The Zonation of Carp Lake River and the Fish Species that Occupy Each Region

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Abstract
The purpose of this study was to understand how abiotic factors change along Carp Lake River and how these factors influence species abundance and distribution. Temperature, velocity, pH, conductivity, depth, nutrient levels, dissolved oxygen concentration, slope, and substrate were measured at four sites along the stream. The species of fish found at each site were also recorded. We found that groundwater inputs at the third site had a significant impact on the abiotic factors observed. We explored the relationships between the observed trends in abiotic factors and the variation in species diversity over the course of the stream. This study concludes that differences in velocity, substrate, and depth influence the distribution of fish species along Carp Lake River. The presence of a Lake at both ends of the stream also influenced species distribution.

Introduction:

The chemical and physical properties of a stream influence the metabolism of the resident fauna (Wootton 1992, Allan 1995, Cech & Moyle 1996). The distribution, abundance and interactions of species living in a stream are determined by biotic and abiotic factors which are subject to change over the course of the stream (Allan 1992, Hauer & Lamberti 1996).

Longitudinal succession is sequence of communities in streams from headwaters to large rivers. Community structure at a given point in the longitudinal gradient is interpreted in terms of site-specific environmental factors (Fisher, 1983). Along with differences in abiotic factors, is a change in species diversity; headwater fish species become less abundant as we move downstream. Fish have specific habitat preferences which cause them to be limited in their arrangement in streams, which have a graded series of conditions from source to end (Hawkes, 1975).

There are three zones to a river. The erosional or rhithron, the intermediate, and the depositional or potamon. The erosional zone occurs in high gradient regions and is characterized by rocky bottoms and cold water. These shallow, turbulent waters are highly oxygenated, but their small volume causes the water temperature to change as air temperature changes. Fish of the rhithron are stenothermal, preferring cool (<20°C) waters. They are also intolerant of low oxygen concentrations. The fish in this area tend to have streamlined bodies, which is an aid for swimming in faster waters, and tend to dwell on the bottom -- where the current is not as strong and it is easier to be camouflaged. These fish take advantage of the slack water behind obstructions, moving into the stream flow to collect food (Wootton, 1992). They also develop behavioral adaptations for living in the stream bed, such as using crevices and holes between stones for slower current. The distribution and abundance of fish in the rhithron is prone to disruption by adverse abiotic factors, including heavy flooding or periods of drought (Wootton, 1992).

The intermediate zone is made up by long middle reaches or tributary systems (Moyle & Cach, 1996). Moderate gradients and warmer waters are found in this area of the stream. Since this area contains many shallow riffles, the fish species found here are slightly different from fish in the rhithron. The fish found here typically are all adapted to fast-moving streams with warmer waters. They have adapted to these areas with streamlined body shapes and behavioral modifications.

Finally, the depositional or potamon zone occurs in warm, turbid water with muddy bottoms and beds of aquatic plants (Moyle & Cach, 1996). In this zone, the gradient of the river slackens and the morphology of the river course becomes more complex. The greater vegetation and slower flow rates decrease the amount of dissolved oxygen available for fish. At most latitudes, fish of the potamon are more tolerant of low dissolved oxygen conditions than species of the rhithron. Fish species that are more adapted to lake environments can survive in this zone for reasons of food preference, spawning and protection.

The transitions between these zones are not sharp and several species may be found in two or more zones. Studies suggest that interspecific interference competition for suitable resting and feeding stations and the need to avoid exposure to terrestrial predators both play a role in determining the relative abundance of species (Wootton, 1992). However, our study only focuses on the effect of abiotic factors on species distribution.

Stream temperature, a highly variable abiotic factor in streams, can change greatly between habitats only a few meters apart (Hauer & Lamberti 1996). Fish can detect a temperature gradient in the water. This allows them to exert some behavioral control over their body temperature by selecting a range of temperature in which to live (Wootton 1992). Many fish species have specific temperature requirements, which is why certain species are found along different parts of the stream. For example, trout are generally found in cooler zones such as the rhithron, while carp are found in the warmer potamon.

Egg hatching, growth, feeding activity, rate of digestion, migration cues and respiration rate are all influenced by temperature (Wootton 1992). For many riverine species which move upstream to spawn, migration is triggered by a change in temperature (Wootton 1992).

Like temperature, pH also affects fish metabolism by influencing the catalytic properties of enzymes (Wootton 1992). Changes in pH, along with changes in conductivity, which measures the amount of dissolved ions, can be used to indicate an anomaly along the stream. Nutrient content (nitrogen and phosphorus) is important to fish species distribution in a stream because it affects the extent of autotrophic production in aquatic environments (Stumm & Morgan 1981).

Velocity is another important abiotic factor influencing where fish prefer to live. Velocity usually decreases as the water progresses downstream. This decrease is due to ground water and run-off which widen the stream and slow it down. The velocity of water determines the sediment load carried, with finer sediment being deposited in pools and coarser particles forming the bed of the riffles. The speed of the water affects the fish, though indirectly, because it controls the delivery and removal of nutrients and food particles. Furthermore, different fish are adapted to living at different velocities, based on their morphology.

If the velocity of the water decreases as expected, the inorganic substrate composition will also change. There will be a shift from large, stony inorganic substrates at the source to sandier substrates towards the end (Allan 1995). As the velocity decreases downstream, it loses its ability to hold suspended particles; heavier pebbles are released first, while finer sandy substrates are carried until the end. Slope and elevation affect substrate by causing heavier particles to sink. Slope is directly proportional to velocity and tends to be steeper over a riffle than it is over a pool (Hynes 1972).

Depth is another abiotic factor that varies along a stream. The depth of the stream will vary based on its width and the amount of ground water flowing into it. Different species of fish are best suited for different depths based on their body shape and other morphological features (Wootton 1992). With the development of deeper pools, the number of species present increases, but there is a decrease in the number of large individuals (Allan 1995). Fish will live at different depths for reasons of hiding, feeding, spawning.

Organic substrates, such as fallen logs and leaves from the landscape, also play a role in where fish prefer to live. They serve as surfaces for algae growth (food for some fish) , for breeding and as hiding places from predators. In general, species diversity increases with the presence of organic substrate (Allan 1995).

