
4
5
6
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.5
1.0
1.5
2.0
2.5
3.0
3.5



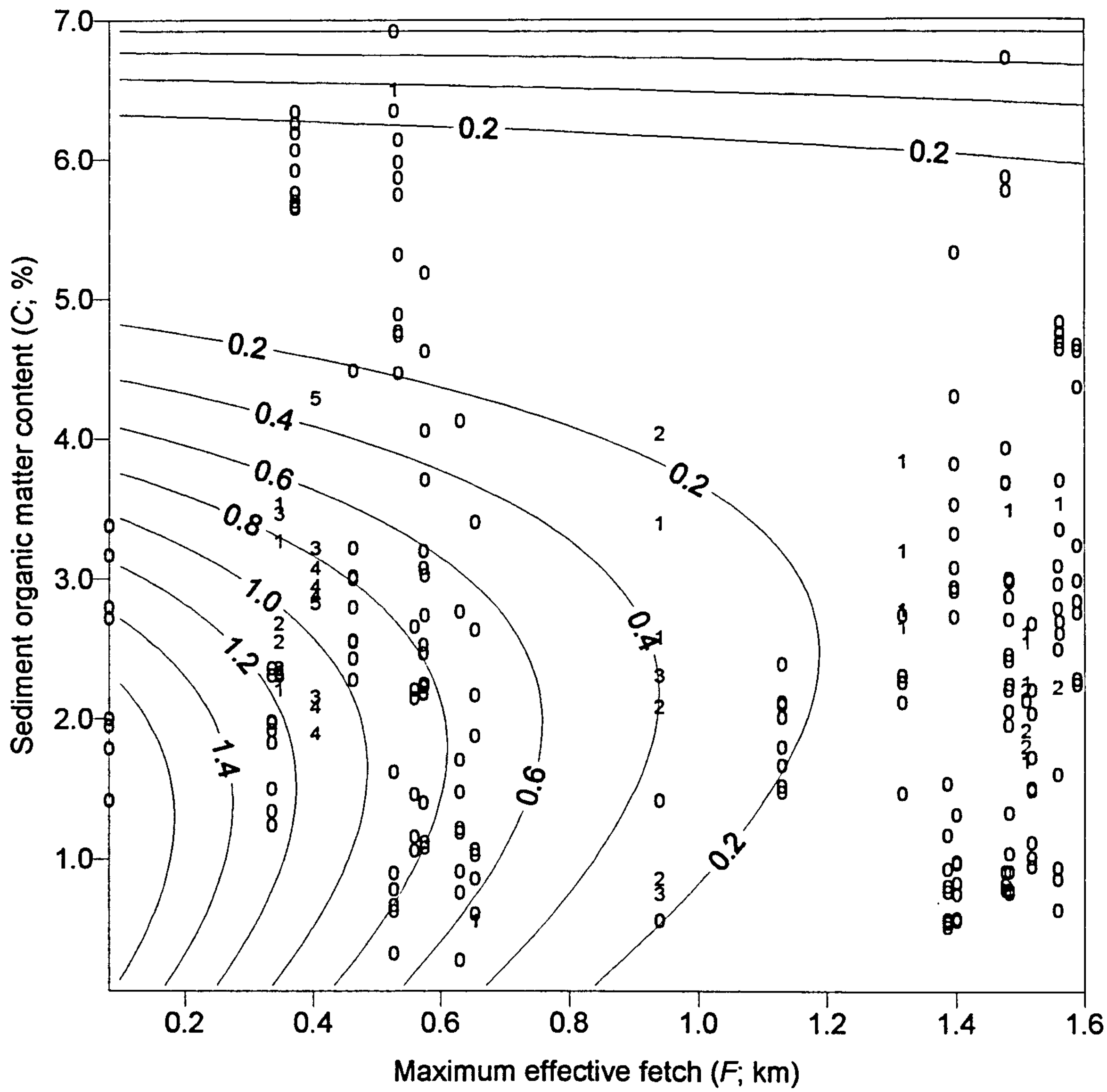
Maximum effective fetch (F;km)
Slope (S; m/m)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1.0
1.5
2.0
2.5
2.5
2.5
2.5
3.0
3.5
4.0


Sediment organic matter content (C; %)
Slope (S; m/m)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

