COMPARATIVE ENERGY FLOW TO THE FISH COMMUNITY IN A PRAIRIE STREAM AND A FORESTED STREAM USING GROWTH RATE AND STABLE ISOTOPE ANALYSIS

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We compared energy flow to the fish community in two contrasting streams in northwest Iowa. Analysis focused on creek chubs (*Semotilus atromaculatus*) collected from an open prairie stream (Anderson Creek) and a forested stream (School Creek). Creek chubs from the prairie stream had significantly higher growth rates than fish from the forested stream. Mean weights for age 0+ fish increased from 7.4g in the forested stream to 10.3g in the prairie stream. Mean weights for age 1+ fish increased from 12.5g to 22.3g. By contrast, age 2+ fish were comparable in size in the two streams.

These results are consistent with the well-known river continuum concept which predicts increased energy flow to food webs in open-canopied streams due to increased in-stream primary (autochthonous) production resulting from higher light availability compared to heavily-shaded forested streams which rely more on detritus-based (allochthonous) energy sources from the watershed. We attempted to trace shifts in food sources to food webs of the study streams using stable isotopes, however the results were mixed. The $\delta^{15}N$ values for creek chubs from the prairie stream were significantly higher than from the forested stream, although the magnitude of the increase was small (0.5 ‰). There was no difference in $\delta^{13}C$ values in fish from the two streams.

INTRODUCTION

In the upper midwest, prairie streams with open canopies predominate. However, there are scattered forested areas where closed-canopied streams are found. Small forested streams typically have allochthonous-based food webs (Minshall 1967; Fisher and Likens 1973; Cummins et al. 1982), while open-prairie streams have autochthonous-based food webs. Allochthonous-based food webs are supported by substantial inputs of terrestrial plant material with limited autochthonous production due to shading by terrestrial vegetation. Autochthonous-based food webs rely primarily on internal carbon sources such as periphyton as their chief energy source (Minshall 1978; Busch and Fisher 1981). Greater autochthonous production and decreased inputs of terrestrial materials can influence consumer trophic levels within the stream (Murphy and

Meehan 1991). Invertebrates that consume autochthonous energy sources benefit from improved food resources when more sunlight reaches the stream channel, nutrient concentrations are elevated, and algal growth is stimulated (Weber 1981). Such enrichment may also have an impact on higher trophic levels, such as fish.

Analysis of fish growth can be an indirect method of comparing energy flow to contrasting stream ecosystems. In the present study, we compared fish populations from a prairie stream and a forested stream. We focused on creek chubs *(Semotilus atromaculatus)*, the most common predatory fish in the study streams. In addition to standard analysis of fish growth and food habits, we also used stable isotope analysis as an indirect means of studying the flow of organic material through stream food webs (Peterson and Fry 1987). In previous work, Rosenfeld and Roff (1992) found that algal carbon was significantly more ^{13}C depleted (-35.5‰) than terrestrial carbon (-27‰), and Junger and Planas (1994) found that stable isotope values of $\delta^{13}C$ can be used as tracers in providing signatures consistent with allochthonous carbon sources in small shaded streams, while autochthonous carbon signatures are more prevalent in open streams. Despite these findings, other studies have demonstrated an absence of a distinct isotopic signature or an extensive variability among various plant types (Fry and Sherr 1984; Ehrlinger and Rundel 1989). In effect, this may limit the accuracy or usefulness of $\delta^{13}C$ as a tracer in food webs. In a recent review, France (1994) analyzed 803 published measurements of $\delta^{13}C$ for allochthonous litter and both lotic attached algae and consumers, and concluded that for 50% of the fishes and 70% of the invertebrates it was impossible to discriminate between allochthonous and autochthonous carbon dependency based upon $\delta^{13}C$ analysis. In some cases, an enhanced analysis of food sources can be accomplished through the use of $\delta^{15}N$ in addition to $\delta^{13}C$ (Fry 1991). Therefore, we conducted dual isotope analyses in the present study in attempting to trace the flow of allochthonous and autochthonous food sources in two contrasting streams.

STUDY SITES

We selected two second-order study streams in northwest Iowa near the town of Estherville. School Creek, a relatively clear, rocky-bottomed stream runs through the central valley of Fort Defiance State Park, an area characterized by steep valleys with heavy forest cover of deciduous type. It is important to note that at the time when samples were taken from this stream (mid-October, 1997), free-flowing conditions did not exist. Rather, the stream was characterized by intermittent pools separated by stretches of dry stream bed. These conditions were quite different than those of a preliminary sampling effort in the spring of 1997, when School Creek flowed continuously through Fort Defiance Park.