Based on prior studies of stream systems (Allan 1992, Hauer & Lamberti 1996), we predicted that Carp Lake River would change in many ways as it progresses from Carp Lake to Lake Michigan. We believed that temperature, depth, and conductivity would increase, while velocity, dissolved oxygen content and nutrient concentration would decrease. We also expected that the substrate composition would gradually shift from rocky to sandy. We proposed that fish species diversity would change in response to the variation in abiotic factors.

The objective of this study is to gain a greater understanding of the fish species and how their habitats change as a function of varying abiotic factors, in a lotic stream. This study describes the abiotic factors and species composition at different points along Carp Lake River. We also explore the relationship between fish diversity and the physio-chemical environment of the stream.

Materials and Methods:

In order to test our hypotheses, we sampled the abiotic factors and fish species composition at four sites along Carp Lake River (50.5 km), which flows out of Carp Lake, Northwest into Lake Michigan. The study was performed between May 21, 1997 and May 31, 1997. We picked four, 100 meter sites along the river. The first site (T

38N; R 4W; S22) is 6 km from the source. The second site (T 38N; R 4W; S 17) is 12.5 km from the source, the third site (T 39N; R 4W; S 32) is 36 km from the source, and the fourth site (T 39N; R 4W; S 29) is 47 km from the source. Each site was divided into four transects of 25 meters each. Along each transect, at every one meter, we measured velocity using a Marsh -Mcbirney velocity meter, and classified the substrate with regard to percent sand, percent gravel, and percent pebble. If the substrate was less than 0.5 mm, it was classified as sand. It was classified as gravel if it was between .5 and 16 mm. Anything over 16 mm was classified as pebble. We also measured pH using a Hach pen, dissolved oxygen using YSI, and temperature using a continuous temperature recorder. A mean was taken for each individual site. Conductivity was taken at each transect using a Hach pen. Water samples were collected at each site and taken to Lakeside Laboratory for nutrient (nitrogen and phosphorous) analysis. The amount of organic substrate was described based on our observations.

Fish species composition for each site was determined using electrofishing and seining. The fish were captured and identified. They were then measured on a fish board to determine whether they were adults or juveniles, and finally released. Shocking and collecting was done for twenty-minute intervals at each site, except for the fourth site, where shocking was not done due to depth which exceeded 160 cm. At the fourth site, seines were used to capture fish that were hiding in surrounding vegetation.

Species diversity was measured using the Shannon-Weiner index. We also calculated the evenness of species distribution. Sorensen's equation was used to determine the coefficient of community. Differences of abiotic factors were assessed using an ANOVA. A Chi-squared test for independence was performed to evaluate differences in species distribution among sites. In order to analyze the relationship between changes in abiotic factors and changes in species abundance, we performed a regression analysis of these biotic and abiotic factors. We also plotted the abiotic factor and species abundance over the distance of the river.

Results:

Temperature was greater at the first two sites (~18.5 °C) than at the last two (~17.1°C) (p=.05) (Figure 1*)*. Dissolved oxygen content decreased between the first two sites (~8.6 mg/L) and the last two sites (~5.7 mg/L) (Figure 2). An ANOVA could not be performed on the oxygen data because there was not enough variance between the sites.

The total amount of nitrogen (~0 .48 ppm) remained fairly constant over the course of the stream (Figure 3). The total amount of phosphorous available (~15 ppb) also remained constant (Figure 3). The pH increased significantly in acidity between the first two sites (8.4) and the last two sites (~6.7) (Tukey, $p= 2 \times 10^{-5}$) (Figure 4).

The depth of the stream decreased among sites one (57.5 cm), two (44.0 cm), and three (38.9 cm)., but the stream became deeper between sites three and four (57.7 cm) (Tukey, p=0.01) (Figure 5).

There was an increase in velocity between the first two sites (~0.33 m/s) and the third site (0.68 m/s). Velocity again decreased between site three and four (0.28 m/s) (Tukey, p=0.002) (Figure 6). There wasn't a significant difference between the slopes at each site with sites one and four at .002 and sites two and three at .003.

The mean discharge generally increased over the course of the stream (.13 to .20 m^3/s) (p=0.31) (Figure 7). Conductivity of the water at the first two sites (~16.5) was less than the last two sites (18) (Figure 8).

The amount of pebble in the substrate composition increased with distance along the river. The amount of sand initially decreased between sites one, two, and three, but then increased between sites three and four. The amount of gravel in the substrate increased along all four sites. (Table 2)

The amount of organic detritus in the stream was constant between the first three sites, where the riparian was thick and evenly forested. Based on our observations, there was less organic detritus in the fourth site, which had few surrounding trees. However, we noted that the fourth site had more aquatic vegetation.

Fifteen species were captured along the course of Carp Lake River. Species diversity increased over the course of the stream (H = 1.00 -- 2.26) (X^2= 241.12). These trends held true even after adjusting for evenness. Calculation of coefficients of community showed that there was overlap in fish species composition between the different zones. The values were 0.18 between sites one and two, 0.44 between one and three, and 0.27 between one and four. The greatest overlap was between sites two and three (0.71). Coefficient of community was 0.5 between sites two and four, and 0.44 between sites three and four.

Discussion:

The purpose of this study was to observe how abiotic factors change along Carp Lake River and how these changes affect species diversity. We observed significant changes in pH, depth, velocity, and conductivity over the course of the river. We found that species diversity responds to these changes and increases from Carp Lake to Lake Michigan.

We had predicted that temperature would increase with distance from the source. However, the temperature decreased between sites two and three. This may be due to the influx of groundwater at site three, cooling the stream; groundwater is usually around 9°C. Depth may also play a role in keeping the stream cool by acting as a buffer against the ambient temperature. The more shallow areas of the stream are more greatly affected by air temperature than the deeper areas; it takes more time for a deeper stream to recover from cold temperatures because of its large area and resistance to change.

This explanation about depth holds true for site three as well, although it was more shallow than the other sites. The transects selected for the third site were not representative of that area; they were chosen due to greater accessibility. The depth of most of the river surrounding the third site was greater than the depth of our transects. In general, depth increases as the water moves downstream. Depth is inversely related to velocity. As we had predicted, velocity decreased significantly over the course of the stream.

We had expected dissolved oxygen to decrease as temperature increased over the course of the stream. Although temperature did not increase, dissolved oxygen decreased. The level of dissolved oxygen was probably a function of the groundwater, which is low in oxygen because it has not had exposure to air.