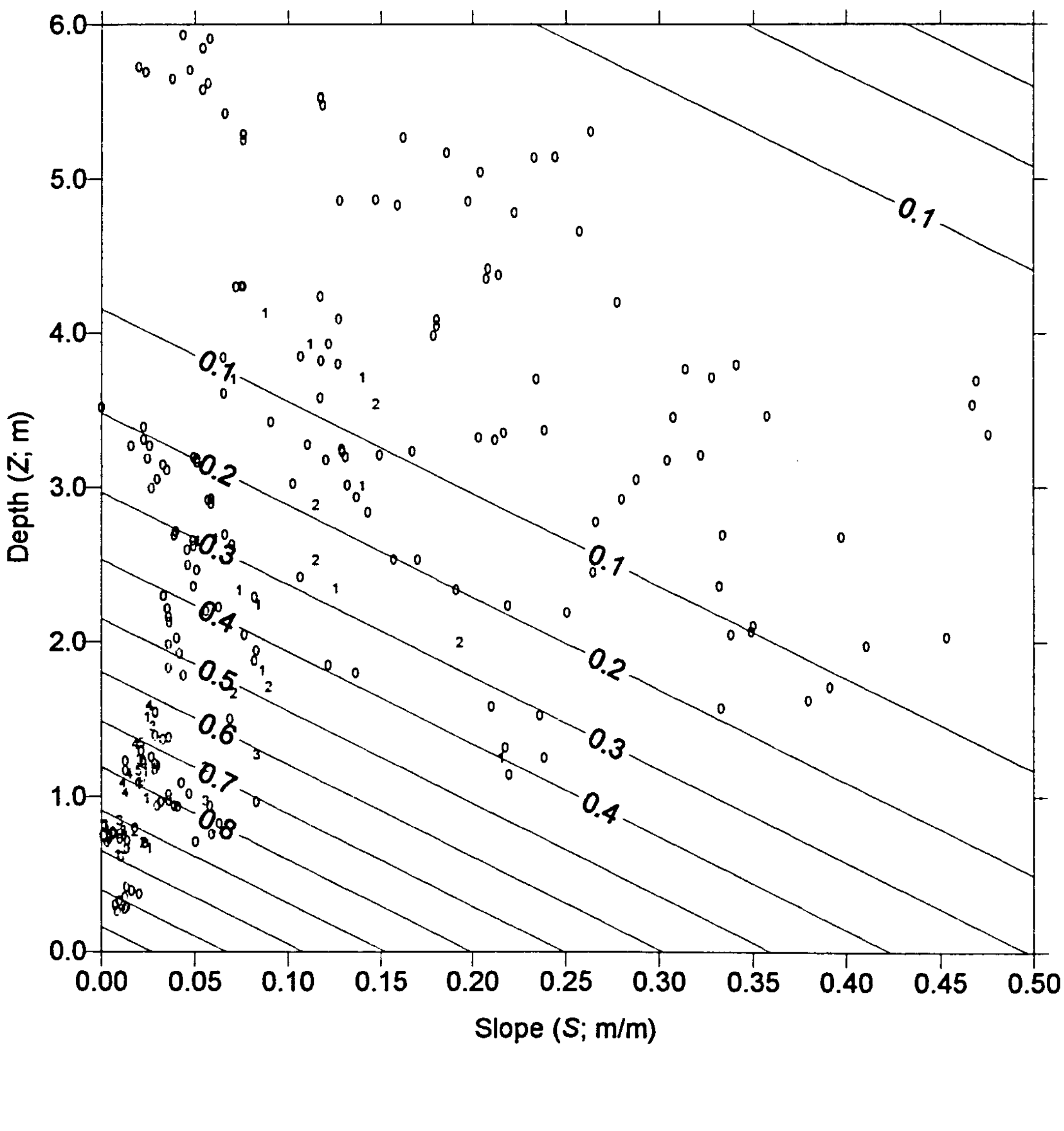

Sediment organic matter content (C; %)
Depth (Z; m)
0.2
0.4
0.6
0.8



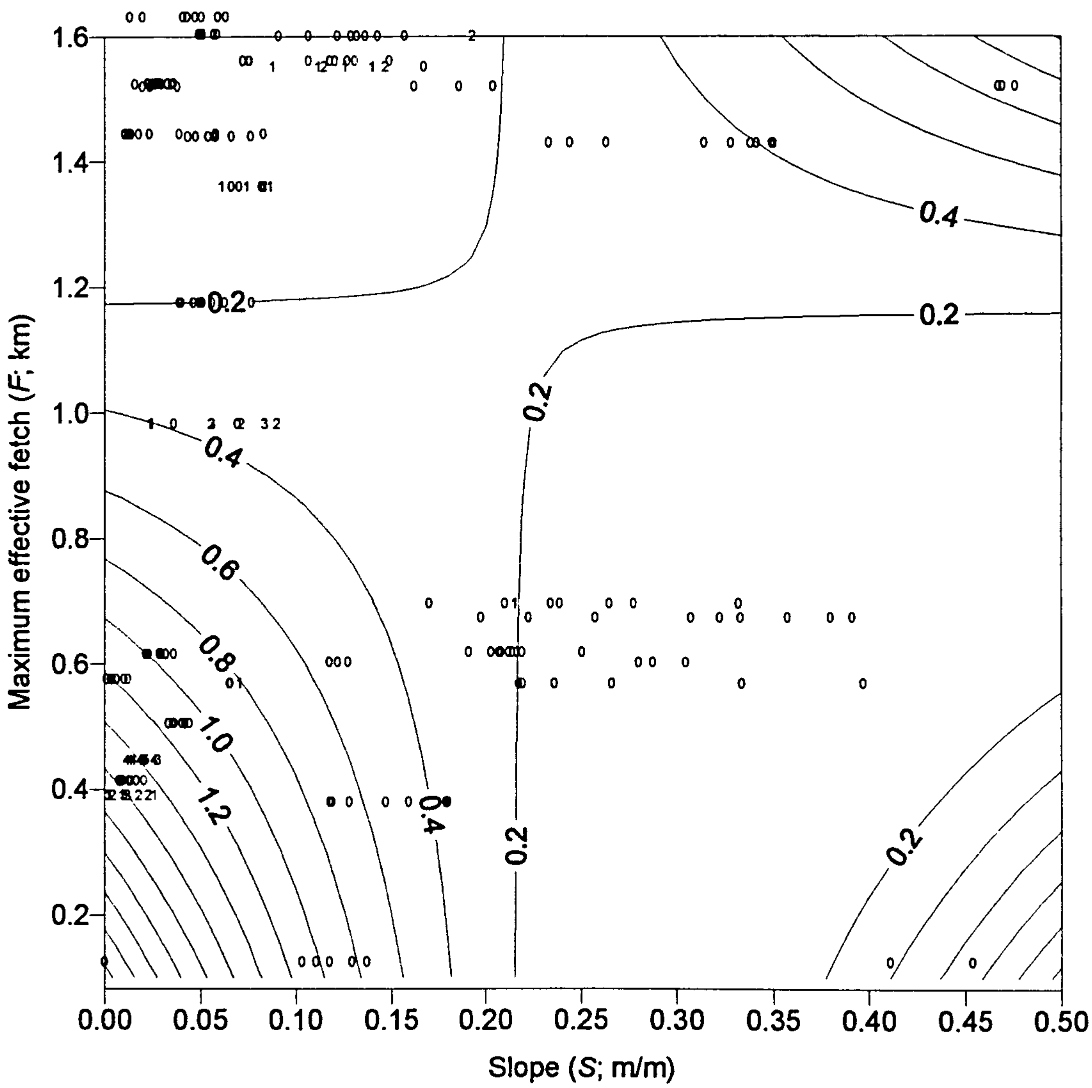
Depth (Z; m)
Maximum effective fetch (F; km)
0
1
2
3
4
5
6
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0.5
1.0
1.5
2.0
2.5
0.5
1.0

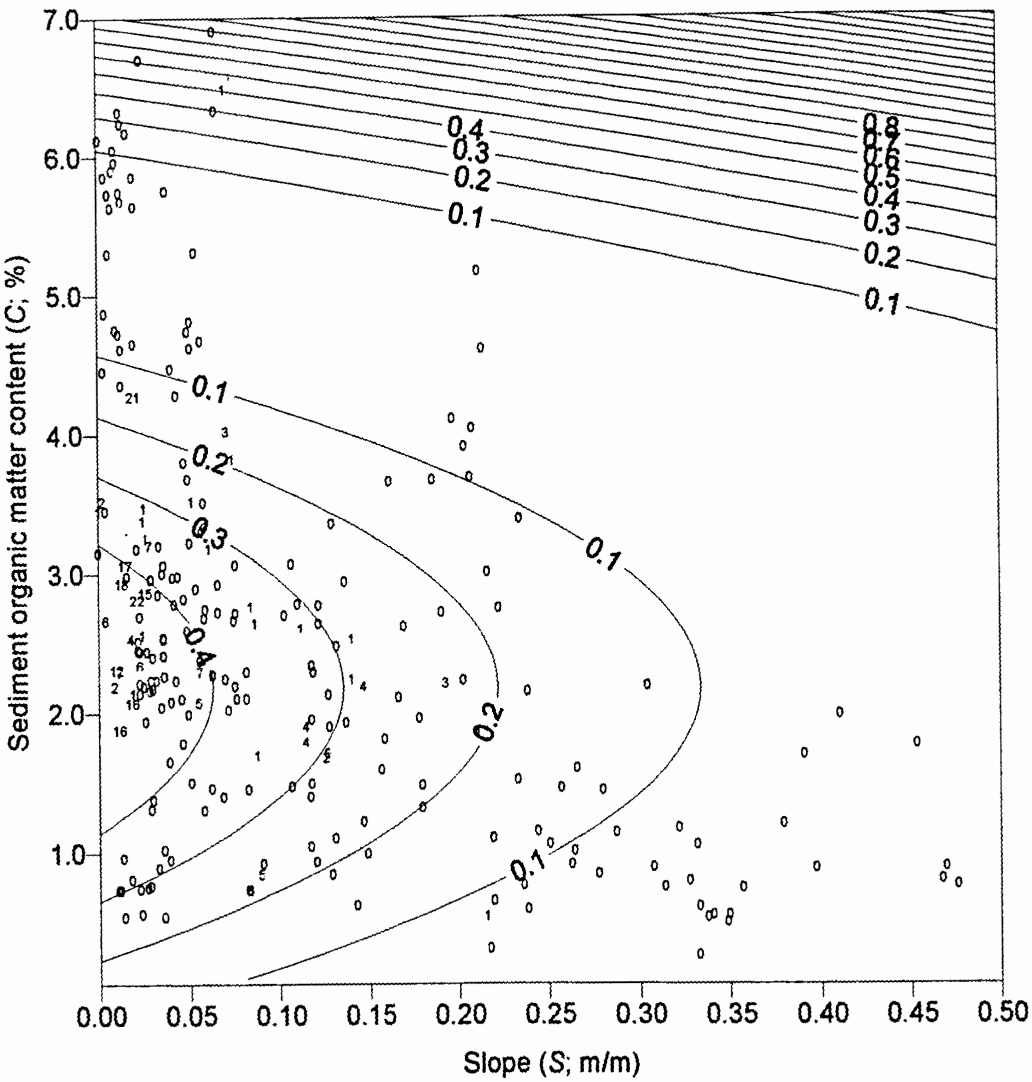


Sediment organic matter content (C; %)
Maximum effective fetch (F; km)
0.2
0.4
0.6
0.8
1.0
1.2
1.4

