5-1981

Stream Insect Production as a Function of Alkalinity and Detritus Processing

Thomas G. Osborn

Recommended Citation

Osborn, Thomas G., "Stream Insect Production as a Function of Alkalinity and Detritus Processing" (1981). *All Graduate Theses and Dissertations*. 3759.
https://digitalcommons.usu.edu/etd/3759

STREAM INSECT PRODUCTION AS A FUNCTION OF ALKALINITY AND DETRITUS PROCESSING

by

Thomas G. Osborn

A dissertation submitted in partial fulfillment
of the requirements for the degree
of
DOCTOR OF PHILOSOPHY
in
Wildlife Science

Approved:

Utah State University
Logan, Utah
1981

ACKNOWLEDGEMENTS

I would like to thank Dr. William T. Helm, my major professor, for his interest in this project. His advice was both welcome and stimulating. Also, his provision of materials and facilities made the study possible.

Dr. Vincent A. Lamarra deserves thanks for all his advice on limnological matters. His generous contribution of laboratory space, materials, and assistance is greatly appreciated.

Scott Reger developed the idea of sizing invertebrates using sieves and the time and effort he spent on subsamples and production calculations greatly helped me. The discussions we had on invertebrate ecology improved my understanding of the subject and helped make all those hours in the lab bearable. Finally, I must thank Scott for showing me how to effectively harvest Cache Valley pheasants.

Tim Martin, my scientific angler bugpicker, deserves very special thanks. His knowledge of stream insects gained through years of fly-fishing is remarkable. His enthusiasm at finding a new insect, even after months at the microscope, demonstrates why his presence in the lab made it a pleasant place to be.

I would like to thank Mark Story, forest hydrologist for the Shoshone National Forest for his interest in and assistance with the study and for a warm dry place to stay on a couple of nasty nights.

Bill Clark is a special friend and he spent many hours helping me design the study. We also shared many hours on some of the best darn bird hunts one could ask for.

Bob Davison went through the joys of writing a dissertation at the same time I did and his opinions on style and interpretation were very helpful.

I would like to thank the Utah State University Ecology Center for the support they provided for travel and data analysis.

Finally to Kit, my wife, thanks for the patience, understanding, support, and love.

Thomas G. Osborn

Thomas G. Osborn

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

ABSTRACT

Stream Insect Production as a Function of Alkalinity and Detritus Processing

by

Thomas G. Osborn, Doctor of Philosophy

Utah State University, 1981

Major Professors: Dr. William T. Helm and Dr. Vincent A. Lamarra
Department: Wildlife Science

The study was conducted to determine if aquatic insect production was significantly different between high and low alkalinity mountain streams and if any differences were associated with food availability factors. The major objectives included determining: (1) if annual production differences occur between high and low alkalinity streams; (2) if processing rates of terrestrial detritus differs between high and low alkalinity streams; (3) if detrital processing rates are related to stream insect productivities; (4) if primary productivity varies between high and low alkalinity streams; (5) if toxic effects or micronutrient limitations exist in high or low alkalinity streams that could limit insect survivals. A high alkalinity stream was defined as one having over 150 milligrams per liter average total alkalinity while a low alkalinity stream has less than 50 milligrams per liter average total alkalinity. Six study sites on four high alkalinity streams were located in the Wasatch National Forest near

Logan in northern Utah. Six study sites on four low alkalinity streams were located in the Shoshone National Forest near Yellowstone National Park in northern Wyoming. Sites from each region were shown to not differ significantly for all physical parameters tested.

The mean annual production of 22 of the 29 invertebrate taxa analyzed were significantly higher in the high alkalinity streams, while 2 taxa were significantly more productive in the low alkalinity streams. The mean annual production of all taxa summed was significantly higher in the high alkalinity streams. All high alkalinity sites had significantly higher production than any low alkalinity site.

Alder leaf packs left open to allow invertebrate activity had a significantly higher rate of weight loss in the high alkalinity stream. Alder leaf packs placed inside fine mesh bags to exclude invertebrate activity showed no significant differences in weight loss when the experiments were terminated. The patterns of weight loss for these mesh packs did differ between the two stream types. In the high alkalinity stream, the leaves had a early rapid weight loss phase followed by a period of reduced weight loss. In the low alkalinity stream, the leaves experienced little weight loss during the early phase of the study but lost weight rapidly during the latter phase.

The standing crops of chlorophyll on styrofoam substrates were significantly higher in the high alkalinity streams. Standing crops of chlorophyll for all high alkalinity sites were higher than for any low alkalinity site.

The survivorships of all taxa tested did not differ significantly between high and low alkalinity water.

Estimates of detrital inputs based on drift measurements and standing crops of detritus collected with invertebrate samples showed no significant differences between regions.

The following conclusions resulted from the study. The high alkalinity streams had a significantly much higher production of aquatic invertebrates than did the low alkalinity streams. The high alkalinity streams also had significantly higher standing crops of attached algae and faster processing of alder leaves. Algae and processed allochthonous detritus are two major food sources for many aquatic invertebrates. It is concluded that a major reason for the great difference in invertebrate production between the physically similar high and low alkalinity streams in this study was the availability difference of these two food sources. The insects in the high alkalinity streams had much more of both food types available to them so a much higher annual production of aquatic invertebrates was supported.

(182 pages)

INTRODUCTION

Water Chemistry and Stream Processes

Much work has been done on the breakdown of leaf litter in streams since the Kaushik and Hynes (1968) statement that "autumn shed leaves have received little attention from aquatic biologists." Studies have looked at breakdown rates of various leaf species (Petersen and Cummins 1974), the fungi and bacteria associated with leaf packs (Kaushik and Hynes 1968, Mathews and Kowalczewski 1969, Triska 1970, Barlocher and Kendrick 1974, Suberkropp and Klug 1976), the protein and nitrogen content of leaf packs (Mathews and Kowalczewski 1969, Howarth and Fisher 1976, Davis and Winterbourn 1977), the leaching of material from leaf packs (Wetzel and Manny 1972), the effect of temperature on leaf packs (Suberkropp, et al. 1975, Müller-Haeckel 1977, Short and Ward 1980), the role of shredders in leaf pack processing (Cummins et al. 1973, Petersen and Cummins 1974, Barlocher and Kendrick 1974, Short and Maslin 1977), the role of bottom composition and pack size on processing (Reice 1974), and the effect of stream size on leaf processing (Sedell et al. 1975, Triska et al. 1975). There has even been a model developed for detritus processing in streams (Boling et al. 1975). There have been no studies, however, on the role of stream water chemistry in leaf pack processing.

High alkalinity streams are often assumed to be more productive than low alkalinity streams in terms of aquatic macroinvertebrates, although little scientific evidence exists to support this. Fishermen have long known that the limestone streams of Pennsylvania and the chalk streams of England are richer than the nearby freestone streams, but the reasons were never clear. Some scientists, as by-products of their investigations, have speculated that alkalinity or water hardness may play some role in aquatic productivity. Hynes (1970) reported that water hardness appears to be of some importance to stream invertebrates, but he also stated that this remains to be proved. Ricker (1934) used alkalinity as a variable in his classification of Ontario streams and suggested that high alkalinity limestone streams are richer in biota than the low alkalinity freestone streams. Armitage (1958) found that in the Firehole River, Yellowstone National Park, a significant positive relationship existed between total alkalinity and both numbers and weights of aquatic insects. However, he also found that while Trichoptera showed a significant positive relationship to alkalinity, Ephemeroptera had a significant negative relationship. This data is confusing, for it suggests that in streams dominated by Trichoptera, increased alkalinity would have a positive effect on numbers and weights, while in streams dominated by Ephemeroptera, the same increase in alkalinity would have a negative effect.

Some workers have related alkalinity or water hardness to organisms other than stream insects. Greene (1970) showed a positive relationship between water hardness and fish production in plastic pools, while McFadden and Cooper (1962) showed that growth rate of brown trout was significantly correlated with specific conductance in six Pennsylvania trout streams. Moyle (1956) related productivity of Minnesota lakes to total alkalinity. Osborn (unpublished data), in his study of 95 mountain streams, determined that the above chemical parameters, total alkalinity, total hardness, and specific conductance, had strong positive relationships with each other.

These studies, while suggesting a relationship between insect densities and water chemistry, do not offer any definite evidence that stream insect productivities are related to gross water chemistry. Egglishaw and Morgan (1965), while not working with productivities, did find that levels of bottom fauna were much lower in streams having a concentration of less than 400 micro equivalents of total cations per liter than in streams having higher concentrations of cations. Osborn (unpublished data) found significant positive relationships between alkalinity and biomass of aquatic insects in a number of western mountain streams. This positive correlation existed for all orders found. Standing crop and biomass studies such as these suggest that perhaps stream insect productivities are a function of alkalinity.

Woodland Streams as Heterotrophic Systems

Numerous recent studies have shown that many small woodland streams are heterotrophic systems (Nelson and Scott 1962, Hynes 1970, Cummins 1974, 1975, Cummins et al. 1973, Fisher and Likens 1972, 1973). Fisher and Likens (1973) determined that over 99 percent of the annual energy source for Bear Brook was allochthonous input, while autochthonous primary production accounted for less than 1 percent of the total energy. Nelson and Scott (1962) determined that primary consumer organisms in a Piedmont stream derived 66 percent of their energy from allochthonous materials. In these small woodland streams, the combination of current, water temperatures, and especially, low light availability appear to limit primary production. Production is often less than respiration ($P<R$). Therefore, these systems depend upon input from terrestrial

sources, such as leaves, for energy to drive them. As a result, many stream insects are facultative detritivores, utilizing these terrestrial inputs.

Detritus Processing and Food Availability

One possible mechanism that may work to make high alkaline woodland streams more productive than low alkaline woodland streams is the breakdown rate of terrestrial detrital inputs. Water alkalinity may play an important role in stream productivity by affecting detrital processing rates. Egglishaw (1968) found that in high alkaline streams, rice broke down quicker than in low alkaline streams, even if insects were excluded. Therefore, in high alkaline streams, the organic material brought into the system in the form of leaves may be made available to the insects faster than it is in low alkaline streams. This rate increase would make food available to the detritus eating insects quicker. In food limited systems such as streams (Lellak 1965), an increase in food supply may increase the productive ability of the systems.

An increase in mechanical processing rates can also lead to increased food availability. Detritus decomposition can take place by microbial activity alone (Triska 1970), but an increase of up to 20 percent in the processing rate may occur if shredder organisms are present (Petersen and Cummins 1974). Short and Maslin (1977) have demonstrated, using radiophosphorus labeled leaves, that shredder organisms increase the amount of nutrient material available to collector organisms. When large particles are broken into many smaller particles by shredder activity, more sites are made available for bacterial colonization and more materials are leached into the system. In this way, food becomes more available to collector organisms. A chemical-biological rate increase would likely lead to the same result.

Fate of Detrital Inputs

Incoming terrestrial material initially experiences rapid leaching of organic matter (Wetzel and Manny 1972, Boling et al. 1975). It is then colonized by hyphomycete fungi and bacteria which begin the biological breakdown process (Kaushik and Hynes 1968, Mathews and Kowalczewski 1969, Triska 1970, Barlocher and Kendrick 1974). Since this colonization actually increases the nitrogen and protein content of the leaves (Mathews and Kowalczewski 1969, Howarth and Fisher 1976), the fungi and bacteria apparently use both material from the leaves and dissolved organic material in the stream water as nutrient sources (Barlocher and Kendrick 1974). This material is attacked by organisms that utilize these large particles (shredders), breaking the material into smaller particle sizes (Cummins 1974, Barlocher and Kendrick 1974). This takes place by two processes--the actual shredding of the material which is not ingested, and the passing of the ingested material through the animal back into the system as feces (Cummins et al. 1973). It has been suggested (Kaushik and Hynes 1971, Barlocher and Kendrick 1974, Cummins 1975b) that these shredders derive little energy from the leaves themselves, but get most of their nutrients from the fungi and bacteria that have colonized the detritus. A large portion of the original leaf material is not utilized by the shredders and is excreted back into the system in the feces as fine particulate organic matter (FPOM). This material is recolonized by fungi and bacteria (Madsen 1972, Barlocher and Kendrick 1974) and serves as a rich food source for a number of fine particle feeding detritivores or collectors (Cummins et al. 1973). It is therefore logical to assume that if the colonization and processing rate of detritus is increased, the above process will take place sooner, thereby making more food available to the organisms more quickly.

Another process, that of particle formation from dissolved organic matter (DOM), may also play an important role in food availability in streams. Lush and Hynes (1973) found that the proportion of DOM that precipitates depends on turbulence and the presence of ions, especially calcium, in the water, and the exact sequence of precipitation is much influenced by pH. They discovered in laboratory studies that at about neutral pH, small particles form from the DOM. These grow rapidly, composed largely of microorganisms, and settle out of the water as larger particles. At lower pH, this particle formation is greatly delayed. Therefore, in alkaline streams food created from the DOM apparently becomes available to the organisms much quicker than it does in low alkaline waters.

Food Concentration

In high alkaline streams, large particles may be colonized and processed into smaller particles and dissolved leachate may be turned into particulate matter more quickly. There are time and space factors operating in these examples. Detrital processing rates and DOM particle formation are slower in the low alkaline streams. As a result, the input material and its leachate is likely to move further downstream before becoming available to the organisms. Since streams are one-way systems, materials do not recycle in place but are continually moved downstream. If materials are not utilized when they are in an organism's vicinity, they will flow downstream becoming unavailable to that organism. Therefore, production advantages may be gained in systems with quicker turnover times of detritus and DOM particle formation.

The mechanism operating in these examples appears to be one of food availability rather than food input. Systems that have either low or high detrital turnover rates or DOM particle formation may have the same amount of detrital input, yet the high detrital turnover rate or DOM particle formation system probably has more food available to it. Since the detrital input begins the breakdown process rapidly, it becomes food for the shredder organisms much earlier. The material then passes through the shredder organisms and becomes available to the next level of detritivores earlier. Also, the leachate formed from this input material becomes particulate material more quickly. This is all taking place while the material is moving downstream. When the material is used rapidly, it has less opportunity to move as far as it would if used slowly. The material is used within a shorter span of stream distance which, in effect, concentrates the amount of food available at any point. More food material becomes available to more organisms in a shorter period of both time and space. In nutrient limited systems, this increased availability of nutrients would allow greater productivity.

Primary Production and Toxicity Factors

Other factors may also be operating to make high alkaline streams more productive. A stream with higher primary productivity would likely have a higher productivity of primary consumers resulting in higher secondary productivity for the system. In nutrient limited systems, a higher turnover rate of detritus would make more nutrients available to primary producers thereby supporting a greater number of them. If woodland streams are light or temperature limited, this increase in nutrient supply should have no great effect on primary productivities. In open area streams, where light is not limiting, a higher turnover rate of nutrients may be an important factor in the primary productivity. Where nutrients for plants are limiting, a faster processing rate of detritus, regardless of origin, may improve primary production.

Toxicity factors may also operate to influence secondary productivity. This may be the result of too large a concentration of an element or the scarcity of an essential element that may affect some life process. Minshall and Minshall (1978) determined that in the River Duddon, potassium limited *Gammarus*, not food. In soft water streams, by definition, low concentrations of divalent cations are present. This may be accompanied by a low concentration of many other common elements, making an elemental limitation a real possibility.

If alkalinity is associated with differences in stream processes, it would be valuable to the field of stream ecology to determine what these relationships are and how they operate. The predictive capabilities of stream researchers may be significantly enhanced if the knowledge of a few physical-chemical parameters allowed for the effective prediction of stream properties. More detailed studies of chemical-biological relationships may also result if it can be shown that water chemistry does play an important role in stream productivity.

STUDY AREAS

Site Selection

Sites for this study were chosen to meet the requirements of alkalinity concentration, winter accessibility, and similar physical characteristics. For this study, high alkalinity streams were defined as those having over 150 mg/l average total alkalinity, while low alkalinity streams had less than 50 mg/l average total alkalinity. The high alkalinity sites were located on tributaries of the Logan and Blacksmith Fork Rivers in northern Utah, while the low alkalinity sites were located on tributaries of the North Fork Shoshone River in northwestern Wyoming.

High Alkalinity Sites

Six sites on four streams were located on tributaries of the Logan and Blacksmith Fork Rivers, Wasatch National Forest, Cache County, Utah (Figures 1 and 2). Three sites were located on one stream, Left Fork Blacksmith Fork, to determine if within stream differences were as great as between stream differences within this region. These sites were designated from lower to upper as LFBF(L), LFBF(M), and LFBF(U), and all were located within a 150 meter stretch of river. The upper site was located 15 meters downstream from the first bridge on the Left Fork road, Forest Service #055, approximately 0.5 kilometer from Utah Highway 101. The Left Fork road is a secondary road that connects Utah Highway 101 to U.S. 89 in Logan Canyon. Most traffic is recreational and the road is not maintained in the winter. The middle and lower sites were located approximately 75 and 125 meters downstream respectively from

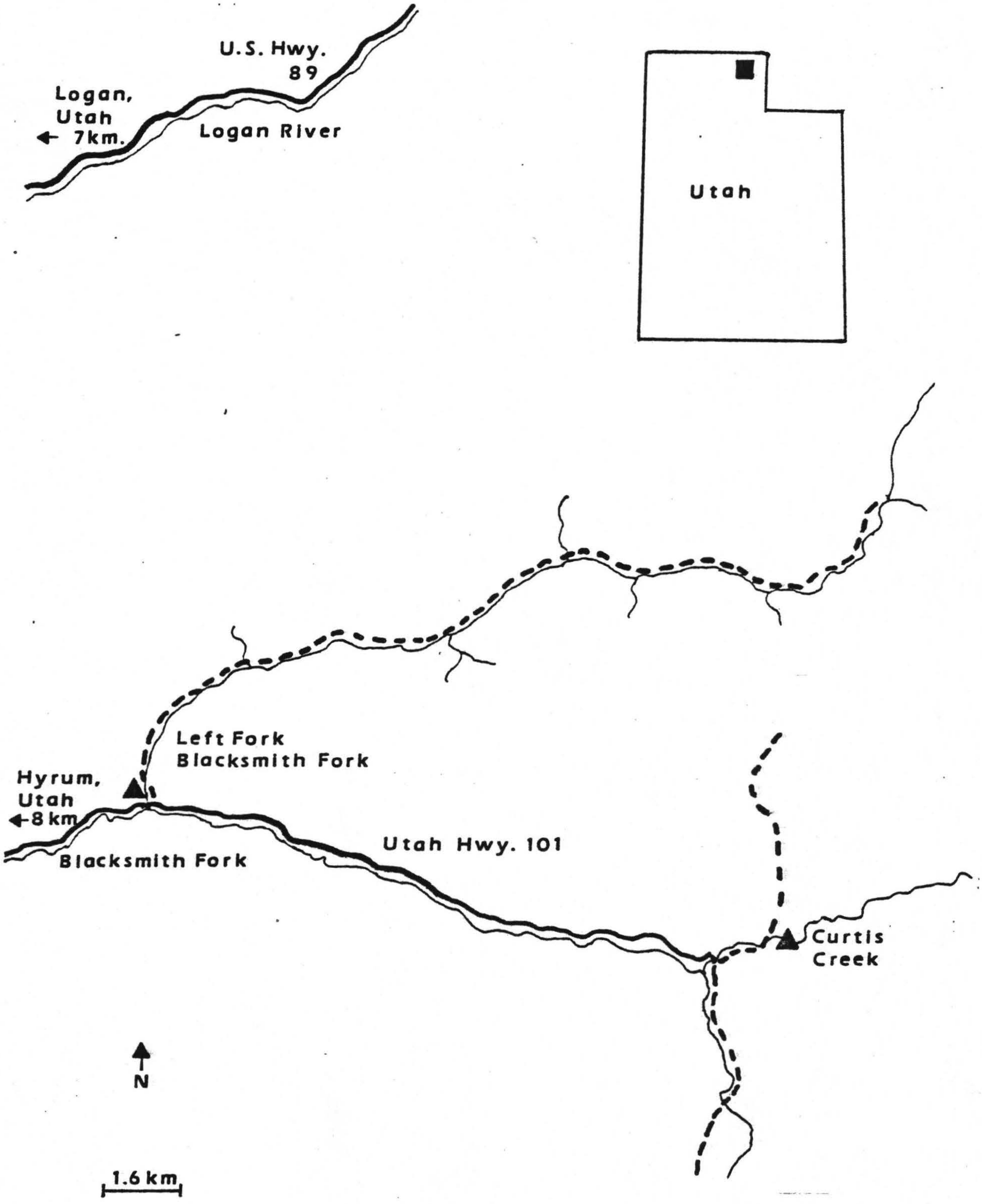

Figure 1. Location of Left Fork Blacksmith Fork and Curtis Creek study sites, Cache County, Utah.

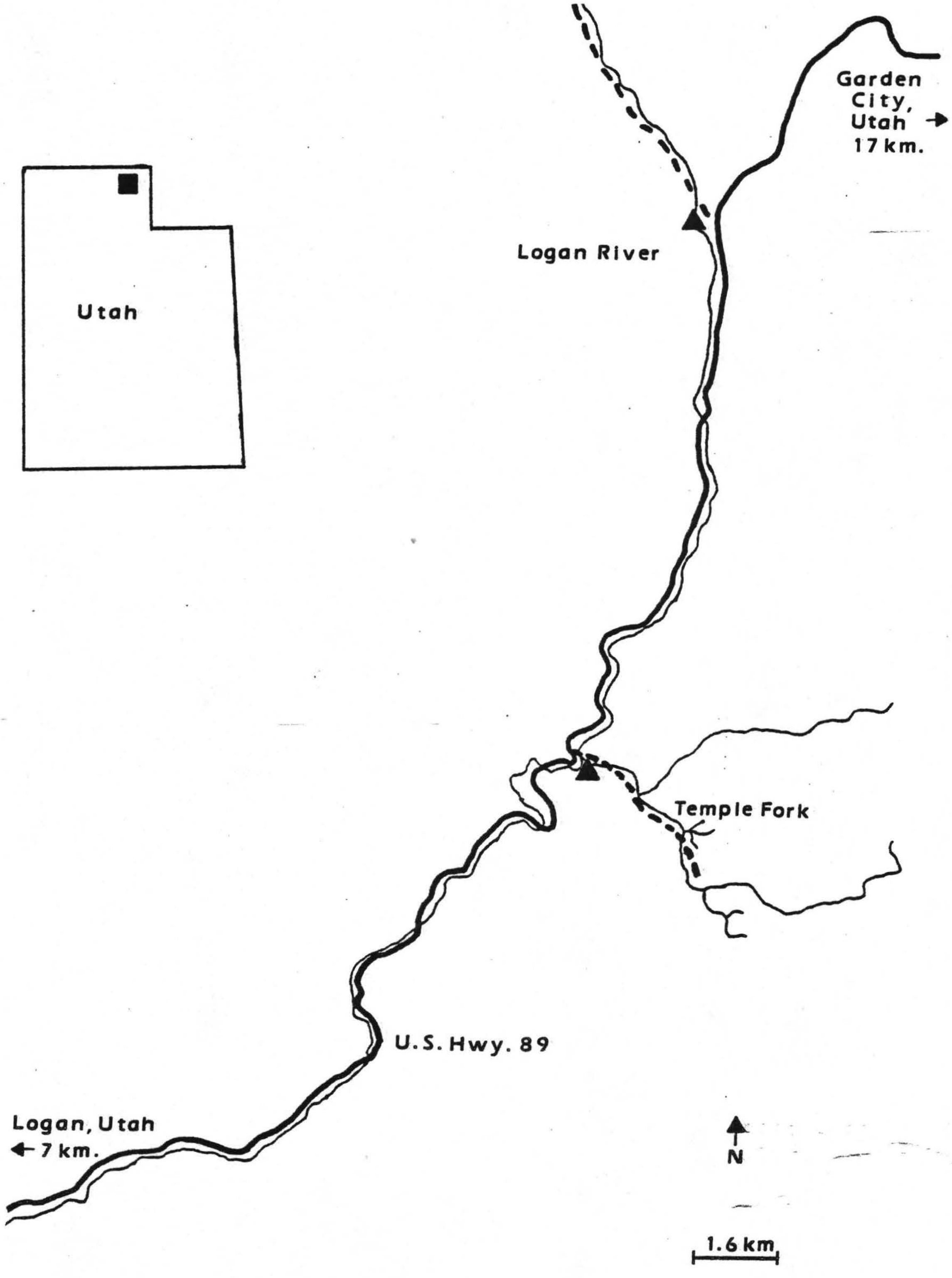

Figure 2. Location of Logan River and Temple Fork study sites, Cache County, Utah.

the upper site. These three sites were quite open with a canopy of large cottonwood trees lining the stream. Brush cover was restricted to the edges.

