THE INFLUENCE OF LENTIC-LOTIC INTERACTIONS ON FISH ASSEMBLAGES

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ABSTRACT

Lentic-lotic interactions commonly occur in regulated water systems and are of primary economic importance to the bordering communities. Because these communities attempt to use lentic-lotic systems for maximum benefit, knowledge of biological trends that result from this interaction is helpful in perpetuating the resource. In this study, a lentic-lotic interaction in an unregulated natural system was surveyed for fish, benthos, and chemical trends along lake/stream gradients. It was apparent that spatial differences in fish and benthic populations occurred such that component organisms maximized their food source and minimized their risk to predation. Benthic distribution was determined primarily by habitat differences (discharge, vegetation, substrate). Although subjected to the effects of habitat, fish also were found to be distributed as a result of the different benthic populations and the distance from the lake. Physio-chemical parameters (particularly D.O. and pH) evidenced the dynamics of water drainage from a lake. These baseline studies of a natural system provide a control for regulated lentic-lotic systems.

INTRODUCTION

Although changes in animal populations along a lentic-lotic gradient have been documented for regulated streams (e.g. Pflieger and Grace 1987, Li and Scheuk 1987), they have not been studied very extensively in natural systems. Previous studies have examined reservoir outflows in regulated stream systems or in waterways subject to varying degrees of human influence (eg. industry, boat traffic, pollution). In these habitats, a greater number of variables control the fish and benthic communities making trophic interactions less predictable. Before one can speculate on the anthropogenic factors that have influenced an ecosystem, one must understand the natural processes and how they function in an unregulated system. Presently, natural systems are at a premium as humans attempt to make use of all the resources at their disposal. The Tenderfoot Lake- Tenderfoot Creek system, protected from manipulation as part of the University of Notre Dame Environmental Research Center, provides a system that is relatively undisturbed by humans. This system provides a suitable model of interaction with enough access to study general trends in fish populations, benthic community structure, and water quality across spatial gradients along the creek. Choosing sites that show diverse habitat types along a spatial gradient, I will try to outline the trophic structure at each habitat, relying on published information on the component species. I will use these outlines to speculate on the relationship between sites and reasons for differences between lentic and lotic populations. From these, I will form general conclusions as to what factors result in a lentic system showing lotic characteristics along the length of its outflow.

Many variables will affect the changes one might see across gradients in any natural system. In ten weeks of study, it would be futile to examine all the possible inputs of such a system. I chose to focus my lentic-lotic study on fish, benthos, and selected chemical parameters, using these as descriptors of the ecosystem. These biological factors are well documented as individual units and, for the most part, easy to sample. It is particularly advantageous to look at fish populations because they are of primary economic and recreational concern when decisions are made on the regulation and access of waterways. A diminished fish community is often the first concern of people economically dependent on a system. The benthic community is important to examine not only because it supports fish, but because it is so drastically changed when streams are regulated. Water chemistry along this gradient enables us to establish trends that are a result of the dynamics of the water outflow. In this system, we are able to assume these progressions are due to natural factors rather than anthropogenic impacts that result from regulation.

In the present freshwater system, the species we find will be those adapted for freshwater lakes and streams. However, by looking at the patterns moving from lake to stream, we would hope to see a graded difference of benthic communities due to variations in substrate, macrophyte growth, discharge, and physical barriers. By examining the physiological mechanisms that account for the presence of certain organisms, we can relate the findings to lentic-lotic linkages in other types of systems. The benthos will likely be an important factor in the differences in fish communities found along the gradient because many fish commonly found in these waters are known to swim a distance much larger than that between all four sites in the study area. It is likely that distance downstream, channel barriers, and water depth will be other factors that will govern distribution. We would expect to find small insectivorous and algivorous fish in stretches of stream that have high insect densities or high algal biomass and suitable shelter from predators. Large piscivores are more likely be found in deeper water, and will reduce the number of small, non-predatory species where they coexist. In shallow stretches and those further from the lake, I would expect to see fewer large piscivores. Fish will most likely appear in gradations of the interaction that will maximize their food resource and minimize predation risk. It is the resulting community structure of these series of interactions that I will attempt to elucidate in this study.

Freshwater streams and lakes are some of the most valuable resources available to man. Natural linkages of these systems are vital to the survival of fish species especially with regard to spawning and escape from winterkill conditions. The events that have brought about the conditions that allow for these mechanisms originated from natural events. As man attempts to use these resources for maximum long-term benefit, it is imperative that knowledge of the factors that have produced and maintained the systems be assets to the people responsible for their continuation. An understanding of the most basic supporting mechanisms that allow for a species rich ecosystem may allow people to utilize every aspect of the system in a manner that perpetuates it. The study of lentic-lotic interactions is especially valuable because a large part of human regulation of waterways is based on this interaction. The thousands of dams and reservoirs that people benefit from today may be left with a large part of their potential, especially biological potential, inhibited. By establishing the baselines to the maintenance of natural systems, we may be able to increase the efficiency and longevity of our water resources.

STUDY AREA

Tenderfoot Lake is a boundary water in Vilas County, Wisconsin bordering Gogebic County, Michigan. The lake is public access but has very limited access due to private residences. The northeast bay of the lake is bordered by property owned by the University of Notre Dame. This area of the lake includes the outflow into Tenderfoot Creek. Tenderfoot Creek flows north to the limits of the research center property. This study was conducted from the mouth of the lake and included four sites along a 3.2 km stretch of the creek. The bay of the lake was 4 meters at its deepest point and between 1 and 2 m within 200 m of the mouth. The creek was between 1 and 2 m deep in the thalweg downstream to the first riffle area (approximately 2.5 km downstream). The outflow of the lake was approximately 40 m wide at the mouth where the discharge was slow to negligible. At a point approximately 0.3 km from the mouth was a culvert allowing a road to overpass. At 0.8 km the width was about 35 m, and the discharge variable, ranging from negligible to a slight run around bends in the stream. The sediment was mostly mud or silt with considerable amounts of both fine and coarse organic matter. The creek meanders considerably down to the first riffle area at 2.5 km downstream. The pool area downstream from the riffle was similar in morphology and sediment type to the winding stretch previously discussed. The second riffle was 360 m downstream from the first riffle area, with the following pool stretching another 500 m to the end of the study site. The two riffle areas were morphologically similar and characterized by high current velocities and large rock substrata. The depth ranged from 0.5 m to 1 m in the riffles. Some large woody debris stretching the length of the creek was also present.