We had correctly predicted that discharge would increase along the course of the river. This could have been due to more water from tributaries and groundwater flowing across a greater area. The discharge was abnormally high in site one, which could have been due to effect of having Carp Lake as its source.

There was a significant increase in acidity between the first two sites and the latter two sites. This unexpected difference could be attributed to an influx of groundwater at site three. There was a golf course located near site three; it is possible that run-off from its chemically treated lawns may have infiltrated the ground water and polluted the stream. There may also have been an affect from acidic tannins found on decaying leaves in the water. The acidity from the lawns and the tannins overrides the buffering effect of the Calcium Carbonate which probably came in with the groundwater. However, the addition of Calcium Carbonate did increase the conductivity of the stream at sites three and four.

We had predicted that nitrogen and phosphorous levels would decrease with the decreasing levels of organic detritus in the water. However, nutrient levels remained fairly constant along the river, indicating that a moderate change in the amount of decaying organic matter (such as the shift observed between sites three and four) does not have a significant impact on nutrient levels.

Our results showed that the amount of pebble in the substrate increased over the course of the stream. We had expected that the fourth site would be sandier than the rest because as the velocity of the stream decreases, the suspended load settles to the bottom. Our results do not correspond to this expectation because of the transects that we chose at site four. Again, we had to choose the more shallow area due to accessibility and the shallow parts tended to be rockier.

Fish species diversity increased over the course of the stream. It was greatest at site four, probably because of the effect of Lake Michigan. *Salmo salar* (Atlantic salmon), *Notropis hudsonius* (spottail shiner), *Rhinichthys cataractae* (longnose dace) and the *Fundulus diaphanus* (banded killifish), all of which were found at site four, are most commonly found in lakes (Crossman &Scott, 1973). The *Luxilus cornutus* (common shiner) was also found in great numbers at site four, probably due to its preference for deeper waters (Crossman &Scott, 1973). Like most of the species at site four, it is also often found in lakes.

Site four was also the preferred habitat for *Etheostoma nigrum* (johnny darters) because of the site's sandy areas and slow current. Johnny darters also prefer heavily vegetated areas near the shore (Crossman &Scott, 1973), such as those found at the edges of site four.

Pimephales notatus (blunt-nose minnow) was also found at site four. This species prefers shallow waters with organic detritus (Crossman &Scott, 1973). Even though site four was the deepest site, it did have shallow pools. These pools were where we found the blunt-nose minnows. Their presence in this site could also have been due to a possible spawning effect.

Rhinichthys atratulus (blacknose dace) was found at sites four and three. This species is usually found in small, clear, swiftly flowing areas with gravelly substrate. In May or June, spawning takes place over gravel bottoms in the fast water of shallow riffles, where the water is a few inches to a foot deep. This could explain why we found blacknose dace at site three. Site three has a high velocity and many areas with gravelly substrate.

The *Semoltilus atromaculatus* (creek chub), which prefers to live in small, clear streams and brooks (Crossman &Scott, 1973), was found at site three. It is a sight-feeder so the clarity of the water is especially important. The abiotic factors at site three correspond to the species' requirements.

Most of *Nocomis buguttatus* (hornyhead chubs) were found in sites one and two. This may be because this species prefers to live in clear, slow, shallow waters (Crossman &Scott, 1973). The second site had several riffles, providing hornyhead chubs with rocks to escape the fast current. The *Umbra limi* (mud minnow) was also most abundant at site two. This site had large amounts of organic detritus at the bottom. Mud minnows usually bury into thick detritus to escape predators. They also prefer slow, warm pools, such as those found at site two (Crossman &Scott, 1973). The *Chrosomus eos* (northern redbelly dace) was found at site two for the same reasons (Crossman &Scott, 1973).

Cottus biardi (mottled sculpin) was most abundant in sites two and three with fast-moving rapids. These areas provide efficient shade from the surrounding forest canopy, which is a habitat sculpins prefer. Adult mottled sculpins prefer sandier bottoms, and can utilize this substrate to cryptically hide. However, the young are most often found in muddy areas (Crossman &Scott, 1973). This explains why a juvenile mottled sculpin was found in site four which contained muck at the edges.

Culaea inconstans (brook stickleback) prefers clear, cold, densely vegetated waters (Crossman &Scott, 1973). This species was found at site two. *Perca flavescens* (yellow perch), was found exclusively at site one -- close to Carp Lake. This is because the yellow perch is a lake species. Although they are usually found in lakes, this species is highly adaptable and can thrive in a wide variety of habitats, such as quiet rivers (Crossman &Scott, 1973).

Depth, velocity, substrate, and distance from Lake Michigan and Carp Lake influenced the species distribution along Carp Lake River. Depth, velocity, and pH were the only factors shown to have significant differences among the four sites. Depth is important because deeper waters may provide protection from predators. Some species also prefer to spawn in more shallow waters (Crossman &Scott, 1973).

Different species of fish are also adapted to specific velocities. Fish that have stream-lined bodies and energy allocations for maintaining position in fast waters are more likely to be found in areas with high velocity (Wootton, 1992). Fish such as the mottled sculpin, long-nose dace, and black nose dace, which were found in swiftly flowing portions of the stream, probably have such adaptations.

Very few fish have adaptations to acidic environments. Therefore, we would have expected species diversity and abundance to decrease after site three, where the pH decreased. However, this did not happen. Possibly, the water was not acidic enough to affect fish metabolism; if the pH were lower than six, enzyme function may have been inhibited (Wootton, 1992).

Different fish are also adapted to different kinds of substrate. Sandier substrates are less stable than areas with more gravel and pebbles. Johnny darters, in particular, may have adaptations to unstable substrates. The other fish may have preferred areas with more pebbles and gravel because of the potential hiding places rocks offer.

The type of organic and inorganic substrate, along with other abiotic factors may also influence the abundance and distribution of small, aquatic invertebrates. All the fish species we found were carnivores, and therefore dependent on the location of their invertebrate prey.

Other factors that usually affect fish species distribution and abundance are temperature, dissolved Oxygen concentrations, and nutrient content. Temperature affects enzyme function. Changes in temperature can trigger activities such as spawning, hatching and migration. Oxygen concentration affects respiration, and nutrient levels can limit metabolism. However, there were not significant differences between the sites with regard to any of these factors. The distribution of fish is only affected by extremes in such factors (Wootton, 1992).