The Curtis creek site was located near Hardware Ranch Game Management Area, 100 meters upstream from Forest Service Road #054. This site was approximately two kilometers upstream from the confluence with the Blacksmith Fork River and had a moderately heavy shrub and tree canopy.

The Logan River site was located approximately 0.5 kilometer up the Franklin Basin road, Forest Service Road #006, from U.S. 89. The site was approximately 15 meters downstream from the first bridge and was somewhat open, with one large birch overhanging the river and moderate shrub cover along the banks.

The Temple Fork site was located approximately 250 meters upstream from the confluence with the Logan River. This site had a moderately heavy canopy of shrubs and small trees.

Low Alkalinity Sites

Six sites on four streams were located on tributaries of North Fork Shoshone River, Shoshone National Forest, Park County, Wyoming (Figure 3). Three sites were located on one stream, Gunbarrel Creek, to determine if within stream differences were as great as between stream differences within this region. These sites were designated from lower to upper as Gun(L), Gun(M), and Gun(U), and all were located in a 150 meter stretch of stream. The lower site was located approximately 50 meters upstream from U.S. 14. The middle site was located approximately 50 meters upstream from the lower site and the upper site was located approximately

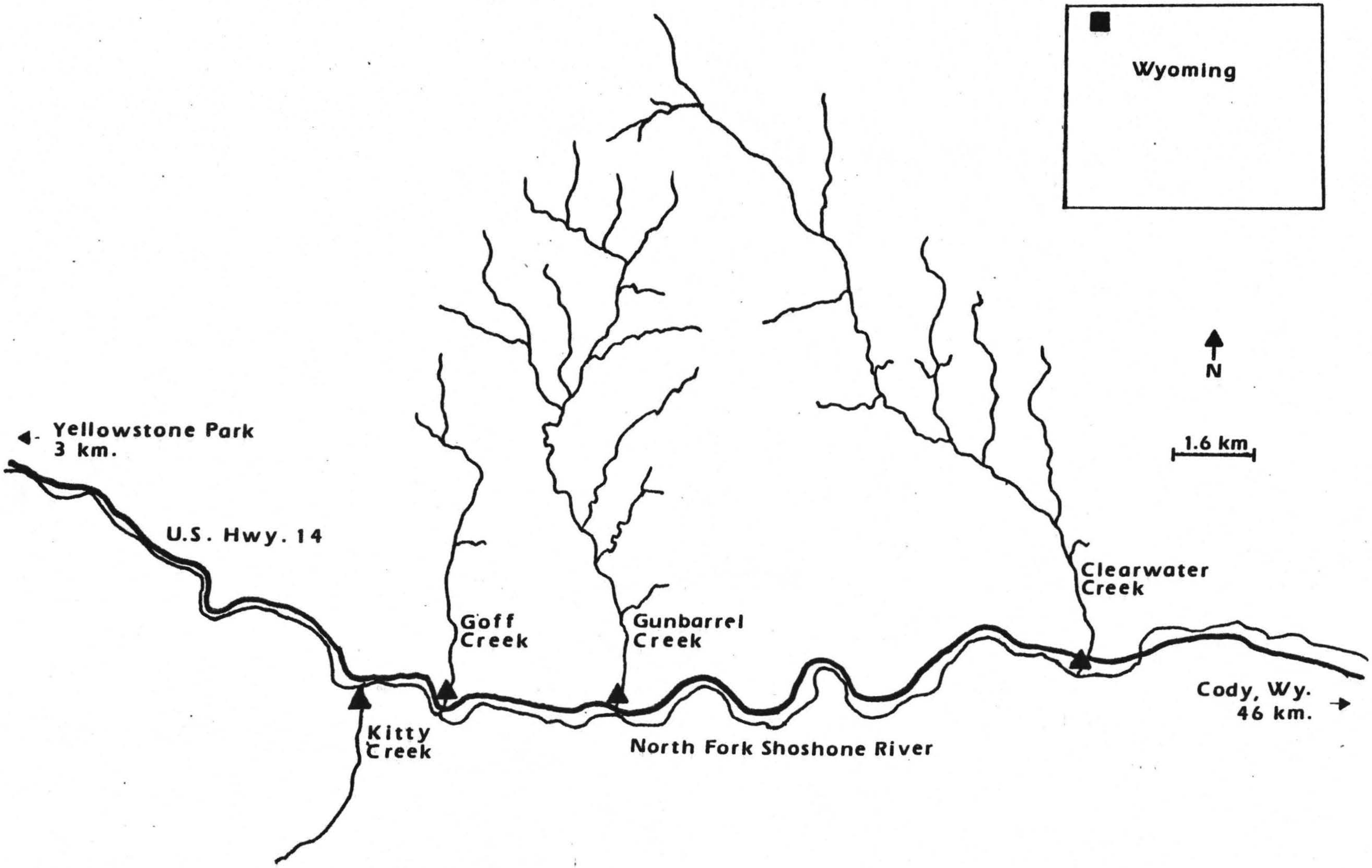

Figure 3. Location of Wyoming study sites, Park County, Wyoming.

70 meters upstream from the middle site. These sites are all moderately open with a heavy cover of shrubs along the banks but open at mid-stream.

The Clearwater Creek site was located approximately 50 meters downstream from U.S. 14. This site was moderately open with dense shrub cover along the banks but open at mid-stream.

The Goff Creek site was located approximately 15 meters upstream from U.S. 14. This site was well shaded, with overhanging shrubs and small trees covering most of the stream.

The Kitty Creek site was located approximately 70 meters downstream from Forest Service Road #446, approximately 40 meters upstream from the confluence with North Fork Shoshone River. This site was moderately shaded, with a dense bank cover of shrubs and with several large firs and cottonwoods rising above the stream.

As a result of a November sub-zero (^{O}F) cold spell, all of the low alkalinity sites in Wyoming were covered with ice for the November sampling period. These same sites were mostly snow covered for the December, January, and March sample periods. This ice and snow cover insulated the stream, resulting in no anchor ice observations, even when sampling was done during sub-zero (^{O}F) temperatures. Most of the Utah high alkalinity streams were free of ice and snow cover during the winter. The Logan River site was an exception to this, with ice cover during the December sampling period and ice and snow cover during the January and March sampling periods. The Left Fork Blacksmith Fork sites were partially ice covered during these winter periods, but also experienced extensive anchor ice formation during the winter sampling periods. Temple Fork and Curtis Creek remained essentially ice and snow free but both sites received no sunlight during the mid-winter period due to the high canyon walls surrounding the sites. This lack of sun resulted in heavy buildups of hoar frost on the overhanging vegetation.

The study areas differed in latitude by approximately 300 kilometers which may have affected solar input slightly. Altitudinal differences were slight.

OBJECTIVES AND APPROACH

Objectives

A primary objective of this study was to determine whether production differences in aquatic insects do exist between high and low alkalinity streams. A second objective was to determine if detrital processing rates differ between high and low alkalinity streams. The third objective was to determine if detrital processing was in any way related to stream insect production. A fourth objective was to determine if alkalinity was related to primary production in streams and if this could be a factor in insect density levels. Objective five was to determine if limiting factors existed in high or low alkalinity streams that could limit insect survivals. The following hypotheses were examined:

H_1: Annual production of stream insects is the same in both high and low alkalinity streams.

H_2: Detritus processing times are the same in both high and low alkalinity streams.

H_3: Annual production of stream insects is not related to detritus processing time.

H_4: Alkalinity is not related to the primary productivities of streams.

H_5: Limiting factors do not affect insect survivals in either high or low alkalinity streams.

Approach

This study was an investigation of possible differences in several biological processes between streams of differing alkalinities. Since the main concern was whether certain processes do differ with alkalinity or water hardness, and because of logistic limitations, the study was limited to streams on the high and low end of alkalinities in natural waters of the mountain west. Streams were selected based on a preliminary study of 95 mountain streams. In this study, the author determined that total alkalinity, total hardness and specific conductance were very strongly correlated. Because of this strong correlation, total alkalinity was used in this study as an indicator of total hardness and specific conductivity. Since the range of waters between these alkalinity extremes was not studied, regression analysis was not a possibility. However, enough replicate sites from each alkalinity region were included to allow statistical comparisons between regions.

Total annual production of aquatic insects was calculated at six sites on four streams from each of two geologic regions. In each region, three sites were on the same stream, within 150 meters of each other. Production was calculated separately for each of these sites and the values compared to determine if the variability between similar sites on one stream was more than the variability between the remaining three streams. The mean of these three same-stream values was calculated and used as a single stream value. This value was used with the values from each of the other three streams for regional calculations and comparisons. In this way, the stream with three sites carried no more weight in the regional calculations than did the three single site streams.

In addition to comparing insect productivities between a high and low alkalinity region, the study also determined productivity differences associated with two important stream processes--production of attached algae and processing rate of allochthonous detritus. Both algae and "processed" detritus are important foods for aquatic macroinvertebrates and any differences in the availability of these foods may affect insect production. Therefore, the availability of these two foods was tested in each region.

Primary production was studied in three streams in each region by determining standing crops of algae (chlorophyll) on artificial substrates. Values were compared to determine if either within or between region differences occurred.

Leaf pack processing rates were studied both in autumn and spring in one stream from each region. Leaf packs were placed in each stream, and the rate of weight loss over time was monitored. Two types of packs were studied, one that allowed access to insects and one that excluded insect activity, to determine if processing rate differences were a function of differing water chemistries or simply differential insect densities.

To determine if the survivorship of insects was a function of water type alone, various insect taxa were placed in both high and low alkalinity water and their survivals monitored over time.

The study was conducted over one calendar year from May 1978 to May 1979, except for some leaf processing work which continued to September 1979.

MATERIALS AND METHODS

Collection Periods

Samples were collected ten times during a one-year period, beginning mid-May, 1978, and finishing April, 1979. These samples were collected at from four- to six-week intervals, depending upon season. During winter months, samples were collected at six-week intervals; during spring and autumn, collections were made at five-week intervals, while during summer, samples were collected every four weeks. This was an attempt to compensate for slower and faster growth rates of insects during the respective seasons.

Water Chemistry

Water samples were collected at each stream during each sampling period. These samples were analyzed for total solids, total dissolved solids, total alkalinity, pH, total phosphorus, total dissolved phosphorus, nitrates, calcium, magnesium, potassium, sodium, and specific conductance. Samples were collected in plastic nalgene bottles and placed in a chilled cooler. Total alkalinity and pH analyses, and the filtration for total dissolved phosphorus and total dissolved solids, were done immediately upon completion of sample collection for a given day. Alkalinity and pH analyses were done using a portable Corning model 610A pH meter and titrated with .025 N solution of H_2SO_4 to pH 4.5. The pH meter was calibrated against pH 9.0 and 4.0 buffered solutions before each round of analyses. Filtration for total dissolved phosphorus and total dissolved solids were carried out using Whatman

GF/C glass fiber filters and a Millipore portable filtering apparatus. Two hundred ml of water were filtered for total dissolved solids and 50 ml for total dissolved phosphorus. Water was filtered into 125 ml Erlenmeyer flasks and sealed with parafilm and aluminum foil.

Total phosphorus and total dissolved phosphorus were analyzed by the ascorbic acid method with persulfate digestion as described in Standard Methods (American Public Health Association 1975).

Total solids and total dissolved solids were analyzed by pouring 200 ml of unfiltered and filtered water respectively into pre-dried and weighed 250 ml beakers. These were placed in an 85°C drying oven for 24 hours, cooled in a dessicator, and weighed on a Mettler model H51 analytic balance.

Nitrates were analyzed by the cadmium reduction method as described in Standard Methods (American Public Health Association 1975).

Calcium, magnesium, potassium, and sodium were measured using a Perkin-Elmer model 303 atomic absorption spectrophotometer.

Specific conductance was analyzed using a YSI model 31 conductivity bridge standardized against a known solution. All readings were corrected to 25°C.

Water temperatures were measured at each stream during each sampling period using Taylor minimum-maximum thermometers.

Aquatic Insects

Aquatic insects were collected at each of the twelve sites during each sample period using a modified Hess bottom sampler with a sampling area of 1380 cm^2 and a 0.250 mm nitex mesh net. During each sample period, three Hess samples were taken in close proximity from areas of similar substrate and water depth. Special care was taken to minimize between site physical differences. The substrate was loosened and stirred to a depth of 10-15 cm and all larger particles were scrubbed to remove attached insects. The three samples were combined in one sample container and preserved in 10 percent formalin in the field. Samples were returned to the laboratory to be processed.

Samples were sugar floated at least three times to remove organic from inorganic material (Anderson 1959). The inorganic sand and gravel was discarded and the organic fraction was washed through a graded series of sieves, one at a time, to separate the sample into size classes. The material retained in each sieve was washed into a sample jar and preserved with 10 percent formalin until sorted. The sieve series used for this study had mesh openings of 4.00, 2.80, 2.00, 1.40, 1.00, 0.71, 0.50, 0.35, and 0.25 mm. These correspond with U. S. standard sieve numbers 5, 7, 10, 14, 18, 25, 35, 45, and 60. This series corresponds to alternate sieves in the test sieve aperature series recommended by the International Standards Organization, Geneva, Switzerland. The log of the opening in mm is highly correlated with sieve size (each sieve size = 1 x axis unit) and can be described by the regression $y = -0.150104311X + 0.749940750$; $r = .999988$ (Reger 1980). The smallest size is the same recommeded by Barber and Kevern (1974) for use in production estimates.

Invertebrates were sorted from detritus by hand using illuminating magnifiers and dissecting microscopes. The larger sieve sizes (4.00, 2.80, and 2.00 mm) were sorted in their entirety. The smaller sieve sizes (1.40 to 0.25) were subsampled when necessary using a mechanical subsampler (Waters 1969a). This subsampler gives statistically random samples (Reger 1980, Elliot 1971). Adequate numbers of subsamples were sorted to give a total invertebrate count of 100. In particularly high density samples, subsamples of subsamples were sorted (Elliot 1971, Cummins 1975).

Identification was made to family, genus, or species, depending upon the insect and the difficulty in keying at the smaller size classes. Samples were dried at 85°C for 12 hours, weighed, ashed at 450°C for 2 hours (Winberg 1971) and weighed to obtain dry and ash-free dry weights for each taxa at each sieve size. The log normalized ash-free weights for each taxa were used to formulate regression equations which were used in the production calculations. The r (correlation coefficient) values for the vast majority of these regression equations were over 0.95 (Appendix III). Separate regression equations were calculated for the Wyoming and Utah representatives of a particular taxon. Since most of the equations were virtually identical for the two regions, they were combined into one equation for each taxon, except for the Chloroperlidae (Plecoptera) and Rhyacophilidae (Trichoptera). For these exceptions, considerable differences in equations for the two regions were noted, so separate equations were used.

Production was calculated using the Hynes or size-frequency method of production estimation (Hynes and Coleman 1968, Hynes 1980, Waters and Hokenstrom 1980) as modified by Hamilton (1969) (Appendix V). One assumption of this method is that an equal amount of time is spent in each size class. Since younger, smaller size groups of insects generally exhibit faster growth than larger size groups, they may grow beyond the smallest size class between sampling periods. For any one particular taxon, this may be remedied by increasing sampling frequencies during this early instar period. However, for a study such as this, which investigates the production of the entire insect community, such sampling modifications are unreasonable. Therefore, as an attempt to compensate for this early rapid growth, the two smallest sieve sizes were combined for production calculations (Minshall 1977). In addition to removing the common negative production between the smallest and next smallest sieve sizes, this correction also reduced the "times lost" factor by one. In most cases, this would have the effect of reducing the final total production figure.

Since it was discovered that several taxa grew beyond the largest sieve size used in this study (4.00 mm), the specimens retained in the largest sieve were resieved through the next three larger sieves in the earlier defined series. These sieves had openings of 5.61, 7.93, and 11.20 mm. These sizes correspond to U. S. series numbers 3 1/2, 2 1/2, and 11.20. The percentages of insects that were retained in each of the above larger sieves were then used as correction factors to be used in the production calculations to determine what number of those originally retained in sieve size 4.00 actually belonged in sizes 5.61, 7.93, or 11.20. Only one taxon grew to size 11.20 mm, but several reached 5.61 and 7.93 mm. These resievings were done before drying and weighing, so the insects that were resieved into larger size classes were included in the calculation of regression equations used in production estimation.

Estimates of mean densities (#/m^2) were calculated for each site using the sample data. Estimates of mean biomass (g/m^2) were calculated using estimates of mean densities and mean weights. Turnover ratios were calculated for each taxon for each site using the calculated production estimates and estimates of standing crop.

Detrital Processing

The rate of allochthonous detrital breakdown for each sample region was measured by placing leaf packs in one representative stream from each region and measuring weight loss of the packs. The streams chosen for this study were Gunbarrel Creek from the low alkalinity region and Temple Fork from the high alkalinity region. In addition to being representative and comparable streams, security factors played a role in choosing these sites for this study. It was decided that these sites afforded the least risk of human disturbance for the duration of the study.

Leaf packs were made from two species present in both study regions, thinleaf alder (*Alnus tenuifolia*) and Douglas-fir (*Pseudotsuga menziesii*). Needles from one Douglas-fir bough were used for the study. These needles were dried for 12 hours at 60°C and weighed into 6.0 gram lots. Samples were placed in nylon mesh bags constructed from nylon stockings with mesh openings of 0.50 mm. The bags were tied to bricks with monofilament line and placed in the streams with the leaf bags facing upstream into the current. Eight leaf bags were placed in each stream. Two leaf bags were removed from each stream after 24 hours and approximately 5, 10, and 20 weeks. These samples were rinsed, dried for 12 hours at 60°C and weighed on a Mettler model H51 analytic balance.

Alder leaf packs were of two basic types, open and mesh, and two separate studies were conducted. All leaves used for this study were collected from one small alder tree in Logan Canyon at Red Banks Campground. Leaves were collected at the time of abscission by placing several sheets around the base of the tree and shaking it. In this way, a large number of unprocessed leaves from a single source were collected.

For the first study, leaves were dried at 60°C for 12 hours and weighed into 6.0 gram quantities using only whole leaves. These leaves were then rewetted and formed into two approximately equal leaf packs by stacking the leaves and securing them using size 4 brass paper fasteners. Eight of these packs were placed into the same type nylon mesh bags as described above, tied to bricks and placed in each stream with the leaf packs facing the current. Nine alder packs were left open for each stream and tied directly to the bricks using monofilament line (Petersen and Cummins 1974). The fine mesh bags effectively excluded insect activity on the leaves while insect activity was allowed on the open packs. Since it was hypothesized that the high alkalinity streams would have higher insect biomass and production, the mesh packs were designed to determine how much leaf weight loss was attributed to factors other than greater insect activity. Samples were collected after 24 hours and approximately 5, 10, and 20 weeks. Leaves were rinsed, dried at 60°C for 12 hours, and weighed on a Mettler model H51 analytic balance.

For the second study, leaves were pre-leached for 24 hours in running water, dried at 60°C for 12 hours, and weighed into 2.0 gram quantities using whole leaves. These leaves were rewetted and loosely packed into course net bags and fine nylon bags, tied to bricks, and placed in the stream with the pack facing upstream. Eight of each pack type were placed in each stream type. The loose pack design was decided upon after investigation of the fastened pack type showed that the inner reaches of a pack remained essentially unchanged even when the remainder of the pack was heavily "processed." It appeared as if the formation of the pack, along with the pressure of the current upon the pack, excluded insect activity and even fungal colonization from the inner reaches of the pack. It has also been suggested (S. G. Fisher, personal communication) that the core of this type of leaf pack may be anaerobic. All of these factors would lead to slower total pack processing times than would be expected if the whole pack was accessible to fungal and insect activity. By loosely packing the leaves in either bag type, the leaves do not stack like pages of a book, but more closely resemble the random assemblage of leaf packs caught behind rocks and sticks in the streams. More surface area is exposed and more avenues of colonization are available to both fungi and insects. This would allow for a more natural processing rate of the packs. The smaller pack size was also selected to assure that all leaves had a chance for equal processing. If packs are too large, a certain percentage, increasing as pack size increases, becomes unavailable to processing organisms until the outer material is removed. Since this is not what wasbeing investigated in this study, but rather the processing rate of freshly introduced leaves, the smaller packs were used. Single leaves would probably have been the ideal subject but this was deemed impractical.

Samples for the second study were collected after approximately 10 and 20 weeks. Immediately upon removal from the stream, the leaves were gently rinsed, split into two approximately equal portions with each portion placed into a 500 ml Erlenmeyer flask filled with stream water. These flasks were then sealed in such a manner that all air bubbles were removed. The sealed flasks were then placed in a cooler partially filled with stream water which was kept at stream temperature. One-half of the flasks were incubated in the dark, cold water bath for 3 hours and the remaining half for 7 hours. The flasks were riding in a moving vehicle during much of the incubation and were periodically shaken by hand. After the proper incubation period, the flasks were gently opened and the water was siphoned from the bottom of the flasks into 101 ml dissolved oxygen bottles. Siphoning was done so that water entered the D. O. bottle at the bottom and was allowed to overflow approximately three times. This water was immediately treated as a standard dissolved oxygen sample. The water was analyzed using standard Winkler technique with azide modification. The amount of oxygen utilized by the packs was standardized to the size of leaf pack in each flask. Two initial D. O. readings from each stream and two blank controls for each incubation period were also analyzed in the same manner. Leaves were then removed from the flasks, placed in whirlpack plastic bags, treated with ethyl alcohol to stop biological activity, and returned to the laboratory. Leaves were dried at 60°C for 12 hours and weighed.

Detrital Standing Crops

All organic detritus collected during alternate insect sampling was retained after sorting to determine if standing stocks of detritus were related to insect standing crop and biomass (Egglishaw 1968). This material was dried at 85°C for 12 hours, weighed, ashed at 450°C for 2 hours, and reweighed. Ash-free dry weights were used because in this way inorganic sand and silt that could not be separated from the detritus were not included in the weight calculations. Large woody pieces (>5 mm diameter) were not included in this analysis because one large piece of wood could weigh more than the rest of the detritus and therefore introduce an inordinate amount of variance into the analysis.

Detrital Input

An estimate of levels of detrital input was made for each stream during peak leaf fall. During the October sampling period, when approximately 50 percent of the leaves from the deciduous riparian vegetation had abscissed, drift samples were collected. These were made by placing a drift net in the current such that the top of the net was just above the surface of the water. Nets were left in the stream for five minutes. All material collected in the nets was placed in a one quart wide mouth plastic jar and preserved in 10 percent formalin. This material was returned to the laboratory where it was dried at 60°C for 12 hours and weighed. Current velocity readings were taken at the location of the drift net at each sampling site and measurements of drift were corrected for velocity.

Insolation

The amount of sunlight reaching the stream surface is an important factor in primary productivity of streams. The lack of solar input in many eastern woodland streams is an important reason why these streams are considered heterotrophic systems ($P<R$) (Hynes 1970, Fisher and Likens 1973). Many western streams are considerably more open than

their eastern counterparts, and it has been suggested that many of these streams are less heterotrophic or even autotrophic (P>R) (G. W. Minshall, personal communication).

Solar input was measured at each study site using a Weston model 756 illumination meter. Measurements were taken 1/4, 1/2, and 3/4 of the way across the stream on a transect at each site. Readings were taken at the water surface between 11:00 A.M. and 1:00 P.M. Mountain Standard Time during the October sample period. Readings were also taken in full sunlight at each site and each stream reading was corrected to percent of full sunlight.

Substrate

All insect samples were collected in riffle areas with gravel-rubble substrate. To determine if substrate size and composition varied between sites and between regions, substrate samples were collected and measured during one sampling period. For one Hess insect sample at each site, all substrate particles capable of being loosened and stirred were removed from the bottom. Each of these particles larger than 2 cm circumference was measured using a plastic tape measure.

Algae Standing Crop

As an estimate of primary production in each of the stream types, algae standing crop was measured on artificial substrates. These standing crop studies were done in three streams from each area. These were Kitty, Goff, and Gunbarrel Creeks from the Wyoming low alkalinity region, and Curtis Creek, Left Fork Blacksmith Fork, and Temple Fork from the Utah high alkalinity region. Samples were collected by stringing 6 cm by 1.3 cm styrofoam tubes on a wire and anchoring it so the tubes were just off the stream bottom. Each sampling unit was placed in the stream so the current ran lengthwise along the unit. Sample units were placed in the vicinity of insect sample locations and each site was at least partially shaded during the day.