During the study conducted from late May to mid July, the air temperatures ranged from nighttime lows of about 10^{o}C to afternoon highs of 28^{o}C. Water temperatures increased throughout the study period from 15^{o}C to 28^{o}C. The general area accumulates large amounts of snow that melt in the spring and drain into the lake. Rainfall during the season also was considerable. The growth of emergent vegetation along the study area was phenomenal. Submerged macrophytes were present in relatively small amounts in late May with no emergents. By July the mouth of the lake was completely colonized by emergent vegetation, and macrophyte beds were abundant. The winding 2.5 km stretch contained large amounts of emergents, Nymphaea and Nuphar, and submergent, Elodea, macrophytes that dominated large areas of the channel. All pool areas contained considerable vegetation by July. The riparian zone of the channel is dominated by hardwoods and conifers distinctive of the northwoods.

METHODS

The study was conducted from May 27 to July 16, 1991. I chose four sites for the study based on distance downstream and access. The first site was 200 m downstream from the mouth of the lake. Site 2 was 1000 m downstream from site 1. Sites 1 and 2 were both pool areas with low current velocity. The width at site 1 was 40 m and at site 2 was 35 m. These sites were accessible by rowboat or canoe from The University of Notre Dame property on Tenderfoot

Lake. Site 3 was 1600 m from site 2. It consisted of a 70 m long riffle and a pool area fifty meters beyond. The average width was 35 m. Site 4 consisted of a riffle 350 m downstream of the site 3 pool and a pool 500 m downstream of the site 4 riffle. The riffle averaged 30 m wide and the pool 35 m. Sites 3 and 4 were accessible by canoe or by land as they both were located near well-traveled gravel pits. The distances are approximate and were determined by canoe, adding together distances sighted using a rangefinder.

FISH SAMPLING:

Fish were sampled by hook and line, fyke nets, and minnow traps. Fyke nets were set in pools at sites 1, 2, and 3 on three separate days in mid-June. Nets were set at approximately 2000h at night and collected at 700h the following day. The number, species, and length of the fish caught were recorded. The setting and collecting of this net required three boats and six people so it was done only once at each site. Site 4 was too shallow and overgrown with macrophytes to allow fyke nets to be set. All sites were sampled by hook and line throughout the study period. Because angling was conducted by different people with different equipment, only species and general abundance were recorded. Night crawlers and leeches were used as bait in all cases. As macrophyte growth became extensive, angling at downstream sites became inefficient. Minnow traps were set weekly at each site, and usually were collected after one night. Three traps baited with bread were set at each site. The species and general abundance of fish were recorded from each trapping event.

BENTHIC SAMPLING:

Benthos was sampled twice during the study period. The first sample date was on 28 May and the second was on 28 June. Ekman samples were collected at sites 1 and 2 from both sides of the channel, and at the deepest point in mid-channel on each of the two sampling dates. Samples were sieved through a 500 micron mesh screen and preserved in 95% ethanol. Pools at sites 3 and 4 were sampled with the Ekman grab using the same sieving procedure. However, samples were collected only at one margin of the stream and in the middle. The site 3 riffle area was sampled on both dates using a kick method and a D-net held down stream. Concomitant with this study, intensive sampling was conducted at the site 3 riffle area using artificial substrates (E. Vogel, pers. comm.) and at the site four riffle area using a 0.09 m^2 Surber sampler (E. Hinchey, pers. comm.)

Ekman samples were sorted using sugar flotation. The D-net samples were also sorted, however sugar flotation was not necessary in all samples. The substrate trays and Surber samples were picked and identified by E. Vogel and E. Hinchey, respectively.

CHEMISTRY:

Analyses for water chemistry were conducted at all sites on 28 June. All water samples were collected during mid-day. Dissolved oxygen, air temperature, and water temperature were measured using a YSI model 42 dissolved oxygen meter; pH was tested with a Hach electronic pH meter. Specific conductance was determined using a Hach electronic conductivity meter. Water samples were collected at each site and transported to the laboratory for testing of nitrate-nitrogen, ortho-phosphate concentrations, and levels of alkalinity and acidity.

RESULTS

The sampling of both fish and benthos at different times during the study period was not believed to have an effect on comparisons over a one month period. The focus of this study was primarily on the spatial dynamics of the system. Results at each site are presented to allow for later comparisons.

Site 1 possessed a diverse fish assemblage that included ten species. Abundant species included Ambloplites rupestris (rock bass), Perca flavescens (yellow perch), and Lepomis gibbosus (pumpkinseed) and Lepomis macrochirus (bluegill). Various sizes of these species were trapped by each of the methods both in the lake and at the mouth. Other species present included a few large Pomoxis nigromaculatus (black crappie) and an occasional Notemigonus crysoleucas (golden shiner) and Luxilus cornutus (common shiner). Larger P. nigromaculatus were collected in sufficient numbers to be considered common, but because only one of each type of minnow was collected (fyke net), it is unlikely there is a large population at this site. The three large netted specimens of Stizostedion vitreum (walleye) suggest that it is the dominant piscivore at the site. S. vitreum was commonly angled in various parts of the lake. Micropterus dolomieui (smallmouth Bass) and Micropterus salmoides (largemouth Bass) were collected by hook and line only once near the lake outflow with no fyke net captures in the creek. There was no evidence of either species in the creek at any site.