Interspecific competition and predation are other factors that may have influenced species distribution. Based on their habitat requirements, most of the species discussed could have adapted to more than two of the sites we studied. However, all of them were found in greatest abundance in only one or two of the sites. This discrepancy could be due to the differences between fundamental and realized niches. Although, a particular species, such as the creek chub, could theoretically live in any of the four sites, its range may be mainly limited to site three due to competitive exclusion and predation by other species. However, these factors were beyond the scope of this study.

Sources of possible error throughout our project could have been reflected in some of our results. One source of error could be our variance in seining and shocking technique, this may have led to a difference in the amount of fish caught. Variance in number of fish caught can effect the calculation of the correct amount of species diversity. Inconsistent seining technique also affected our fish data. Another problem with our capturing technique was the amount of disturbance created. We had little experience in proper seining or shocking technique, so we created a significant amount of disturbance scaring fish away. The depth of our fourth site was an important factor affecting our ability to properly describe substrate. We could not see the bottom of the river, so we had to describe substrate entirely by feel. The depth of site four also prohibited us from using the shocking technique. Therefore, we only seined at this site. After seining at this site and catching more fish, we decided to use this method at the other sites. This seining method didn't prove to be as effective at these sites as the shocking method because of our inexperience and probable better chances of catching fish with shocking at more shallow waters.

When measuring the depth from each site, we took the data over the course of a week. Depth may have changed at the different times that we recorded them because of changing water volume, and velocity. These can increase or decrease the depth over a relatively short time. For our depth measurements at all four sites, we used different tools. At the first and fourth site, we used the Marsh-Mcbirney velocity meter. At the second and third sites, we used a meter stick. This inconsistency in measurement technique was reflected in our results. Depth is used in calculating the discharge rate. Since our depth measurements may have been skewed, the discharge rates were also in error.

In Carp Lake River, ground water is a significant factor adding to the water in the river. Unfortunately, we didn't measure the groundwater influx, so we do not know to what degree it affected our data. More detailed studies of temperature, dissolved oxygen concentrations, conductivity, and pH should be done to understand exactly where the groundwater comes in, and its effect on the stream.

When choosing our site, we were limited to sites that were accessible and on public property. For this reason the distance between sites two and three is greater than the distances between sites one and two, and sites three and four. This makes it difficult to accurately compare habitat changes between sites two and three; the large differences may be partially due to the great distance between them.

In conclusion, we have determined that there is a change in abiotic factors as Carp Lake River progresses from Carp Lake to Lake Michigan. These changes in abiotic factors affected where species were distributed. Our study also demonstrates how groundwater inputs can cause abiotic factors to deviate from their expected patterns. Since many Michigan streams are subject to groundwater influence, our study contributes to the understanding of Michigan's aquatic ecosystems.

Table. 1

FISHDATA Sat, Jun 7, 1997 3:20 PM

	Column 1	SITE 1	SITE 2	SITE 3	SITE 4
1	TEMPERATURE (ºC)	18.74+/-.53	18.28+/-.59	17.10+/-.78	17.13+/-.88
2	PH	8.37+/-.12	8.47+/-.32	6.67+/-.06	6.7+/-.35
3	DISS.OXYGEN (mg/L)	8.78+/-.02	8.54+/-.11	5.57+/-.04	5.86+/-.08
4	DEPTH (cm)	57.50+/-8.64	44.02+/-11.57	38.96+/-6.45	57.71+/-3.76
5	WIDTH (m)	10.35+/-1.29	11.54+/-1.47	10.70+/-1.76	10.50+/-3.00
6	VELOCITY (m/s)	.35+/-.05	.31+/-.05	.68+/-.14	.29+/-.09
7	CONDUCTIVITY	17	16	18	19
8	DISCHARGE (m^3/s)	.17+/-.03	.13+/-.00	.16+/-.04	.20+/-.08
9	SP. DIVERSITY	1.00	1.82	1.65	2.26
10	EVENNESS	.91	.88	.92	.91
11	ADJ. RICHNESS	.43	.29	.43	.18
12	PHOSPHOROUS	13.4	15.6	14.9	15.6
13	NITROGEN	.38	.545	.43	.55
14	ELEVATION (m)	214	212	189	179
15	FISH SPECIES				
16	Horny Head Chub	3	5	1	1
17	Yellow Perch	3	0	0	0
18	Common Shiner	1	0	2	6
19	Mud Minnow	0	8	2	0
20	N. Red Belly Dace	0	4	0	0
21	Mottled Sculpin	0	2	1	1
22	Brook Stickle Back	0	6	0	1
23	Blunt Nose Minnow	0	1	0	7
24	Creek Chub	0	1	4	0
25	Black Nose Dace	0	1	4	3
26	Johnny Darter	0	0	0	23
27	Long Nose Dace	0	0	0	7
28	Spot Tail Shiner	0	0	0	2
29	W. Banded Kilifish	0	0	0	1
30	Salmon	0	0	0	13
31		7	28	14	65
32					total =114
33	DISTANCE (km)	6	12.5	36	47

Table 2
Inorganic Substrate Composition along four sites at Carp Lake River

Site	Percent Sand	Percent Gravel	Percent Pebble
1	78.25	14.50	7.25
2	58.50	21.25	20.25
3	24.50	44.00	31.50
4	41.50	21.00	33.25