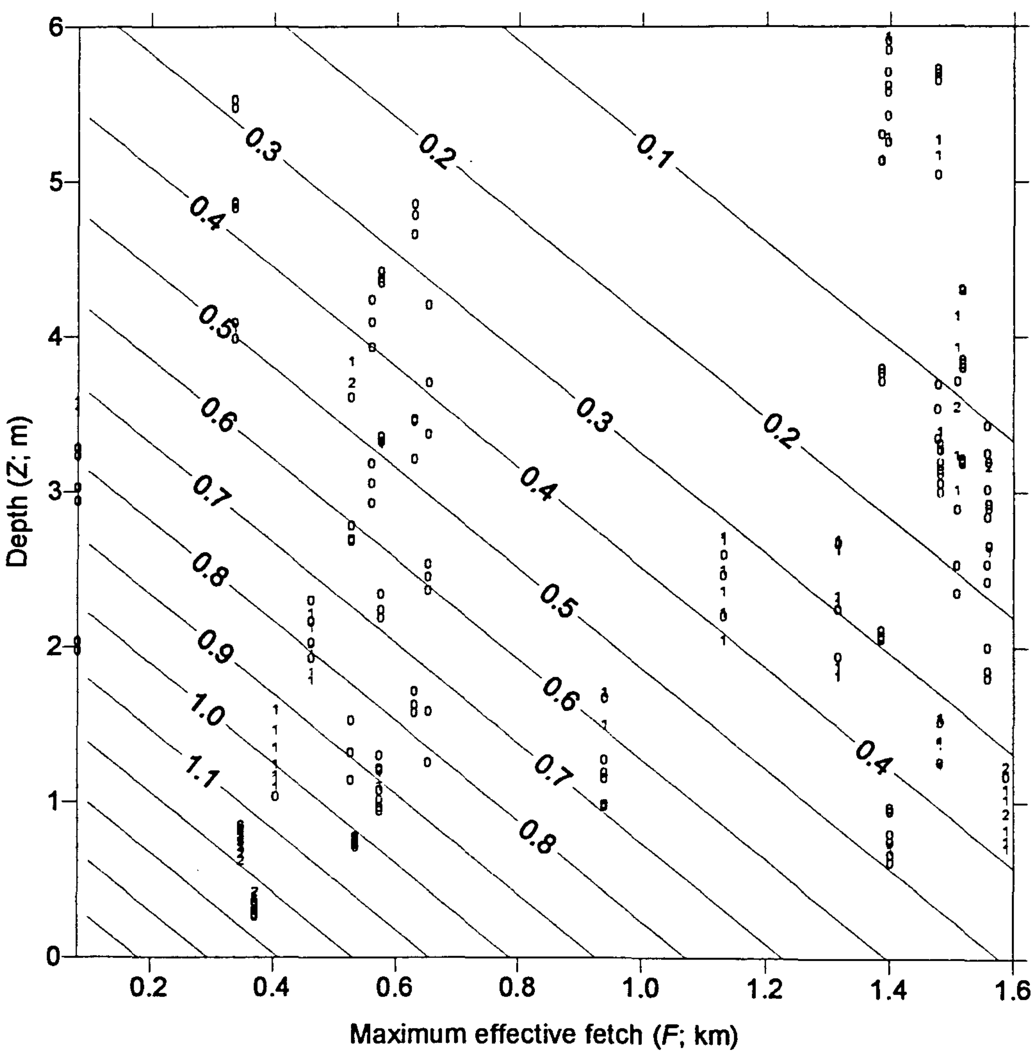


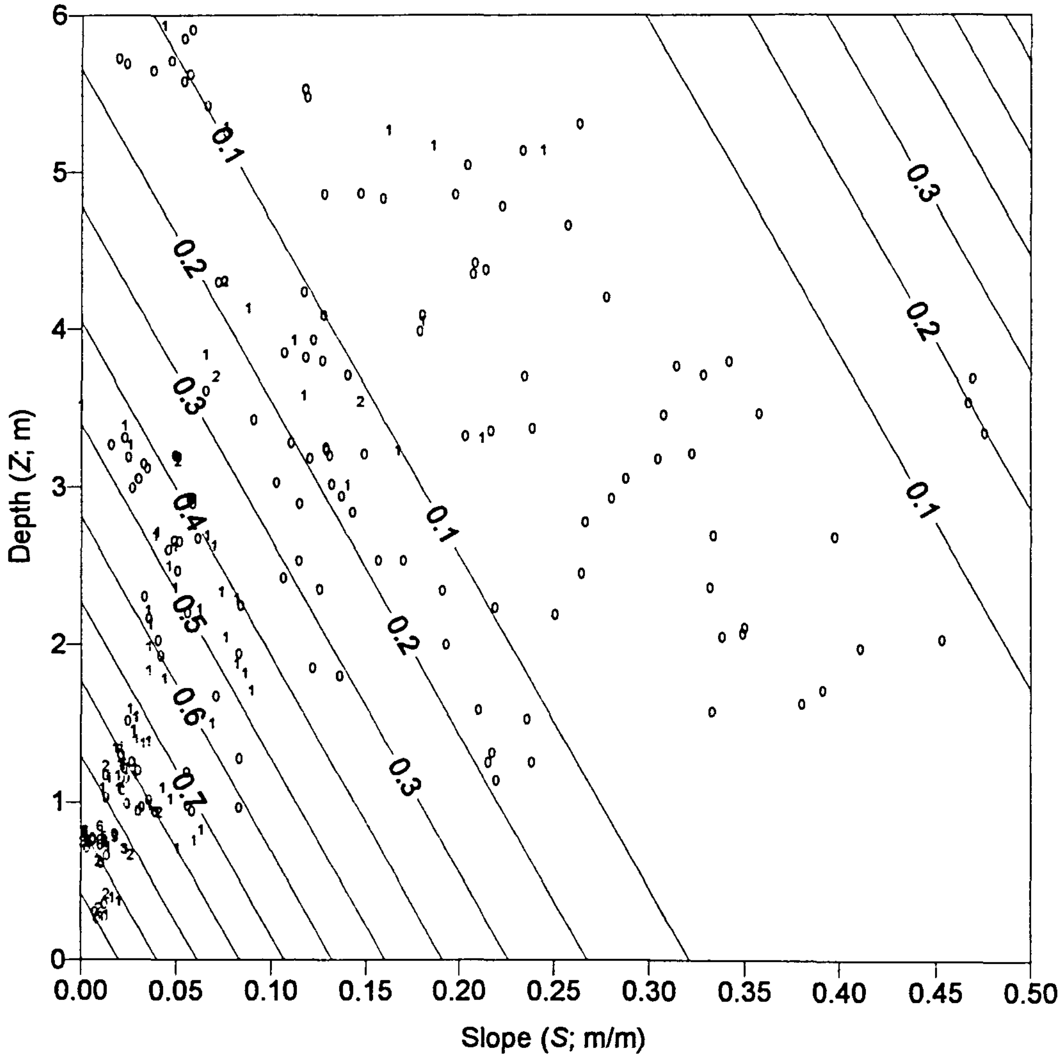
Depth (Z; m)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Slope (S; m/m)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