Benthic samples at site 1 showed Chironomidae (Diptera) to be abundant across the width of the channel. The amphipod Hyalella azteca was also abundant across the entire width. For the most part these were the only benthic taxa common in the channel region at a depth of 1.3 m. Channel margins showed a much higher diversity. Samples in this area were collected between 0.3 and 0.6 meters. In addition to the chironomids and H. azteca, the mayfly Caenis sp. (Ephemeroptera) was a particularly common genus. Two other Ephemeroptera genera also were present in lower numbers: Baetis and Attenella. The dipteran Chrysops (Tabanidae), Ceratopogonidae, and Psychodidae were present only at the margins of the stream bed, as was the trichopteran Glyphopsyche irrorata. Two odonate genera, Cordulegaster (Anisoptera) and Lestes (Zygoptera) were also common. *Diplectrona modesta* was the only hydropsychid caddisfly (Trichoptera) found at this site.

In addition to the benthic insects, two families of gastropods, Physidae and Pleuroceridae were common near the edges of this site. Also common were Pelecypoda and Decapoda.

Fish populations at site 2, although still represented by large numbers of *A. rupestris*, *P. flavescens*, and *Lepomis* spp., showed a marked increase in the number of minnows. A total of 18 *L. cornutus* were collected compared to the one specimen at site 1 and also *Notropis heterolepis* (blacknose shiner) commonly was collected in minnow traps. Although their collection was rare, *Umbra limi* (northern mudminnow) and *Etheostoma exile* (Iowa darter) also were present at this site. Although *E. exile* was collected in only one minnow trap, it is commonly found it in another slow-moving lotic habitat on the property. Previous collections have associated *U. limi* with shallow, densely vegetated waters. *Catostomus commersoni* (white sucker) was collected only at site 2 (3 in fyke net). *S. vitreum* was the only piscivorous fish collected at this site.

The benthic community at site 2 was similar in composition to site 1. Chironomidae and *H. azteca* were abundant across the channel. They occurred in much higher densities compared to site 1. At site 2, *Caenis* and *D. modesta* also were present across the stream. Other taxa sampled from the middle (1.3 m depth) included *Chrysops* and *Glyphopsyche irrorata*. Areas along the margins of the creek included most of the organisms previously collected in the same habitat type at site 1. In addition, however, the caddisfly *Leptocerus*, a predatory beetle *Laccophilus*, and the odonate *Ophiogomphus* were collected. Beetles of the family Chrysomelidae also are relatively common. Also present at this site were species of Hirudinea (leeches) and Haplotaxidae (Oligochaeta). Hirudinea were most often collected directly from field assistants. The remainder of the bottom fauna also was similar in that Physidae and Pelecypoda were well represented.

Site 3, the location of the first riffle area, had a relatively high discharge that varied with atmospheric conditions. The substrate was coarse and rocky. Large woody debris was present and frequently extended the width and depth of the channel. The water flows over this debris at only a few centimeters depth. Fish sampling was conducted both in the riffle and the downstream pool. The minnows *L. cornutus* and *Semotilus atromaculatus* (creek chub) were abundant only in the riffle and collected by minnow traps. *N. heterolepis* although not as abundant as the other two species, was commonly collected in riffle minnow traps. High minnow densities in the riffle might be attributed to the spawning season which extends from May through July. I observed *L. cornutus* males in the vicinity of nests on many occasions. A common species present in both pool and riffle was *A. rupestris*. An occasional *P. flavescens* also was trapped. Few fish were collected in the fyke net at site 3 and included one *P. nigromaculatus* and several *Lepomis* spp. The results indicate that populations of large fish, especially piscivorous fish, were small or absent. Only one *P. nigromaculatus* was collected by angling. The minnows were rarely captured in the pool, and the sunfish rarely in the riffle.

High densities of benthic insects in the riffle at site 3 (approx. total density = 1000/m^2) potentially serve as an abundant food source for fish and insectivorous predators. The insect fauna was dominated by Trichoptera larvae and included the hydropsychids *Cheumatopsyche*, *Hydropsyche*, and *Diplectrona modesta* (approx. total density 900/m^2). They utilize the abundant rock substrata for case construction and attachment. Other caddisflies *Pycnopsyche*, *Nyctiophylax*, and *Chimarra* also were present but not as abundant. The riffle area has a few patches of soft mud substrata in protected shallow bays. The current in these bays varied temporally but they were nevertheless grouped as part of the riffle. Caddisflies were clearly the most prevalent insects in the riffle bottom community. Although these organisms are present upstream and downstream of the riffle, their densities were drastically reduced. Populations of Ephemeroptera, Megaloptera, and Odonata also were common in riffle collections though in much lower densities than Trichoptera. Species richness at site 3 is much higher than the depositional areas of the first two sites (20 taxa at site 3 compared to 12 taxa at sites 1 and 2). In addition to the large number of caddisfly taxa collected, for the first time in the progression from lentic to lotic habitats, there were abundant populations of *Nigronia*, *Stenelmis*, *Acroneuria*, *Progomphus*, and *Boyeria vinosa*. Physidae, Pelecypoda, and Decapoda were extremely abundant in the riffle. The riffle area had a much higher species richness (20 taxa in riffle compared to 12 taxa in pool) and benthic densities (approx. 1000/m^2 in riffle compared to approx. 150/m^2 in pool) than the pool area. Pool densities were composed primarily of Chironomidae and small numbers of organisms characteristic of riffle areas.