Above the valley in the grassland/cropland area of this region, a few miles from School Creek, is an state preserve called Anderson Prairie. It is characterized by little to no tree cover, and gently rolling hills dominated by smooth brome *(Bromus inermis)*, and switchgrass *(Panicum virgatum)*. Through this preserve runs a small stream similar in size to School Creek, which is identified as Anderson Creek. This creek was free-flowing during both of our sampling periods.

METHODS

A preliminary study was conducted on May 3, 1997 focusing on larger fish. Based on results from this preliminary study, a more comprehensive study was designed for the following fall. Field collections for the second phase of the project were conducted on October 15, 1997. Fish were collected from the study sites using seines (mesh size 4-6mm). In the 150m tract where most of our sampling was done on School Creek, only three large pools existed in the October sampling. These pools ranged in length from 12.5m to 14.0m, with an average width of approximately 3m.

Back at the laboratory, fish were sorted by species using a taxonomic key by Eddy and Hodson (1982). The creek chubs were measured for total length and weighed. Scales were removed from both the medial and posterior flank of the largest 25 creek chubs collected from each of the two creeks. An approximate growth rate analysis can be made by aging fish through an interpretation of annual layers laid down in the hard parts of fish, most commonly scales, in conjunction with current size measurements (Graham 1929, Everhart et al. 1953). In order to increase accuracy of our age estimates, each fish was aged independently by two different researchers until both agreed on the correct age. In some cases, large numbers of scales were examined before a useful sample was found.

The stomach contents of several of the Creek Chubs from each site were examined qualitatively under a dissecting scope. We also measured stable isotope values of both carbon and nitrogen on the 15 largest chubs from each stream. Analyses were made on white muscle tissue following lipid removal using a chloroform/methanol extraction (Bligh and Dyer 1959). The remaining muscle tissue was dried overnight at room temperature, freeze dried, and then ground into a fine powder using a mortar and pestle. Samples were then treated with 1 N HCl for 24 hrs. to remove any potential carbonates (Rounick et al. 1982), rinsed with distilled water, and dried at room temperature prior to isotopic analysis. Samples were weighed into foil containers and combusted in a Carlo Erba CHN Analyzer. The remaining CO_2 and nitrogen gasses were then analyzed for stable isotopes with a SIRA-10 isotope ratio mass spectrometer. Carbon samples were standardized to Peedee Belmnite and the nitrogen samples to atmospheric nitrogen. Precision was better than 0.2‰ for C and 0.5‰ for N. Isotope values were calculated as:

$$\delta^{13}C \text{ or } \delta^{15}N = \frac{X_{sample} - X_{standard}}{X_{standard}} \times 1000$$

where X= $^{13}C/^{12}C$ or $^{15}N/^{14}N$.

RESULTS AND DISCUSSION

Growth Data

Creek chubs collected from Anderson Creek and School Creek fell into 3 to 4 age groups (Figure 1). These age groups ranged from the young-of-the -year (YOY), or 0+ age group, to two 3+ age group fish from School Creek. Comparative statistical analyses using 2-way ANOVA were performed to compare size of creek chubs of various ages from the two creeks based upon length as well as weight (Table 1). Overall growth rates were significantly higher in Anderson Creek than School Creek (Figures 2&3, Table 1). There was a significant interaction between age and weight ($p<0.05$), indicating that the difference in size between the two creeks was not uniform across all ages (Table 1). Comparison of individual age class indicated significantly higher growth rates for 0+ and 1+ fish in Anderson Creek but no difference for 2+ fish (Figures 2&3). Mean lengths for age 0+ fish increased from 9.7cm in School Creek to 10.8cm in Anderson Creek, while the mean weights for these fish increased from 7.4g to 10.3g. For age 1+ fish, mean lengths increased from 11.6cm to 13.8cm, while mean weights increased from 12.5g to 22.3g.

The increased growth of creek chubs in the open prairie stream (Anderson Creek) may have resulted from increased invertebrate production, the primary food source of creek chubs, due to the generally higher protein content and digestibility of algae and algal-based detritus compared to most allochthonous plant material in the forested stream (Triska et al. 1975). Moreover, increased light availability in the open-prairie stream may have stimulated autochthonous production, as reported in other studies (Bilby and Bisson 1992). In addition, immediately upstream of the study site, Anderson Creek flows through a pasture heavily laden with grazing cattle, which may also have stimulated autochthonous production through increased nutrient loadings from animal waste material.