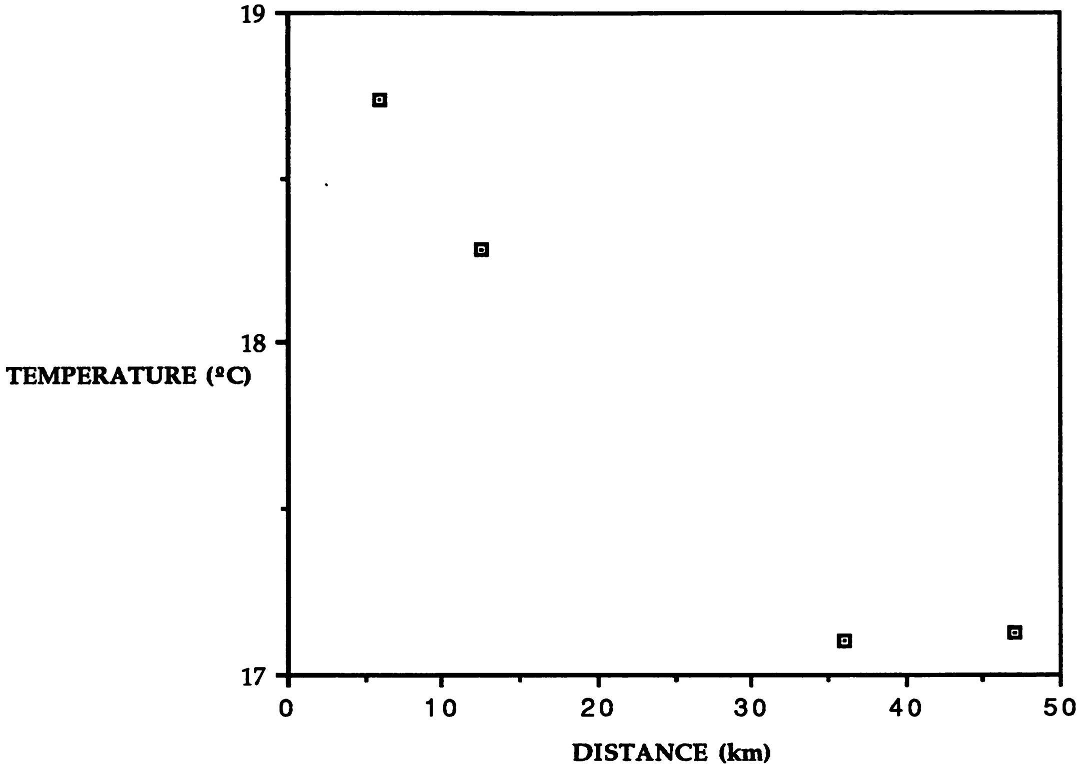

Figure 1. Mean temperature along Carp Lake River.

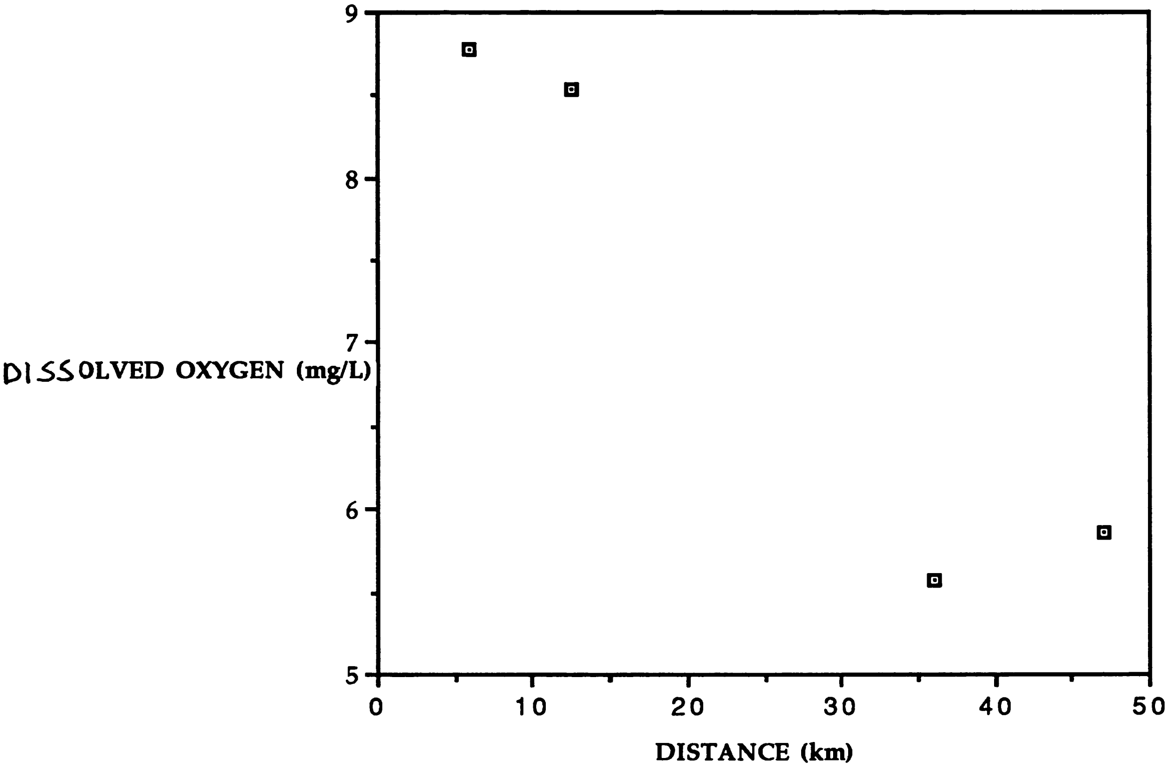

Figure 2. Mean dissolved oxygen content along Carp Lake River.