Samples were collected every sample period except during runoff when the units could not be located or were washed away. This four to six week colonization time was an adequate period for algae standing crop determinations using chlorophyll concentrations (Runke 1979). Samples were collected by removing the styrofoam tubes from the wire and replacing them with fresh ones. The tubes were wrapped in aluminum foil and frozen until analysis. Samples were analyzed by cutting a 0.5 cm disk with an exposed surface area of 2.0 cm^2 from the center of each tube and placing the disks in 25 ml glass tubes with 10 ml of reagent grade acetone for 12 hours. The entire disk dissolved in the acetone. Blank control disks were also analyzed for interference from the styrofoam. Samples were read for chlorophyll in a Turner model 111 fluorometer against known standards.

Insect Survival in Each Water Type

Survival or toxicity factors were investigated using both in-stream and laboratory bioassay-type studies. Studies were done either in each stream type or using water from each stream type. These studies were carried out to determine if lack of a species, or presence in low numbers, in low alkalinity streams was due to differential survivorship as a result of different water types alone.

The in-stream bioassays were patterned after those of Minshall and Minshall (1978). Square boxes, 27 cm on a side and 7 cm deep, were assembled out of 1/2-inch plywood and coated with plastic marine resin. Across the top and bottom of the boxes 1.0 mm mesh netting was stapled prior to tacking on the bottom panel. To assist in water flow through the boxes, the bottom panels had 36 1/8-inch holes drilled through them. These boxes were filled with rubble substrate particles and a known number of the appropriate aquatic insects and stapled shut. Boxes were placed in the streams in a rubble-gravel riffle area for the appropriate period of time.

Ephemerella coloradensis, Baetidae, and Heptageniidae were collected from Temple Fork in Utah and immediately transported to Gunbarrel Creek in Wyoming. Insects were kept alive in transit with the use of ice and portable, battery-operated air pumps. At the stream site, 10 *Ephemerella coloradensis*, 10 Heptageniidae, and 20 Baetidae were placed in each of four boxes. Two of these boxes were left in the stream for 24 hours and two for five weeks. After the appropriate time period, boxes were removed, opened, and the surviving number of each species counted. Heptageniidae and Baetidae were also collected from Gunbarrel Creek and allowed to sit in a cooled tub with bubblers for the same period as it took to transport the Utah insects to Wyoming. Ten Heptageniidae and ten Baetidae each were placed in each of four boxes with rubble and placed in the stream. These were also removed after 24 hours and five weeks, with the survivors counted.

The same type of procedure was undertaken at Temple Fork, with Gunbarrel Creek insects placed in Temple Fork, and Temple Fork insects placed in Temple Fork for 24 hours and five weeks. The same number of each taxa from each stream as above were used, except no *Ephemerella coloradensis* were used.

Laboratory studies were done using water from Temple Fork, Gunbarrel Creek and distilled water. Known numbers of four insect taxa (*Ephemerella coloradensis*, *Ephemerella inermis*, Baetidae, and Lepidostomatidae) from Temple Fork were placed in 500 ml Erlenmeyer flasks filled with the appropriate water. These flasks were bubbled with forced air and kept in a cold room at 8°C. Sticks were provided as substrate for the insects. Observations were made and survivors recorded at periodic intervals.

Data Analysis

For all aspects of this study, it was necessary to determine if values obtained from the four high alkalinity streams were either higher than or different from the values for the four low alkalinity streams. Analysis for differences were done using RANDTEST, a FORTRAN program written by Green (1977), of a nonparametric randomization test developed by R. A. Fisher. The significance level for all analyses was 0.10.

RESULTS

Physical-Chemical

All physical-chemical results, and the two-tailed probabilities that the values between regions were not different are presented in Table 1. All chemical variables, except potassium, were significantly different between regions. Alkalinity, pH, specific conductance, total dissolved solids, calcium, magnesium, and nitrates were significantly higher in the high alkalinity streams. Osborn (unpublished data) found a high correlation between each of these variables, except nitrates, in his investigation of 95 mountain streams. Alkalinity is very difficult to separate from these other factors, especially in the field, and therefore is used as an indicator or predictor variable in this study. Total phosphorus, total dissolved phosphorus, and sodium levels were significantly higher in the low alkalinity streams. Phosphorus is apparently not the limiting nutrient for primary production in the low alkalinity streams. The relatively high phosphorus levels may reflect low algal activity due to some other limiting factor resulting in less phosphorus usage. Potassium levels did not differ between regions. The possibility of potassium deficiency contributing to low production as discussed by Minshall and Minshall (1978) was therefore not a factor in this study.

None of the physical variables investigated in this study were significantly different between regions. The light value for Kitty Creek may be lower than expected due to one large tree obscuring much of the sun when measurements were taken. If readings were taken earlier,

Table 1. Yearly means (S.E.) of physical-chemical variables for streams and stream types. The two-tailed probabilities (P Values) that stream types are not different using Fisher's randomization test are presented. Asterisks denote significance at the 0.10 level.

Stream	Alkalinity (mgCaCO$_3$/l)	pH	Conductivity (umhos/cm) @ 25°C	Total Dissolved Solids (g/l)	Total Phosphorus (ug P/l)
LFBF	194(13)	7.7(0.3)	342(23)	.1789(.013)	20.1(14.0)
Curtis Creek	180(11)	7.7(0.4)	306(30)	.1621(.013)	20.9(8.6)
Logan River	159(12)	7.8(0.4)	267(15)	.1644(.018)	18.2(3.4)
Temple Fork	174(8)	7.9(0.3)	283(25)	.1643(.016)	25.6(6.8)
Mean of High Alkalinity Streams	177(8)	7.8(0.1)	300(17)	.1674(.004)	21.2(1.6)
Gunbarrel Creek	38(5)	6.4(0.5)	80(10)	.0643(.008)	104.9(18.0)
Clearwater Creek	43(6)	6.3(0.5)	90(11)	.0668(.011)	71.6(20.1)
Goff Creek	36(2)	6.3(0.5)	71(4)	.0635(.007)	80.3(8.1)
Kitty Creek	39(4)	6.4(0.5)	78(8)	.0673(.007)	58.8(4.1)
Mean of Low Alkalinity Streams	39(2)	6.4(0.1)	80(4)	.0655(.001)	78.9(9.8)
P Values	.029*	.000*	.029*	.029*	.029*

Table 1. Continued.

Stream	Total Dissolved Phosphorus (ug P/l)	NO_3 (mg N/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)
LFBF	12.2(4.7)	170.0	97.4(5.6)	14.5(1.8)	4.9(0.4)	1.1(0.1)
Curtis Creek	14.1(3.8)	162.0	98.4(3.4)	13.2(2.1)	3.1(0.2)	1.0(0.2)
Logan River	16.6(3.7)	136.1	89.3(4.7)	9.5(1.9)	1.7(0.3)	0.6(0.1)
Temple Fork	15.8(3.4)	136.7	88.5(5.6)	10.6(0.7)	2.1(0.4)	0.8(0.2)
Mean of High Alkalinity Streams	14.7(1.0)	151.2(8.7)	93.4(2.6)	12.0(1.2)	3.0(0.7)	0.9(0.1)
Gunbarrel Creek	85.9(7.3)	24.5	14.0(5.6)	1.3(0.2)	11.6(1.6)	0.7(0.1)
Clearwater Creek	53.8(8.3)	14.5	13.3(1.9)	1.2(0.4)	11.1(2.0)	0.8(0.3)
Goff Creek	68.7(5.8)	7.2	11.1(1.6)	1.5(0.2)	7.5(0.8)	0.4(0.1)
Kitty Creek	53.0(4.2)	100.4	17.7(5.0)	1.8(0.2)	5.4(0.9)	0.9(0.1)
Mean of Low Alkalinity Streams	65.4(7.8)	36.7(21.6)	14.0(1.4)	1.5(0.2)	8.9(1.5)	0.7(0.1)
P Values	.029*	.029*	.029*	.029*	.029*	.229

Table 1. Continued.

Stream	Mean Width (m)	Mean Depth (cm)	Gradient (%)	Mean October Insolation (% full sun)	Mean Substrate (cm circum)	Mean Temperature (°C)
LFBF	7.6	40.6	1.5	43	15.3	6.6
Curtis Creek	4.6	27.9	3.0	36	13.2	6.5
Logan River	9.1	66.0	3.0	53	16.0	6.1
Temple Fork	6.7	33.0	3.0	30	16.4	7.5
Mean of High Alkalinity Streams	7.0(0.9)	41.9(8.5)	2.6(.4)	40.5(4.9)	15.2(.7)	6.7(.6)
Gunbarrel Creek	7.0	38.1	3.0	46	17.5	6.6
Clearwater Creek	9.1	22.9	3.0	38	17.5	6.5
Goff Creek	2.4	22.9	3.0	32	15.1	5.0
Kitty Creek	5.5	20.3	5.0	8	16.7	4.5
Mean of Low Alkalinity Streams	6.0(1.4)	26.1(4.1)	3.5(.5)	31.0(8.2)	16.7(.6)	5.7(1.1)
P Values	.600	.143	.571	.429	.143	.257

the light level would have been somewhat higher. This site did not appear to be a great deal more shaded than the other sites in this study.

Detritus

Open Alder Processing

The breakdown of open alder leaf packs was significantly greater in Temple Fork in both experiments (Figures 4-6). In the first experiment, results were analyzed using both the original, non-leached 6.0 gram starting weights and weights remaining after a one-day leaching period. The non-leached results (Figure 4) show that after the 164-166 day processing period, 55.8 percent of the Gunbarrel Creek packs remained, while only 34.2 percent of the Temple Fork packs remained. These results gave coefficients of decay (K) of .0035 for Gunbarrel Creek packs and .0065 for Temple Fork packs (Table 2). Of the weight lost during this experiment, 17.5 percent of the beginning weight of the Gunbarrel Creek packs and 13.3 percent of the beginning weight of the Temple Fork packs was lost in the first 24 hours as soluble leachate. The leaching coefficients resulting from the one-day leaching periods were .1924 for Gunbarrel Creek and .1431 for Temple Fork (Table 2.)

The one-day leached weights were used as starting weights to simulate preleached leaf packs. This resulted in starting weights of 4.95 grams for Gunbarrel Creek packs and 5.20 grams for Temple Fork packs. After the 164-166 day processing period, 68 percent of the preleached Gunbarrel Creek packs remained while only 39 percent of the preleached Temple Fork packs remained (Figure 5). These results gave

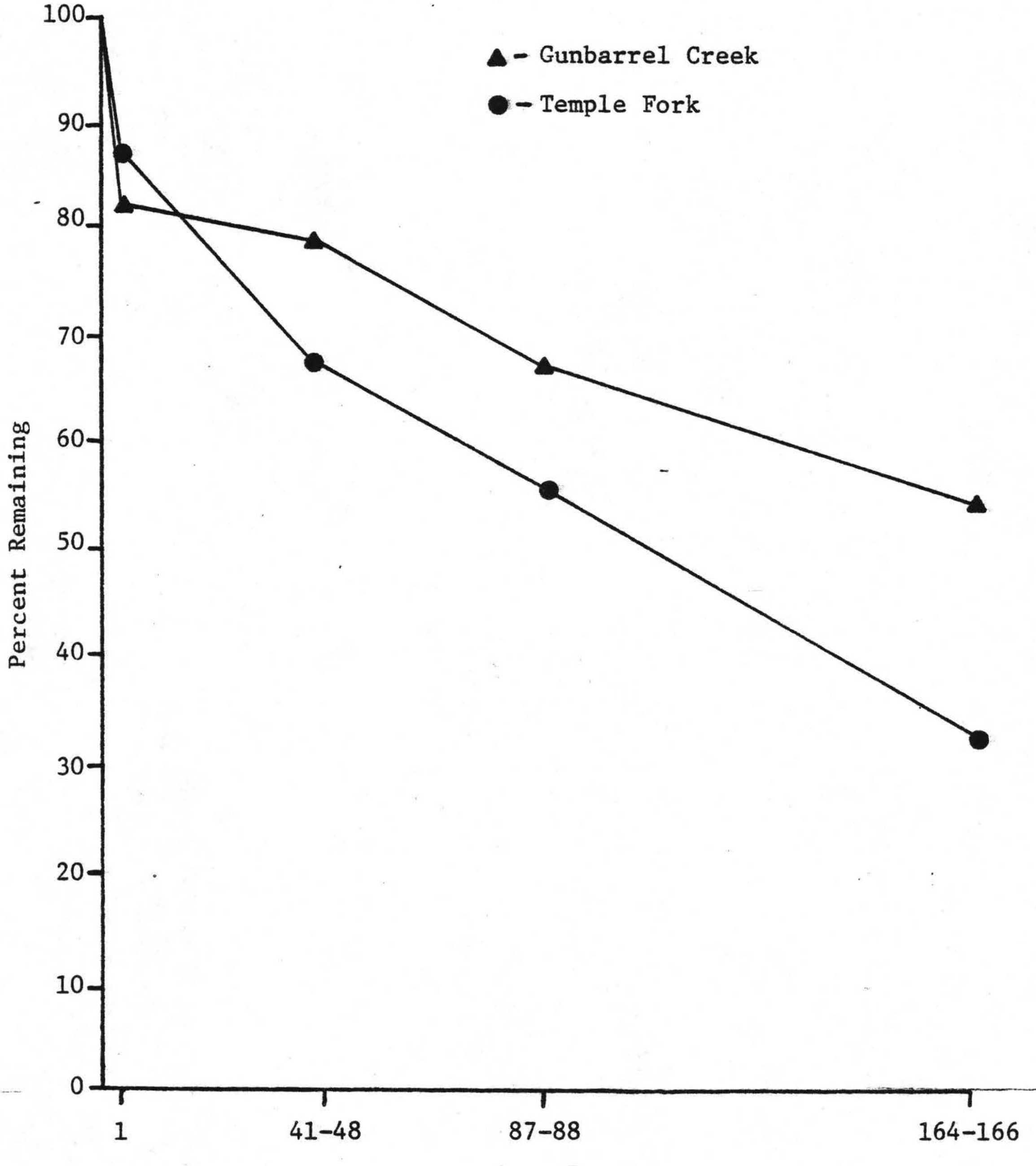

Figure 4. Breakdown of unleached 6.0 g open alder leaf packs in Temple Fork, Utah, and Gunbarrel Creek, Wyoming, October 1978 to March 1979.

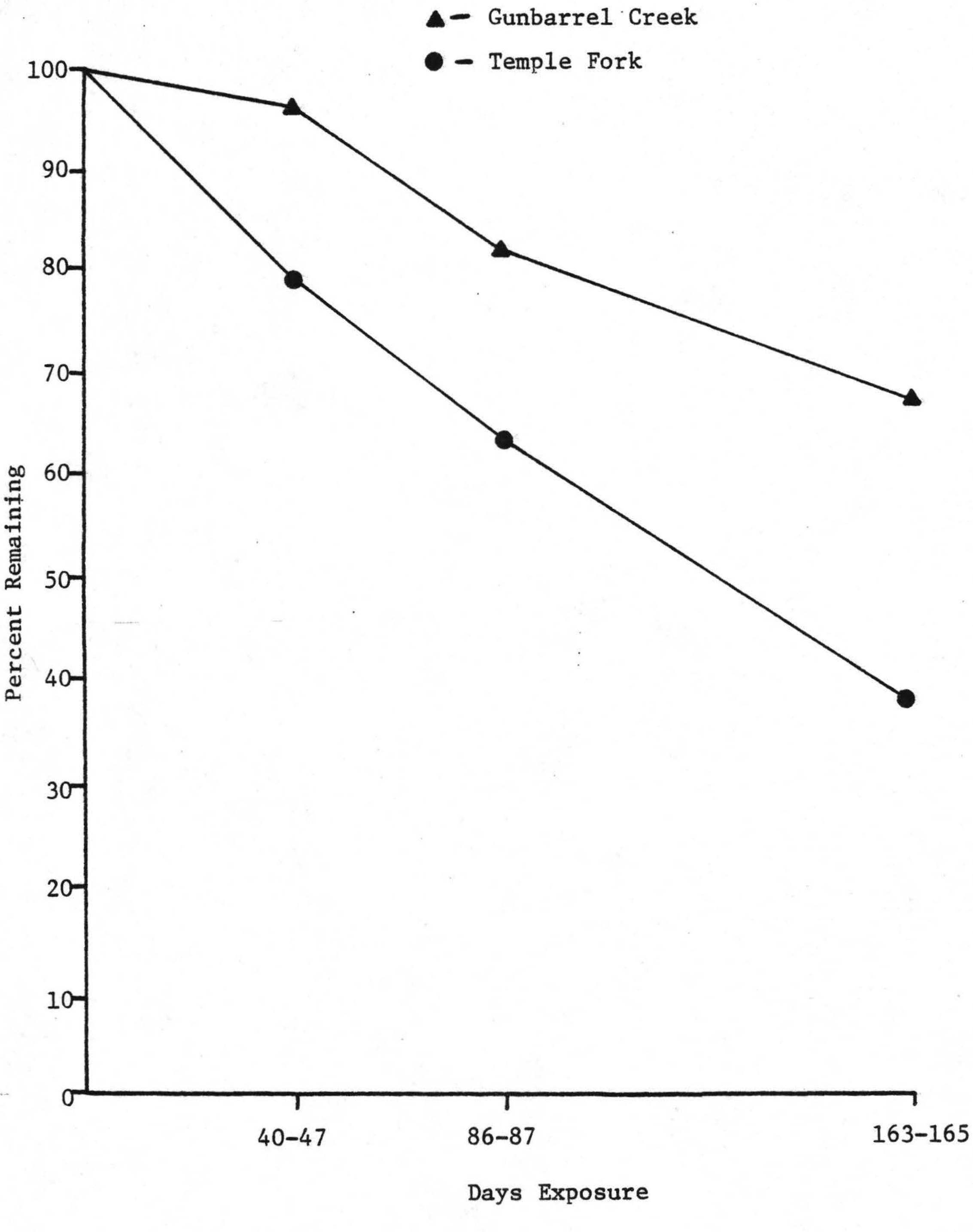

Figure 5. Breakdown of leached open alder leaf packs in Temple Fork, Utah, and Gunbarrel Creek, Wyoming, October 1978 to March 1979.

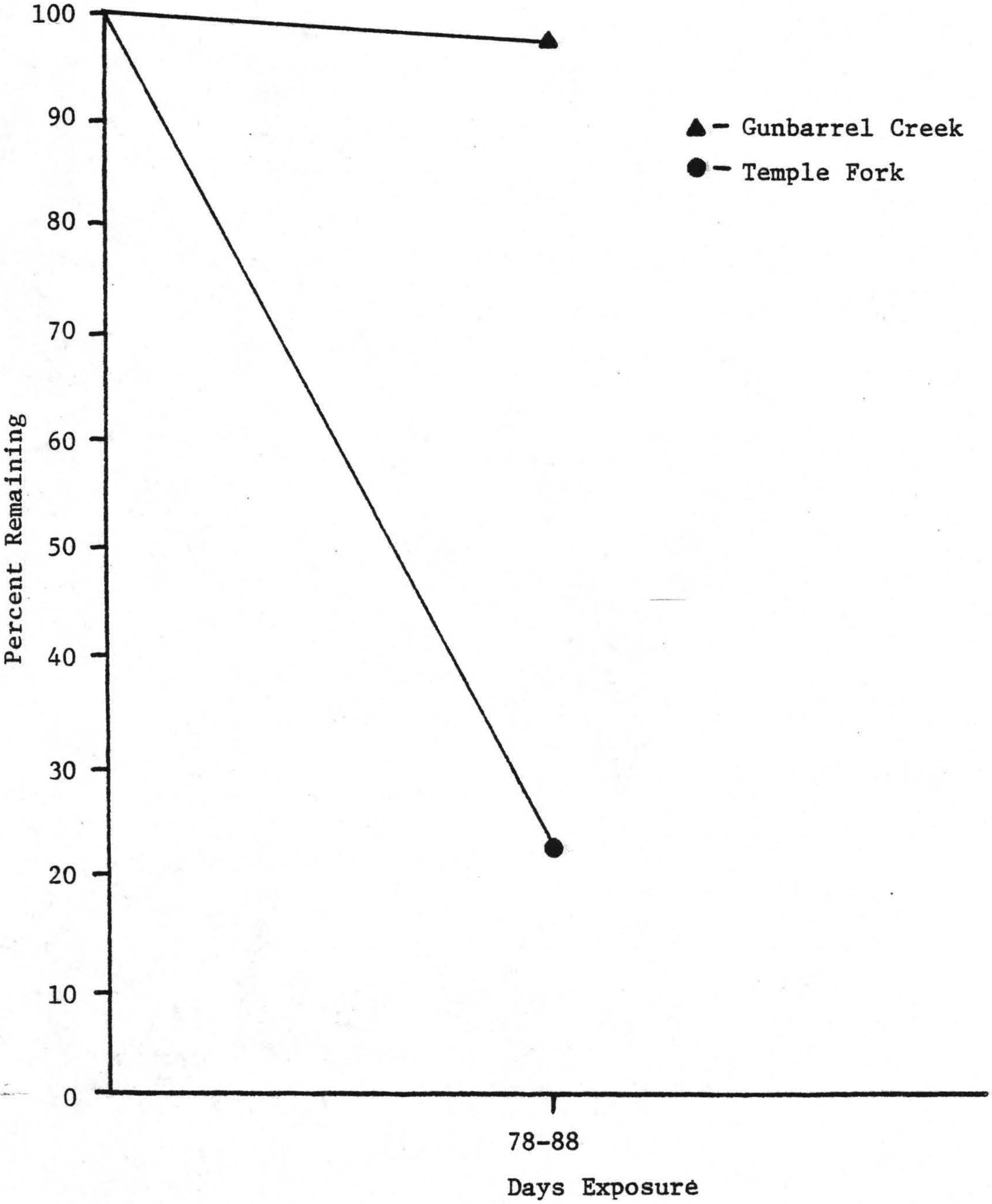

Figure 6. Breakdown of leached 2.0 g open alder leaf packs in Temple Fork, Utah, and Gunbarrel Creek, Wyoming, April 1979 to June-July 1979.

Table 2. Coefficients of decay (K values) of all leaf packs for duration of each study, Temple Fork, Utah, and Gunbarrel Creek, Wyoming, 1978-1979.

	Temple Fork	Gunbarrel Creek
Open Alder Packs		
Oct.-March 6.0 g unleached	.0065	.0035
Oct. 24-hr leaching coefficients of 6.0 g unleached packs	.1431	.1924
Oct.-March preleached	.0057	.0023
April-July 2.0 g preleached	.0174	.0005
Mesh Alder Packs		
Oct.-March 6.0 g unleached	.0034	.0033
Oct.-March preleached	.0025	.0021
April-Sept. 2.0 g preleached	.0064	.0078
Mesh Douglas-Fir Packs		
Oct.-March 6.0 g unleached	.0020	.0019

K values of .0023 for the Gunbarrel Creek packs and .0057 for the Temple Fork packs (Table 2).

In the second experiment, open leaf packs were collected only once due to loss of packs during runoff. These packs were collected after 78 days in Gunbarrel Creek and 88 days in Temple Fork. Since only pre-leached leaves were used in this experiment, no non-leached analysis was made. After the 78-day processing period in Gunbarrel Creek, 97 percent of the leaf packs remained giving a K of .0005. After the 88-day processing period in Temple Fork, only 22 percent of the leaf packs remained, giving a K of .0173 (Figure 6, Table 2).

Mesh Alder Processing

Because most insect activity was excluded from mesh packs, breakdown was attributed mainly to activity by fungi and bacteria. This activity led to breakdown patterns different from the open packs (Figures 7-9). In the first experiments, with weights corrected for one-day leaching, the final weights after 164-166 days were not significantly different in the two streams (Figure 8). The differences after 87-88 days were also not significant in this experiment. After 41-48 days, however, weights were significantly lower in Temple Fork. In the second experiment, the same pattern emerged, although the scale was different (Figure 9). Weight differences after 147-151 days were not significantly different between the two streams. After the first 78-88 days, however, the weights were significantly lower in Temple Fork.