Our growth rate data suggests there may be a period of critical growth for creek chubs climaxing near the end of the second growing season, when nutritional variability and enrichment may have its greatest impact on creek chub growth. After the first two years of growth, the nutritional benefits of the prairie stream may diminish, allowing those fish from a forested stream such as School Creek to catch up in size to their autochthonous counterparts (Figures 2&3). The older surviving chubs are likely more mobile and may move to favorable feeding areas whereas younger fish may be restricted to smaller feeding areas.

Our field data lends further evidence of a more favorable environment for creek chubs in Anderson Creek. We noted greater survival among the young age classes in Anderson Creek than School Creek (Figure 1). We actually collected more age 1+ chubs from Anderson Creek than age 0+ chubs, while our collections in School Creek showed a marked reduction of age 1+ chubs compared to age 0+ chubs (Figures 1a & 1b). Additionally, the reduced water volume in School Creek observed in the Fall of 1997 likely limited the feeding areas available to the creek chubs creating an intensified competitive feeding situation in which the increased mobility of the older fish would have been a great advantage. Finally, it is also possible that the small sample size (n=10) of the 2+ age groups limited our ability to discern growth rate differences in these older fish. We had a much larger sample size for the two younger age classes (0+, n= 137).

In a preliminary study in the Spring of 1997, stream flows were higher, and we collected a larger number of older creek chubs from both creeks. Analysis of these fish also provides evidence for enhanced fish growth in Anderson Creek (Figure 4). For age 3+ creek chubs, the weight of creek chubs from Anderson Creek was significantly greater than School Creek ($p<0.05$, t-test). Although we caught significant numbers of smaller creek chubs in the spring of 1997, we released most of them and thus did not have sufficient numbers for statistical comparison.

There was no appreciable difference in length vs. mass ratios for the creek chubs from the two streams (Figure 5), indicating that creek chubs reaching a given length have similar mass in both streams. Although nutritional status appeared to differ in the two streams, the basic developmental growth patterns of the fish appeared unaffected. Although the 0+ and 1+ fish in School Creek were smaller, their condition factor was nearly identical to fish from Anderson Creek.

Stable Isotope Analysis

Mean $\delta^{13}C$ values for creek chubs were not statistically different for the two streams (Figure 6). The mean $\delta^{13}C$ value for Anderson Creek chubs was -23.82‰ compared to -23.74‰ for School Creek (Figure 6). By contrast, the mean $\delta^{15}N$ value was significantly higher in Anderson Creek (mean = 13.65‰) than School Creek (mean = 13.17‰) (Figure 7).

There are several possible explanations for the nearly identical $\delta^{13}C$ values in fish from the two streams. First, the diet of the chubs from both streams could be based on similar carbon sources which would result in analogous $\delta^{13}C$ values in the fish. Such an explanation would be in conflict with previous conjectures concerning the relative importance of allochthonous and autochthonous food sources in prairie and forested streams. However, in a recent review, France (1995) concluded that the overlap in $\delta^{13}C$ values for allochthonous and autochthonous carbon sources makes it impossible to discriminate between carbon dependencies in many stream ecosystems. Therefore, an alternative explanation could be that the carbon sources of the fishes' diets from our two streams are different, but that the different food sources possess nearly identical $\delta^{13}C$ values. This possibility remains open as we did not measure isotope ratios in potential food sources in this study.

Previous studies have shown $\delta^{15}N$ values to be an effective indicator of trophic level with an increase of 1.5-5% per trophic position due to a mass-dependent isotopic fractionation during nitrogen excretion (Cabana and Rasmussen 1994). The slightly higher $\delta^{15}N$ for chubs in Anderson Creek could indicate higher trophic placement for these fish (Figure 7). This interpretation lends further support to our previous conclusions about the Anderson Creek food webs in that a broader trophic spectrum with additional intermediate levels may indicate a more productive system capable of supporting a more elaborate trophic system. Nevertheless, one must be careful not to place too much emphasis on this point as $\delta^{15}N$ values only differed by 0.5‰ between the two streams.