Site 4 also consisted of both pool and riffle areas. The pool was located 500 m downstream of the riffle. *N. heterolepis* was the most prevalent fish species in riffle site 4. *L. cornutus* was common, but not as common as *N. heterolepis* and certainly not as abundant as at riffle 3. *S. atromaculatus* also was commonly collected. similar to upstream sites, *A. rupestris*, *P. flavescens*, and *Lepomis* spp. were present in minnow traps, primarily in the pool areas. The only species present not previously collected at upstream sites was *Cottus cognatus* (slimy sculpin). The fish assemblage at this site appears to be comprised of primarily younger fish as the sunfish sampled were much smaller in comparison to those at the first two sites. However, because angling was difficult and the fyke net was not facilitated, we cannot be sure that there are no large fish. All species collected at this site were collected at least once in the pool area, but only *L. cornutus* and *N. heterolepis* were collected at the riffle.

The benthic community at site 4 is very similar to site 3. Hydropsychid larvae numerically dominated the riffle area and most of the species present at site 3 also were present in similar numbers at site 4. The one notable difference between the two sites was the especially large number of odonates in both areas of site 4. Hylogomphus, Ophiogomphus and Boyeria were abundant in the riffle while Boyeria, Ophiogomphus and Perithemis were present in the pool.

Water chemistry analyses at the four sites were conducted 28 June under clear sunny skies in unshaded areas. All measurements were taken between 1100h and 1600h. Specific conductance and nitrate-nitrogen values did not differ appreciably between the four sites. Results from the phosphate test were not recorded due to errors in procedure during the Hach analysis test. Water temperature was 26^{0}C at the first two sites, and 27^{0}C at the second two sites. Changes in pH and D.O. were observed along a downstream gradient. The pH of the lake at the outflow was measured as 8.05, and site 1 averaged 8.00. Site 2 showed a considerable drop in pH to 6.95. At site 3, the riffle pH was 7.91 and the pool 7.84. The site 4 riffle pH was 8.47 and the pool 8.50. All dissolved oxygen (D.O.) readings were collected at the surface. The D.O. of the lake was 8.0 ppm. In the mouth of the lake it was 7.6 ppm. Site 2 displayed a drop in D.O. (5.3 ppm) and the riffle at site 3 was 9.1 ppm while the pool D.O. was 8.8 ppm. The riffle at site 4 was the highest at 11.0 ppm while the pool dropped to 9.0 ppm.

DISCUSSION

The diverse habitats resulting from the Tenderfoot Lake-Creek interaction lead to distinct differences in animal populations along a spatial gradient in the system. Analysis of the benthic community gives us insight as to how aquatic invertebrates adapt for survival at each site. Because movement patterns of benthic organisms occur on a smaller scale relative to spatial patterns under investigation, examination of their distribution and adaptations will be a key to determining community-level transitions in lake/stream systems. The differences we find in fish communities are harder to relate to specific sites because of the relatively high mobility of fish. However, the preferred habitat of particular species can be observed based on their relative abundance at different sites and the availability of their food source. Using these determinants, I will present baseline trends of a lentic-lotic interaction.

The first relationship to consider is that of the benthic community to the physical characteristics of the system. Ecological information on the component aquatic invertebrate taxa was derived from the literature (Merritt and Cummins 1978, McCafferty 1981, Pennak 1989). Comparisons between the four sites resulted in the presence of substantially different animal communities. The benthos, comprised of relatively immobile organisms (in relation to the two mile study area) allows us to more easily detect transitions in characteristic species along the gradient. The reasons for the presence of the dominant taxa at each site are discussed below.

Site 1 possesses taxa most common in lentic or lotic-depositional habitats. The Chironomidae and H. azteca were distributed across the entire width of the channel. They are adapted to take advantage of the soft substrate and have feeding habits classifying them as collector-gatherers. Both are known to be common in streams and lakes. Caenis was the only other insect collected in the thalweg of this site. Because the margins possess a much more diverse insect population, it is likely that the middle of the channel is very similar to the deeper regions of the lake. Even though macrophytes were abundant in the thalweg, they do not provide as much vegetative shelter as marginal areas. The banks of the creek support three genera of Ephemeroptera (Caenis, Baetis, and Attenella) that are clingers or sprawlers. They apparently take advantage of the abundant vascular hydrophytes for protection from predators and for the collection of food. Large burrowing dipterans, Chrysops, Ceratopogonidae, and Psychodidae likely need the added shelter from predators and make use of the soft substrate for predator avoidance as well as for finding food. Lestes and Cordulegaster are large burrowers common to depositional and lentic areas. The Odonata are predatory and can easily find prey in the shallow margins. Adaptations of the component taxa to this habitat were very apparent. Clingers and sprawlers possess morphological adaptations (holdfast mechanisms, streamlined bodies) to cling to vascular hydrophytes and debris. The slow current allows fine particulate matter to settle and provide food for the collector-gatherers. Some also have mechanisms to keep their respiratory system silt free. D. modesta occurred occasionly at this site and is a net spinning Trichoptera usually found in lotic-erosional habitats. However, the presence of this taxa could be due to wind induced currents at the mouth or the ability to take advantage of even the slow discharge of the creek at this site.

The benthic community at site 2 has a very similar species composition to that at site 1. The densities of both Chironomidae and H. azteca are higher, and Caenis and D. modesta are present in the middle of the creek. The channel is about 8 m narrower and macrophyte growth is very dense throughout the width of the channel. This increased shelter and smaller channel width likely accounts for these higher occurrences. Most of the lotic-depositional species collected at site 1 are also present in similar numbers at site 2. The appearance of three additional insect genera does not particularly distinguish this site from site 1. Leptocerus is a shredder herbivore common to lentic habitats with vascular hydrophytes. Laccophilus, one of the few Coleoptera collected, is predatory and common in depositional areas. Ophiogomphus, a burrowing odonate can be thought of as transitional as it is common to both depositional and erosional lotic environments. The Hirudinea and Haplotaxidae are also common to both lentic and lotic systems. It is not surprising that the burrowers, climber-sprawlers and collector-gatherers dominate this site as they do at site 1. The increased densities might just be a result of random distribution, but the absence of a lentic open water zone, and increased influence from the closer riparian zone could have contributed also. Influences of predators are discussed below.