Douglas-Fir Processing

The non-insect processing of Douglas-fir needles was not

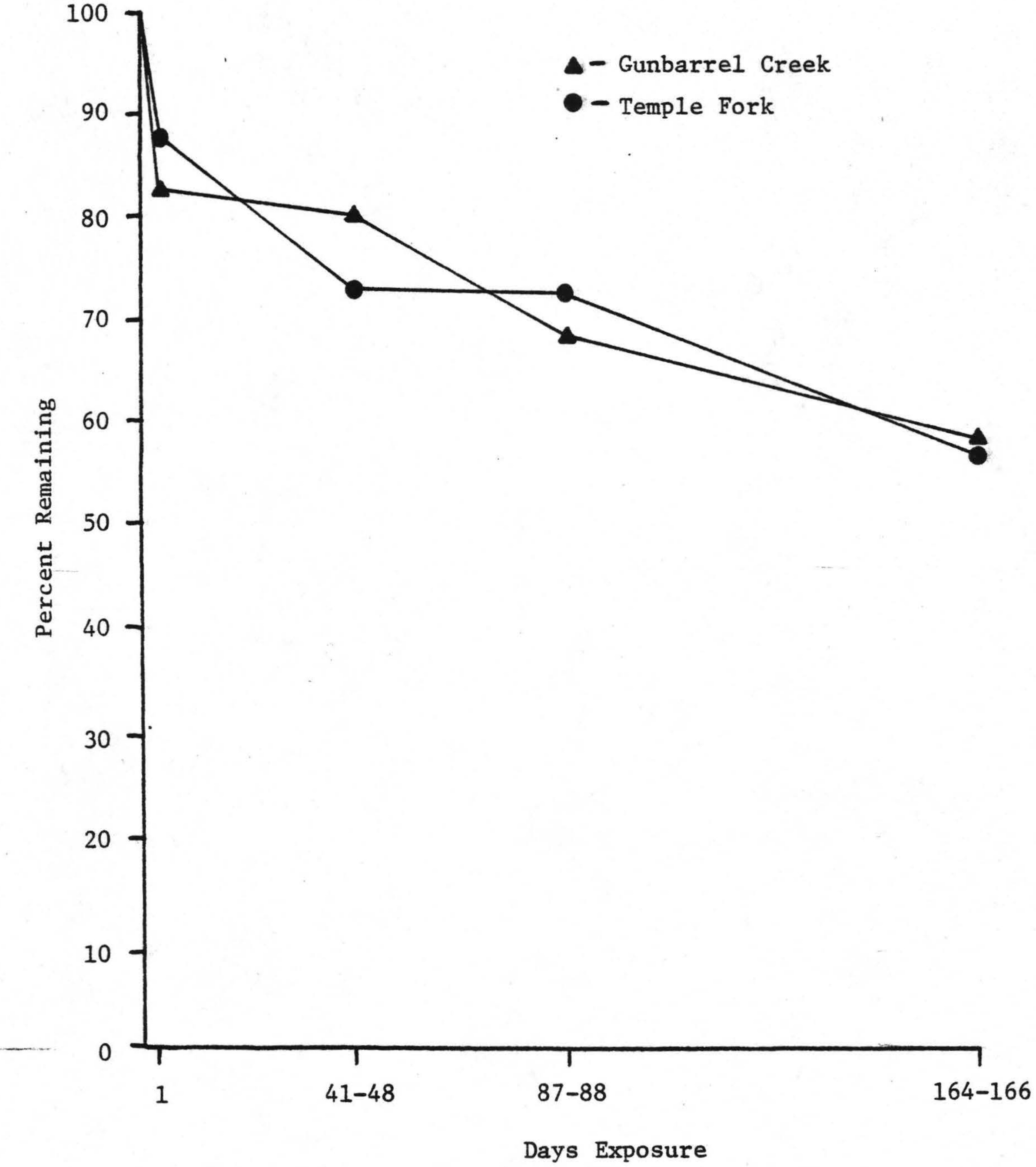

Figure 7. Breakdown of unleached 6.0 g mesh alder leaf packs in Temple Fork, Utah, and Gunbarrel Creek, Wyoming, October 1978 to March 1979.

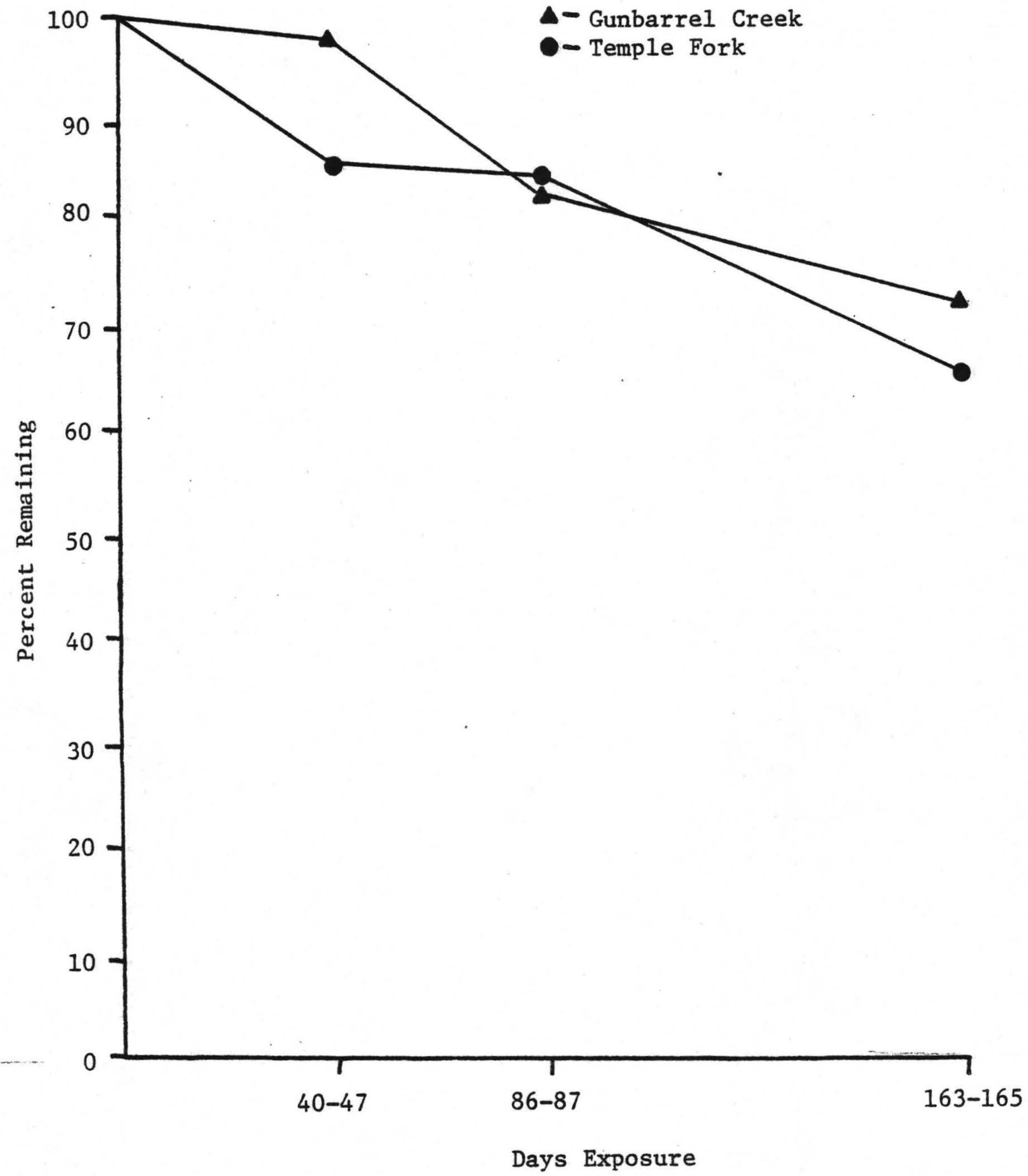

Figure 8. Breakdown of leached mesh alder leaf packs in Temple Fork, Utah, and Gunbarrel Creek, Wyoming, October 1978 to March 1979.

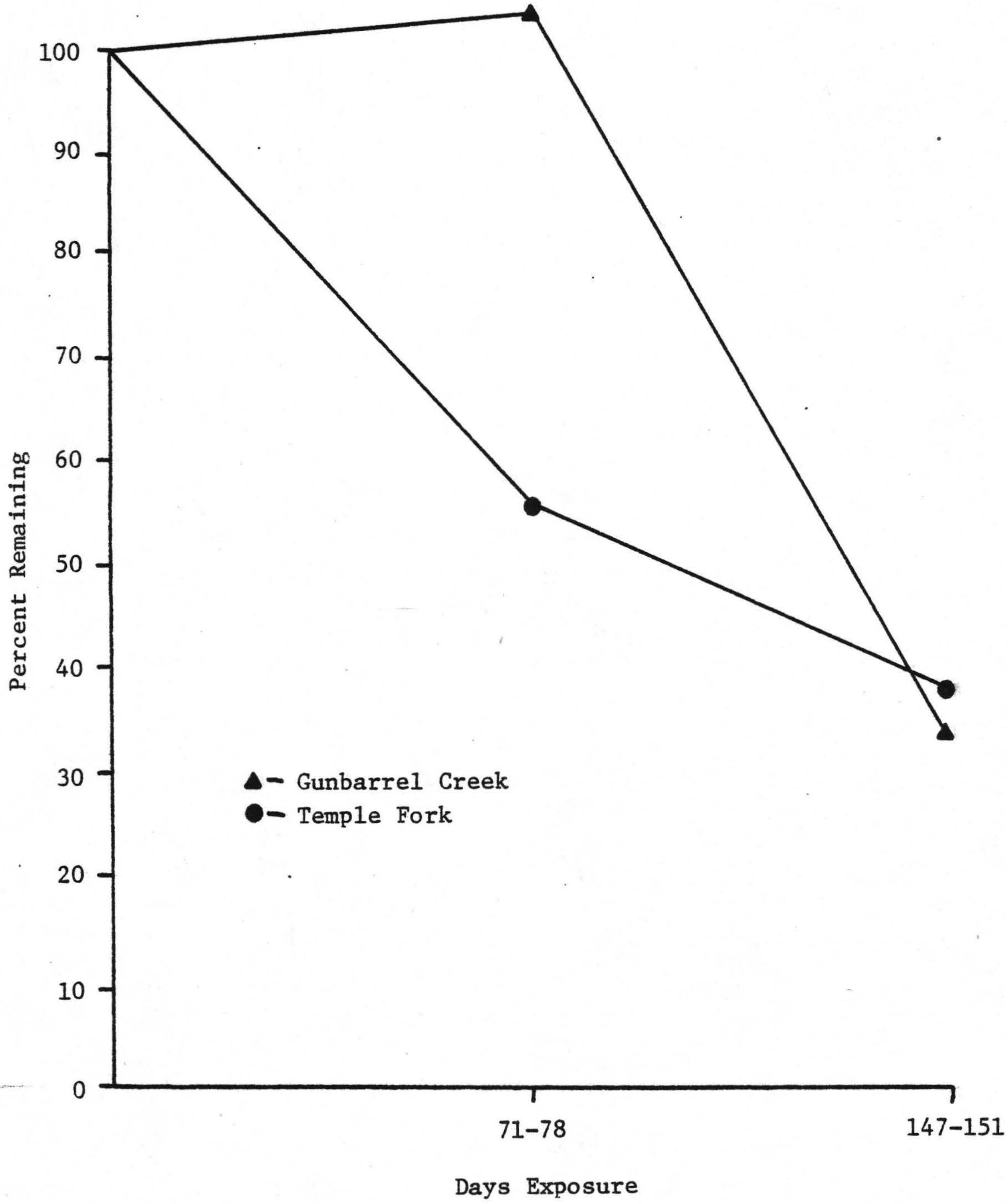

Figure 9. Breakdown of leached 2.0 g mesh alder leaf packs in Temple Fork, Utah, and Gunbarrel Creek, Wyoming, April 1979 to October 1979.

significantly different in the two streams for any time period (Figure 10). Breakdown was also much slower than for either open or mesh alder packs, with a final K value of only .0019 and .0020 for the unleached packs (Table 2).

Leaf Pack Respiration

Respiration rates for leaf packs used in the second experiment are presented in Table 3. The results were highly variable, often with more variance seen between replicates of a single treatment than between treatments. Also, in some cases, more oxygen was used after three hours than after seven hours, even though the flasks were kept in the dark.

Detrital Drift

There was no significant difference ($P<.10$) in the amount of terrestrial detritus drifting in the streams of the two regions during peak leaf-fall (Table 4). The mean value for the high alkalinity region was considerably higher than that for the low alkalinity region, but the high variability between sites in the high alkalinity region contributed to the insignificant difference. It should also be noted that there was a gusty wind blowing when sampling was done at the high alkalinity sites which was not the case during sampling at the low alkalinity sites. This wind was particularly strong at the Left Fork Blacksmith Fork site and could have contributed to the high value at this stream. There were no subjective differences noted in the amount or type of streamside vegetation between streams in the two regions that would lead to differential input levels of detritus.

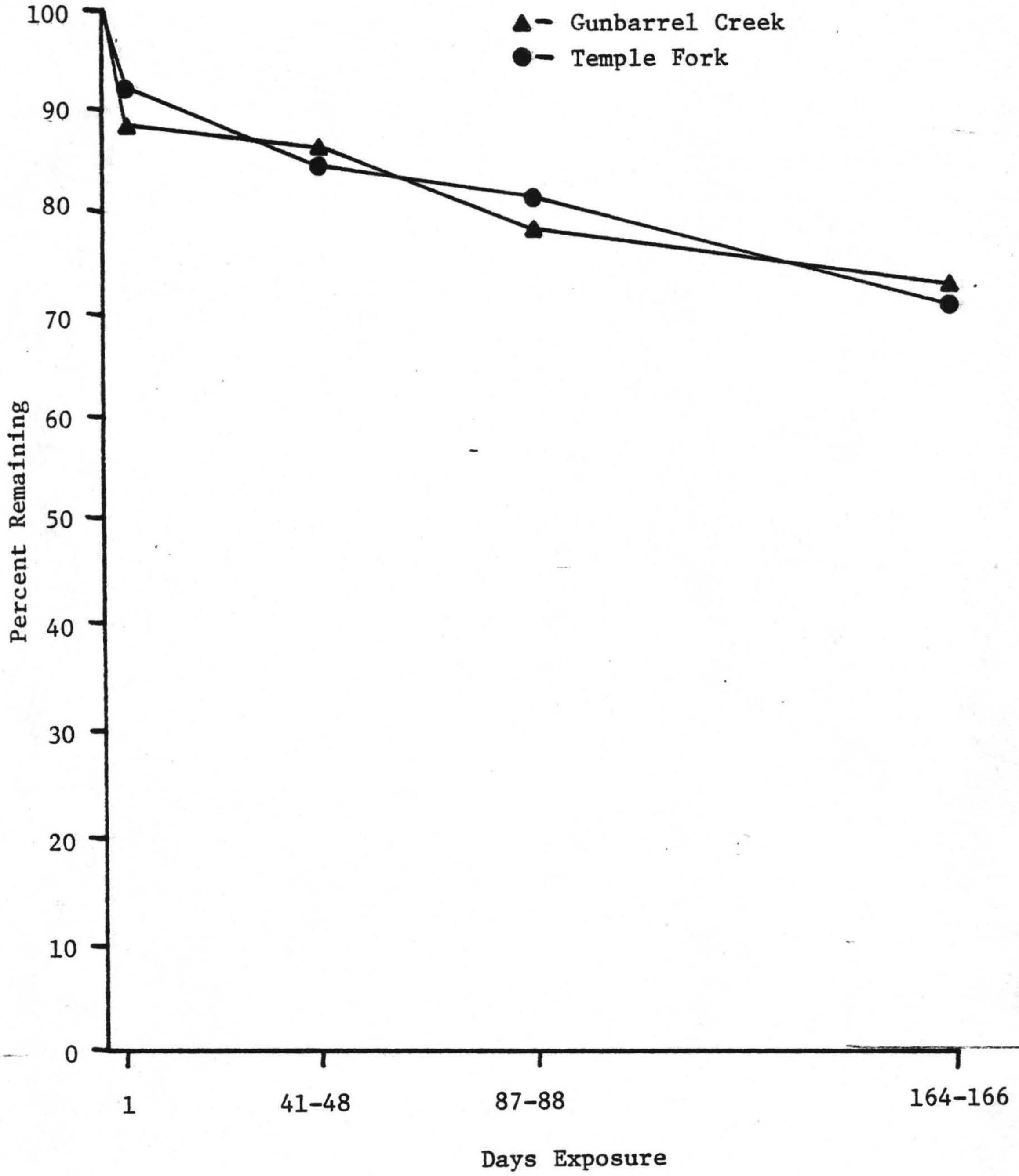

Figure 10. Breakdown of unleached 6.0 g mesh Douglas-fir leaf packs in Temple Fork, Utah, and Gunbarrel Creek, Wyoming, October 1978 to March 1979.

Table 3. Mean(S.E.) respiration rates (mg O_2 used/l H_2O/g leaf pack) for both open and mesh alder leaf packs in Temple Fork, Utah, and Gunbarrel Creek, Wyoming, for processing periods April-July and April-September, 1979. Values are for both 3-hour and 7-hour incubation periods.

Open Packs		Mesh Packs
	APRIL-JULY	
	Gunbarrel Creek	
3-hr. = 1.98(.31)		3-hr. = 2.56(.87)
7-hr. = 2.29(.15)		7-hr. = 2.50(.34)
	Temple Fork	
3-hr. = 2.62(1.51)		3-hr. = 2.46(.63)
7-hr. = 3.23(1.17)		7-hr. = 2.80(.41)
	APRIL-SEPTEMBER	
	Gunbarrel Creek	
		3-hr. = 2.70(.36)
		7-hr. = 2.45(.40)
	Temple Fork	
		3-hr. = 1.14(.71)
		7-hr. = 2.77(.50)

Table 4. Five minute drift weights (g dry weight) of detritus in each stream during peak leaf fall, October 1978. All values are corrected to 0.50 m/sec velocity.

High Alkalinity Streams	
Left Fork Blacksmith Fork	11.342
Curtis Creek	0.296
Temple Fork	3.050
Logan River	11.422
Low Alkalinity Streams	
Gunbarrel Creek	1.662
Goff Creek	1.883
Kitty Creek	0.961
Clearwater Creek	1.350
Probability that high alkalinity streams were not different than low alkalinity streams.	= .143

Detritus Standing Crop

The mean annual standing crop of detritus collected in Hess bottom samples on alternate sampling periods did not differ significantly (P<.10) between high and low alkalinity streams (Table 5). There was also less variance between the three Left Fork Blacksmith Fork and Gunbarrel Creek sites than between the three remaining high and low alkalinity sites respectively.

Insect Survivals

The results of the in-stream box survival study are presented in Table 6. The results are highly variable due to changes in the physical environment of the boxes. The results were not used and the experiment was abandoned.

There were no significant differences (P<.10) in survivorship of any of the four insect taxa tested between high or low alkalinity water upon termination of the laboratory experiment (Table 7). The only case of a difference occurring during the experiment was with the mayfly Baetidae after six days. At this stage of the experiment, the representatives in the high alkalinity water had higher survivorships than those in the low alkalinity water. After five more days, however, survivorship was the same. Incidentally, the Baetidae had much lower survivorships in both water types than any of the other taxa used.

Algal Standing Crop

Chlorophyll standing crops in each high alkalinity stream were significantly higher than levels in any low alkalinity stream (Table 8). This was true at all times of the year despite high variability between

Table 5. Mean annual standing crops (g m^{-2} ash-free dry weight) of detritus collected on alternate sampling dates in the modified Hess bottom sampler.

High Alkalinity Sites Mean (S.E.)	Low Alkalinity Sites Mean (S.E.)
Left Fork Blacksmith Fork (L) 15.086(5.519)	Gunbarrel Creek (L) 7.700(1.679)
Left Fork Blacksmith Fork (M) 18.086(6.014)	Gunbarrel Creek (M) 7.444(3.696)
Left Fork Blacksmith Fork (U) 13.673(3.647)	Gunbarrel Creek (U) 8.049(4.094)
Left Fork Blacksmith Fork Mean 15.615	Gunbarrel Creek Mean 7.731
Curtis Creek 17.267(4.360)	Goff Creek 18.903(8.551)
Temple Fork 10.200(1.618)	Kitty Creek 10.390(2.500)
Logan River 22.888(4.155)	Clearwater Creek 5.117(2.053)

Probability that high alkalinity streams were not different than low alkalinity streams. = .200

Table 6. Number of insects surviving to each collection period for box enclosure study.

	NUMBER ALIVE			
	Heptageniidae	Baetidae	*Ephemerella coloradensis*	Total
Boxes in Gunbarrel Creek				
Gunbarrel Creek Insects				
Beginning number	10	10	0	20
24 hours -A	3	1		4
B	4	1		5
5 weeks -A	7	0		7
B	4	0		4
Temple Fork Insects				
Beginning number	10	20	10	40
24 hours -A	7	19	8	34
B	8	17	9	34
5 weeks -A	0	0	0	0
B	3	0	0	3
Boxes in Temple Fork				
Gunbarrel Creek Insects				
Beginning number	10	10	0	20
24 hours -A	7	10		17
B	9	8		17
5 weeks -A	8	8		16
B	3	0		3
Temple Fork Insects				
Beginning number	10	20	0	30
24 hours -A	10	19		29
B	10	19		29
5 weeks -A	0	2		2
B		Missing Box		

Table 7. Mean number of survivors of each taxa in each water type for the designated time period. Each experiment started with ten representatives per container.

Taxa Water Type			Mean(S.E.) number of survivors			
	1 day	6 days	9 days	11 days	18 days	30 days
Ephemerella coloradensis						
High Alkaline			5.33(.33)		4.33(.66)	
Low Alkaline			5.00(.00)		4.00(.58)	
Distilled			5.33(.66)		2.67(1.20)	
E. inermis						
High Alkaline	10(0)	7.5(.5)		5.0(3.0)		5.0(3.0)
Low Alkaline	10(0)	9.5(.5)		7.5(2.5)		7.5(2.5)
Baetidae						
High Alkaline	8.5(.5)	6.5(1.5)		1.0(0)		0(0)
Low Alkaline	6.5(.5)	1.0(1.0)		1.0(1.0)		0.5(.5)
Lepidostomatidae						
High Alkaline	10(0)	10(0)		10(0)		9.0(1.0)
Low Alkaline	10(0)	9.5(.5)		9.5(.5)		9.0(0)

Table 8. Two-tailed probabilities that chlorophyll levels between streams were not different as calculated by Fisher's randomization test. Asterisks denote significance at the 0.10 level.

	High Alkalinity			Low Alkalinity		
High Alkalinity	LFBF	Curtis Creek	Temple Fork	Goff Creek	Kitty Creek	Gunbarrel Creek
LFBF						
Curtis Creek	.364					
Temple Fork	.907	.366				
Low Alkalinity						
Goff Creek	.001*	.000*	.001*			
Kitty Creek	.002*	.001*	.003*	.095*		
Gunbarrel Creek	.004*	.003*	.006*	.267	.048*	

seasons (Figure 11). Both regions experienced an autumn and spring peak in chlorophyll concentrations indicating relatively higher colonization rates during these seasons, when the streams were most open. Both regions experienced low chlorophyll standing crops during the winter months, with the exception of the December sample in Kitty Creek. No January or March samples were collected from Kitty Creek. The summer results were quite variable and varied from stream to stream. No attempts were made to identify the dominant algal species, but if the algae was equally acceptable to all grazer species as food, the high alkalinity streams provided more food during all seasons.

Within the high alkalinity streams, no significant differences existed in chlorophyll standing crops between streams. In the low alkalinity region, Kitty Creek had a significantly higher chlorophyll standing crop than either Gunbarrel Creek or Goff Creek. Gunbarrel Creek was not significantly different than Goff Creek.

Macroinvertebrates

Annual Production

The mean annual production of all taxa summed was much higher in the high alkalinity streams, with an average production of 34.4626 g/m^2, than in the low alkalinity streams, with an average production of 4.6668 g/m^2 (Table 10). All high alkalinity sites had significantly higher production than any low alkalinity site (Table 10).