Stomach Contents

In addition to stable isotope analysis, we also analyzed stomach contents of chubs as an indicator of food sources. Many components encountered in fish stomachs are either unidentifiable (e.g. detritus) or non-plant items (e.g., animals) and thus contain no apparent information about the original plant carbon source (Forsberg et al. 1993). In addition, the identifiable components in a fish's stomach may actually represent the least digestible elements in its diet. Finally, stomach contents only provide a snapshot of the immediate food sources. By contrast, fish growth and isotope values are integrated over the lifespan of the fish. Nonetheless, qualitative observations of stomach contents of the creek chubs were indicative of stream conditions and food availability at the time of capture. Stomach contents of the largest chubs from Anderson Creek contained a variety of identifiable material including snails, beetle exoskeletons, earthworms and insect appendages. In comparison, the stomachs of all the School Creek chubs evaluated were either empty, or contained amorphous organic material that was not identifiable. It is worth recalling the physical conditions of School Creek at the time of sampling which more than likely contributed to depleted stomach contents; the stream flow was non-existent, fish were confined in pools where the food supplies would likely have been depleted. Qualitative analysis of stomach contents collected during the Spring of 1997, when both creeks were free-flowing, indicate that the stomach contents were comparable, including adult Midge larvae *(Tendipes)* and adult Black Flies *(Simuliidae)*, at the time of study, suggesting food availability was different in the Spring of 1997 than in the Fall of 1997.

CONCLUSIONS

Results from this study suggest that the open prairie stream (Anderson Creek) may be more productive than the forested stream (School Creek), as revealed by analysis of creek chubs, a common top-level consumer. This conclusion is based upon significantly higher age/length and age/weight growth rates, increased survivorship, greater $\delta^{15}N$ values, and higher quality of stomach contents of creek chubs in Anderson Creek compared to School Creek. It is also possible that the periodic cessation of stream flow in School Creek contributed to reduced growth and development of fish in that stream compared to Anderson Creek, which remained free-flowing all year.

A long-term study, gathering data throughout the year would likely contribute to more definitive conclusions as to the structure and dynamics of these stream ecosystems. Additional research on other components of the ecosystem including primary production, macroinvertebrates, and water chemistry would also contribute to a better understanding of energy flow through these ecosystems.

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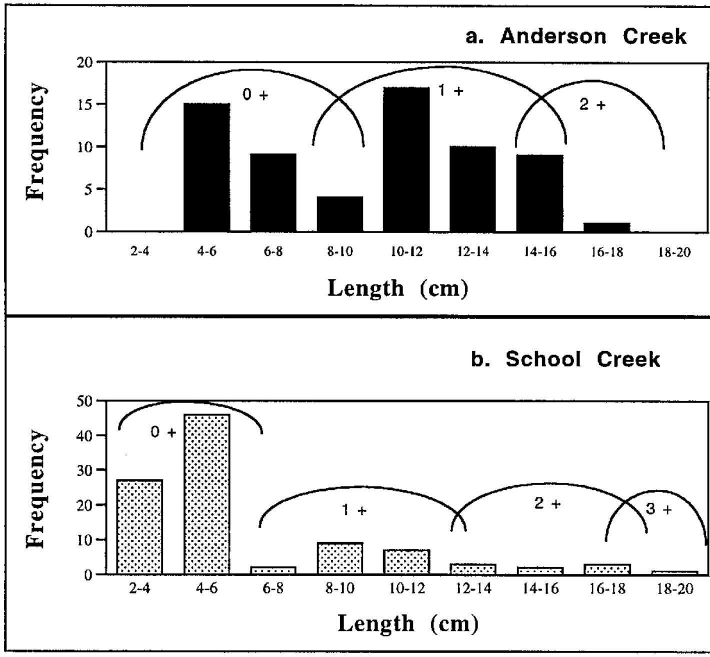

Figure 1. Diagram for Creek Chubs' Length Frequencies with Age Class Estimates in a prairie stream (Anderson Creek) (1a) and a forested stream (School Creek) (1b).