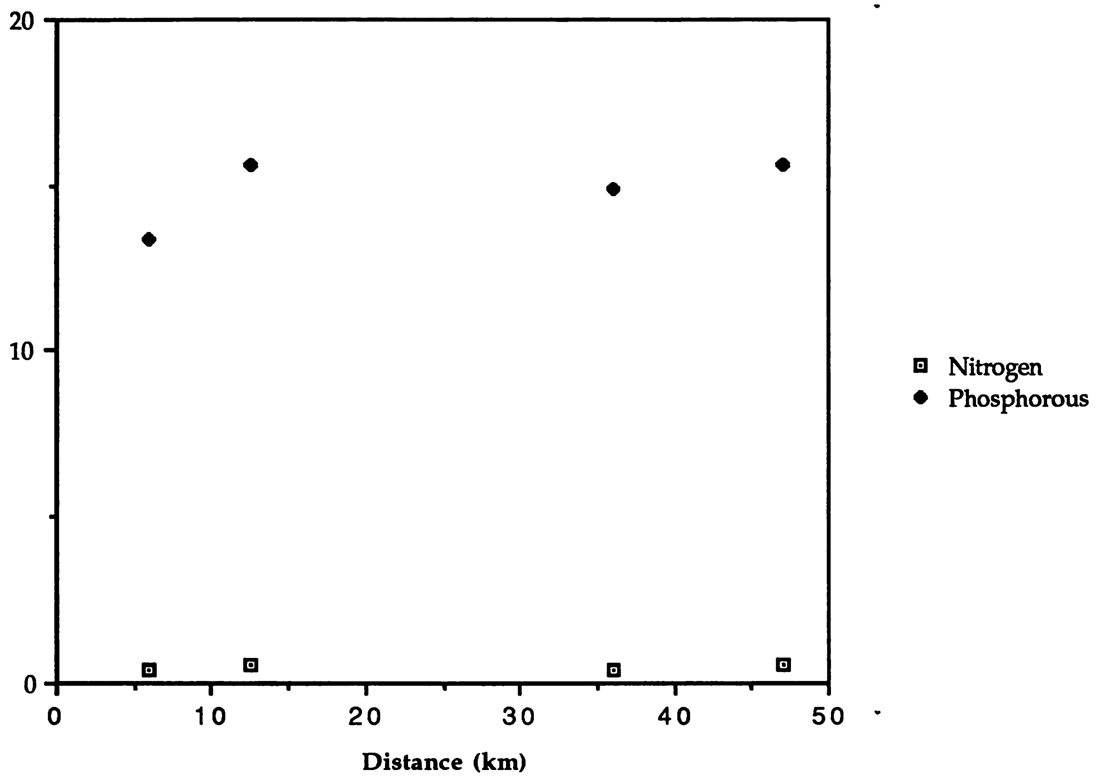

Figure 3. Total nitrogen and phosphorous along the Carp Lake River.

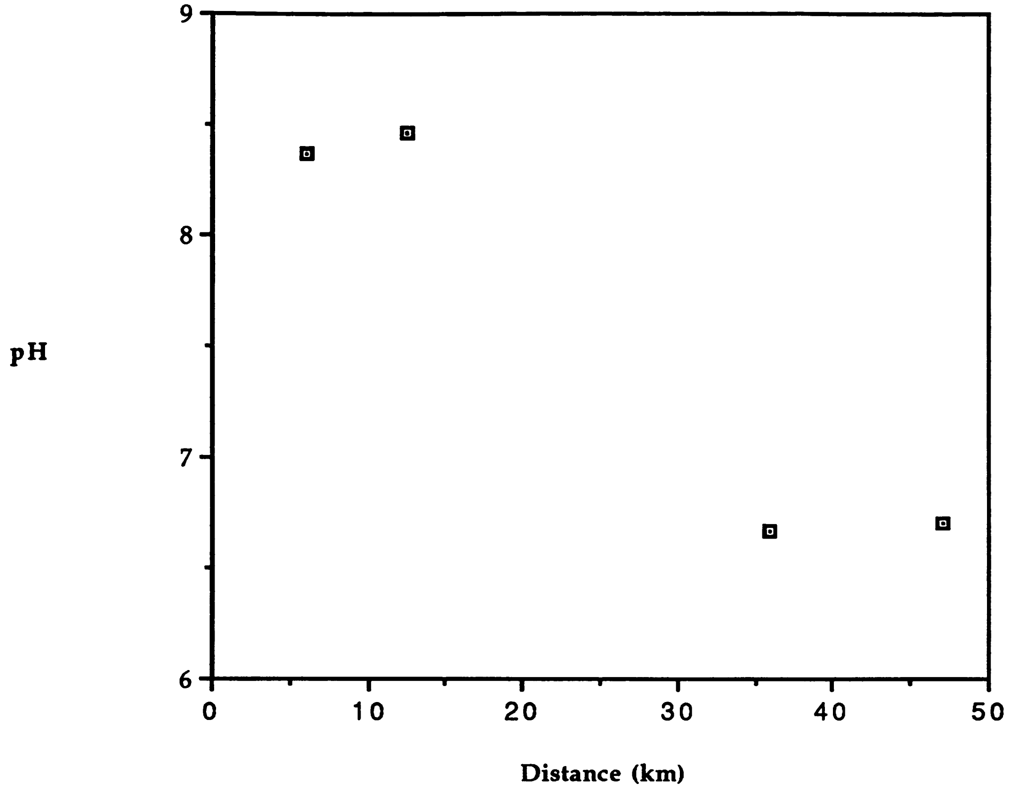

Figure 4. Mean pH along Carp Lake River.

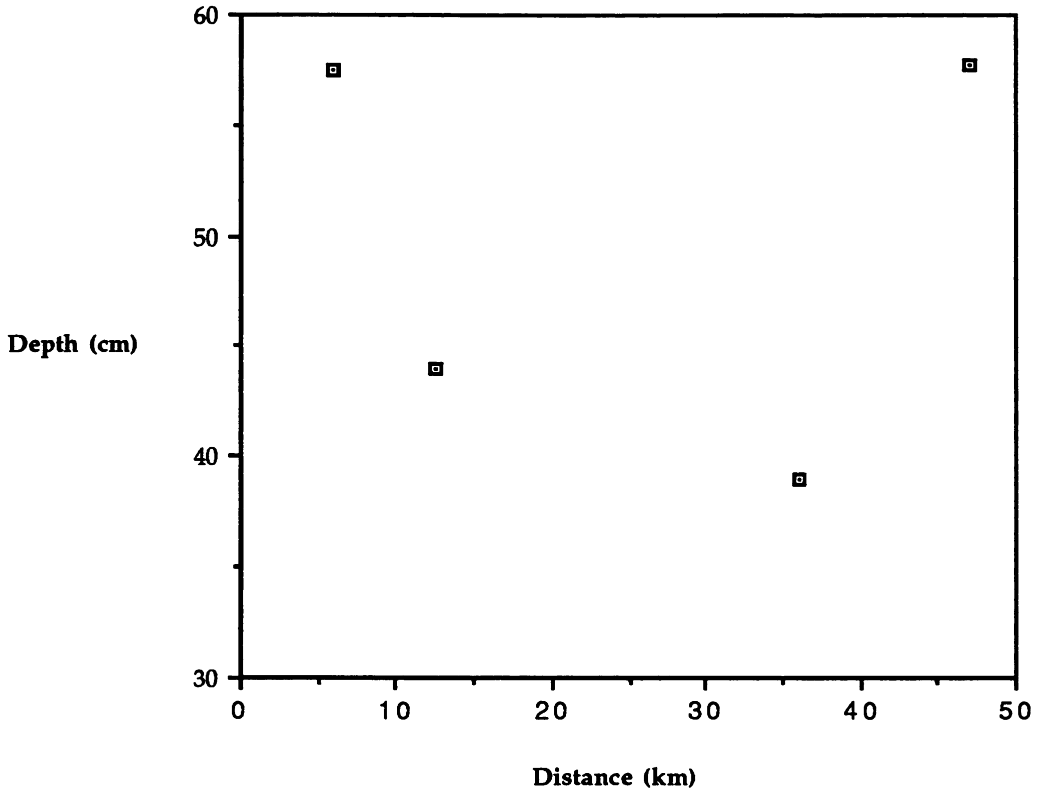

Figure 5. Mean depth along the Carp Lake River.