The mean annual production of 22 of the 29 taxa analyzed were significantly higher in the high alkalinity streams than the low alkalinity streams (Table 9). Site by site production values are presented in Appendix I. The only taxa that were not significantly more

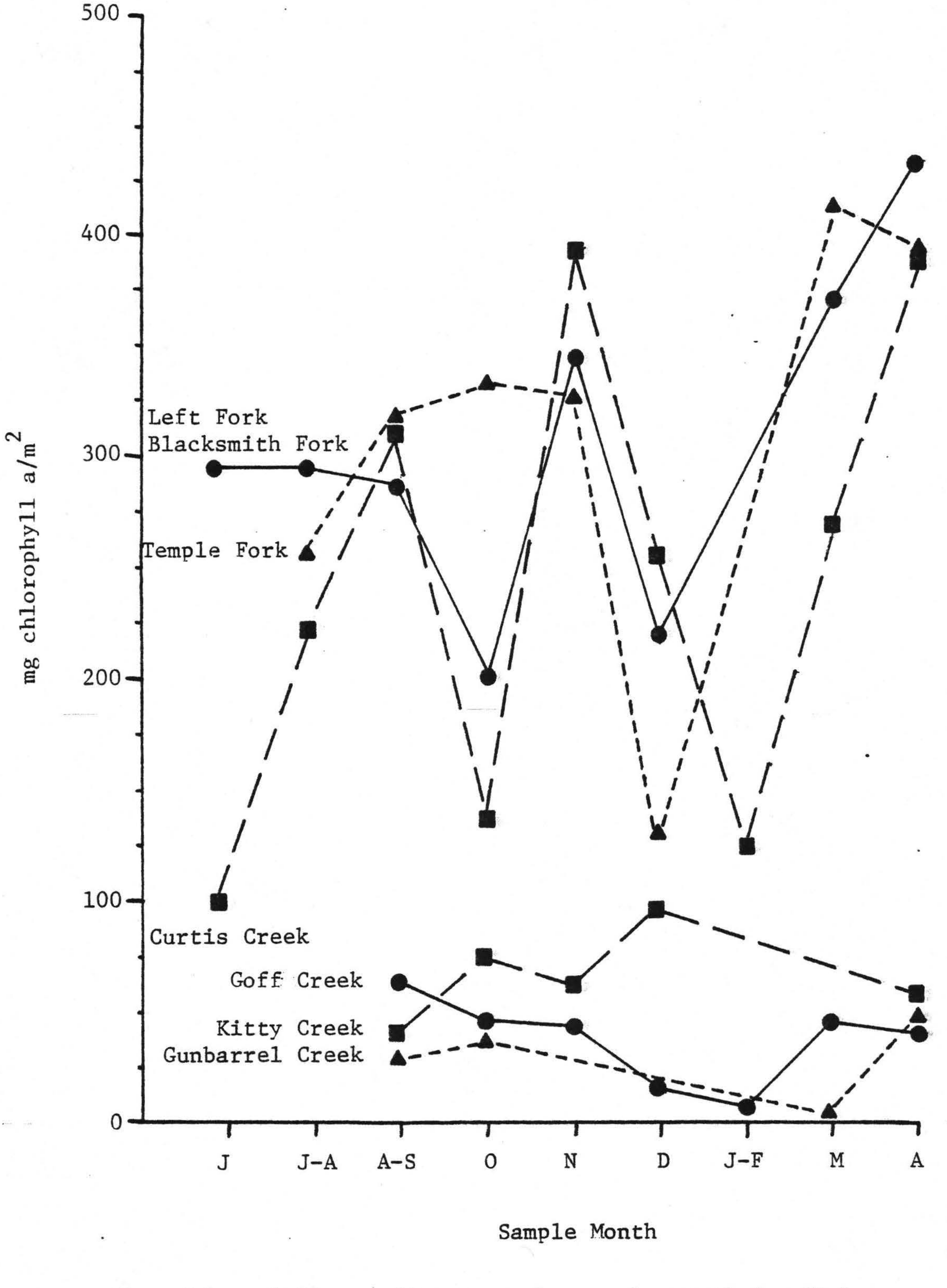

Figure 11. Chlorophyll standing crops by sample month for Utah high alkalinity and Wyoming low alkalinity streams, 1978-1979.

Table 9. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$), and mean density (# m^{-2}) for each taxa for Utah high alkalinity streams and Wyoming low alkalinity streams, 1978-1979. P Values represent one-tailed probabilities (two-tailed for TR) that the high alkalinity values are not higher than the low alkalinity values as calculated by Fisher's randomization test. Asterisks denote significance at the 0.10 level.

Taxon	Production Mean(S.E.)	Standing Crop Mean(S.E.)	Turnover Ratio Mean(S.E.)	Density Mean(S.E.)
Nemouridae				
High Alk	.2166(.048)	.0440(.010)	4.92(.13)	824(191)
Low Alk	.2764(.054)	.0588(.013)	4.80(.18)	1124(185)
P Value	.229	.171	.486	.186
Perlodidae				
High Alk	.8938(.325)	.1185(.043)	7.55(.05)	103(35)
Low Alk	.6234(.069)	.1070(.013)	5.86(.09)	46(7)
P Value	.271	.414	.029*	.043*
Chloroperlidae				
High Alk	.5110(.281)	.1071(.062)	4.97(.11)	234(132)
Low Alk	.0930(.020)	.0186(.004)	4.95(.18)	177(50)
P Value	.043*	.043*	.914	.429
Perlidae				
High Alk	.5794(.420)	.1312(.095)	4.42(.01)	14(10)
Low Alk	.0000(.000)	.0000(.000)	---------	0(0)
P Value	.000*	.000*	----	.000*
Pteronarcidae				
High Alk	.0400(.040)	.0341(.034)	1.17(.05)	6(6)
Low Alk	.0000(.000)	.0000(.000)	---------	0(0)
P Value	.500	.500	----	.500
Rhithrogena				
High Alk	1.2810(.447)	.1979(.065)	6.62(.64)	564(265)
Low Alk	.9199(.349)	.1425(.050)	6.20(.52)	185(64)
P Value	.286	.257	.314	.143
Cinygmula				
High Alk	.6006(.219)	.0804(.030)	7.47(.08)	1661(588)
Low Alk	.1782(.056)	.0240(.008)	7.59(.27)	768(232)
P Value	.057*	.057*	.857	.129

Table 9. Continued.

Taxon	Production Mean(S.E.)	Standing Crop Mean(S.E.)	Turnover Ratio Mean(S.E.)	Density Mean(S.E.)
Epeorus				
High Alk	.0603(.010)	.0087(.002)	6.95(.59)	204(104)
Low Alk	.1562(.042)	.0284(.009)	5.90(.55)	439(182)
P Value	.043	.014	.200	.143
Ephemerella doddsi				
High Alk	1.9625(1.027)	.2253(.119)	9.03(.25)	183(99)
Low Alk	.6152(.261)	.0858(.034)	7.00(.32)	74(49)
P Value	.171	.171	.029*	.414
E. coloradensis				
High Alk	4.6404(2.942)	.7848(.519)	7.22(.87)	1674(856)
Low Alk	.0789(.019)	.0154(.003)	4.93(.30)	177(66)
P Value	.071*	.071*	.057*	.071*
E. grandis				
High Alk	2.2990(2.122)	.3823(.354)	6.19(.10)	125(111)
Low Alk	.0000(.000)	.0000(.000)	---------	0(0)
P Value	.071*	.071*	----	.071*
E. inermis				
High Alk	.5274(.352)	.0750(.050)	7.10(.19)	1322(888)
Low Alk	.0420(.015)	.0070(.002)	5.89(.31)	98(55)
P Value	.071*	.071*	.057*	.071*
Baetidae				
High Alk	10.2174(.423)	.9890(.046)	10.38(.13)	14683(1457)
Low Alk	.5295(.070)	.0535(.009)	10.03(.40)	792(126)
P Value	.014*	.014*	.600	.014*
Paraleptophlebia				
High Alk	.0988(.069)	.0171(.012)	6.26(.32)	487(274)
Low Alk	.0001(.000)	.0000(.000)	---------	1(0)
P Value	.071*	.071*	----	.071*
Siphlonuridae				
High Alk	.0073(.007)	.0010(.001)	---------	1(1)
Low Alk	.0206(.009)	.0036(.002)	5.80(.57)	4(3)
P Value	.071	.071	----	.086
Hydropsychidae				
High Alk	3.2471(1.261)	.3591(.140)	9.04(.07)	196(95)
Low Alk	.6062(.143)	.0765(.019)	8.00(.09)	29(6)
P Value	.029*	.029*	.029*	.043*

Table 9. Continued.

Taxon	Production Mean(S.E.)	Standing Crop Mean(S.E.)	Turnover Ratio Mean(S.E.)	Density Mean(S.E.)
Rhyacophilidae				
High Alk	1.3536(.514)	.2867(.118)	5.39(.58)	243(94)
Low Alk	.1175(.053)	.0253(.011)	4.41(.25)	106(56)
P Value	.043*	.057*	.171	.143
Glossosomatidae				
High Alk	.2434(.084)	.0353(.014)	7.36(.39)	273(71)
Low Alk	.0002(.000)	.0000(.000)	---------	1(1)
P Value	.014*	.014*	----	.014*
Brachycentridae				
High Alk	.1368(.065)	.0225(.011)	6.58(.38)	93(60)
Low Alk	.0054(.005)	.0008(.001)	7.05(.01)	2(3)
P Value	.043*	.043*	.114	.029*
Limnephilidae				
High Alk	.7042(.401)	.1169(.067)	5.66(.53)	1292(642)
Low Alk	.0453(.041)	.0075(.007)	6.48(.59)	97(88)
P Value	.029*	.029*	.800	.029*
Tipulidae(Small)				
High Alk	.3051(.096)	.0614(.019)	4.93(.10)	385(154)
Low Alk	.0106(.003)	.0032(.001)	3.29(.38)	29(10)
P Value	.014*	.014*	.029*	.014*
Tipulidae(Large)				
High Alk	.8921(.393)	.3403(.130)	2.90(.51)	5(1)
Low Alk	.0095(.002)	.0043(.001)	2.22(.07)	2(0)
P Value	.014*	.014*	.200	.029*
Athericidae				
High Alk	.2788(.260)	.1214(.120)	2.13(.23)	10(17)
Low Alk	.0000(.000)	.0000(.000)	---------	0(0)
P Value	.071*	.071*	----	.071*
Psychodidae				
High Alk	.3071(.111)	.0532(.020)	5.83(.11)	356(79)
Low Alk	.0010(.000)	.0001(.000)	5.95(.03)	2(1)
P Value	.014*	.014*	.400	.014*
Simuliidae				
High Alk	1.1651(.651)	.1135(.065)	10.74(.25)	1394(812)
Low Alk	.0363(.018)	.0026(.001)	13.57(.83)	104(63)
P Value	.014*	.014*	.057*	.029*

Table 9. Continued.

Taxon	Production Mean(S.E.)	Standing Crop Mean(S.E.)	Turnover Ratio Mean(S.E.)	Density Mean(S.E.)
Empididae				
High Alk	.0401(.017)	.0133(.006)	3.07(.18)	169(80)
Low Alk	.0149(.005)	.0045(.001)	3.33(.24)	64(23)
P Value	.100*	.071*	.400	.100*
Chironomidae				
High Alk	1.3198(.667)	.1144(.059)	11.82(.30)	5200(2463)
Low Alk	.2664(.048)	.0227(.005)	12.09(.67)	1159(220)
P Value	.014*	.014*	.743	.014*
Elmidae				
High Alk	.3478(.117)	.0651(.022)	5.27(.12)	668(216)
Low Alk	.0008(.000)	.0002(.000)	5.35(.17)	2(1)
P Value	.014*	.000*	.629	.014*
Hydracarina				
High Alk	.1861(.095)	.0434(.026)	5.03(.41)	1892(713)
Low Alk	.0193(.003)	.0039(.001)	5.06(.57)	236(51)
P Value	.014*	.014*	.857	.014*
Total				
High Alk	34.4626	4.9429	6.97	34261
Low Alk	4.6668	0.6962	6.70	5718

Table 10. Total annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratios (P/SC), and average density (# m^{-2}), by site of the 29 most numerous taxa for Utah high alkalinity streams and Wyoming low alkalinity streams, 1978-1979.

	P	SC	TR	D
Low Alkalinity Sites				
Clearwater Creek	2.8866	0.4475	6.45	4154
Goff Creek	5.3233	0.8424	6.32	4080
Kitty Creek	7.0035	0.9951	7.04	7999
Gunbarrel Creek (L)	3.5198	0.4974	7.08	5490
Gunbarrel Creek (M)	2.8760	0.4060	7.08	6903
Gunbarrel Creek (U)	3.9556	0.5949	6.65	7478
Mean Gunbarrel Creek	3.4505	0.4994	6.91	6624
Mean Non-Gunbarrel Sites	5.0711	0.7617	6.66	5411
Mean Wyoming Streams	4.6660	0.6961	6.70	5714
High Alkalinity Sites				
Curtis Creek	27.5234	3.7996	7.24	34341
Logan River	40.1639	5.9680	6.73	30306
Temple Fork	26.6495	3.5197	7.57	22623
Left Fk. Blacksmith Fk. (L)	43.3545	5.8214	7.45	49899
Left Fk. Blacksmith Fk. (M)	49.2865	7.7056	6.40	49237
Left Fk. Blacksmith Fk. (U)	37.8932	5.9209	6.40	50107
Mean Left Fk. Blacksmith Fk.	43.5114	6.4826	6.71	49748
Mean Non-LFBF Sites	31.4456	4.4291	7.10	29090
Mean Utah Streams	34.4621	4.9425	6.97	34254

productive in the high alkalinity streams were the stonefly (Plecoptera) families Nemouridae, Perlodidae, and Pteronarcidae, the mayfly (Ephemeroptera) genera *Rhithrogena* and *Epeorus* (Heptageniidae), the mayfly family Siphlonuridae, and the mayfly species *Ephemerella doddsi* (Ephemerellidae). Three of these taxa, Nemouridae, *Epeorus*, and Siphlonuridae, had higher mean production values in the low alkalinity streams, with the difference being significant for *Epeorus* and Siphlonuridae. All production values for representatives of the orders Trichoptera, Diptera, and Coleoptera were significantly higher in the high alkalinity streams. Production calculations for Baetidae (Ephemeroptera), Simuliidae (Diptera), and Chironomidae (Diptera) were based on two generations per year. Calculations for Pteronarcidae (Plecoptera) were based on three years per generation and those for Perlidae (Plecoptera) on two years per generation. The remaining taxa were assumed to be univoltine.

Standing Crop

The mean annual standing crop of all taxa summed was much higher in the high alkalinity streams, with an average standing crop of 4.9429 g/m^2, than the low alkalinity streams, with an average standing crop of 0.6962 g/m^2 (Table 10). All high alkalinity sites had significantly higher standing crops than any low alkalinity site (Table 10).

The mean annual standing crop of 22 of the 29 taxa analyzed were significantly higher in the high alkalinity streams than in the low alkalinity streams (Table 9). Site by site standing crop values are presented in Appendix I. The taxa which were not significantly higher in the high alkalinity streams included all taxa which did not have significantly greater production values in the high alkalinity streams, Nemouridae, Perlodidae, Pteronarcidae, *Rhithrogena*, *Epeorus*, Siphlonuridae, and *Ephemerella doddsi*. Three of these taxa, Nemouridae, *Epeorus*, and Siphlonuridae had higher mean standing crop values in the low alkalinity streams, with the difference being significant for *Epeorus* and Siphlonuridae.

Turnover Ratios

The average annual turnover ratios for all taxa combined (summed production divided by summed standing crop) were very similar between regions, with an average high alkalinity value of 6.97 and low alkalinity value of 6.70 (Table 10).

The annual turnover ratios of only 7 of the 29 taxa analyzed were significantly different between the two stream types. Six of these taxa had mean turnover ratios which were higher in the high alkalinity streams. These were Perlodidae, *Ephemerella doddsi*, *Ephemerella coloradensis*, *Ephemerella inermis*, Hydropsychidae (Trichoptera), and Tipulidae (Small) (Diptera). The only taxa which had a significantly higher mean turnover ratio in the low alkalinity streams was Simuliidae (Diptera). Mean turnover ratios for seven taxa were not computed for one of the two stream types due to non-representation in that stream type, or representation in such low numbers that the turnover ratio could not be accurately computed, (Appendix I).

Density

The mean density of all taxa summed was much higher in the high alkalinity streams with an average density of 34,261, than in the low alkalinity streams with a mean density of 5,718 per m^2. All high alklalinity sites had a significantly higher mean density than any low alkalinity site (Table 10).

The mean density of 21 of the 29 taxa analyzed was significantly higher in the high alkalinity streams than in the low alkalinity streams (Table 9). Site by site density values are presented in Appendix I.

Percent of Production

As seen in Tables 11-15, the high alkalinity streams had only five taxa that accounted for over 5 percent of average total annual production and three of these were members of the same genus. The low alkalinity streams, however, had seven taxa with over 5 percent of average total annual production and all were from different families. The high alkalinity streams had 12 more taxa that had between 1 and 5 percent of the average total annual production and 11 more that contributed at least 0.1 percent of the total. The low alkalinity streams had only six taxa contributing between 1 and 5 percent of the total and only eight more that contributed at least 0.1 percent of the total. Of the eight remaining taxa studied, four were found in the low alkalinity streams but only in very low numbers, and four were not collected in these streams.

Predators

The large predaceous stonefly, Perlodidae, was the second most productive insect in the low alkalinity streams, accounting for 13.4 percent of average total production (Table 11). The most productive predator in the high alkalinity streams was the caddisfly family Rhyacophilidae, accounting for 3.9 percent of production. Production of predators in the low alkalinity streams accounted for 18.2 percent

Table 11. Summary of annual production (afd gm m^{-2} yr^{-1}) and mean percentage of total production for predators for Utah high alkalinity and Wyoming low alkalinity streams, 1978-1979.

Taxon	Production	Percent of Total Production
Perlodidae		
High Alk	.8938	2.6%
Low Alk	.6234	13.4%
Chloroperlidae		
High Alk	.5110	1.5%
Low Alk	.0930	2.0%
Perlidae		
High Alk	.5794	1.7%
Low Alk	.0000	0.0%
Rhyacophilidae		
High Alk	1.3536	3.9%
Low Alk	.1175	2.5%
Athericidae		
High Alk	.2788	0.8%
Low Alk	.0000	0.0%
Empididae		
High Alk	.0401	0.1%
Low Alk	.0149	0.3%
Total		
High Alk	3.6567	10.6%
Low Alk	.8488	18.2%

Table 12. Summary of annual production (afd gm m^{-2} yr^{-1}) and mean percentage of total production for filterers for Utah high alkalinity and Wyoming low alkalinity streams, 1978-1979.

Taxon	Production	Percent of Total Production
Hydropsychidae		
High Alk	3.2471	9.4%
Low Alk	.6062	13.0%
Simuliidae		
High Alk	1.1651	3.4%
Low Alk	.0363	0.8%
Total		
High Alk	4.4122	12.8%
Low Alk	.6425	13.8%

Table 13. Summary of annual production (afd gm m^{-2} yr^{-1}) and mean percentage of total production for shredders for Utah high alkalinity and Wyoming low alkalinity streams, 1978-1979.

Taxon	Production	Percent of Total Production
Pteronarcidae		
High Alk	.0400	0.1%
Low Alk	.0000	0.0%
Nemouridae		
High Alk	.2166	0.6%
Low Alk	.2764	5.9%
Limnephilidae		
High Alk	.7042	2.0%
Low Alk	.0453	1.0%
Tipulidae		
High Alk	1.1972	3.5%
Low Alk	.0201	0.4%
Total		
High Alk	2.1580	6.2%
Low Alk	.3418	7.3%

Table 14. Summary of annual production (afd gm m^{-2} yr^{-1}) and mean percentage of total production for gatherers for Utah high alkalinity and Wyoming low alkalinity streams, 1978-1979.

Taxon	Production	Percent of Total Production
Rhithrogena		
High Alk	1.2810	3.7%
Low Alk	.9199	19.7%
Cinygmula		
High Alk	.6006	1.7%
Low Alk	.1782	3.8%
Epeorus		
High Alk	.0603	0.2%
Low Alk	.1562	3.3%
Ephemerella doddsi		
High Alk	1.9625	5.7%
Low Alk	.6152	13.2%
E. coloradensis		
High Alk	4.6404	13.5%
Low Alk	.0789	1.7%
E. grandis		
High Alk	2.2990	6.7%
Low Alk	.0000	0.0%
E. inermis		
High Alk	.5274	1.5%
Low Alk	.0420	0.9%
Baetidae		
High Alk	10.2174	29.6%
Low Alk	.5295	11.3%
Paraleptophlebia		
High Alk	.0988	0.3%
Low Alk	.0001	0.0%
Siphlonuridae		
High Alk	.0073	0.0%
Low Alk	.0206	0.4%
Brachycentridae		
High Alk	.1368	0.4%
Low Alk	.0054	0.1%

Table 14. Continued.

Taxon	Production	Percent of Total Production
Psychodidae		
High Alk	.3071	0.9%
Low Alk	.0010	0.0%
Chironomidae		
High Alk	1.3198	3.8%
Low Alk	.2664	5.7%
Elmidae		
High Alk	.3478	1.0%
Low Alk	.0008	0.0%
Total		
High Alk	23.8062	69.0%
Low Alk	2.8142	60.1%

Table 15. Summary of annual production (afd gm m^{-2} yr^{-1}) and mean percentage of total production for scrapers for Utah high alkalinity and Wyoming low alkalinity streams, 1978-1979.

Taxon	Production	Percent of Total Production
Glossosomatidae		
High Alk	.2434	0.7%
Low Alk	.0002	0.0%

of total production while predator production in the high alkalinity streams accounted for only 10.6 percent of the total. The insects used for this predator calculation included Perlodidae, Perlidae, Chloroperlidae, Rhyacophilidae, Empididae, and Athericidae (Merritt and Cummins 1978). It is known that certain species of Tipulidae and Chironomidae are predators (Merritt and Cummins 1978) but the level of identification used in this study did not separate these insects. Some large organisms (Pteronarcidae and Ephemerella grandis) are known to engulf smaller organisms (Merritt and Cummins 1978), but this is considered incidental to normal detritus consumption and is not considered here.

Filterers

Only two taxa were classified as filterers for this study, Hydropsychidae and Simuliidae (Merritt and Cummins 1978) (Table 12). Even though both were significantly more productive in the high alkalinity streams, their combined percents of total production were very similar between areas. In the high alkalinity systems, an average of 12.8 percent of total production was made up of these two filterers, while in the low alkalinity systems, they comprised 13.8 percent of total production.

Shredders

The stonefly families, Pteronarcidae and Nemouridae, the combined caddisfly group, Limnephilidae, and the cranefly family, Tipulidae (large and small combined), were treated as shredders in this study (Merritt and Cummins 1978) (Table 13). Merritt and Cummins (1978) report that some Limnephilidae are gatherers and scrapers and some

Tipulidae are gatherers and predators. Since in this study further identification was not conducted, all members of a taxon were grouped into the first or dominant functional grouping reported.

Total production of shredders was much higher in the high alkalinity streams with 2.16 g/m^2 than it was in the low alkalinity streams with a total production of 0.35 g/m^2. This was true even though the Pteronarcidae, which were found in only one stream, were not significantly more productive in the high alkalinity streams, and the Nemouridae were actually more productive in the low alkalinity streams. The percent of total production made up by shredders, however, was very similar in the two stream types. In the low alkalinity streams, 7.3 percent of total production was made up of shredders while, in the high alkalinity streams, an average of 6.2 percent of total production was made up of the same shredder taxa.

Gatherers

For all remaining taxa except Glossosomatidae, a scraper, Merritt and Cummins (1978) list gatherer as the first or dominant functional grouping. This includes all Ephemeroptera, Elmidae, Brachycentridae, Psychodidae, and Chironomidae and is the functional group that contains by far the largest percentage of production (Table 14).

Total production of gatherers was much higher in the high alkalinity streams with 23.81 g/m^2, which was more than an order of magnitude higher than the 2.81 g/m^2 production of gathers found in the low alkalinity streams. The percentage of total production, however, was only slightly higher in the high alkalinity streams with 69.0 percent being made up of gatherers compared to 60.1 percent of total production being gatherers in the low alkalinity streams.

Scrapers

Merritt and Cummins (1978) listed the functional group scrapers as a secondary functional group for several of the gatherers studied above. However, only one insect, the caddisfly family Glossosomatidae, was considered primarily a scraper (Table 15). This insect was not an important contributor to total production in either stream region. In the high alkalinity systems, it had an average production of 0.24 g/m^2 which accounted for 0.7 percent of total production. In the low alkalinity systems, it was collected in very low numbers and accounted for 0.0 percent of total production.

DISCUSSION

Physical-Chemical

Since the two stream regions were selected for differences in total alkalinity, it is not surprising to find that pH, specific conductance, total dissolved solids, calcium and magnesium levels were also significantly higher in the high alkalinity streams. The author, in a previous study, found that in 95 mountain streams from several regions these variables were highly correlated. The parent rock over which streams flow is a strong determinant of water chemistry. Since the high alkalinity streams flow through an area dominated by limestone and dolomite and the low alkalinity streams flow through the volcanic Absaroka Plateau, these differences in water chemistry were expected.