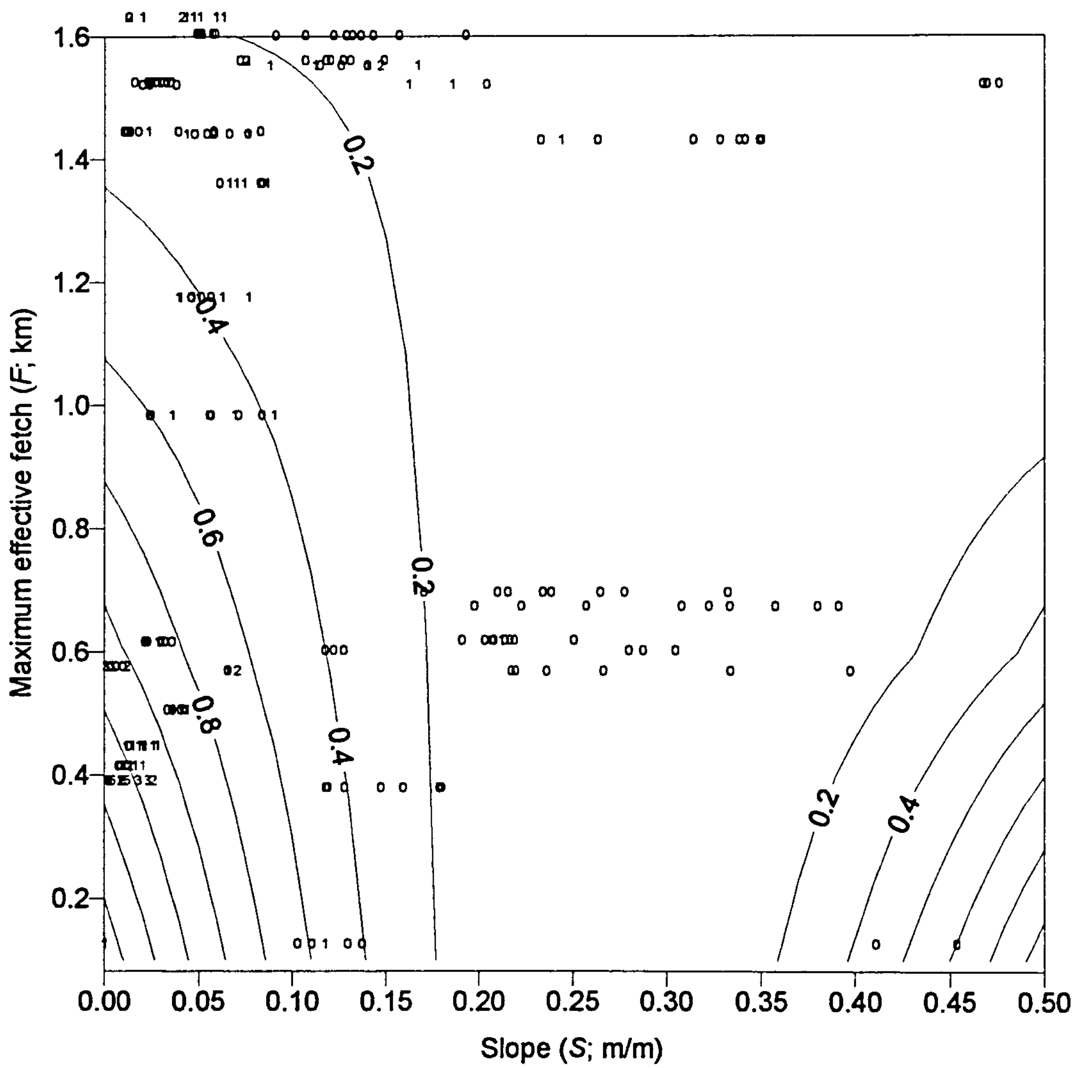

Maximum effective fetch (F; km)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Slope (S; m/m)
0.2
0.4
0.6
0.8
1.0
1.2



Sediment organic matter content (C; %)
Slope (S; m/m)
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.1
0.2
0.3
0.4
0.8
0.7
0.6
0.5


Depth (Z; m)
Maximum effective fetch (F; km)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1


Depth (Z; m)
Slope (S; m/m)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0
1
2
3
4
5
6
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.1
0.2
0.3
0.3
0.2
0.1


Maximum effective fetch (F; km)
Slope (S; m/m)
0.2
0.4
0.6
0.8

APPENDIX C. DATA TABLE

This is the data that was collected, analyzed, and presented in this paper. The first two columns of the table indicate the Site and Quadrat from which the data came. *Z* = water depth, *S* = bottom slope, *F* = maximum effective fetch, and *C* = sediment organic matter content. AG = *Anodonta grandis*, PA = *Potamilus alatus*, LS = *Lampsilis siliquoidea*, UT = *Uniomerus tetralasmus*, and CF = *Corbicula fluminea*.

Site	Quadrat	*Z* (m)	*S* (m/m)	*F* (km)	*C* (%)	AG	PA	LS	UT	CF
1	1	0.091	0.009	0.371	5.7	0	0	0	0	0
1	2	0.101	0.013	0.371	6.12	1	0	0	0	0
1	3	0.116	0.014	0.371	5.48	0	2	0	0	0
1	4	0.131	0.008	0.371	5.43	0	0	0	0	0
1	5	0.156	0.01	0.371	5.85	2	3	0	0	0
1	6	0.181	0.013	0.371	5.54	3	0	0	0	0
1	7	0.201	0.021	0.371	5.44	1	1	0	0	0
1	8	0.221	0.017	0.371	5.97	0	2	0	0	0
1	9	0.246	0.014	0.371	6.04	1	3	0	0	0
2	1	2.479	0.052	1.561	3.32	1	0	1	0	0
2	2	2.483	0.049	1.561	2.39	0	0	0	0	0
2	3	2.449	0.05	1.561	3.48	0	2	0	0	0
2	4	2.754	0.059	1.561	2.48	2	0	0	0	0
2	5	2.748	0.057	1.561	4.47	0	0	0	0	0
2	6	2.719	0.059	1.561	3.13	0	0	0	0	0
2	7	3.024	0.05	1.561	4.54	2	0	0	0	0
2	8	3.018	0.051	1.561	4.61	0	0	0	0	0
2	9	2.993	0.051	1.561	4.42	0	3	0	0	0
3	1	1.353	0.236	0.526	0.56	0	0	0	0	0
3	2	1.144	0.218	0.526	0.11	0	0	0	0	0

Site	Quadrat	Z (m)	S (m/m)	F (km)	C (%)	AG	PA	LS	UT	CF
3	3	0.969	0.22	0.526	0.45	0	0	0	0	0
3	4	2.608	0.266	0.526	1.4	0	0	0	0	0
3	5	2.521	0.334	0.526	0.41	4	0	0	0	0
3	6	2.511	0.398	0.526	0.68	2	0	0	0	0
3	7	3.436	0.066	0.526	6.13	1	0	0	0	0
3	8	3.531	0.071	0.526	6.28	0	4	1	0	0
3	9	3.668	0.065	0.526	6.7	1	1	0	0	0
4	1	0.538	0.003	0.533	4.25	0	0	0	0	0
4	2	0.555	0.01	0.533	5.76	0	0	0	0	0
4	3	0.57	0.012	0.533	4.52	4	4	0	0	0
4	4	0.555	0.004	0.533	4.67	2	2	0	0	0
4	5	0.578	0.001	0.533	5.92	1	7	0	0	0
4	6	0.603	0.006	0.533	5.53	0	0	0	0	0
4	7	0.59	0.01	0.533	4.55	0	0	0	0	0
4	8	0.585	0.004	0.533	5.65	1	7	0	0	0
4	9	0.585	0.006	0.533	5.1	0	0	0	0	0
5	1	2.175	0.126	1.509	1.48	2	0	2	4	0
5	2	2.358	0.115	1.509	1.59	5	0	4	2	0
5	3	2.718	0.115	1.509	1.7	5	0	4	0	0
5	4	2.84	0.14	1.509	2.04	0	1	1	1	0

Site	Quadrat	Z (m)	S (m/m)	F (km)	C (%)	AG	PA	LS	UT	CF
5	5	3.063	0.167	1.509	1.91	7	2	0	1	0
5	6	3.373	0.147	1.509	1.99	2	3	4	0	0
5	7	3.54	0.14	1.509	2.33	13	0	1	0	0
5	8	3.76	0.112	1.509	2.4	4	1	1	0	0
5	9	3.96	0.088	1.509	1.49	3	1	1	0	0
6	1	0.98	0.024	0.94	2.36	1	0	1	0	0
6	2	0.816	0.025	0.94	3.18	1	0	1	0	0
6	3	0.803	0.036	0.94	0.34	1	1	0	0	0
6	4	0.803	0.056	0.94	2.09	3	0	7	0	0
6	5	1.016	0.056	0.94	1.87	2	0	5	0	0
6	6	1.101	0.084	0.94	0.53	3	0	8	0	0
6	7	1.498	0.071	0.94	3.82	1	0	3	0	0
6	8	1.328	0.069	0.94	1.2	2	2	0	0	0
6	9	1.535	0.09	0.94	0.64	6	1	5	0	0
7	1	0.675	0.01	0.347	2.11	8	41	12	0	0
7	2	0.605	0.018	0.347	2.33	3	12	4	0	0
7	3	0.495	0.026	0.347	3.05	2	4	1	0	0
7	4	0.645	0.002	0.347	3.25	6	32	10	0	0
7	5	0.57	0.004	0.347	2.46	0	21	6	0	0
7	6	0.453	0.009	0.347	1.99	0	3	2	0	0

Site	Quadrat	*Z* (m)	*S* (m/m)	*F* (km)	*C* (%)	AG	PA	LS	UT	CF
7	7	0.645	0.002	0.347	3.32	5	16	2	0	0
7	8	0.61	0.012	0.347	2.09	8	24	7	0	0
7	9	0.533	0.023	0.347	2.14	1	9	6	0	0
8	1	0.858	0.013	0.404	2.73	0	0	18	0	0
8	2	0.978	0.015	0.404	2.86	0	1	17	1	0
8	3	1.169	0.019	0.404	1.87	0	2	16	0	0
8	4	0.919	0.012	0.404	1.68	0	1	16	0	0
8	5	1.068	0.021	0.404	1.94	0	1	10	0	0
8	6	1.285	0.028	0.404	3	1	1	7	0	0
8	7	0.998	0.02	0.404	4.07	0	1	21	0	0
8	8	1.174	0.022	0.404	2.61	0	1	22	0	0
8	9	1.42	0.026	0.404	2.66	4	1	15	0	0
9	1	0.534	0.051	1.588	3.02	4	1	0	0	0
9	2	0.583	0.059	1.588	2.54	15	2	0	0	0
9	3	0.653	0.063	1.588	2.07	16	2	0	0	0
9	4	0.763	0.041	1.588	2.77	11	4	0	0	0
9	5	0.848	0.047	1.588	2.62	2	1	0	1	0
9	6	0.918	0.043	1.588	2.03	0	1	0	0	0
9	7	0.915	0.02	1.588	4.45	4	1	0	0	0
9	8	0.998	0.013	1.588	4.41	2	0	0	0	0