The most drastic change in habitat occurred at site 3. The riffle at this site, having higher species richness reflects the lotic characteristics at this site: high discharge, large substrata, and increased woody debris. The hydropsychids *Cheumatopsyche*, *Hydropsyche*, and *D. modesta* were the most numerically dominant insect taxa. These are all commonly found in erosional areas and are net spinners. The densities of *Cheumatopsyche* and *Hydropsyche* were much higher than any other genus at any sample site. There were some protected bays of the riffle that had a slower current and a soft mud substrate. This would account for the presence, in smaller numbers of the caddisflies *Pycnopsyche*, *Nyctiophylax* (filterer), *Polycentropus* (burrower) and *Ceraclea* (shredder-herbivore), all commonly found in depositional and erosional lotic systems. *Chimarra* was collected only occasionally and is a filterer common to erosional areas. Trichoptera is by far the numerically dominant order at this site. The ability to cling to rocks and collect food by filtering makes caddisflies particularly well adapted. The species richness at site 3 is also higher. Clingers *Baetis*, *Isonychia* (both Ephemeroptera), and *Stenelmis* (Coleoptera) are common in lotic-erosional habitats. The predators *Nigronia* (Megaloptera), *Acroneuria*, *Progomphus*, *Ophiogomphus*, and *Boyeria vinosa* (all Odonata) are either clingers or burrowers and benefit from the varying substrate and discharge of the riffle area. The abundant caddisfly larvae and chironomids are likely prey for these bottom-dwelling predators. Gastropoda and Pelecypoda also occur in very high densities at this site. They take advantage of the available refuge in substrate and debris. It appears that discharge and substrate of the riffle area play a major role in distinguishing this community from the first two sites. Only two genera found in the riffle, *Baetis* and *Ophiogomphus* are also found at the upstream sites. Sampling of the pools upstream of the riffle showed a chironomid assemblage similar to that at the first site. Gastropoda and Pelecypoda were found in similar numbers to site 1 as well. *Baetis* and *Glyphopsyche irrorata* also were found in pools upstream of the riffle. The remainder of organisms represent primarily riffle taxa (e.g. Hydropsychidae) although they occur in lower numbers.

The riffle community at site 4 is very similar to site 3. The site 3 pool was sampled 500 m downstream of the riffle and revealed another aspect of the lentic-lotic system. The pool contains representative populations of Chironomidae, Tabanidae, Ceratopogonidae, Gastropoda, and Pelecypoda similar to those found at the first two sites. *Ophiogomphus* is the only other insect taxon represented at sites 1, 2, and 4. *Ephemera* is a burrowing mayfly common to lotic and lentic depositional habitats and *Perithemis*, a sprawler, is common to lotic depositional areas. These two genera were not collected at other sites. It is apparent that whereas this habitat is very similar to that at site 1 and 2, the 3 km stretch of creek upstream of this site possesses variations in morphology and habitat quality that have prevented organisms associated with the lake from colonizing.

Predator-prey relationships in the benthic community largely determine the abundance of component organisms. This relationship also determines the fish community structure in a given habitat. Substrate, discharge, and depth are other factors that could account for differences in fish populations. Because fish travel greater distances than benthic organisms during the course of this study, it is more relevant to discuss their dependance on the lake system especially at the first two sites. Biological characteristics of the resident fish taxa were taken from the literature (Becker 1983, Eddy and Underhill 1974).

Of the ten species present at site 1, the *A. rupestris*, *P. flavescens*, *L. gibbosus*, and *L. macrochirus* are abundant insectivores common to both lakes and streams. The insect population associated with this densely vegetated littoral zone supports their presence by providing an abundant food source. The diverse size-structure of these fish taxa suggest that many age classes appear at this site. *P. nigromaculatus* is another insectivorous sunfish common at site 1, however it also has some piscivorous habits. Single specimens of *N. crysoleucas* and *L. cornutus* were collected at this site. These low numbers are probably a result of susceptibility to predation by *S. vitreum*. Adult *S. vitreum* collected in the mouth and many parts of the lake show this piscivore to be prevalent in the system. We angled piscivorous *M. dolomieui* and *M. salmoides* in the lake very near the mouth of the outflow, but none were collected in the creek. *S. vitreum* and *Micropterus spp*. are natural enemies (Niemuth 1959 as cited in Becker 1983). *S. vitreum* appears to have out competed *Micropterus spp*. in the creek as we find substantial populations at sites 1 and 2. *S. vitreum* feeds primarily on darters, minnows, and perch (85% of diet) with insects making up the balance (Courey 1935 as cited in Becker 1983). Turtles, otters, and beavers also eat fish at this site.

At site 2 we again see a population of *S. vitreum*. It is likely that these fish forage downstream to take advantage of the large minnow population. Greater numbers of *L. cornutus* and the common collection of *N. heterolepis* made this an ideal site for *S. vitreum* feeding. A large insectivore *C. commersoni* seems to be relatively common and feeds from the substrate at this site. Two other small species, *E. exile* and *U. limi* were collected and are common in slow-moving shallow water with hydrophytes and feed on amphipods and insect larvae. The large populations of *H. azteca* and Chironomidae serve as an abundant food source for *E. exile* and *U. limi* as well as for *A. rupestris*, *P. flavescens*, and *Lepomis spp*.

The fish populations at site 3 are directly influenced by the morphology of the channel as we might have suspected. The riffle population is dominated by *L. cornutus* and *S. atromaculatus* that may prey on the large hydropsychid populations. N. heterolepis, A. rupestris, and P. flavescens were found only occasionally in the riffle. For the most part, the sunfish and perch were smaller than those collected at the first two sites and much less abundant. They were found more often in the pools where they are less susceptible to predation but close enough to feed in the riffle. The minnows were more abundant in the riffle because of available spawning areas (males were commonly seen circling nests). P. nigromaculatus, although collected at this site, are more commonly found in larger pools of rivers. It is likely found in this area to take advantage of the available food resources. The absence of large fish, especially S. vitreum can be attributed to the distance from the lake. The abundance of minnows would tend to lure piscivores to this area. However, because this site is so far from the open water of the lake, the large fish are susceptible to predation by eagles, turtles, bears, beavers, and otters. Escape to deeper water is not possible from this site.