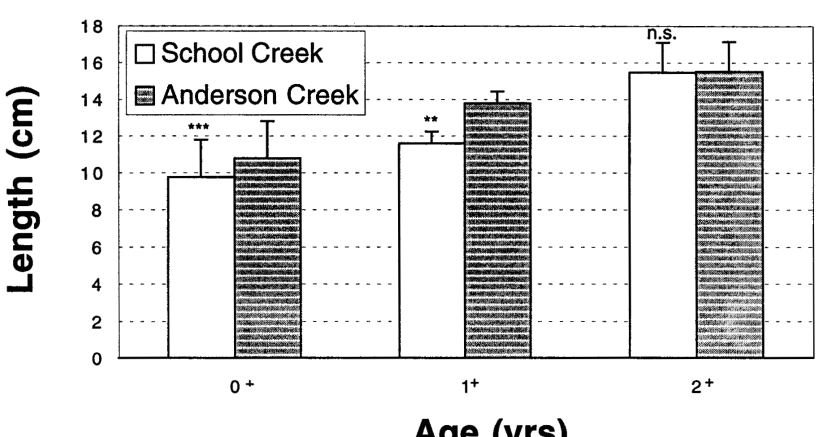

Figure 2. Comparative lengths (mean ± 1SD) of creek chubs from a prairie stream (Anderson Creek) and a forested stream (School Creek). (* = significant at p = 0.001, ** = significant at p < 0.001, n.s. = not significant)**

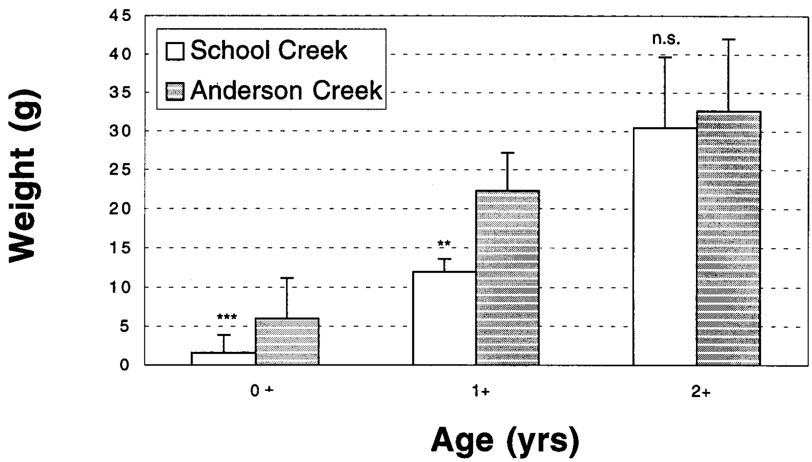

Figure 3. Comparative weights (mean ± 1SD) of creek chubs from a prairie stream (Anderson Creek) and a forested stream (School Creek). (*** = significant at p = 0.001, ** = significant at p < 0.001, n.s. = not significant)

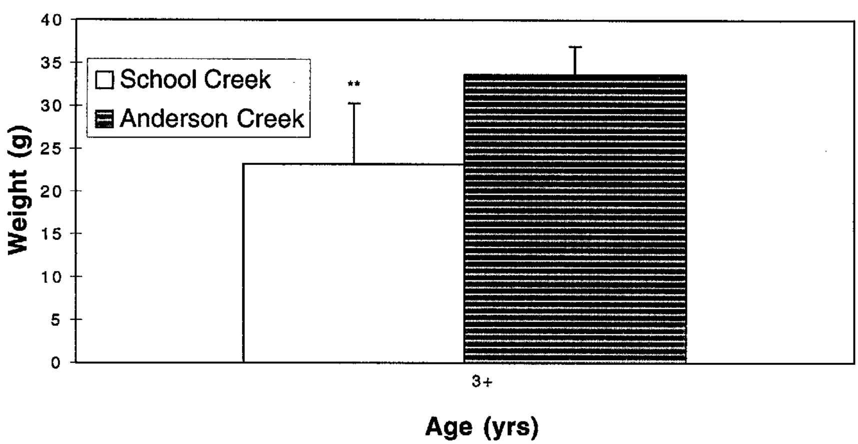

Figure 4. Comparitive growth rates (mean ± 1SD) of Creek Chubs from a prairie stream (Anderson Creek) and a forested stream (School Creek) in the Spring of 1997. (** = significant at p < 0.001)