Site	Quadrat	Z (m)	S (m/m)	F (km)	C (%)	AG	PA	LS	UT	CF
9	9	1.058	0.013	1.588	4.15	4	3	0	0	0
10	1	1.61	0.044	0.462	2.78	5	1	0	0	0
10	2	1.66	0.036	0.462	2.33	1	1	0	0	0
10	3	1.755	0.042	0.462	2.58	4	0	0	0	0
10	4	1.81	0.036	0.462	2.34	0	1	0	0	0
10	5	1.851	0.041	0.462	4.27	0	0	0	0	0
10	6	1.951	0.037	0.462	2.06	3	2	0	0	0
10	7	1.99	0.036	0.462	2.21	3	0	0	0	0
10	8	2.041	0.036	0.462	2.8	3	1	0	0	0
10	9	2.126	0.034	0.462	3	4	0	0	0	0
11	1	3.17	0.476	1.477	0.56	0	0	0	0	0
11	2	3.361	0.468	1.477	0.6	0	0	0	0	0
11	3	3.516	0.47	1.477	0.69	0	0	0	0	0
11	4	4.87	0.204	1.477	3.71	1	0	0	0	0
11	5	4.995	0.186	1.477	3.47	2	1	0	0	0
11	6	5.095	0.162	1.477	3.46	2	1	0	0	0
11	7	5.475	0.038	1.477	5.55	2	0	0	0	0
11	8	5.52	0.024	1.477	6.5	1	0	0	0	0
11	9	5.55	0.02	1.477	5.65	0	0	0	0	0
12	1	0.84	0.036	0.573	2.86	1	0	0	0	0

Site	Quadrat	Z (m)	S (m/m)	F (km)	C (%)	AG	PA	LS	UT	CF
12	2	0.795	0.032	0.573	2.03	2	0	0	0	0
12	3	0.77	0.03	0.573	1.18	1	0	0	0	0
12	4	1.001	0.029	0.573	1.96	1	1	0	0	0
12	5	0.93	0.022	0.573	2.31	0	1	0	0	0
12	6	0.9	0.022	0.573	2.25	0	0	0	0	0
12	7	1.126	0.022	0.573	2.98	1	0	0	0	0
12	8	1.043	0.023	0.573	2.01	3	0	0	1	0
12	9	1.03	0.03	0.573	1.97	0	0	0	0	0
13	1	1.768	0.083	1.317	1.25	3	0	0	0	1
13	2	1.705	0.082	1.317	1.9	2	2	0	0	0
13	3	1.644	0.087	1.317	2.44	1	2	1	0	0
13	4	2.16	0.074	1.317	3.62	1	1	1	0	0
13	5	2.115	0.082	1.317	2.09	4	1	0	0	0
13	6	2.07	0.084	1.317	2.56	1	0	1	0	0
13	7	2.498	0.061	1.317	2.98	1	0	1	0	0
13	8	2.519	0.066	1.317	2.52	1	1	0	0	0
13	9	2.455	0.07	1.317	2.04	3	2	0	0	0
14	1	1.044	0.029	1.482	0.56	1	1	0	0	0
14	2	1.064	0.023	1.482	0.54	6	2	0	1	0
14	3	1.083	0.027	1.482	0.55	6	0	0	0	0

Site	Quadrat	*Z* (m)	*S* (m/m)	*F* (km)	*C* (%)	AG	PA	LS	UT	CF
14	4	1.198	0.033	1.482	0.69	3	2	0	0	0
14	5	1.21	0.036	1.482	0.82	0	1	0	0	0
14	6	1.223	0.029	1.482	2.03	4	2	0	0	0
14	7	1.343	0.025	1.482	3.27	4	0	1	7	0
14	8	1.373	0.029	1.482	2.76	8	1	0	6	1
14	9	1.368	0.029	1.482	1.11	14	1	0	3	0
15	1	3.038	0.149	1.517	0.79	7	0	0	0	1
15	2	3.028	0.131	1.517	0.9	5	0	0	0	0
15	3	3.009	0.121	1.517	0.73	3	0	0	0	0
15	4	3.678	0.107	1.517	1.27	6	0	0	0	0
15	5	3.65	0.118	1.517	1.29	8	0	0	0	0
15	6	3.628	0.127	1.517	1.51	5	0	0	0	0
15	7	4.125	0.072	1.517	1.82	1	0	0	0	0
15	8	4.133	0.076	1.517	1.99	1	3	0	0	0
15	9	4.133	0.075	1.517	2.46	2	0	0	0	0
16	1	2.943	0.035	1.481	1.84	3	0	0	0	0
16	2	2.88	0.03	1.481	2.2	10	0	0	1	0
16	3	2.823	0.027	1.481	2.24	17	0	0	0	0
16	4	3.095	0.026	1.481	1.74	25	2	0	0	0
16	5	3.018	0.025	1.481	1.99	18	0	0	0	0

Site	Quadrat	Z (m)	S (m/m)	F (km)	C (%)	AG	PA	LS	UT	CF
16	6	2.973	0.033	1.481	2.65	15	0	0	0	0
16	7	3.218	0.023	1.481	2.24	28	1	0	1	0
16	8	3.138	0.023	1.481	2.49	15	0	0	0	0
16	9	3.095	0.016	1.481	2.78	18	0	0	0	0
17	1	2.025	0.056	1.132	2.17	14	0	0	0	0
17	2	2.051	0.063	1.132	1.26	22	1	0	0	2
17	3	1.871	0.077	1.132	1.9	23	2	0	4	0
17	4	2.293	0.051	1.132	1.3	18	0	0	0	0
17	5	2.324	0.047	1.132	1.58	10	1	0	1	0
17	6	2.186	0.05	1.132	1.79	25	2	0	0	0
17	7	2.518	0.039	1.132	1.45	7	2	0	3	0
17	8	2.54	0.04	1.132	1.88	19	1	0	1	0
17	9	2.425	0.046	1.132	1.9	15	0	0	0	0
18	1	0.441	0.011	1.401	0.53	12	0	0	0	0
18	2	0.491	0.014	1.401	0.76	6	0	0	0	0
18	3	0.545	0.014	1.401	0.34	6	1	0	0	0
18	4	0.526	0.024	1.401	0.36	7	1	0	0	0
18	5	0.575	0.012	1.401	0.53	3	0	0	0	0
18	6	0.625	0.018	1.401	0.61	1	0	0	0	0
18	7	0.793	0.083	1.401	0.53	1	0	0	0	1

Site	Quadrat	*Z* (m)	*S* (m/m)	*F* (km)	*C* (%)	AG	PA	LS	UT	CF
18	8	0.77	0.058	1.401	1.1	8	0	0	0	0
18	9	0.768	0.039	1.401	0.75	2	0	0	0	0
19	1	5.08	0.076	1.397	2.86	1	0	0	0	0
19	2	5.115	0.076	1.397	2.51	1	1	0	0	0
19	3	5.25	0.066	1.397	2.72	0	0	0	0	0
19	4	5.405	0.054	1.397	5.11	2	0	0	0	0
19	5	5.448	0.057	1.397	3.1	3	0	0	0	0
19	6	5.534	0.048	1.397	3.6	0	0	0	0	0
19	7	5.675	0.054	1.397	2.69	2	0	0	0	0
19	8	5.735	0.058	1.397	3.31	1	0	0	0	0
19	9	5.761	0.044	1.397	4.08	0	1	0	0	0
20	1	1.828	0.193	1.558	2.01	0	0	3	0	0
20	2	1.629	0.137	1.558	2.74	3	0	0	0	0
20	3	1.675	0.122	1.558	2.57	0	0	0	0	0
20	4	2.668	0.143	1.558	0.42	2	0	0	0	0
20	5	2.363	0.157	1.558	1.39	0	0	0	0	0
20	6	2.248	0.107	1.558	2.87	1	0	0	0	0
20	7	3.253	0.091	1.558	0.72	1	0	0	0	0
20	8	3.078	0.129	1.558	0.64	3	0	0	0	0
20	9	2.845	0.132	1.558	2.28	2	0	0	0	0