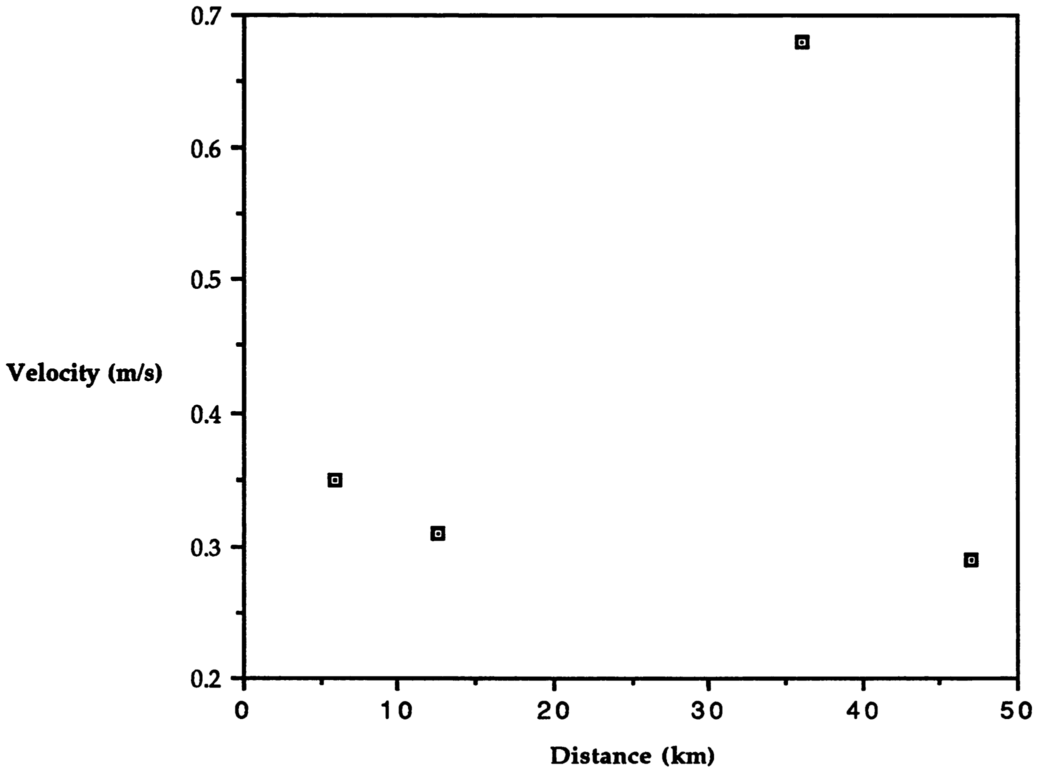

Figure 6. Mean velocity along the Carp Lake River.

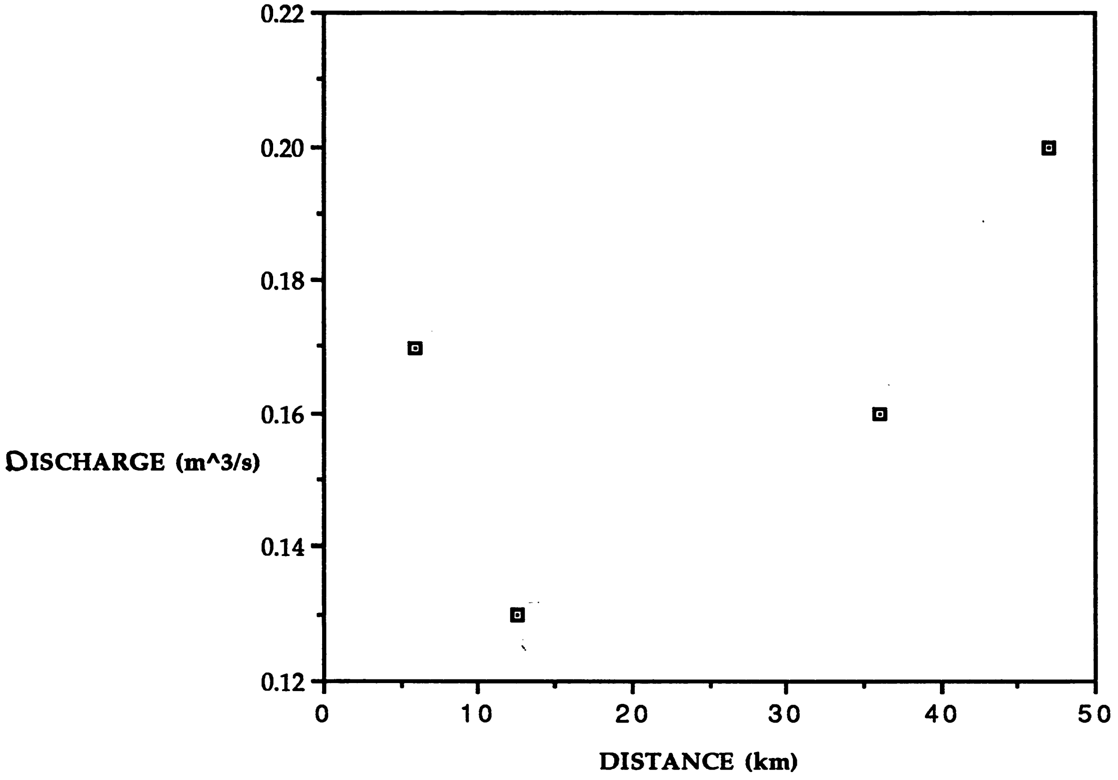

Figure 7. Mean discharge along Carp Lake River.