The small size-structure of A. rupestris, P. flavescens, and Lepomis spp. populations present at site 4 suggests that younger fish tend to be more common in downstream areas. In addition, L. cornutus and S. atromaculatus also are common. Another insectivore collected at this site C. cognatus provides more evidence that fish with insectivorous feeding habits predominate in this area. The one particularly interesting feature of site 4 is that N. heterolepis was the most abundant species in the riffle, whereas L. cornutus and S. atromaculatus dominate the riffle area at site 3. The two riffles are extremely similar, and I can only speculate on reasons for this distribution.

The two determining factors of the fish distribution are the availability of benthic populations and refuge from predators. For the fish populations in general, distance from the lake was an integral factor in the decrease in size-structure of the fish populations. The study site appeared to be large enough to establish where species tended to be found along the gradient. S. vitreum is the best example of this range determination as populations are high in the lake and decrease further downstream. It has been shown that these larger fish inhabit waters that are deeper for protection from predators, while the smaller fish inhabit shallow, fast-moving areas for the same reason (Gormon in Matthews and Heins 1987). It has also been shown that fish will take risks to find abundant food sources (Fraser, Dimattia, and Duncan in Matthews and Heins 1987).

The water analysis of the system does not seem to be an important factor determining the distribution of fish and invertebrate populations. However, a pattern does exist that explains the morphological dynamics of the water system in the D.O. and pH . The alkaline pH and high D.O. at site 1 are characteristics similar to those in the lake. The higher acidity and lower oxygen content at site 2 could be a result of the slow moving water being more protected from wind and thus less mixed. The water takes on characteristics of more stagnant bodies Because it is not as susceptible to wave action, it does not come in contact with air as much, and does not move acidic allochthonous material (leaves, woody debris) as well. The winding stretch also contains large amounts of macrophytes and visible algae. This primary production would also contribute to a low pH. The riffle areas then cause the water to become saturated with oxygen as the fast current aerates it. Both riffles show higher D.O. levels than the adjacent pools, and the pH increases as the water mixes and the organic material is rapidly moved through the channel. The riffles show chemical parameters characteristic of smaller streams.

The basic controls over this lentic-lotic system are those that govern many systems. The distribution of organisms is supported by the mechanisms that allow for nutrition and avoidance of danger. Relating these mechanisms to the habitats created by physical factors of the system, we are able to establish a baseline survey of trophic interactions that maintain the observed structure. The survey of the Tenderfoot Lake-Creek system is only representative of one set of physical inputs, but hopefully some of the trends established will be applicable to aspects of many lentic-lotic interactions.

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APPENDIX

ORIGINAL DATA

KEY
VA = very abundant
A = abundant
C = common
R = rare

SITE 1

A. FISH

1. Fike Net (74)

3 walleye	*Stizostedion vitreum*
6 black crappie	*Pomoxis nigromaculatus*
45 rock bass	*Ambloplites rupestris*
1 golden shiner	*Notemigonus crysoleuces*
11 pumpkinseed	*Lepomis gibbosus*
1 common shiner	*Luxilus cornutus*
6 yellow perch	*Perca flavescens*
1 bluegill	*Lepomis macrochirus*

2. Angling (crawlers)

yellow perch	A	
bluegill	C	
pumpkinseed	A	
rock bass	A	
small mouth bass	R	*Micropterus dolomieui*
large mouth bass	R	*Micropterus salmoides*

3. Minnow Traps

yellow perch	A
rock bass	A
bluegill	C
pumpkinseed	C

B. INSECTS 5/30

1. Left side Ekman (0.5 m)
   - 9 Chironomidae
   - 18 Taltridae *Hyallella azteca*

- 1 Tabanidae _Chrysops_
- 1 Caenidae _Caenis_
- 2 Limnephilidae _Glyphopsyche_ _irrorata_
- 1 Pleurocoridae _Gyraulus_
- 3 Physidae (A shell only)
- 1 Pelecypoda (C shell only)

2. Middle Ekman (1.3 m)
    - 13 chironomidae
3. Right side Ekman (0.5 m)
    - 1 Odonata Cordulgastridae _Cordulgaster_
    - 3 Lestidae _Lestes_
    - 21 Chironomidae
    - 11 _Caenis_
    - 2 Baetidae _Baetis_
    - 41 _H_. _azteca_
    - 1 Ephemerillidae _Attenella_
    - 2 _Diplectrona_
    - 3 Physidae (C shell only)
    - 1 Pelecypoda (C shell only)
    - 2 Decapoda _Palneumidae_ _Macrobrachium_

Insects 6/28

1. left side Ekman (0.5 m)
    - 36 Chironomidae
    - 7 Annelida
    - 4 _Gyraulus_
    - 23 _H_. _azteca_
    - 2 Physidae
    - 2 Pelecypoda
    - 5 _Caenis_
    - 2 Psychodidae
    - 3 Ceratopogonidae
2. middle Ekman (1.3 m)
    - 17 Chironomidae
    - 1 _Caenis_
    - 8 _H_. _azteca_
3. right side Ekman (0.5 m)
    - 4 _Caenis_
    - 21 Chironomidae
    - 1 Glyphopsyche irrorata
    - 4 _H_. _azetca_

C. Chemistry 6/28

Lentic-lotic Interactions

1. left side h1145 (0.5 m)
   - pH- 7.90
   - O_2- 7.7
   - air temp. - 27 C
   - H_2O temp. - 26 C
   - Cond.- 96.9 micro S/cm
   - NO_3- .03 mg/L N NO_3- L
   - PO_4- 1.81 mg/L PO_4^{3-} -PV