Site	Quadrat	*Z* (m)	*S* (m/m)	*F* (km)	*C* (%)	AG	PA	LS	UT	CF
21	1	1.935	0.35	1.386	0.35	0	0	0	0	0
21	2	1.875	0.338	1.386	0.33	1	0	0	0	0
21	3	1.898	0.349	1.386	0.3	1	0	0	0	0
21	4	3.595	0.314	1.386	0.55	0	0	0	0	0
21	5	3.54	0.328	1.386	0.59	1	0	0	0	0
21	6	3.623	0.341	1.386	0.35	3	0	0	0	0
21	7	4.963	0.233	1.386	1.32	1	0	0	0	0
21	8	4.97	0.244	1.386	0.95	0	1	0	0	0
21	9	5.133	0.263	1.386	0.71	0	0	0	0	0
22	1	1.45	0.38	0.63	1	4	0	0	0	0
22	2	1.536	0.392	0.63	1.49	4	0	0	0	0
22	3	1.403	0.333	0.63	0.06	8	0	0	0	0
22	4	3.294	0.358	0.63	0.54	2	0	0	0	0
22	5	3.284	0.308	0.63	0.69	0	0	0	0	0
22	6	3.04	0.322	0.63	0.97	2	0	0	0	0
22	7	4.681	0.198	0.63	3.91	2	0	0	0	0
22	8	4.609	0.223	0.63	2.55	4	0	0	0	0
22	9	4.488	0.257	0.63	1.26	5	0	0	0	0
23	1	2.016	0.251	0.575	0.86	6	0	0	0	0
23	2	2.063	0.219	0.575	0.9	4	0	0	0	0

Site	Quadrat	Z (m)	S (m/m)	F (km)	C (%)	AG	PA	LS	UT	CF
23	3	2.168	0.191	0.575	2.52	3	0	0	0	0
23	4	3.184	0.217	0.575	2.81	1	0	0	0	0
23	5	3.14	0.212	0.575	4.97	1	1	0	0	0
23	6	3.153	0.203	0.575	2.03	6	0	0	0	0
23	7	4.245	0.208	0.575	3.84	1	0	0	0	0
23	8	4.205	0.214	0.575	4.41	1	0	0	0	0
23	9	4.178	0.207	0.575	3.49	6	0	0	0	0
24	1	3.814	0.179	0.336	1.76	0	0	0	0	0
24	2	3.875	0.18	0.336	1.12	2	1	0	0	0
24	3	3.915	0.18	0.336	1.28	1	0	0	0	0
24	4	4.658	0.159	0.336	1.61	0	0	0	0	0
24	5	4.693	0.147	0.336	1.02	0	0	0	0	0
24	6	4.685	0.128	0.336	1.7	0	0	0	0	0
24	7	5.35	0.118	0.336	2.14	0	0	0	0	0
24	8	5.355	0.118	0.336	1.75	5	0	0	0	0
24	9	5.303	0.119	0.336	2.09	1	0	0	0	0
25	1	1.08	0.239	0.653	0.39	10	0	0	0	0
25	2	1.08	0.216	0.653	0.34	12	0	1	0	0
25	3	1.41	0.21	0.653	1.66	8	0	0	0	0
25	4	2.19	0.332	0.653	0.85	9	0	0	0	0

Site	Quadrat	Z (m)	S (m/m)	F (km)	C (%)	AG	PA	LS	UT	CF
25	5	2.28	0.265	0.653	0.81	6	0	0	0	0
25	6	2.36	0.17	0.653	2.42	2	0	0	0	0
25	7	4.03	0.278	0.653	0.64	0	0	0	0	0
25	8	3.53	0.234	0.653	3.19	2	0	0	0	0
25	9	3.2	0.239	0.653	1.95	0	0	0	0	0
26	1	1.859	0.454	0.082	1.57	2	0	0	0	0
26	2	1.803	0.411	0.082	1.78	2	0	0	0	0
26	4	3.348	0	0.082	2.95	3	1	0	0	0
26	5	3.106	0.111	0.082	2.58	4	0	0	0	0
26	6	2.853	0.103	0.082	2.5	2	0	0	0	0
26	7	3.409	0.118	0.082	1.2	6	2	0	0	0
26	8	3.059	0.13	0.082	3.16	2	0	0	0	0
26	9	2.768	0.137	0.082	1.73	1	0	0	0	0
27	4	2.755	0.28	0.559	1.24	2	0	0	0	0
27	5	2.881	0.288	0.559	0.94	11	0	0	0	0
27	6	3.009	0.305	0.559	1.99	13	0	0	0	0
27	7	3.76	0.122	0.559	2.44	1	0	0	0	0
27	8	3.919	0.128	0.559	1.93	2	0	0	0	0
27	9	4.064	0.118	0.559	0.84	3	0	0	0	0

APPENDIX D. UNUSED DATA TABLE

This table contains data that was collected at the time of field work but not used in analysis. The first two columns indicate the Site and Quadrat from which each row of data were collected. AG# = actual *Anodonta grandis* abundance, PA# = actual *Potamilus alatus* abundance, LS# = actual *Lampsilis siliquoidea* abundance, UT# = actual *Uniomerus tetralasmus* abundance, and CF# = actual *Corbicula fluminea* abundance. Each "Length" column represents the respective mean shell length of each species in millimeters (mm) from each Quadrat. AGfra = fragments of *A. grandis* identified as long-dead individuals. PAfra = fragments of *P. alatus* identified as long-dead individuals. LSfra = fragments of *L. siliquoidea* identified as long-dead individuals. UTfra = fragments of *U. tetralasmus* identified as long-dead individuals. CFfra = fragments of *C. fluminea* identified as long-dead individuals. Long-dead individuals were not a part of the living population at the time of the draw-down at Big Creek Lake and therefore were not representative of actual mussel abundances.

Site	Quadrat	AG#	Length	PA#	Length	LS#	Length	UT#	Length	CF#	Length	AGfra	PAfra	LSfra	UTfra	CFfra
1	1	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
1	2	1	144.43	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
1	3	0	NA	2	143.99	0	NA	0	NA	0	NA	0	2	0	0	0
1	4	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
1	5	2	153.23	3	112.36	0	NA	0	NA	0	NA	2	3	0	0	0
1	6	3	135.1	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
1	7	1	118	1	85.56	0	NA	0	NA	0	NA	1	1	0	0	0
1	8	0	NA	2	95.55	0	NA	0	NA	0	NA	0	2	0	0	0
1	9	1	194.16	3	115.21	0	NA	0	NA	0	NA	1	3	0	0	0
2	1	1	72.98	0	NA	1	19.79	0	NA	0	NA	1	0	1	0	0
2	2	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
2	3	0	NA	2	48.57	0	NA	0	NA	0	NA	0	2	0	0	0
2	4	2	103.47	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
2	5	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
2	6	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
2	7	2	61.84	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
2	8	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
2	9	0	NA	3	110.63	0	NA	0	NA	0	NA	0	3	0	0	0
3	1	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
3	2	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
3	3	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
3	4	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
3	5	4	30.67	0	NA	0	NA	0	NA	0	NA	5	0	0	0	0
3	6	2	63.8	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
3	7	1	150.79	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
3	8	0	NA	4	109.71	1	105.41	0	NA	0	NA	0	4	1	0	0
3	9	1	134.25	1	142.22	0	NA	0	NA	0	NA	1	1	0	0	0
4	1	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
4	2	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
4	3	4	158.38	4	126.71	0	NA	0	NA	0	NA	6	4	0	0	0
4	4	2	150.23	2	166.07	0	NA	0	NA	0	NA	3	3	0	0	0
4	5	1	156.91	7	146.65	0	NA	0	NA	0	NA	1	7	0	0	0
4	6	0	NA	0	NA	0	NA	0	NA	0	NA	0	2	0	0	0
4	7	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
4	8	1	160.9	7	132.73	0	NA	0	NA	0	NA	1	7	0	0	0