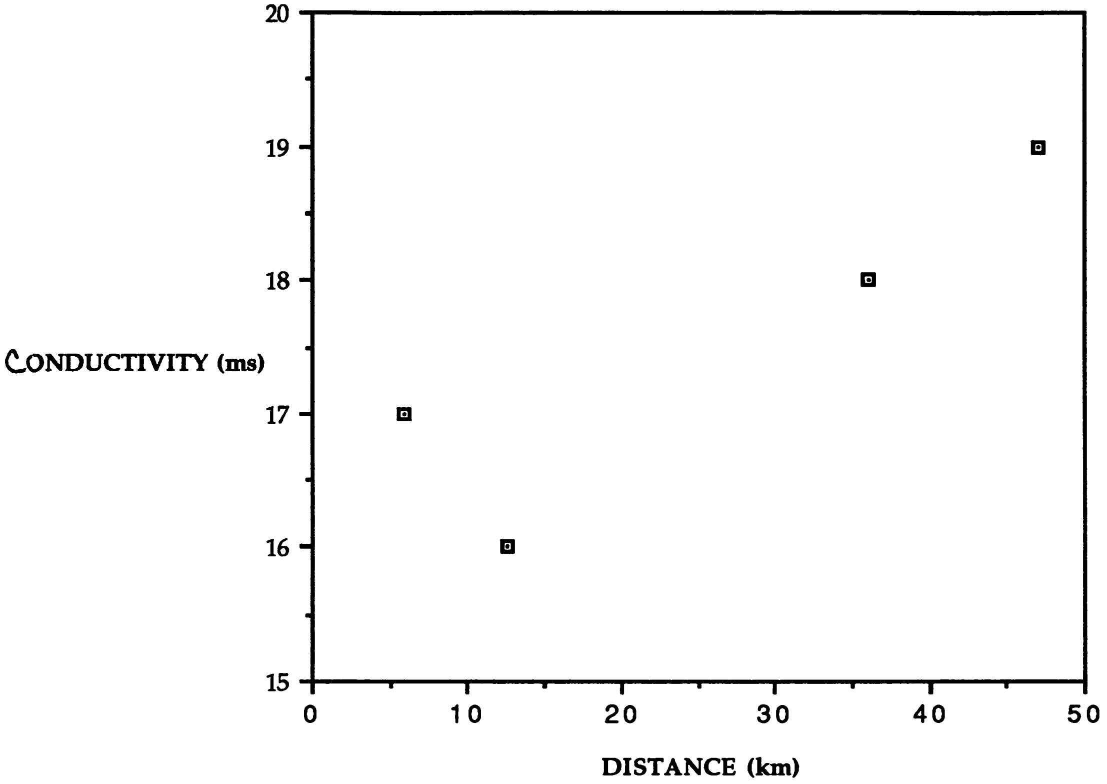

Figure 8. Conductivity measure along Carp Lake River

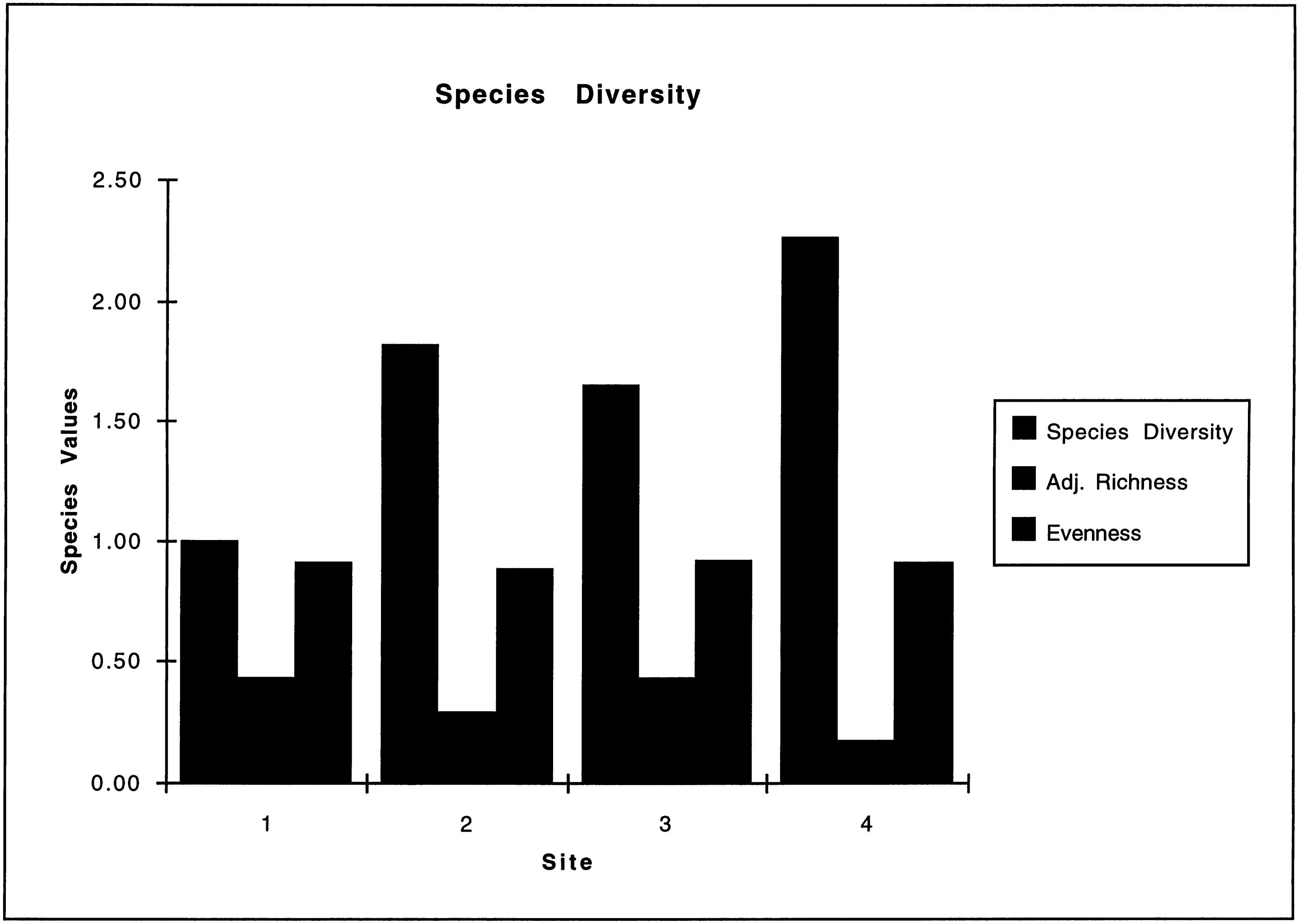

Figure 9. Measures of species diversity, adjusted richness, and evenness along Carp Lake River.

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