2. middle h1150 (1.3 m)
   - pH- 8.09
   - O_2- 7.5 1M- 7.2
   - air temp.- 27 C
   - H_2O temp. - 26 C
   - Cond. - 101 micro S/L
   - NO_3- .02 mg/L N NO_3- L
   - PO_4- 1.57 mg/L PO_4^{3-} -PV

SITE 2

A. FISH

1. Fike Net
   - 5 Stizostedion vitreum
   - 33 Ambloplites rupestris
   - 1 Notemigonus crysoleucas
   - 4 Lepomis gibbosus
   - 18 Luxilus cornutus
   - 18 Perca flavescens
   - 12 Lepomis macrochirus

2. Angling

yellow perch	C
rock bass	C
bluegill	C
pumpkinseed	C

note: Angling extremely inefficient due to macrophytes at site 2.

3. Minnow Traps

yellow perch	C	
rock bass	A	
blacknosed shiner	C	Notropis heterolepis
mudminnow	R	Umbra limi
Iowa darter	R	Etheostoma exile

B. INSECTS 5/30

1. Left side (0.5 m)
   - 32 Chironomidae
   - 3 Tric. Hydropsyche Diplectrona
   - 2 Lestidae Lestes
   - 1 Annelida Haplotaxidae
   - 16 Amphipoda Taltridae H. azteca
   - 2 Physidae (C shell only)
   - 1 Pleurochoridae Gyraulus

2. middle (1.3 m)
   - 19 Chironomidae
   - 1 Diptera Tabanidae Chrysops
   - 2 Diplectrona modesta
   - 3 Taltridae H. azteca
   - 12 Physidae
   - 7 Caenidae Caenis
   - 1 Pelecypoda

3. Right Side (0.5 m)
   - 21 Chironomidae
   - 23 Hyalella azteca
   - 11 Physidae
   - 3 Pleurochoridae Gyraulus
   - 3 Pelecypoda
   - 2 Leptoceridae Leptocerus
   - 1 Lestidae Lestes
   - 1 Gomphidae Ophiogomphus

Insects 6/28

1. left side Ekman (0.5 m)
   - 16 Physidae
   - 3 Pelecypoda
   - 1 Chrysops
   - 3 Chrysomelidae
   - 3 Annelida
   - 29 Chironomidae

- 8 Caenis
- 2 Psychodidae
- 3 Ceratopogonidae

2. middle Ekman (1.3 m)
    - 1 Gyraulus
    - 14 Chironomidae
    - 1 Glyphopsyche irrorata
    - 6 H. azteca
3. right side Ekman (0.5 m)
    - 14 Physidae
    - 11 Gyraulus
    - 2 Pelecypoda
    - 1 Glyphopsyche irrorata
    - 1 Lestes
    - 69 Chironomidae
    - 116 H. azteca
    - 6 Ceratopogonia
    - 1 Caenis
    - 1 Dytiscidae Laccophilus

C. CHEMISTRY

1. left side 1115h (0.6 m)
    - pH- 6.89
    - O_2- 5.5
    - air temp- 27 C
    - H_2O temp. 26.5 C
    - Cond.- 99.4 microS/cm
    - NO_3- .06 mg/L N NO_3- L
    - PO_4- .45 mg/L PO_4^{3-} -PV

2. Middle 1120h (1.3 m)
    - pH- 7.05
    - O_2- 5.2 1m- 4.7
    - air temp- 26 C
    - H_2O temp- 26 C 1m- 25.5 C
    - Cond.- 103 microS/cm
    - NO_3-.05 mg/L N NO_3- L
    - PO_4- .45 mg/L PO_4^{3-} -PV

Lentic-lotic Interactions

SITE 3

A. FISH
- 1. Fike Net
  - 1 Pomoxis nigromaculatus
  - 9 Ambloplites rupestris
  - 2 Lepomis macrochirus
  - 1 Lepomis gibbosus
  - 1 crayfish
- 2. Angling

bluegill	C
yellow perch	R
black crappie	R

note: Angling difficult due to macrophytes.

- 3. Minnow Traps

common shiner	VA	
creek chub	VA	Notropis venustus
blacknose shiner	A	
rock bass	C	
yellow perch	R	
crayfish	C	

B. INSECTS 5/30
- 1. D-net riffle (0.3 m)
  - 10 Chironomidae
  - Hydropsychidae
    - Cheumatopsyche-------------VA
    - Hydropsyche-----------------VA
    - Diplectrona modesta-----------C
  - 1 Lepistomatidae Lepistoma
  - 4 Isonychia
  - 5 Baetis
  - 1 Aeshnidae Boyeria
- 2. D-net Riffle .3 m
  - 1 Lepistoma
  - 2 Decapoda
  - 14 Chironomidae
  - Cheumatopsyche-------------VA
  - Hydropsyche----------------VA
  - Diplectrona modesta---------C
  - 12 Baetis
  - 1 Boyeria vinosa

Lentic-lotic Interactions

1 Limnephilidae Pycnopsyche

Insects 6/19

1. riffle (collected by Elizabeth Vogel using artificial substrates)
   - Trichoptera-
     - Hydropsychidae
       - Cheumatopsyche--------------VA
       - Hydropsyche------------------VA
       - Diplectrona modesta-----------C
     - Limnephilidae
       - Pycnopsyche
     - Polycentropidae
       - Nyctiopylax
       - Polycentropus
     - Philopotamidae
       - Chimarra
     - Leptoceridae
       - Ceraclea
   - Diptera
     - Tanypodinae
     - Chironomidae
   - Ephemeroptera
     - Baetidae Baetis------------------C
     - Oligoneuridae Isonychia
   - Megaloptera
     - Corydalidae Nigronia serricornis
   - Coleoptera
     - Elmidae Stenelmis
   - Plecoptera
     - Perlidae Acroneuria
   - Odonata
     - Gomphidae Progomphus
     - Gomphidae Ophiogomphus
     - Aeshnidae Boyeria vinosa