Site	Quadrat	AG#	Length	PA#	Length	LS#	Length	UT#	Length	CF#	Length	AGfra	PAfra	LSfra	UTfra	CFfra
4	9	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
5	1	2	78.53	0	NA	2	101.91	4	22.49	0	NA	2	0	2	4	0
5	2	5	74.46	0	NA	4	111.42	2	62.55	0	NA	8	0	4	2	0
5	3	5	53.06	0	NA	4	113.72	0	NA	0	NA	10	0	4	0	0
5	4	0	NA	1	120.62	1	111.3	1	23.16	0	NA	3	1	1	1	0
5	5	7	66.57	2	96.65	0	NA	1	88.29	0	NA	8	2	0	1	0
5	6	2	100.05	3	110.53	4	107.95	0	NA	0	NA	5	3	4	0	0
5	7	13	69.11	0	NA	1	117.11	0	NA	0	NA	21	0	1	0	0
5	8	4	70.35	1	135.4	1	105.96	0	NA	0	NA	4	1	1	0	0
5	9	3	72.92	1	117.34	1	101.43	0	NA	0	NA	3	1	1	0	0
6	1	1	85.8	0	NA	1	30.14	0	NA	0	NA	1	0	1	0	0
6	2	1	55.46	0	NA	1	110.03	0	NA	0	NA	1	0	1	0	0
6	3	1	112.85	1	106.77	0	NA	0	NA	0	NA	2	1	0	0	0
6	4	3	97.14	0	NA	7	75.89	0	NA	0	NA	3	0	7	0	0
6	5	2	116.94	0	NA	5	43.24	0	NA	0	NA	2	0	5	0	0
6	6	3	102.73	0	NA	8	47	0	NA	0	NA	10	0	8	0	0
6	7	1	75.93	0	NA	3	53.26	0	NA	0	NA	1	0	3	0	0
6	8	2	59.26	2	109.24	0	NA	0	NA	0	NA	2	2	0	0	0
6	9	6	87.1	1	121.34	5	102.47	0	NA	0	NA	9	2	5	0	0
7	1	8	154.47	41	152.48	12	132.66	0	NA	0	NA	8	41	12	0	0
7	2	3	159.28	12	142.44	4	123.76	0	NA	0	NA	3	12	4	0	0
7	3	2	125.34	4	138.77	1	91.36	0	NA	0	NA	2	4	1	0	0
7	4	6	154.17	32	149.48	10	131.63	0	NA	0	NA	6	32	10	0	0
7	5	0	NA	21	154.32	6	126.73	0	NA	0	NA	0	21	6	0	0
7	6	0	NA	3	145.51	2	113.14	0	NA	0	NA	0	3	2	0	0
7	7	5	146.65	16	148.55	2	123.19	0	NA	0	NA	5	16	2	0	0
7	8	8	143.83	24	145.03	7	124.31	0	NA	0	NA	8	24	7	0	0
7	9	1	135.57	9	151.14	6	108.79	0	NA	0	NA	1	9	6	0	0
8	1	0	NA	0	NA	18	118.64	0	NA	0	NA	0	0	18	0	0
8	2	0	NA	1	149.23	17	120.66	1	26.33	0	NA	0	1	17	1	0
8	3	0	NA	2	146.15	16	127.99	0	NA	0	NA	0	2	16	0	0
8	4	0	NA	1	95.23	16	120.69	0	NA	0	NA	0	1	16	0	0
8	5	0	NA	1	124.39	10	123.89	0	NA	0	NA	0	1	10	0	0
8	6	1	108.36	1	156.42	7	123.3	0	NA	0	NA	1	1	7	0	0
8	7	0	NA	1	155.19	21	123.29	0	NA	0	NA	0	1	21	0	0

Site	Quadrat	AG#	Length	PA#	Length	LS#	Length	UT#	Length	CF#	Length	AGfra	PAfra	LSfra	UTfra	CFfra
8	8	0	NA	1	89.89	22	121.65	0	NA	0	NA	0	1	22	0	0
8	9	4	96.94	1	148.48	15	126.8	0	NA	0	NA	4	1	15	0	0
9	1	4	132.73	1	130.89	0	NA	0	NA	0	NA	4	1	0	0	0
9	2	15	116.2	2	144.86	0	NA	0	NA	0	NA	27	2	0	0	0
9	3	16	119.82	2	153.14	0	NA	0	NA	0	NA	25	2	0	0	0
9	4	11	146.63	4	152.21	0	NA	0	NA	0	NA	11	4	0	0	0
9	5	2	173.69	1	51.64	0	NA	1	99.9	0	NA	2	1	0	1	0
9	6	0	NA	1	145.33	0	NA	0	NA	0	NA	0	1	0	0	0
9	7	4	141.77	1	126.22	0	NA	0	NA	0	NA	4	1	0	0	0
9	8	2	115.65	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
9	9	4	149.94	3	80.09	0	NA	0	NA	0	NA	4	3	0	0	0
10	1	5	135.4	1	159.91	0	NA	0	NA	0	NA	5	1	0	0	0
10	2	1	129.46	1	98.54	0	NA	0	NA	0	NA	1	1	0	0	0
10	3	4	135.5	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
10	4	0	NA	1	47.35	0	NA	0	NA	0	NA	0	1	0	0	0
10	5	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
10	6	3	141.69	2	109.96	0	NA	0	NA	0	NA	3	2	0	0	0
10	7	3	140.28	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
10	8	3	139.62	1	167.47	0	NA	0	NA	0	NA	3	1	0	0	0
10	9	4	140.53	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
11	1	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
11	2	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
11	3	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
11	4	1	109.3	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
11	5	2	95.81	1	130.18	0	NA	0	NA	0	NA	2	1	0	0	0
11	6	2	59.55	1	127.63	0	NA	0	NA	0	NA	2	1	0	0	0
11	7	2	88.87	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
11	8	1	95.4	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
11	9	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
12	1	1	92.9	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
12	2	2	131.27	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
12	3	1	119.53	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
12	4	1	118.14	1	103.77	0	NA	0	NA	0	NA	1	1	0	0	0
12	5	0	NA	1	166.74	0	NA	0	NA	0	NA	0	1	0	0	0
12	6	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0

Site	Quadrat	AG#	Length	PA#	Length	LS#	Length	UT#	Length	CF#	Length	AGfra	PAfra	LSfra	UTfra	CFfra
12	7	1	51.59	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
12	8	3	88.66	0	NA	0	NA	1	25.22	0	NA	3	0	0	1	0
12	9	0	NA	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
13	1	3	104.72	0	NA	0	NA	0	NA	1	10.29	3	0	0	0	1
13	2	2	117.47	2	134.94	0	NA	0	NA	0	NA	2	2	0	0	0
13	3	1	111.98	2	131.13	1	141.57	0	NA	0	NA	1	2	1	0	0
13	4	1	107.95	1	129.93	1	102.08	0	NA	0	NA	1	1	1	0	0
13	5	4	86.68	1	132.09	0	NA	0	NA	0	NA	4	1	0	0	0
13	6	1	107.41	0	NA	1	134.63	0	NA	0	NA	1	0	1	0	0
13	7	1	108.76	0	NA	1	109.46	0	NA	0	NA	1	0	1	0	0
13	8	1	98.39	1	130.56	0	NA	0	NA	0	NA	1	1	0	0	0
13	9	3	93.38	2	108.29	0	NA	0	NA	0	NA	3	2	0	0	0
14	1	1	141.62	1	122.16	0	NA	0	NA	0	NA	1	1	0	0	0
14	2	6	118.74	2	125.55	0	NA	1	17.27	0	NA	6	2	0	1	0
14	3	6	117.93	0	NA	0	NA	0	NA	0	NA	6	0	0	0	0
14	4	3	120.07	2	126.33	0	NA	0	NA	0	NA	3	2	0	0	0
14	5	0	NA	1	147.24	0	NA	0	NA	0	NA	0	1	0	0	0
14	6	4	105.67	2	132.41	0	NA	0	NA	0	NA	4	2	0	0	0
14	7	4	105.95	0	NA	1	104.01	7	17.86	0	NA	4	0	1	7	0
14	8	8	109.7	1	42.42	0	NA	6	25.86	1	10.17	8	1	0	6	1
14	9	14	97.65	1	60.6	0	NA	3	17.98	0	NA	14	1	0	3	0
15	1	7	81.47	0	NA	0	NA	0	NA	1	11.09	14	0	0	0	1
15	2	5	91.25	0	NA	0	NA	0	NA	0	NA	7	0	0	0	0
15	3	3	115.7	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
15	4	6	92.85	0	NA	0	NA	0	NA	0	NA	9	0	0	0	0
15	5	8	104.82	0	NA	0	NA	0	NA	0	NA	11	0	0	0	0
15	6	5	84.95	0	NA	0	NA	0	NA	0	NA	5	0	0	0	0
15	7	1	110.39	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
15	8	1	116.64	3	132.09	0	NA	0	NA	0	NA	1	3	0	0	0
15	9	2	102.8	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
16	1	3	96.78	0	NA	0	NA	0	NA	0	NA	6	0	0	0	0
16	2	10	108.67	0	NA	0	NA	1	28.11	0	NA	10	0	0	1	0
16	3	17	120.51	0	NA	0	NA	0	NA	0	NA	17	0	0	0	0
16	4	25	118.69	2	151.62	0	NA	0	NA	0	NA	27	2	0	0	0
16	5	18	102.74	0	NA	0	NA	0	NA	0	NA	18	0	0	0	0