The higher phosphorus levels in the low productivity streams were not expected since phosphorus is often a limiting nutrient in fresh waters. Phosphorus is apparently not the limiting nutrient for primary production in these low alkalinity streams. The relatively high phosphorus levels may reflect low algal activity due to some other limiting factor resulting in less phosphorus usage.

Since the potassium levels did not differ between regions, the possibility of potassium deficiency contributing to low production as discussed by Minshall and Minshall (1978) was not a factor in this study.

The streams and stream sites were chosen to minimize physical differences as much as possible. Since there were no significant differences in width, depth, gradient, substrate size, solar insolation or temperature between regions, it was assumed that these factors did not play a significant role in productivity or processing differences, at least at the level seen in this study.

Detrital Processing

Alder Leaves

The typical leaf pack processing study involves the use of open stacks of leaves, fastened together in some manner, tied to a brick, and placed in a stream facing the current (Petersen and Cummins 1974). After various periods of time, the leaves are usually removed from the stream, dried and weighed (Petersen and Cummins 1974, Reice 1974, Sedell et al. 1975). These weights are then compared with the initial weights to determine percent remaining (Sedell et al. 1975, Benfield et al. 1977, Short and Ward 1980), percent lost (Petersen and Cummins 1974, Reice 1974), and/or coefficients of decay or K (Petersen and Cummins 1974, Benfield et al. 1977, Short and Ward 1980). Some studies have looked at other factors associated with leaf processing, such as numbers and kinds of insects associated with the packs (Sedell et al. 1975, Reice 1977), nutrient concentrations of the packs (Triska et al. 1975, Howarth and Fisher 1976, Suberkropp et al. 1976), or the microbial communities associated with the packs (Barlocher and Kendrick 1974, Suberkropp and Klug 1976, Barlocher et al. 1978).

Part of this study utilized the classic leaf pack style and analyzed the packs for percent of weight remaining and coefficients of decay to investigate whether the processing of leaves in high and low alkalinity streams is different. The results showed that for open packs during fall and winter maximum input periods, a very significant difference existed in the rate at which leaf packs lost weight in the two stream types. Packs in both stream types showed a steady decline in weight, but the rate of loss in the high alkalinity stream was much more rapid. Between sampling dates, the percent of weight loss from the previous weight was greater in the high alkalinity stream, except for the initial leaching period, when the low alkalinity stream had a slightly greater loss. This meant that the average rate of loss was greater for packs in the high alkalinity stream. This was particularly true during the early phase of the experiment. During this phase of the study, the rate of loss in the high alkalinity stream was almost four times as great as that of the low alkalinity stream.

A second leaf pack study was carried out during the following spring, typically the period of a second detrital input peak (Hynes 1970), especially with regard to nutrient concentration of the detritus (Lang and Forman 1978). This peak is due to runoff from snowmelt carrying autumn-shed leaves into the stream and rising stream levels inundating areas where piles of leaves collected near the stream the previous fall (Bell et al. 1978). The opening of leaf and flower buds somewhat later in the spring continues this input period.

Packs for this second study were somewhat different than the classical type used during the autumn study, and the ramifications of this will be discussed later. Due to runoff washing away or otherwise rendering some of the packs unusable, only one collection period was possible for the open type of leaf pack during the spring study. The results of this one collection, however, indicated the same pattern of much greater weight loss in the high alkalinity stream.

The higher processing rate in the high alkalinity stream can likely be attributed to two factors, faster colonization by microbes and higher insect biomass in the high alkalinity streams. A faster colonization of microbes alone would account for a faster weight loss in the leaf packs, at least to a point where microbial activity declines. Petersen and Cummins (1974) and Triska (1970) found that microbes alone do process leaves, although the addition of shredder organisms greatly speeds up the process. This latter point of shredder activity is probably of great importance here. It has been well established that although shredder organisms eat large leaf particles, they actually gain most of their nutrients from the fungi and bacteria that have colonized the leaf (Kaushik and Hynes 1971, Barlocher and Kendrick 1974, Cummins 1975a, b). Shredders usually do not start eating a leaf until a certain amount of colonization or "processing" by microbes has taken place (Barlocher and Kendrick 1974, Cummins 1975b). Some invertebrates have even shown a preference for certain species of fungi (Visser and Whittaker 1977). Therefore, a leaf that is colonized more rapidly by microbes will be viewed as "food" for shredders more rapidly. This would result in more insect activity on the leaf packs and a more rapid weight loss even if the number of shredders were the same in both stream types.

A confounding factor in this study, however, is the fact that insect productivities and biomass, including shredders, are not the same in the two stream types. It could be argued that the fact that the high alkalinity stream had more insects in it capable of processing a leaf pack resulted in the faster processing rates. If more insects are chewing on a leaf pack in one stream than another, it will lose more weight more rapidly (Cummins et al. 1973, Harrison 1977, Short and Maslin 1977).

Because of this complication of differential insect productivity, a second leaf pack type was tested that excluded most insect activity in both stream types. Packs, identical in all other respects to the packs used in the open pack studies, were tied inside fine mesh nylon bags constructed from nylon stockings. It was assumed that since most shredder organisms were excluded from the packs, any loss in weight would be attributed to microbial activity. Some problems are associated with packs of this type. The fine mesh size cuts down on water current so rates cannot be compared to open packs. Also because of the lower turnover of water, some oxygen deficiencies may exist inside these packs (Petersen and Cummins 1974, Reice 1974). The relatively small pack sizes (6.0 and 2.0 grams) used in this study resulted in this being less of a problem than in studies utilizing larger leaf packs. With larger packs there is a greater area that is not exposed to direct water flow. With the smaller packs, a larger percentage of the pack is exposed to relatively oxygen-rich water, reducing the importance of oxygen limitation. It was observed that some silt which collected inside the bags may have contributed to the oxygen deficiency problem. However, the purpose of this study was to compare weight loss in these packs between stream types, not between open and mesh packs. The same pack types were used in both streams under the same conditions, so the comparisons are assumed to be valid.

The results from the mesh pack experiments shed important light on the open pack results. Although the mesh leaf packs from both streams had the same weights at the conclusion of the study, the pattern of weight loss showed one very important difference. The leaf packs in the high alkalinity stream exhibited rapid early weight loss at the first collection period followed by more moderate weight loss. The packs in the low alkalinity streams, on the other hand, showed essentially no weight loss at the first collection period followed by rapid weight loss later. This pattern was seen during both the autumn-winter and spring-summer studies.

These results indicate that leaf packs in the high alkalinity stream experienced more rapid microbial colonization than packs in the low alkalinity stream and, as a result, experienced more rapid weight loss even in the absence of shredders. The results also indicate that only a certain amount of the leaf pack can be processed in a rapid manner by microbes alone. The packs in the high alkalinity streams, after experiencing rapid early processing, showed decreased weight loss later, allowing the packs in low alkalinity streams to catch up in total weight loss after a later, rapid loss phase.

These results suggest that packs in the high alkalinity stream do experience more rapid colonization by microbes. This means leaves in the high alkalinity stream may be "processed" into acceptable food for shredder organisms more rapidly. Therefore, the hypothesis that detritus processing times are the same in both high and low alkalinity streams is rejected.

Douglas-Fir Leaves

It has been shown that dead conifer leaves break down at a much slower rate than most deciduous leaves in streams. Barlocher et al. (1978) found that the maximum colonization of *Pinus resinosa* needles by hyphomycete fungi did not take place until after the leaves were in the stream for 216 days. Sedell et al. (1975) found that needle packs of Pseudotsuga menziesii and Tsuga heterophylla had to be in the stream for 140 days before any substantial insect activity took place on the leaves. The Douglas-fir needles in this study experienced very little weight loss during the study and showed no significant difference between stream types. The duration of this study was less than the time spans mentioned above and since the needles were enclosed in fine mesh bags, any potential insect activity was excluded.

Since streams in both areas flow through areas of Douglas-fir, input from this tree may be a significant food source. However, the extremely slow processing rates seen for conifer needles shows that the food value is limited. Woodall and Wallace (1972) found that of four streams, the lowest density and biomass of insects were in the stream flowing through a white pine plantation. For these sites used in this study, Douglas-fir was not an important part of the riparian canopy except for the Kitty Creek site, the highest productivity, low alkalinity stream.

Autumn vs. Spring Leaf Packs

There were two important differences in the make-up of leaf packs between the autumn and spring processing studies. These were size of packs and pack structure. At the conclusion of the autumn study, it was felt that the classic way of stacking leaves and fastening them together exhibited certain deficiencies. It was also decided that smaller leaf packs would be more favorable. The results show that although patterns of processing were similar for both studies, rates were different. Nearly twice as much weight was lost in the mesh packs during the spring study as was lost during the autumn study. A portion of this increased weight loss may be attributed to the change in pack structure and size. The spring pack style was loosely packed with fewer leaves. This allowed for improved colonization potential because a smaller percentage of the pack was inaccessible to microbe colonization or insect activity. Other factors, however, also changed between study periods. The spring packs were placed in the stream in mid-April, prior to runoff and were collected in late June and mid-September. These packs, therefore, were in the stream during late spring runoff and during the warm temperatures of summer. The autumn packs, on the other hand, were in the stream during the period of the year that water levels are lowest and during the cold water periods of late autumn and winter.

The heavy runoff during spring may have contributed to breakdown by increasing mechanical wear on the packs. The increased force of the water against the packs may have assisted in tearing the packs apart. Also, during runoff, much silt and sand is carried in the current, possibly resulting in a sandblasting effect on the leaves. This again would result in mechanical removal of leaf material. The heavy current, however, may reduce microbial and insect activity on the leaves for the same reasons, strong current and the scouring effect.

The temperature effect very likely had an important influence on the differential rates of processing between sampling periods. This temperature effect has been suggested by other workers (Suberkropp et al. 1975, Short and Ward 1980). Microbial and insect activity may be higher during the warmer months, leading to possible higher rates of detrital processing, although Müller-Haeckel (1977) found maximum production of Hyphomecetes conidia in September/October in a sub-arctic stream and concluded that the maximum production of this important group of detrital processors was not related to high water temperatures. The September/October maximum production period was during the period of maximum leaf fall, though, which could have been more important than water temperatures in stimulating conidia production. One may wonder what conidia production would be if maximum leaf fall coincided with high water temperatures.

Breakdown Coefficients

The coefficients of decay (K) for leached open thinleaf alder (*Alnus tenuifolia*) packs ranged from .0173 for spring and .0057 for autumn-winter high alkalinity packs to .0023 for autumn-winter and .0005 for spring low alkalinity packs. These values fell into the range of K values found by Petersen and Cummins (1974) for deciduous leaves in Augusta Creek, Michigan. The K values for this study, however, ranged from what Petersen and Cummins defined as "slow" processing leaves ($K<.005$) to "fast" processing leaves ($K>.010$) depending upon stream and season. Both the autumn-winter and spring values for the low alkalinity stream fell into the slow processing category, while the autumn-winter value for the high alkalinity stream fell into the medium processing category. There was as much difference between stream types and between seasons for a single species of leaf in this study as there was for the range of leaf species in the Petersen and Cummins (1974) study.

Short and Ward conducted a leaf pack processing study during autumn and winter using the same species of alder in two low alkalinity (11.0 and 22.5 mg/l) Colorado streams. The K values they calculated were much higher than any of the values reported in the review of leaf litter processing literature presented by Petersen and Cummins (1974). This was true even for studies carried out during the warm summer months and in experimental streams with a high biomass of shredders. The Short and Ward (1980) K values were also much higher than the values calculated for this study, although the same species of leaf was used and both experiments were carried out in mountain streams. The streams in the Short and Ward study were much larger than those in this study, but Short et al. (1980) report a similarly very high K for a small Colorado headwater stream nearby. Short and Ward (1980) report that 90 percent of alder packs would be processed in just 50 days in one of their streams, the Colorado River, and that this rate nearly equals the rate Hart and Howmiller (1975) found for much warmer southern California streams. Petersen and Cummins (1974), on the other hand, report a 90 percent processing time of 240 days for two of their fastest processing leaves, Cornus and Fraxinus. The small, well-shaded, hard water Augusta Creek, which depends largely upon leaf input as a major energy source and has a high productivity of aquatic insects, including shredders, has a slower processing time than the larger, more open, soft water Colorado River, which Short and Ward (1980) report has virtually no shredders. The authors explain the extremely high K values on the increased water temperatures below an upstream impoundment and the resultant increased microbial activity, and on surficial scraping by the large numbers of the scraper-collector (Merritt and

Cummins 1978) Ephemerella infrequens. Microbial action alone accounts for significant amounts of detrital processing as noted in this study and others (Triska 1970, Benfield et al. 1977), but studies have demonstrated that the addition of shredder organisms greatly increases processing (Cummins et al. 1973, Barlocher and Kendrick 1974, Short and Maslin 1977), even to the point of doubling it (Petersen and Cummins 1974). This author feels it is unlikely that the increase in water temperature alone in the Short and Ward (1980) study, particularly with shredder absence, could account for the processing rate approaching that seen in much warmer southern California streams (Hart and Howmiller 1975) in which shredders were present. The activity by Ephemerella infrequens was supposition, not documentation. Activity by large numbers of these mayflies may affect the packs, but probably not to the extent seen in their example, since they do not shred leaves. These explanations also do not account for the very high coefficients of decay seen in the other two streams discussed. Other factors may be operating to remove weight from the packs. A stronger current pushing on the packs, silt and sand particles sandblasting the packs, breaking off or sloughing of parts of the packs, different methods of pack construction and handling, or the preservative used are just a few possible reasons for the comparatively higher K factors found in the Short and Ward (1980) study.

Leaf Pack Respiration

Because of the highly variable results, the leaf pack respiration data were not used in this study. A respiration study likely would give some valuable insight to the patterns of detrital colonization in high and low alkalinity streams. However, the simple closed-bottle respiration experiment used in this study had too many apparent flaws to give reliable results. A more advanced flow-through type respiration experiment may give more reliable results.

Detrital Drift

The amount of detritus input to a stream may affect aquatic insect productivities due to differential food inputs alone. Some studies, such as that by Fisher and Likens (1973), have intensively studied inputs of allochthonous organic matter into streams. This type of study, however, is detailed and very time consuming and was deemed beyond the scope of this study. A crude estimate of detrital input differences, however, was made by taking drift measurements of leaves and other detritus in each of the streams during peak leaf fall. No significant difference in detrital drift was noted between stream types. This was expected because each of the streams had the same general character, that of a western mountain stream with a well-defined deciduous riparian zone. None of the streams was totally shaded as small eastern woodland streams often are (Minshall 1967, Cummins et al. 1972, 1973, Fisher and Likens 1973), yet none was of the open desert type such as Deep Creek, Curlew Valley, Utah and Idaho (G. W. Minshall, personal cummunication). The mean drift value for the high alkalinity streams was higher than that for the low alkalinity streams, but it is suggested that the canyon wind blowing during the high alkalinity sampling period contributed to this difference.

Detrital Standing Crops

If detritus is processed more rapidly in high alkalinity streams. as noted herein, and if inputs are the same in the two stream types, as suggested above, then one may conclude that there would be a lower mean annual standing crop of detritus collected from the high alkalinity streams. This, however, was not the case as there was no significant difference in detritus standing crops between stream types. Egglishaw (1964, 1968), on the other hand, found higher numbers of invertebrates at sites that had higher amounts of detritus. This also did not occur in this study. In fact, one of the high productivity sites, Curtis Creek, had one of the lowest detrital standing crops. A relatively large amount of riffle bottom was sampled and combined in one container and this may have masked possible detritus-invertebrate relationships at the microhabitat level. This type of sampling was intentional, however, to mask any invertebrate differences attributable to small, local variations in the physical environment. Also, no particle size differentiation was made for detrital standing crops. When detritus is processed, it is not totally removed from the system, but often merely reduced in size. Therefore, in equal input systems, the faster processing system may still have similar detrital standing crops made up of smaller particles.

Insect Survivals in Each Water Type

Two separate experiments were conducted to determine if insects from the high productivity, high alkalinity streams survived equally well in the low productivity, low alkalinity water. The original box experiment was a modification of one conducted by Minshall and Minshall (1978) in the River Duddon, which changes water chemistry after crossing a fault. They found differential survivals of Gammarus in the two water types, and after several other experiments, determined that the reason for the lower survivals in the softer water upstream regions was a lack of potassium in the water. As has already been discussed, potassium levels for the streams used in the present study did not differ significantly and were ruled out as a possible contributing factor. This experiment encountered several major problems. One was heavy siltation between the rubble particles in the boxes, eliminating habitat for the insects inside. Another was the growth of algae on the mesh across the top of the boxes, reducing flow of water into the boxes. Finally, one box was washed downstream in Temple Fork. These factors led to extremely variable and unreliable results.

A second experiment was designed to test the same factors, but under the controlled conditions of the laboratory. By using flasks filled with each water type and bubbled to produce current and high oxygen concentrations, the insects could be observed often, without destroying the experiment. Other confounding factors could also be eliminated. Experiments were terminated when conditions inside the flasks had obviously changed, or, in the case of Ephemerella coloradensis, emergence started.

Since none of the insects tested showed any difference in survival between water types, it is concluded that the water chemistry of the streams was not directly responsible for the differences noted in insect abundance and production between stream types. In fact, for Ephemerella coloradensis, survivals were the same in distilled water as in the two other water types. Apparently, there was no micronutrient limitation or presence of a toxic substance that killed the insects outright. Therefore, the hypothesis that limiting factors do not affect insect survivals in either high or low alkalinity streams is not rejected.

Algal Standing Crop

The results of the algal standing crop studies indicate that more food is available to grazer organisms in the high alkalinity streams during all times of the year. Although true primary production was not measured, the consistently higher standing crops in the high alkalinity streams are a good indication that primary productivity is higher in these streams than in the soft water streams. The hypothesis that alkalinity is not related to the primary productivities of streams is therefore rejected.

The autumn and spring peaks in chlorophyll can easily be explained. Upon abscission of leaves from the deciduous streamside vegetation, the stream becomes much more open. This increase in solar input occurs when water temperatures are still above the very cold winter levels, and the angle of the sun is still such that much of the light penetrates the water rather than being reflected. The large amount of soluble material leached from the leaf litter inputs also increases the nutrient content of the stream water. These factors can combine for a spurt in algal activity. In the winter, the stream is free of deciduous shading, but water temperatures are low, snow and ice cover some parts of the stream, day length is short, and the angle of the sun is such that much of the light is reflected off the water surface. This all combines to greatly reduce primary productivity during the winter. During the spring, the sun is higher in the sky, stream water temperatures have risen, nutrient availability increases with runoff, and the deciduous shrubs have not yet opened their leaves. Primary production rises. In the summer, the water temperatures are high and the sun is high in the sky, but much of the stream is shaded. If the shading is great enough, primary production will be reduced during the summer months.

Macroinvertebrates

Invertebrate Production

Although many recent papers have discussed various procedures for estimating secondary production in streams (Waters 1962, 1969b, 1977, 1979, Hynes and Coleman 1968, Hamilton 1969, Fager 1969, Allen 1971, Waters and Crawford 1973, Zwick 1975, Benke and Waide 1977, Cushman et al. 1978, LeBlond and Parsons 1977, 1978, Benke 1979, Gillespie and Benke 1979, Krueger and Martin 1980, Menzie 1980), relatively few authors have calculated production using actual field data. Most of those that have used field data investigated only one (Kimerle and Anderson 1971, Waters and Crawford 1973, McClure and Stewart 1976, Hall et al. 1980, Waters and Hokenstrom 1980) or a few taxa (Gillespie 1969, Eckblad 1973, Zelinka 1973, Winterbourn 1974, Cushman et al. 1975, Benke 1976, Martien and Benke 1977, Cover and Harrel 1978, Benke and Wallace 1980), or the entire stream fauna as a whole (Hynes and Coleman 1968). Reger (1980) calculated production of the 12 most important taxa from disturbed high alkalinity sites in the Logan River, Utah, system. The present study calculated the annual production of 29 taxa at 12 sites on eight undisturbed streams from two geologic regions.

A few workers have studied the relationship between aquatic insects and water hardness. Armitage (1958) concluded that alkalinity had an effect on aquatic insect standing crops in the Firehole River, Wyoming, and that for Trichoptera, it was a positive correlation, while for Ephemeroptera, it was a negative correlation. The present study differed from that conclusion, finding that both Trichoptera and Ephemeroptera had higher productivities and standing crops in the high alkalinity streams.

Slack (1955) compared a high with a low alkalinity Indiana stream and concluded that the high alkalinity stream was more productive than the low alkalinity stream. Two important problems with his study must be noted, namely that the streams were considerably different in size and that the high alkalinity stream was permanent while the low alkalinity stream was intermittant. Either of these factors alone could account for differences in productivity. In the present study, special care was taken to avoid such discrepancies.

Even though a large part of the total difference between stream types in this study was due to a few insects with very high production in the high alkalinity streams (<u>Ephemerella</u>, Baetidae, Hydropsychidae) most insects were significantly more productive in the high alkalinity streams, indicating that factors were affecting production of most taxa, not just a few very abundant ones. Although most taxa were more productive in the high alkalinity streams, four actually had higher mean productivities in the low alkalinity streams. This may be because these insects react favorably to the reduced competition and/or the factors that reduced the productivities of the other taxa did not affect these in the same manner. There may also have been some subtle habitat or other environmental difference not noted that was more favorable to these insects in the low alkalinity streams.

Plecoptera

The mean production for the order Plecoptera in the high alkalinity streams was over twice that of those in the low alkalinity streams, yet production of only two of the families was significantly higher in the high alkalinity streams. The family Nemouridae was one of four taxa that had a mean production value that was higher in the low alkalinity streams, although the difference was insignificant. There was comparatively little difference between all 12 sites for this taxon and the coefficients of variation for both regions were quite low compared to other taxa. Since the total annual production of all insects was much higher in the high alkalinity streams, and there was no significant difference in production of Nemouridae between regions, the Nemouridae made up a much larger percentage of total production in the low alkalinity streams. In fact, the total annual production was so much higher in the high alkalinity streams that there were several other taxa that were significantly much more productive in the high alkalinity streams but made up a larger percentage of the total in the low alkalinity streams.

The family Perlodidae was one of three predaceous stonefly families encountered. The production, although higher in the high alkalinity streams, was not significantly higher. The other two predaceous stonefly families, Chloroperlidae and Perlidae, were significantly more productive in the high alkalinity streams, with the Perlidae being absent from the low alkalinity stream samples.

Of the four high alkalinity streams, three had a combined predaceous stonefly production of over 2.0 g/m^2. In each of these three streams, one of the three stoneflies dominated, with a different one dominating in each stream. Perlidae was the most numerous taxon in Curtis Creek, Chloroperlidae was most numerous in Logan River, and

Perlodidae dominated the predaceous stoneflies of Left Fork Blacksmith Fork. Temple Fork had a much lower production of predaceous stoneflies than the other three high alkalinity sites with less than 1.0 g/m^2. As will be seen later, though, this stream had the highest production of the predaceous caddisfly, Rhyacophilidae. More discussion of the predaceous insects and the apparent ecological replacement will be presented later.

The large shredder stonefly, Pteronarcidae, was found in low numbers at only one stream, Left Fork Blacksmith Fork. Because it was found at only this one stream, the production was not significantly higher in the high alkalinity region.

Ephemeroptera

Of the ten mayfly taxa studied, six had significantly higher production in the high alkalinity streams, two had mean values that were non-significantly higher in the high alkalinity streams, and two had significantly higher production in the low alkalinity streams.

Three genera of the family Heptageniidae were collected in this study, Rhithrogena, Cinygmula, and Epeorus. The Cinygmula was significantly more productive in the high alkalinity streams, the Rhithrogena was non-significantly more productive in the high alkalinity streams, while the Epeorus was significantly more productive in the low alkalinity streams. Within the high alkalinity streams, summed production of the three Heptageniids was very similar for three of the four streams. The production in Left Fork Blacksmith Fork, however, averaged more than an order of magnitude less than the other three streams, indicating that this family is of much less importance in this stream reach. This also points out the variability that may be encountered between similar streams in a single small region.