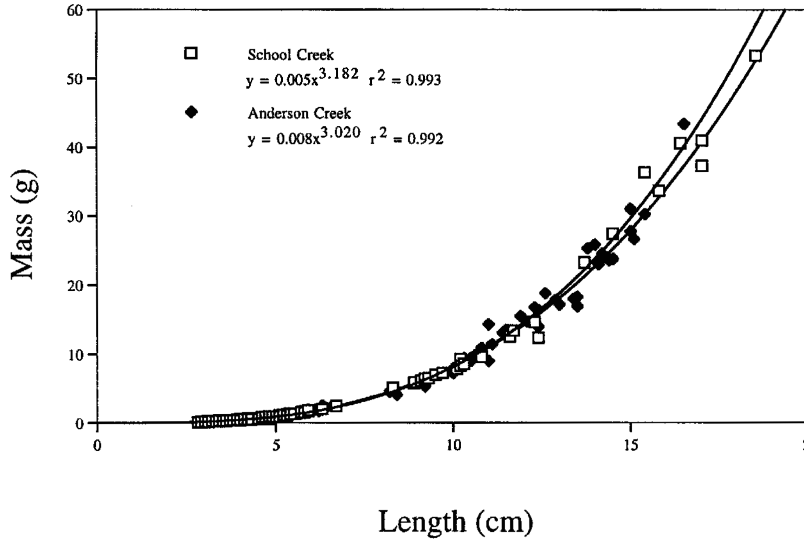

Figure 5. Relationship between length and weight of creek chubs from a prairie stream (Anderson Creek) and a forested stream (School Creek).

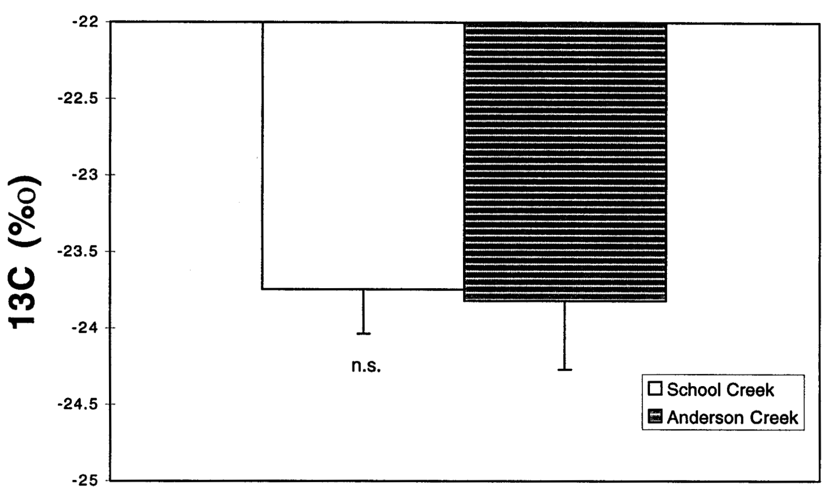

Figure 6. δ13C Values (mean ± 1SD) of creek chubs from a prairie stream (Anderson Creek) and a forested stream (School Creek). (n.s. = not significant)

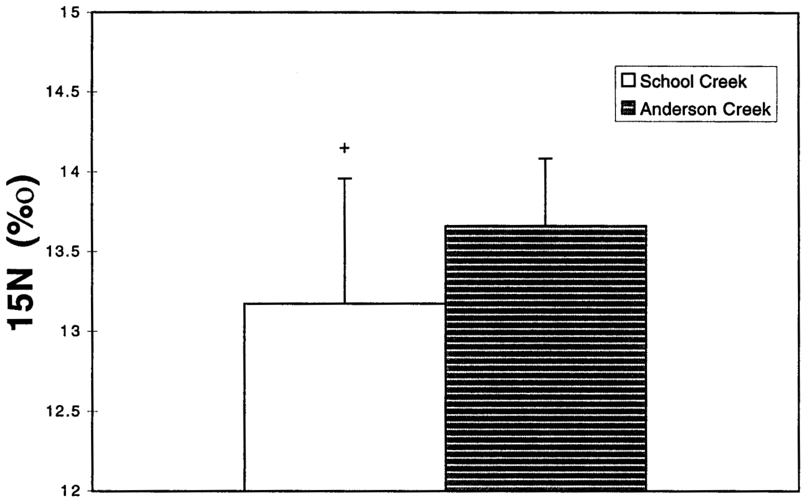

Figure 7. δ15N Values (mean ± 1SD) of creek chubs from a prairie stream (Anderson Creek) and a forested stream (School Creek). (+ = significant at $p < 0.05$)

Table 1a.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Creek	1	41.619	41.619	9.066	0.0030
Age	3	1170.42	390.140	84.988	0.0001
Creek * Age	2	16.101	8.051	1.754	0.1764
Residual	160	734.482	4.591		

Table 1b.

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Creek	1	346.038	346.038	19.603	0.0001
Age	3	11018.96	3672.987	2.08E+02	0.0001
Creek * Age	2	114.743	57.371	3.250	0.0413
Residual	160	2824.330	17.652		

Table 1. Two-way ANOVA for length (a) and weight (b) of creek chubs in Anderson Creek and School Creek.