Site	Quadrat	AG#	Length	PA#	Length	LS#	Length	UT#	Length	CF#	Length	AGfra	PAfra	LSfra	UTfra	CFfra
16	6	15	92.69	0	NA	0	NA	0	NA	0	NA	15	0	0	0	0
16	7	28	93.75	1	90.94	0	NA	1	33.96	0	NA	28	1	0	1	0
16	8	15	112.24	0	NA	0	NA	0	NA	0	NA	15	0	0	0	0
16	9	18	95.93	0	NA	0	NA	0	NA	0	NA	22	0	0	0	0
17	1	14	78.27	0	NA	0	NA	0	NA	0	NA	14	0	0	0	0
17	2	22	78.26	1	92.47	0	NA	0	NA	2	10.83	22	1	0	0	2
17	3	23	84.48	2	64.81	0	NA	4	43.81	0	NA	23	2	0	4	0
17	4	18	77.4	0	NA	0	NA	0	NA	0	NA	18	0	0	0	0
17	5	10	97.52	1	137.01	0	NA	1	105.34	0	NA	10	1	0	1	0
17	6	25	72.31	2	72.09	0	NA	0	NA	0	NA	25	2	0	0	0
17	7	7	74.99	2	99.47	0	NA	3	20.61	0	NA	10	2	0	3	0
17	8	19	76.95	1	140.77	0	NA	1	97.8	0	NA	19	1	0	1	0
17	9	15	74.36	0	NA	0	NA	0	NA	0	NA	15	0	0	0	0
18	1	12	136.89	0	NA	0	NA	0	NA	0	NA	12	0	0	0	0
18	2	6	139.4	0	NA	0	NA	0	NA	0	NA	6	0	0	0	0
18	3	6	115.04	1	119.05	0	NA	0	NA	0	NA	6	1	0	0	0
18	4	7	130.83	1	137.43	0	NA	0	NA	0	NA	7	1	0	0	0
18	5	3	103.02	0	NA	0	NA	0	NA	0	NA	10	0	0	0	0
18	6	1	140.58	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
18	7	1	132.89	0	NA	0	NA	0	NA	1	12.79	7	0	0	0	1
18	8	8	143.06	0	NA	0	NA	0	NA	0	NA	16	0	0	0	0
18	9	2	130.51	0	NA	0	NA	0	NA	0	NA	6	0	0	0	0
19	1	1	67.13	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
19	2	1	40.59	1	119.17	0	NA	0	NA	0	NA	1	1	0	0	0
19	3	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
19	4	2	117.41	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
19	5	3	79.26	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
19	6	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
19	7	2	94.59	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
19	8	1	95.59	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
19	9	0	NA	1	124.33	0	NA	0	NA	0	NA	0	1	0	0	0
20	1	0	NA	0	NA	3	20.28	0	NA	0	NA	1	0	3	0	0
20	2	3	43.02	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
20	3	0	NA	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
20	4	2	84.18	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0

Site	Quadrat	AG#	Length	PA#	Length	LS#	Length	UT#	Length	CF#	Length	AGfra	PAfra	LSfra	UTfra	CFfra
20	5	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
20	6	1	65.8	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
20	7	1	84.01	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
20	8	3	66.97	0	NA	0	NA	0	NA	0	NA	6	0	0	0	0
20	9	2	91.38	0	NA	0	NA	0	NA	0	NA	5	0	0	0	0
21	1	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
21	2	1	88.55	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
21	3	1	53.75	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
21	4	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
21	5	1	91.6	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
21	6	3	53.07	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
21	7	1	64.42	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
21	8	0	NA	1	61.56	0	NA	0	NA	0	NA	0	1	0	0	0
21	9	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
22	1	4	115.33	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
22	2	4	79.62	0	NA	0	NA	0	NA	0	NA	6	0	0	0	0
22	3	8	100.1	0	NA	0	NA	0	NA	0	NA	12	0	0	0	0
22	4	2	132.12	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
22	5	0	NA	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
22	6	2	104.94	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
22	7	2	132.3	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
22	8	4	116.61	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
22	9	5	121.16	0	NA	0	NA	0	NA	0	NA	5	0	0	0	0
23	1	6	85.99	0	NA	0	NA	0	NA	0	NA	13	0	0	0	0
23	2	4	102.6	0	NA	0	NA	0	NA	0	NA	12	0	0	0	0
23	3	3	16.37	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
23	4	1	128.66	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
23	5	1	100.57	1	127.47	0	NA	0	NA	0	NA	1	1	0	0	0
23	6	6	65.54	0	NA	0	NA	0	NA	0	NA	6	0	0	0	0
23	7	1	50.36	0	NA	0	NA	0	NA	0	NA	5	0	0	0	0
23	8	1	66.73	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
23	9	6	98.29	0	NA	0	NA	0	NA	0	NA	6	0	0	0	0
24	1	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
24	2	2	98.33	1	130.86	0	NA	0	NA	0	NA	2	1	0	0	0
24	3	1	84.58	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0

Site	Quadrat	AG#	Length	PA#	Length	LS#	Length	UT#	Length	CF#	Length	AGfra	PAfra	LSfra	UTfra	CFfra
24	4	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
24	5	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
24	6	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
24	7	0	NA	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
24	8	5	114.49	0	NA	0	NA	0	NA	0	NA	5	0	0	0	0
24	9	1	73.3	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
25	1	10	78.51	0	NA	0	NA	0	NA	0	NA	34	0	0	0	0
25	2	12	79.66	0	NA	1	24.99	0	NA	0	NA	24	0	1	0	0
25	3	8	90.56	0	NA	0	NA	0	NA	0	NA	15	0	0	0	0
25	4	9	84.94	0	NA	0	NA	0	NA	0	NA	20	0	0	0	0
25	5	6	80.46	0	NA	0	NA	0	NA	0	NA	16	0	0	0	0
25	6	2	89.29	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
25	7	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
25	8	2	84.83	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
25	9	0	NA	0	NA	0	NA	0	NA	0	NA	0	0	0	0	0
26	1	2	130.84	0	NA	0	NA	0	NA	0	NA	2	0	0	0	0
26	2	2	94.92	0	NA	0	NA	0	NA	0	NA	7	0	0	0	0
26	4	3	112.85	1	151.64	0	NA	0	NA	0	NA	3	1	0	0	0
26	5	4	126.67	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
26	6	2	89.88	0	NA	0	NA	0	NA	0	NA	8	0	0	0	0
26	7	6	134.9	2	98.95	0	NA	0	NA	0	NA	9	2	0	0	0
26	8	2	130.27	0	NA	0	NA	0	NA	0	NA	3	0	0	0	0
26	9	1	84.36	0	NA	0	NA	0	NA	0	NA	1	0	0	0	0
27	4	2	107.54	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
27	5	11	109.99	0	NA	0	NA	0	NA	0	NA	23	0	0	0	0
27	6	13	120.97	0	NA	0	NA	0	NA	0	NA	27	0	0	0	0
27	7	1	72.95	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
27	8	2	119	0	NA	0	NA	0	NA	0	NA	4	0	0	0	0
27	9	3	131.89	0	NA	0	NA	0	NA	0	NA	6	0	0	0	0

APPENDIX E. ENVIRONMENTAL BIVARIATE REGRESSION RESULTS

Bivariate correlations between each possible pair of environmental variables found at 239 sampling locations at 27 sites in Big Creek Lake. S = bottom slope; Z = water depth; F = maximum effective fetch; C = sediment organic matter content. t-values represent tests to determine if correlations exist between environmental variables. P is the probability of each correlation occurring by chance alone. Each r represents the correlation coefficient of each relationship.

Bivariate Relationship	t	P	r
S vs. Z	5.59	<0.001	0.34
S vs. F	-0.95	0.343	-0.06
S vs. C	-7.84	<0.001	-0.45
F vs. Z	3.49	0.001	0.22
C vs. Z	-0.50	0.618	-0.03
C vs. F	-2.71	0.007	-0.17

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