Variability was also seen between streams in a single region among the four species of the genus *Ephemerella* that were collected. All species, with the exception of *E. doddsi*, were significantly more productive in the high alkalinity streams. Ecological replacement, similar to that seen in the predaceous stoneflies before, is suggested with these mayflies. All are classified as collectors-gatherers by Merritt and Cummins (1978) and all occupy similar habitat (Merritt and Cummins 1978). All four high alkalinity streams were dominated by one or two species but no stream had all four in high numbers. *E. doddsi* was very productive in the Logan River and Curtis Creek but of less importance in Temple Fork and almost non-existent in Left Fork Blacksmith Fork. *E. coloradensis* was very productive in Logan River and Temple Fork and somewhat productive in Curtis Creek, but again essentially absent from Left Fork Blacksmith Fork. *E. grandis*, on the other hand, was absent from Logan River and of little importance in Temple Fork and Curtis Creek. This species was very abundant in Left Fork Blacksmith Fork, the stream that had low densities of the other species in this genus. *E. inermis* was somewhat abundant in Left Fork Blacksmith Fork, but less so at the other three sites. Production of the family Ephemerellidae was an important factor contributing to the great difference in production between regions. The summed mean annual production of this family was over an order of magnitude higher in the high alkalinity streams than in the low alkalinity streams.

The mayfly family Baetidae was also an important contributor to the production difference between regions, with over an order of magnitude difference. This family was the most important single taxon in the high alkalinity streams, accounting for 29.1 percent of total production.

Neither Paraleptophlebia or Siphlonuridae were important contributors to production in either region. Siphlonuridae was one of the taxa that had significantly greater production in the low alkalinity streams. Paraleptophlebia, being almost absent from low alkalinity streams, was significantly more productive in the high alkalinity streams.

Trichoptera

Five caddisfly families were collected in numbers great enough to allow production calculation, and all five were significantly more productive in the high alkalinity streams.

The family Hydropsychidae was the most productive caddisfly in both the high and low alkalinity streams, ranking among the highest producing organisms in both regions. As a result, it is of approximately equal importance to total production in each region, although its production is nearly an order of magnitude higher in the high alkalinity streams.

The caddisfly family Rhyacophilidae was also an order of magnitude higher in production in the high alkalinity streams. This predator was found in lowest densities in the high alkalinity region in Left Fork Blacksmith Fork. This stream, on the other hand, had a high production of the predaceous dipteran, Athericidae, which was lacking or found in low numbers in the other streams.

Of the remaining three taxa, only the Limnephilidae group accounted for over 1.0 percent of average annual production in either region. This was a variable group, with some streams having a high production and others, a very low production of the taxon. This, of course, led to a very high coefficient of variation in each region.

Diptera

Production was calculated for seven groups from six families of the order Diptera. The family Tipulidae was split into two groups, large and small, based on the great difference in maximum size attained by members of the two groups. All members of this order were significantly more productive in the high alkalinity streams.

The Chironomidae was the most productive family of Diptera in both regions, making up 5.7 percent of total low alkalinity production and 3.8 percent of total high alkalinity production.

Only one other Diptera, Simuliidae, averaged over 1.0 g/m^2 production in the high alkalinity streams. With an average production of 1.1651 g/m^2, it accounted for 3.4 percent of total high alkalinity production. It was less important in low alkalinity streams, with its average production of 0.0363 g/m^2 accounting for only 0.8 percent of average total production.

The large members of Tipulidae accounted for 2.6 percent of high alkalinity production, but only 0.2 percent of low alkalinity production. By combining both Tipulidae groups and getting one family value, average high alkalinity production became 1.1972 g/m^2 and 3.5 percent of total production. The family was still relatively unimportant in low alkalinity streams with an average production of 0.0201 g/m^2 accounting for only 0.4 percent of total production.

The remaining taxa each accounted for less than 1.0 percent of total production for either stream type.

Coleoptera

The family Elmidae was the only representative of the beetles and it was almost absent from the low alkalinity streams. Production was calculated using only the larval forms, since after becoming adults, no growth or net production is realized. This insect was significantly more productive in the high alkalinity streams and accounted for 1.0 percent of average total production in the high alkalinity streams.

Hydracarina

This aquatic mite is the only non-insect invertebrate considered in this study. It was included because it accounted for a considerable percentage of invertebrates sorted from the smaller sieve sizes. Its production was significantly higher in the high alkalinity streams, although its percent of total production was nearly the same in both stream types. These production values are conservative because the smallest sieve size used in this study had openings larger than its smaller instars. As a result, only larger size classes of Hydracarina were used in production calculations.

Standing Crops

The standing crops of all invertebrates very closely mirrored the production values. All invertebrates that were significantly more productive in the high alkalinity streams also had significantly higher standing crops. The levels of significance were also very similar. This would suggest that standing crop may be an effective predictor of production.

No size class separation is necessary for standing crop determination, and since the smaller size classes account for a relatively small percentage of total biomass, less emphasis need be placed on finding the smallest individuals. Because of this, determination of standing crop is much less tedious than the estimation of annual production. For certain applications, production may be adequately predicted from standing crop data. For many management applications, the exact production value is not necessary, but a rough estimate would be useful.

The standing crop estimations that are so closely related to annual production in this study are mean annual standing crop values calculated from year-round sampling. Standing crop estimates calculated from samples taken at one time of the year would be less likely to effectively predict production for any particular taxon due to biomass changes associated with position in the life cycle. If samples were taken just before emergence, very high biomass values would be calculated, while if samples were taken only a few weeks later, just after emergence, very low biomass values would be calculated. These two samples would lead to two very different estimates of production. Some estimate of mean annual standing crop would still be necessary, but even here it is less likely that samples need to be taken as often as for direct annual production calculations.

Turnover Ratios

The average annual turnover ratios (TR) of 6.97 for high alkalinity stream insects and 6.70 for low alkalinity stream insects were considerably higher than the TR of 3 to 4 suggested by Waters (1969b) for aquatic insects. Waters' turnover ratios are life-cycle turnover ratios, however, while those in this study are annual turnover ratios. A certain percentage of time is spent in the egg, pupae and/or adult stages which is taken into account with life-cycle TR calculations but not with annual TR calculations. Also, some insects produce more than one cohort per year, which would again lead to a life-cycle TR that is different than the annual TR. Since all other phases of production in this study used annual values, annual TR values were also used. The results indicate that for an entire insect community, in either high or low alkalinity streams, the annual TR value may be very similar. This value, combined with an estimate of mean annual standing crop, can be used to calculate the annual production of the community.

Density

Invertebrate density estimates exhibit certain weaknesses that hinder their usefulness as predictors of production. The total mean density of invertebrates in the high alkalinity streams was significantly much higher than densities in low alkalinity streams. However, for some taxa, the production was higher in high alkalinity streams, but density was not. For others, the density was higher but production was not. Also, density estimates depend upon accurate enumeration of all individuals of a particular taxon, even the smallest. This is very tedious and expensive. In many management studies, only the relatively few, larger specimens are sorted. The easily overlooked, yet very numerous early instar individuals usually make up a relatively small percentage of biomass. Therefore, it is not likely that density would be as effective an estimator of production as would standing crop.

Predators

Percentage wise, predators were more numerous in the low alkalinity streams than they were in the high alkalinity streams. However, in terms of absolute production, predators were still more productive in the high alkalinity streams. This is true even for the Perlodidae which made up 13.4 percent of production in the low alkalinity streams but only 2.6 percent in the high alkalinity streams. Total average production was still higher in the high alkalinity streams for this predaceous stonefly.

The reasons for the higher percentage of predators in the low productivity stream are not clear. There is, however, one speculative factor that may contribute to the discrepancy. In the high alkalinity streams, prey is very abundant relative to predators. Therefore food may not be a factor limiting production of the predaceous insects. Other factors such as habitat or predation may be limiting predator numbers before food limitation comes into play. If food supply is not an important factor affecting productivities of these insects, they, in turn, may not greatly affect the numbers of prey organisms. This would lead to relatively high numbers of prey insects, thereby reducing the percentage of predator insects in the total, although predator production remains high.

In the low alkalinity streams, prey production is much lower. Prey may be so scarce as to limit production of the predaceous insects. This could account for the lower total production of predators in the low alkalinity waters. If prey is scarce, predator activity may affect prey abundance in a significant way. By cropping back prey abundance because of heavy predator pressure, the percent composition of predators in the streams increases although predator production decreases. These factors are discussed by Varley et al. (1973) in discussions of parasite-host situations and by Hassell (1978) regarding arthropod predator-prey relationships.

Filterers

The percent of total production for filterers was very similar for both stream regions even though total production of filterers was much higher in the high alkalinity streams. The lower total production value in the low alkalinity streams likely reflects the reduced amount of available food to filterers in these streams. The similar percent of total figures for both stream regions, however, suggest that filterer production, as a group, is not affected by reduced food availability any more than any of the other functional groups, and their contribution to community composition is the same under both high and low food availability conditions.

Shredders

The shredder results were very similar to those seen with the filterers. Actual production values were very much higher in the high alkalinity streams, although percents of total production were almost the same. This likely reflected the reduced microbial colonization rates on large particle detritus in the low alkalinity streams. Both stream types had similar inputs of allochthonous detritus, yet shredder production was much lower in the low alkalinity systems. This supports the idea that just because leaves fall into the stream does not mean that they are immediate food for the invertebrates. They must be colonized or "processed" first, and this processing takes place more rapidly in the high alkalinity streams. The high alkalinity streams can therefore support a higher productivity of shredder organisms.

The role that shredders play in preparing food for the filterers and gatherers is demonstrated by the fact that even though productivity differences are great between regions, percents of total production are very similar. This would support the premise that collector production is at least partially affected by shredder activity.

Gatherers

Gatherers were by far the largest functional group of stream insects in both stream types, and their productivity pattern was quite similar to that seen with the shredders and filterers. Production differences between the two regions were great, but percents of total production were quite similar. The reduced production in the low alkalinity streams likely reflects reduced food availability in these streams, but the similar percents of total production values demonstrate that gatherers, as a group, suffer little more from lack of food than do the other detritus-eating groups. The 9 percent total difference is greater than the differences seen for the other detritus-eating groups, but 9 percent of 60 percent or 69 percent is not much different than 1.1 percent of 6.2 percent or 7.3 percent as seen for shredders. Also, many of these gatherers are small, mobile insects that are likely prey for predaceous insects. If higher predator pressure does exist in the low alkalinity streams, as discussed earlier, this is the group that would be most affected by such pressure.

Scrapers

Only one taxon was considered primarily a scraper, and it accounted for less than 1.0 percent of total production in both stream types. It appears, therefore, that scrapers are very unimportant insects in these streams. This is misleading, though, for Merritt and Cummins (1978) list scraper as a secondary functional group for several taxa. Many more insects than just Glossosomatidae are scraping algae in these streams. Therefore, an increase in attached algae production in one stream type over another is an increase in available food for that stream type.

Interspecific Competition

In at least two situations, two or more invertebrates in a region had very similar food, feeding, and/or habitat requirements, although one or more were absent from one stream and dominant in another. This was true with the three large species of *Ephemerella* mayflies, *E. grandis*, *E. coloradensis*, and *E. doddsi* in the high alkalinity streams. In streams in which *E. grandis* was absent, *E. coloradensis* and/or *E. doddsi* were abundant. In Left Fork Blacksmith Fork, however, *E. grandis* was abundant and *E. coloradensis* and *E. doddsi* were absent. A similar situation was also noted for the predaceous stoneflies where, in three high alkalinity streams, three different stoneflies dominated to the exclusion or near exclusion of the others. These two situations suggest strong interspecific competition to the extent that one or more species are eliminated in favor of the survivors. This is, of course, just one possible explanation for the situations. Others may include geographic isolation, climatic conditions during the previous emergence, disease, and/or environmental factors which favor one species.

Macroinvertebrate Production and Food Availability

This study had two primary objectives. One was to determine if high alkalinity mountain streams had higher productivities of aquatic macroinvertebrates than low alkalinity mountain streams. The second was to determine if any productivity difference might be related to the availability of two important invertebrate foods, attached algae and "processed" detritus.

As noted herein, the high alkalinity streams had significantly higher total production of invertebrates and higher production of most individual taxa than the low alkalinity streams. The standing crops of attached algae on artificial substrates were statistically higher in the high alkalinity streams. Also, the processing rate of alder leaves was faster in the high alkalinity streams indicating that detrital inputs become available food to invertebrates faster in these streams. Since detrital input, insect survival and physical differences between study regions were insignificant, the differences in food availability most likely were important factors contributing to the differences in insect production.

With attached algae, the increased food availability appears to be simply a faster growth rate of algae in the high alkalinity streams. While standing crops on artificial substrates are not measures of primary production in the strict sense, they can be used as reliable estimates of productive capabilities, especially in a comparative manner. This study did not attempt to determine the causes of the differential algal production between stream types, but it did demonstrate that the more productive high alkalinity streams had a greater availability of an important food in lotic ecosystems, attached algae.

With detrital inputs, the higher processing rate in the high alkalinity streams resulted in more highly concentrated food in these streams even if detrital inputs were the same in both stream regions. Detrital material is utilized in a stream system over and over again following microbial colonization and recolonization (Barlocher and Kendrick 1974). In the high alkalinity system, leaf pack processing was more rapid, indicating leaf inputs would become available food more rapidly in these systems. Shredders would therefore attack large leaf particles more rapidly in the high alkalinity streams. Since material is constantly being flushed downstream in lotic ecosystems, organisms must utilize potential food when it is in their vicinity or they risk losing the food downstream. Because shredders can feed on leaves more quickly in the high alkalinity streams, the leaves would travel less distance downstream before being attacked. Since shredder activity results in smaller food particles for the next detritivore level, the earlier shredder activity in the high alkalinity system would result in smaller particles being available more rapidly. This increased rate of detrital availability would hold for each additional level of detrital usage. Therefore, for any given time or stream distance, more detritus can be utilized by more organisms in the high alkalinity system. This system would be able to support more invertebrates for a given stream reach on a given amount of detrital input due to a higher efficiency of resource utilization. The hypothesis that annual production of stream insects is not related to detritus processing time is therefore rejected.

SUMMARY AND CONCLUSIONS

Numerous studies have investigated differences in stream processes associated with stream size, substrate, temperature, detrital species or other factors. However, little work has been done comparing processes between high and low alkalinity streams. This study investigated macroinvertebrate productivity differences, and factors that may be associated with such differences, in several high and low alkalinity streams.

It was determined that at the sites selected for study, the streams did not differ statistically in any of the physical characteristics measured. These included mean width, mean depth, gradient, solar insolation, substrate size and mean temperature.

In addition to total alkalinity, nine of ten chemical variables measured were significantly different between regions. Five of these variables, pH, specific conductance, total dissolved solids, calcium and magnesium, are usually associated with alkalinity and were all higher in the high alkalinity streams. Nitrate nitrogen was also significantly higher in the high alkalinity streams. Total phosphorus, total dissolved phosphorus and sodium were significantly higher in the low alkalinity streams. Potassium was found to be not different between regions.

Total annual production of the 29 most abundant invertebrate taxa was calculated for each of the 12 stream sites. Total production of all taxa summed was much higher at each of the high alkalinity sites. Production of 22 of the 29 taxa studied was also statistically higher in the high alkalinity streams. Only two taxa were significantly more productive in the low alkalinity streams.

Survivals of insects in water from the two regions showed no differences for all taxa tested.

Standing crops of algae on artificial substrates were statistically higher in the three high alkalinity streams studied than the three low alkalinity streams investigated.

Estimates of detrital inputs based on drift measurements, and standing crops of detritus collected with invertebrate samples showed no significant differences between regions.

Leaf pack processing studies were conducted with both thinleaf alder (Alnus tenuifolia) and Douglas-fir (Pseudotsuga menziesii) leaves. There was no difference in the processing rates of Douglas-fir between regions.

Alder leaf packs were constructed in two different styles. One was the normal open leaf pack which allowed access to invertebrates. The second style took the same kind of leaf pack as above and tied it inside a fine mesh bag to eliminate access to all but the tiniest invertebrates. The open style packs experienced a much greater loss of weight in the high alkalinity stream. The mesh packs showed no difference in total weight loss in the two stream types at the conclusion of the experiments, but the pattern of weight loss was considerably different for the two stream types. In the high alkalinity streams, the packs experienced a rapid early weight loss which then stabilized. In the low alkalinity stream, the packs experienced little or no weight loss in the early phase, but then had a later rapid weight loss phase.

The high alkalinity streams in this study had a much higher productivity of aquatic macroinvertebrates than the low alkalinity streams. They also had higher standing crops of attached algae and faster processing of alder leaves. Algae and processed allochthonous detritus are two major food sources for many aquatic invertebrates. It is concluded that a major reason for the great difference in invertebrate production between the physically similar high and low alkalinity streams in this study was the availability difference of these two food sources. The insects in the high alkalinity streams had much more of both food types available to them so a much higher annual production of aquatic invertebrates was supported.

These results show the value of using total alkalinity, or some other highly correlated variable such as specific conductance or total hardness, as a predictor of aquatic productivity. Since only two alkalinity ranges were compared in this study, linear predictability values cannot yet be formulated. However, the great differences in production seen between the two alkalinity ranges studied would suggest that further work with other alkalinity ranges may be warranted.

Since the productivity differences were the result of complex food availability processes, there appears to be little that a stream manager could do to alter the conditions governing the food availability given the low intensity of most stream management practices. Fish stocking procedures and creel regulations could be affected by such productivity differences, however. Decisions about whether to use the stream as a natural food source to support planted fingerlings versus raising fish to catchable size in hatcheries, then stocking would be wiser if knowledge of stream productivity was available. Decisions about creel limits, size limits and seasons would also benefit from such information.

LITERATURE CITED

Allen, K. R. 1971. Relation between production and biomass. J. Fish. Res. Bd. Canada 28:1573-1581.

American Public Health Association. 1975. 14th ed., Amer. Public Health Assoc., Washington, D. C. 874 pp.

Anderson, R. O. 1959. A modified flotation technique for sorting bottom fauna samples. Limnol. Oceanogr. 4:223-225.

Armitage, K. B. 1958. Ecology of the riffle insects of the Firehole River, Wyoming. Ecology 39:571-580.

Barber, W. E. and N. R. Kevern. 1974. Seasonal variation of sieving efficiency in a lotic habitat. Freshwater Biology 4:293-300.

Barlocher, F. and B. Kendrick. 1974. Dynamics of the fungal population on leaves in a stream. J. Ecol. 62:761-791.

Barlocher, F., B. Kendrick and J. Michaelides. 1978. Colonization and conditioning of Pinus resinosa needles by aquatic hyphomycetes. Arch. Hydrobiol. 81:462-474.

Bell, D. T., F. L. Johnson and A. R. Gilmore. 1978. Dynamics of litter fall, decomposition, and incorporation in the streamside forest ecosystem. Oikos 30:76-82.

Benfield, E. F., D. S. Jones and M. F. Patterson. 1977. Leaf pack processing in a pastureland stream. Oikos 29:99-103.

Benke, A. C. 1976. Dragonfly production and prey turnover. Ecology 57:915-927.

Benke, A. C. 1979. A modification of the Hynes method for estimating secondary production with particular significance for multivoltine populations. Limnol. Oceanogr. 24:168-171.

Benke, A. C. and J. B. Waide. 1977. In defense of average cohorts. Freshwater Biology. 7:61-63.

Benke, A. C. and J. B. Wallace. 1980. Trophic basis of production among net-spinning caddisflies in a southern Appalachian stream. Ecology 61:108-118.

Boling, R. H., Jr., E. D. Goodman, J. A. VanSickle, J. O. Zimmer, K. W. Cummins, R. C. Petersen and S. R. Reice. 1975. Toward a model of detritus processing in a woodland stream. Ecology 56:141-151.

Cover, E. C. and R. C. Harrel. 1978. Sequences of colonization, diversity, biomass, and productivity of macroinvertebrates on artificial substrates in a freshwater canal. Hydrobiologia 59:81-95.

Cummins, K. W. 1974. Structure and function of stream ecosystems. Bioscience 24:631-641.

Cummins, K. W. 1975a. Macroinvertebrates. Chapter 7 _in_ B. A. Whitton, ed. River Ecology. Univ. California Press.

Cummins, K. W. 1975b. The importance of different energy sources in freshwater ecosystems. Pages 50-54 _in_ Productivity of world ecosystems. National Academy of Sciences.

Cummins, K. W., M. J. Klug, R. G. Wetzel, R. C. Petersen, K. F. Suberkropp, B. A. Manny, J. C. Wuychek and V. I. Holt. 1972. Organic enrichment with leaf leachate in experimental lotic ecosystems. Bioscience 22:719-722.

Cummins, K. W., R. C. Petersen, F. O. Howard, J. C. Wuychek and V. I. Holt. 1973. The utilization of leaf litter by stream detritivores. Ecology 54:336-345.

Cushman, R. M., J. W. Elwood and G. W. Hildebrand. 1975. Production dynamics of _Alloperla mediana_ Banks (Plecoptera: Chloroperlidae) and _Diplectrona modesta_ Banks (Trichoptera: Hydropsychidae) in Walker Branch, Tennessee. Oak Ridge National Lab. ORNL-TM 4957. 66 pp.

Cushman, R. M., H. H. Shugart, Jr., S. G. Hildebrand and J. W. Elwood. 1978. The effect of growth curve and sampling regime on instantaneous-growth, removal-summation, and Hynes/Hamilton estimates of aquatic insect production: A computer simulation. Limnol. Oceanogr. 23:184-189.

Davis, S. F. and M. J. Winterbourn. 1977. Breakdown and colonization of _Nothofagus_ leaves in a New Zealand stream. Oikos 28:250-255.

Eckblad, J. W. 1973. Population studies of three aquatic gastropods in an intermittent backwater. Hydrobiologia 41:199-219.

Egglishaw, H. J. 1964. The distributional relationship between the bottom fauna and plant detritus in streams. J. Anim. Ecol. 33:463-476.

Egglishaw, H. J. 1968. The quantitative relationship between bottom fauna and plant detritus in streams of different calcium concentrations. J. Appl. Ecol. 5:731-740.

Egglishaw, H. J. and N. E. Morgan. 1965. A survey of the bottom fauna of streams in the Scottish Highlands. Part II. The relationship of the fauna to the chemical and geological conditions. Hydrobiologia 26:173-183.

Elliot, J. M. 1971. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biol. Assoc., Sci. Publ. 49. 148 pp.

Fager, E. W. 1969. Production of stream benthos: A critique of the method of assessment proposed by Hynes and Coleman. Limnol. Oceanogr. 14:766-770.

Fisher, S. G. and G. E. Likens. 1972. Stream ecosystem: Organic energy budget. Bioscience 22:33-35.

Fisher, S. G. and G. E. Likens. 1973. Energy flow in Bear Brook, New Hampshire: An integrative approach to stream ecosystem metabolism. Ecol. Monog. 43:421-439.

Gillespie, D. M. 1969. Population studies of four species of molluscs in the Madison River, Yellowstone National Park. Limnol. Oceanogr. 14:101-114.

Gillespie, D. M. and A. C. Benke. 1979. Methods of calculating cohort production from field data--some relationships. Limnol. Oceanogr. 24:171-176.

Green, B. F. 1977. A practical interactive program for randomization tests of location. American Statistician 31:37-39.

Greene, G. N. 1970. Effects of water hardness on fish production in plastic pools. Proc. 23rd Ann. Conf. Southeastern Assn. Game and Fish Commr. 1969:455-461.

Hall, R. J., T. F. Waters and E. F. Cook. 1980. The role of drift dispersal in production ecology of a stream mayfly. Ecology 61:37-43.

Hamilton, A. L. 1969. On estimating annual production. Limnol. Oceanogr. 14:771-782.

Harrison, P. G. 1977. Decomposition of macrophyte detritus in seawater: effects of grazing by amphipods. Oikos 28:165-169.

Hart, S. D. and R. P. Howmiller. 1975. Studies on the decomposition of allochthonous detritus in two southern California streams. Verh. Int. Verein. Limnol. 19:1665-1674.

Hassel, M. P. 1978. The dynamics of arthropod predator-prey systems. Princeton Univ. Press, Princeton, N. J. 237 pp.

Howarth, R. W. and S. G. Fisher. 1976. Carbon, nitrogen, and phosphorus dynamics during leaf decay in nutrient-enriched stream microecosystems. Freshwater Biology 6:221-228.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. Toronto Press, Toronto. 555 pp.

Hynes, H. B. N. 1980. A name change in the secondary production business. Limnol. Oceanogr. 25:778.

Hynes, H. B. N. and M. J. Coleman. 1968. A simple method of assessing the annual production of stream benthos. Limnol. Oceanogr. 13:569-573.

Kaushik, N. K. and H. B. N. Hynes. 1968. Experimental study on the role of autumn-shed leaves in aquatic environments. J. Ecol. 56:229-243.