Insects 6/28

1. D-net riffle (0.5 m)
   - Pelecypoda-------------------C
   - Physidae----------------------C
   - Gyraulus
   - 2 Boyeria vinosa
   - 10 Chironomidae
   - Cheumatopsyche------------------VA
   - Hydropsyche----------------------VA

   - *Diplectrona*-----------------------C
   - 1 Annelida
   - 2 *Pycnopsyche*
   - 4 *Chimarra*
   - 2 *Polycentropus*
   - 2 *Baetis*
2. middle pool (0.5 m)
   - 10 Chironomidae
   - Pelecypoda-----------------------C
   - Physidae------------------------C
   - Gyraulus-------------------------C
   - 5 *Hydropsyche*
   - 3 *Cheumatopsyche*
   - 1 *Pycnopsyche*
3. left side pool (1.3 m)
   - 15 *Hydropsyche*
   - 8 *Cheumatopsyche*
   - 19 Chironomidae
   - 3 *Diplectrona*
   - 5 Pelecypoda
   - 2 Gyraulus
   - 2 *Baetis*
   - 1 *Glyphopsyche* *irrorata*

C. CHEMISTRY

1. Riffle 1500h (0.6 m)
   - pH- 7.91
   - O_2- 9.1
   - air temp. - 27 C
   - H_2O temp- 27 C
   - Cond.- 106.5 microS/cm
   - NO_3-.06 mg/L
   - PO_4-.24 mg/L
   - Total Alkalinity- 58 mg/L

2. Pool 1515h (1.3 m)
   - pH-7.84
   - O_2-8.8 1m- 8.4
   - air temp.- 27 C
   - H_2O temp.- 27 C
   - Cond.- 106 microS/cm.
   - NO_3- .03 mg/L

PO_4- .23 mg/L
Total Alk. 50 mg/L

SITE 4

A. FISH

1. Fike Net

The shallow depth, macrophytic growth, and the limited access to site four made it impossible to set a fike net.

2. Angling

yellow perch	R
rock bass	R

note: While these species were rarely caught angling, this does not accurately depict their true presence because angling was difficult at this site due to macrophytes and access.

3. minnow traps

rock bass	C	
common shiner	A	
creek chub	C	
yellow perch	R	
blacknose shiner	C	
bluegill	C	
slimy sculpin	R	*Cottus cognatus*

B. INSECTS

1.Riffle (collected by Beth Hinchey w/ Surber sampler)

Ephemeroptera

Siphlonuridae

Ameletus-----------------R

Baetidae

Baetis--------------------C

Oligoneuriidae

Isonychia-----------------R

Heptageniidae

Stenacron interpunctatum---R

Stenonema----------------P

Ephemerillidae

Serratella----------------R

Odonata
  Gomphidae
    Hylogomphus-------------P
    Ophiogomphus------------P
Plecoptera
  Perlidae
    Paragnetia media----------R
Trichoptera
  Philopotamidae
    Chimarra-----------------A
  Hydropsychidae
    Cheumatopsyche-----------R
    Hydropsyche---------------A
  Hydroptilidae-------------------R
  Lepidostomatidae
    Lepidostoma---------------P
  Leptoceridae
    Oecetis-------------------R
  Limnephilidae
    Pseudostenophylax uniformis--R
Diptera
  Chironomidae------------------C
  Empididae
    Heterodromia-------------R
  Tipulidae
    Antocha------------------R
Coleoptera
  Elmidae
    Stenelmis-----------------R
    Dubiraphia-----------------R
    Opitoservus---------------R
  Pelecypoda-------------------A
Oligochaeta
  Hirudinoidea----------------C

Insects 6/28
  1. riffle (0.3 m)
    7 *Ophiogomphus*
    1 *Hylogomphus*
    6 *B. vinosa*
    Pelecypoda------------------A

Hydropsyche--------------------A
Cheumatopsyche--------------A
6 Chironomidae
2 *Helicopsyche*
5 Diptera (cases)

2. middle pool (1.3 m)
    6 Chironomidae
    1 Decapoda
    3 Physidae
    1 *B. vinosa*
    1 *Ephemera*
3. left side pool (0.5 m)
    3 Pelecypoda
    1 *Chrysops*
    1 Ceratopogonidae
    1/2 Plecoptera
    Physidae-----------------------C
    Gyraulus-----------------------C
    1 Ophiogomphus
    1 Libellulidae *Perithemis*
    6 Chironomidae

C. CHEMISTRY

1. Riffle 1600h (0.5 m)
    pH-8.47
    0_2-11
    air temp- 27 C
    H_2O temp- 28 C
    Cond. - 104 microS/cm
    NO_3- .05 mg/L
    PO_4- .18 mg/L
    Total Alk. 48mg/L

2. Pool 1615h (1.3 m)
    pH- 8.5
    O_2- 9
    air temp- 26 C
    H20 temp- 27.5 C
    Cond.- 107.2 microS/cm
    NO_3- .03 mg/L

PO_4- .27 mg/L
Total Alk.- 58 mg/L

STUDY SITE DISTANCES:

Mouth to site 1---200 m
site 1 to culvert--- 300 m
culvert to site 2--- 700 m.
site 2 to site 3 riffle--- 1500 m
site 2 to site 3 pool--- 1600 m
site 3 pool to site 4 riffle--- 400 m
site 3 pool to site 4 pool--- 800 m

Total distance- mouth to 4 pool = 3.2 km
mouth to site1 ---200 m
site 1 to site 2--- 1000 m
site 2 to site 3--- 1600 m
site 3 to site 4--- 900 m