Kaushik, N. K. and H. B. N. Hynes. 1971. The fate of the dead leaves that fall into streams. Arch. Hydrobiol. 68:465-515.

Kimerle, R. A. and N. H. Anderson. 1971. Production and bioenergetic role of the midge Glyptotendipes barbipes (Staeger) in a waste stabilization lagoon. Limnol. Oceanogr. 16:646-659.

Krueger, C. C. and F. B. Martin. 1980. Computation of confidence intervals for the size frequency (Hynes) method of estimating secondary production. Limnol. Oceanogr. 25:773-777.

Lang, G. E. and R. T. T. Forman. 1978. Detrital dynamics in a mature oak forest: Hutcheson Memorial Forest, New Jersey. Ecology 59:580-595.

LeBlond, P. H. and T. R. Parsons. 1977. A simplified expression for calculating cohort production. Limnol. Oceanogr. 22:156-157.

LeBlond, P. H. and T. R. Parsons. 1978. Reply to comment by W. E. Ricker. Limnol. Oceanogr. 23:380-382.

Lellak, J. 1965. The food supply as a factor regulating the population dynamics of bottom animals. Mitt. Internat. Verein. Limnol. 13:128-138.

Lush, D. L. and H. B. N. Hynes. 1973. The formation of particles in freshwater leachates of dead leaves. Limnol. Oceanogr. 18:968-977.

Madsen, B. L. 1972. Detritus on stones in small streams. Mem. 1st Ital. Idrobiol. 29 Suppl.:385-403.

Martien, R. F. and A. C. Benke. 1977. Distribution and production of two crustaceans in a wetland pond. Am. Midl. Nat. 98:162-175.

Mathews, C. P. and A. Kowalczewski. 1969. The disappearance of leaf litter and its contribution to production in the River Thames. J. Ecol. 57:543-552.

McClure, R. G. and K. W. Stewart. 1976. Life cycle and production of the mayfly Choroterpes (Neochoroterpes) mexicanus Allen (Ephemeroptera: Leptophlebiidae). Ann. Entomol. Soc. Amer. 69:134-144.

McFadden, J. T. and E. L. Cooper. 1962. An ecological study of six populations of brown trout (Salmo trutta). Trans. Am. Fish. Soc. 91:53-62.

Menzie, C. A. 1980. A note on the Hynes method of estimating secondary production. Limnol. Oceanogr. 25:770-773.

Merritt, R. W. and K. W. Cummins. 1978. An introduction to the aquatic insects of North America. Kendall-Hunt Publishing Company, Dubuque, Iowa. 441 pp.

Minshall, G. W. 1967. Role of allochthonous detritus in the trophic structure of a woodland spring brook community. Ecology 48:139-149.

Minshall, G. W. 1977. Class handout. In Biology 604--Advanced Limnology, Idaho State University, Pocatello.

Minshall, G. W. and J. N. Minshall. 1978. Further evidence on the role of chemical factors in determining the distribution of benthic invertebrates in the River Duddon. Arch. Hydrobiol. 83:324-355.

Moyle, J. B. 1956. Relationships between the chemistry of Minnesota surface waters and wildlife management. J. Wildl. Mgmt. 20:303-320.

Müller-Haeckel, A. 1977. Annual production of Hyphmocytes conidia in a subarctic stream. Oikos 29:396-397.

Nelson, D. J. and D. C. Scott. 1962. Role of detritus in the productivity of a rock-outcrop community in a piedmont stream. Limnol. Oceanogr. 7:396-413.

Petersen, R. C. and K. W. Cummins. 1974. Leaf processing in a woodland stream. Freshwater Biology 4:343-368.

Reger, S. J. 1980. Effects of stream channel alterations on aquatic insect communities. Ph.D. dissertation, Utah State Univ., Logan. 172 pp.

Reice, S. R. 1974. Environmental patchiness and the breakdown of leaf litter in a woodland stream. Ecology 55:1271-1282.

Reice, S. R. 1977. The role of animal associations and current velocity in sediment-specific leaf litter decomposition. Oikos 29:357-365.

Ricker, W. E. 1934. An ecological classification of certain Ontario streams. Univ. Toronto Stud. Biol. Ser. 37:1-114.

Runke, H. M. 1979. Simulation of the lotic periphyton community of a small mountain stream by digital computer. Ph.D. dissertation, Utah State Univ., Logan.

Sedell, J. R., F. J. Triska and N. S. Triska. 1975. The processing of conifer and hardwood leaves in two coniferous forest streams: I. Weight loss and associated invertebrates. Verh. Int. Verein. Limnol. 19:1617-1627.

Short, R. A. and P. E. Maslin. 1977. Processing of leaf litter by a stream detritivore: Effect on nutrient availability to collectors. Ecology 58:935-938.

Short. R. A. and J. V. Ward. 1980. Leaf litter processing in a regulated Rocky Mountain stream. Can. J. Fish. Aquat. Sci. 37:123-127.

Short, R. A., S. P. Canton and J. V. Ward. 1980. Detrital processing and associated macroinvertebrates in a Colorado mountain stream. Ecology. (In press).

Slack, K. V. 1955. A study of the factors affecting stream productivity by the comparative method. Invest. Indiana Lakes Streams 4:3-47.

Suberkropp, K. and M. J. Klug. 1976. Fungi and bacteria associated with leaves during processing in a woodland stream. Ecology 57:707-719.

Suberkropp, K., G. L. Godshalk and M. J. Klug. 1976. Changes in the chemical composition of leaves during processing in a woodland stream. Ecology 57:720-727.

Suberkropp, K., M. J. Klug and K. W. Cummins. 1975. Community processing in leaf litter in woodland streams. Verh. Int. Verein. Limnol. 19:1653-1658.

Triska, F. J. 1970. Seasonal distribution of aquatic hyphomycetes in relation to the disappearance of leaf litter from a woodland stream. Ph.D. dissertation. Univ. Pittsburgh. 189 pp.

Triska F. J., J. R. Sedell and B. Buckley. 1975. The processing of conifer and hardwood leaves in two coniferous forest streams: II. Biochemical and nutrient changes. Verh. Int. Verein. Limnol. 19:1628-1639.

Varley, C. G., G. R. Gradwell and M. P. Hassell. 1973. Insect population ecology. University of California Press, Berkeley and Los Angeles. 212 pp.

Visser, S. and J. B. Whittaker. 1977. Feeding preferences for certain litter fungi by Onychiurus subtenuis (Collembola). Oikos 29:320-325.

Waters, T. F. 1962. A method to estimate the production rate of a stream bottom invertebrate. Trans. Am. Fish. Soc. 91:243-250.

Waters, T. F. 1969a. Subsampler for dividing large samples of stream invertebrate drift. Limnol. Oceanogr. 14:813-815.

Waters, T. F. 1969b. The turnover ratio in production ecology of freshwater invertebrates. Amer. Nat. 103:173-185.

Waters, T. F. 1977. Secondary production in inland waters. Adv. Ecol. Res. 10:91-164.

Waters, T. F. 1979. Influence of benthos life history upon the estimation of secondary production. J. Fish. Res. Bd. Can. 36:1425-1430.

Waters, T. F. and G. W. Crawford. 1973. Annual production of a stream mayfly population: A comparison of methods. Limnol. Oceanogr. 18:286-296.

Waters, T. F. and J. C. Hokenstrom. 1980. Annual production and drift of the stream amphipod Gammarus pseudolimnaeus in Valley Creek, Minnesota. Limnol. Oceanogr. 25:700-710.

Wetzel, R. G. and B. A. Manny. 1972. Decomposition of dissolved organic and nitrogen compounds from leaves in an experimental hard-water stream. Limnol. Oceanogr. 17:927-931.

Winberg, G. G. 1971. Methods for the estimation of production of aquatic animals. Academic Press, New York.

Winterbourn, M. J. 1974. The life histories, trophic relations and production of Stenoperla prasina (Plecoptera) and Deleatidium sp. (Ephemeroptera) in a New Zealand river. Freshwater Biology 4:507-524.

Woodall, W. R. and J. B. Wallace. 1972. The benthic fauna in four small southern Appalachian streams. Am. Midl. Nat. 88:393-407.

Zelinka, M. 1973. Die Eintagsfliegen (Ephemeroptera) in Forellenbachen der Beskiden. II. Produktion. Hydrobiologia 42:13-19.

Zwick, P. 1975. Critical notes on a proposed method to estimate production. Freshwater Biology 5:67-70.

APPENDICES

Appendix I

Site by Site Production, Standing Crop, Turnover Ratio and Density Values

Table 16. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for Nemouridae (Plecoptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.1180	.0233	5.08	611
Goff Creek	.3512	.0807	4.35	1113
Kitty Creek	.2985	.0586	5.09	1443
Gunbarrel Creek (L)	.3214	.0688	4.67	1241
Gunbarrel Creek (M)	.2998	.0623	4.81	1253
Gunbarrel Creek (U)	.3923	.0871	4.50	1496
Mean Gunbarrel Creek	.3378	.0727	4.66	1330
	(.0483)	(.0129)	(.16)	(144)
Mean (SD) Non-Gunbarrel Sites	.2559	.0542	4.84	1056
	(.1223)	(.0290)	(.42)	(419)
Mean (SD) Wyoming Streams	.2764	.0588	4.80	1124
	(.1079)	(.0254)	(.36)	(369)
Curtis Creek	.2176	.0462	4.71	734
Logan River	.1428	.0269	5.30	735
Temple Fork	.1539	.0315	4.88	465
Left Fk. Blacksmith Fk. (L)	.2985	.0586	5.09	1269
Left Fk. Blacksmith Fk. (M)	.3135	.0662	4.73	984
Left Fk. Blacksmith Fk. (U)	.4438	.0893	4.97	1835
Mean Left Fk. Blacksmith Fk.	.3519	.0714	4.93	1363
	(.0799)	(.0160)	(.18)	(433)
Mean (SD) Non-LFBF Sites	.1714	.0349	4.96	645
	(.0404)	(.0101)	(.30)	(156)
Mean (SD) Utah Streams	.2166	.0440	4.92	824
	(.0961)	(.0200)	(.26)	(381)

Table 17. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Perlodidae (Plecoptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.8141	.1432	5.68	31
Goff Creek	.6184	.1055	5.86	42
Kitty Creek	.5712	.0982	5.82	64
Gunbarrel Creek (L)	.3638	.0582	6.25	43
Gunbarrel Creek (M)	.3866	.0635	6.09	54
Gunbarrel Creek (U)	.7187	.1214	5.92	44
Mean Gunbarrel Creek	.4897	.0810	6.09	47
	(.1986)	(.0351)	(.17)	(6)
Mean (SD) Non-Gunbarrel Sites	.6679	.1156	5.79	46
	(.1288)	(.0242)	(.09)	(17)
Mean (SD) Wyoming Streams	.6234	.1070	5.86	46
	(.1378)	(.0262)	(.17)	(14)
Curtis Creek	.6511	.0856	7.60	97
Logan River	.9574	.1292	7.41	69
Temple Fork	.2125	.0279	7.61	44
Left Fk. Blacksmith Fk. (L)	1.2769	.1669	7.65	150
Left Fk. Blacksmith Fk. (M)	1.6920	.2243	7.54	171
Left Fk. Blacksmith Fk. (U)	2.2931	.3022	7.59	286
Mean Left Fk. Blacksmith Fk.	1.7540	.2311	7.59	202
	(.5109)	(.0679)	(.06)	(73)
Mean (SD) Non-LFBF Sites	.6070	.0809	7.54	70
	(.3744)	(.0508)	(.11)	(27)
Mean (SD) Utah Streams	.8938	.1185	7.55	103
	(.6499)	(.0858)	(.10)	(69)

Table 18. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Chloroperlidae (Plecoptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.1318	.0263	5.02	284
Goff Creek	.0412	.0092	4.50	42
Kitty Creek	.0858	.0161	5.34	185
Gunbarrel Creek (L)	.1091	.0219	4.98	168
Gunbarrel Creek (M)	.0874	.0174	5.01	185
Gunbarrel Creek (U)	.1398	.0294	4.76	232
Mean Gunbarrel Creek	.1121 (.0263)	.0229 (.0061)	4.92 (.14)	195 (33)
Mean (SD) Non-Gunbarrel Sites	.0863 (.0453)	.0172 (.0086)	4.95 (.42)	170 (122)
Mean (SD) Wyoming Streams	.0927 (.0392)	.0186 (.0076)	4.95 (.35)	177 (100)
Curtis Creek	.3090	.0602	5.14	140
Logan River	1.3419	.2895	4.64	625
Temple Fork	.2951	.0588	5.02	104
Left Fk. Blacksmith Fk. (L)	.0670	.0131	5.13	24
Left Fk. Blacksmith Fk. (M)	.1139	.0273	4.17	54
Left Fk. Blacksmith Fk. (U)	.1125	.0190	5.92	121
Mean Left Fk. Blacksmith Fk.	.0978 (.0267)	.0198 (.0071)	5.07 (.88)	66 (50)
Mean (SD) Non-LFBF Sites	.6487 (.6004)	.1362 (.1328)	4.93 (.26)	290 (291)
Mean (SD) Utah Streams	.5110 (.5623)	.1071 (.1230)	4.97 (.22)	234 (263)

Table 19. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for Perlidae (Plecoptera) for the Wyoming low alkalinity (<50 mg/1) sites and the Utah high alkalinity (>150 mg/1) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	0	0	---	0
Goff Creek	0	0	---	0
Kitty Creek	0	0	---	0
Gunbarrel Creek (L)	0	0	---	0
Gunbarrel Creek (M)	0	0	---	0
Gunbarrel Creek (U)	0	0	---	0
Mean Gunbarrel Creek	0	0	---	0
Mean (SD) Non-Gunbarrel Sites	0	0	---	0
Mean (SD) Wyoming Streams	0	0	---	0
Curtis Creek	1.8234	.4132	4.41	44
Logan River	.0045	.0007	---	0
Temple Fork	.1638	.0371	4.41	3
Left Fk. Blacksmith Fk. (L)	.2929	.0632	4.64	14
Left Fk. Blacksmith Fk. (M)	.2932	.0671	4.37	9
Left Fk. Blacksmith Fk. (U)	.3911	.0912	4.29	7
Mean Left Fk. Blacksmith Fk.	.3257 (.0566)	.0738 (.0152)	4.43 (.18)	10 (4)
Mean (SD) Non-LFBF Sites	.6639 (1.0073)	.1503 (.2284)	4.41 (.00)	16 (25)
Mean (SD) Utah Streams	.5794 (.8397)	.1312 (.1904)	4.42 (.01)	14 (20)

Table 20. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Pteronarcidae (Plecoptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	0	0	---	0
Goff Creek	0	0	---	0
Kitty Creek	0	0	---	0
Gunbarrel Creek (L)	0	0	---	0
Gunbarrel Creek (M)	0	0	---	0
Gunbarrel Creek (U)	0	0	---	0
Mean Gunbarrel Creek	0	0	---	0
Mean (SD) Non-Gunbarrel Sites	0	0	---	0
Mean (SD) Wyoming Streams	0	0	---	0
Curtis Creek	0	0	---	0
Logan River	0	0	---	0
Temple Fork	0	0	---	0
Left Fk. Blacksmith Fk. (L)	.1654	.1465	1.13	19
Left Fk. Blacksmith Fk. (M)	.1424	.1154	1.23	23
Left Fk. Blacksmith Fk. (U)	.1715	.1476	1.16	23
Mean Left Fk. Blacksmith Fk.	.1598 (.0153)	.1365 (.0183)	1.17 (.05)	22 (2)
Mean (SD) Non-LFBF Sites	0	0	---	0
Mean (SD) Utah Streams	.0400	.0341	1.17	6

Table 21. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/SC) and density (# m^{-2}), by site, for Rhithrogena (Ephemeroptera) for the Wyoming low alkalinity (< 50 mg/l) sites and the Utah high alkalinity (> 150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.2280	.0465	4.90	45
Goff Creek	1.3034	.2228	5.85	188
Kitty Creek	1.7014	.2349	7.24	354
Gunbarrel Creek (L)	.3955	.0571	6.93	112
Gunbarrel Creek (M)	.3116	.0469	6.65	159
Gunbarrel Creek (U)	.6332	.0929	6.82	187
Mean Gunbarrel Creek	.4468	.0656	6.80	153
	(.1668)	(.0242)	(.14)	(38)
Mean (SD) Non-Gunbarrel Sites	1.0776	.1681	6.00	196
	(.7622	(.1055)	(1.18)	(155)
Mean (SD) Wyoming Streams	.9199	.1425	6.20	185
	(.6977)	(.1002)	(1.04)	(128)
Curtis Creek	1.8251	.2402	7.60	874
Logan River	1.2347	.2604	4.74	222
Temple Fork	2.0256	.2854	7.10	1142
Left Fk. Blacksmith Fk. (L)	.0264	.0054	4.99	11
Left Fk. Blacksmith Fk. (M)	.0549	.0068	8.03	16
Left Fk. Blacksmith Fk. (U)	.0348	.0043	8.06	30
Mean Left Fk. Blacksmith Fk.	.0387	.0055	7.03	19
	(.0146)	(.0013)	(1.76)	(10)
Mean (SD) Non-LFBF Sites	1.6951	.2620	6.48	746
	(.4112)	(.0226)	(1.53)	(473)
Mean (SD) Utah Streams	1.2810	.1979	6.62	564
	(.8937)	(.1296)	(1.28)	(530)

Table 22. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for Cinygmula (Ephemeroptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0935	.0112	8.38	655
Goff Creek	.0924	.0126	7.32	267
Kitty Creek	.3309	.0440	7.53	1385
Gunbarrel Creek (L)	.1689	.0220	7.66	709
Gunbarrel Creek (M)	.1891	.0255	7.42	627
Gunbarrel Creek (U)	.2296	.0366	6.27	956
Mean Gunbarrel Creek	.1959 (.0309)	.0280 (.0076)	7.12 (.74)	764 (171)
Mean (SD) Non-Gunbarrel Sites	.1723 (.1374)	.0226 (.0185)	7.74 (.56)	769 (568)
Mean (SD) Wyoming Streams	.1782 (.1128)	.0240 (.0154)	7.59 (.55)	768 (463)
Curtis Creek	.7534	.0981	7.68	2812
Logan River	1.1350	.1548	7.33	2462
Temple Fork	.3780	.0504	7.50	1052
Left Fk. Blacksmith Fk. (L)	.0484	.0068	7.11	104
Left Fk. Blacksmith Fk. (M)	.1958	.0267	7.32	331
Left Fk. Blacksmith Fk. (U)	.1635	.0213	7.66	514
Mean Left Fk. Blacksmith Fk.	.1359 (.0775)	.0183 (.0103)	7.36 (.28)	316 (205)
Mean (SD) Non-LFBF Sites	.7555 (.3785)	.1011 (.0523)	7.50 (.18)	2109 (932)
Mean (SD) Utah Streams	.6006 (.4376)	.0804 (.0595)	7.47 (.16)	1661 (1176)

Table 23. Summary of annual production (afd·gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for *Epeorus* (Ephemeroptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0557	.0090	6.15	114
Goff Creek	.1801	.0359	5.02	212
Kitty Creek	.2564	.0505	5.08	502
Gunbarrel Creek (L)	.0995	.0137	7.28	588
Gunbarrel Creek (M)	.1334	.0164	8.11	1042
Gunbarrel Creek (U)	.1642	.0249	6.59	1148
Mean Gunbarrel Creek	.1324 (.0324)	.0183 (.0058)	7.33 (.76)	926 (297)
Mean (SD) Non-Gunbarrel Sites	.1641 (.1013)	.0318 (.0211)	5.42 (.64)	276 (202)
Mean (SD) Wyoming Streams	.1562 (.0842)	.0284 (.0185)	5.90 (1.09)	439 (364)
Curtis Creek	.0686	.0091	7.56	261
Logan River	.0323	.0056	5.76	23
Temple Fork	.0784	.0127	6.19	60
Left Fk. Blacksmith Fk. (L)	.0463	.0054	8.63	350
Left Fk. Blacksmith Fk. (M)	.0470	.0062	7.58	268
Left Fk. Blacksmith Fk. (U)	.0926	.0108	8.60	795
Mean Left Fk. Blacksmith Fk.	.0620 (.0265)	.0075 (.0029)	8.27 (.60)	471 (284)
Mean (SD) Non-LFBF Sites	.0598 (.0243)	.0091 (.0036)	6.50 (.94)	115 (128)
Mean (SD) Utah Streams	.0603 (.0199)	.0087 (.0030)	6.95 (1.17)	204 (207)

Table 24. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for *Ephemerella coloradensis* (Ephemeroptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0322	.0078	4.13	68
Goff Creek	.0801	.0154	5.13	123
Kitty Creek	.1242	.0225	5.52	368
Gunbarrel Creek (L)	.0748	.0159	4.71	88
Gunbarrel Creek (M)	.0820	.0150	5.46	204
Gunbarrel Creek (U)	.0803	.0171	4.69	152
Mean Gunbarrel Creek	.0790 (.0038)	.0160 (.0011)	4.95 (.44)	148 (58)
Mean (SD) Non-Gunbarrel Sites	.0788 (.0460)	.0152 (.0074)	4.93 (.72)	186 (160)
Mean (SD) Wyoming Streams	.0789 (.0376)	.0154 (.0060)	4.93 (.59)	177 (132)
Curtis Creek	1.0145	.1391	7.30	911
Logan River	12.9604	2.2650	5.72	3996
Temple Fork	4.5852	.7347	6.24	1788
Left Fk. Blacksmith Fk. (L)	.0040	.0004	9.61	1
Left Fk. Blacksmith Fk. (M)	0	0	---	0
Left Fk. Blacksmith Fk. (U)	0	0	---	0
Mean Left Fk. Blacksmith Fk.	.0013 (.0023)	.0001 (.0002)	9.61 (.00)	0 (1)
Mean (SD) Non-LFBF Sites	6.1867 (6.1319)	1.0463 (1.0967)	6.42 (.81)	2232 (1590)
Mean (SD) Utah Streams	4.6404 (5.8848)	.7848 (1.0369)	7.22 (1.73)	1674 (1712)

Table 25. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for *Ephemerella doddsi* (Ephemeroptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.2788	.0442	6.30	18
Goff Creek	.9043	.1339	6.75	41
Kitty Creek	1.1953	.1538	7.77	219
Gunbarrel Creek (L)	.0496	.0072	6.90	18
Gunbarrel Creek (M)	.0926	.0133	6.96	17
Gunbarrel Creek (U)	.1047	.0137	7.66	19
Mean Gunbarrel Creek	.0823	.0114	7.17	18
	(.0290)	(.0036)	(.42)	(1)
Mean (SD) Non-Gunbarrel Sites	.7928	.1106	6.94	93
	(.4683)	(.0584)	(.75)	(110)
Mean (SD) Wyoming Streams	.6152	.0858	7.00	74
	(.5219)	(.0688)	(.63)	(97)
Curtis Creek	2.9503	.3371	8.75	209
Logan River	4.3673	.5046	8.66	450
Temple Fork	.5303	.0592	8.96	71
Left Fk. Blacksmith Fk. (L)	.0049	.0005	9.75	2
Left Fk. Blacksmith Fk. (M)	.0015	.0001	9.75	0
Left Fk. Blacksmith Fk. (U)	0	0	---	0
Mean Left Fk. Blacksmith Fk.	.0021	.0002	9.75	1
	(.0025)	(.0003)	(.00)	(1)
Mean (SD) Non-LFBF Sites	2.6160	.3003	8.79	243
	(1.9402)	(.2250)	(.15)	(192)
Mean (SD) Utah Streams	1.9625	.2253	9.03	183
	(2.0537)	(.2372)	(.50)	(198)

Table 26. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for *Ephemerella grandis* (Ephemeroptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	0	0	---	0
Goff Creek	0	0	---	0
Kitty Creek	0	0	---	0
Gunbarrel Creek (L)	0	0	---	0
Gunbarrel Creek (M)	0	0	---	0
Gunbarrel Creek (U)	0	0	---	0
Mean Gunbarrel Creek	0	0	---	0
Mean (SD) Non-Gunbarrel Sites	0	0	---	0
Mean (SD) Wyoming Streams	0	0	---	0
Curtis Creek	.4774	.0777	6.14	36
Logan River	0	0	---	0
Temple Fork	.0621	.0097	6.41	9
Left Fk. Blacksmith Fk. (L)	6.0658	1.0026	6.05	358
Left Fk. Blacksmith Fk. (M)	10.1450	1.7060	5.95	467
Left Fk. Blacksmith Fk. (U)	9.7591	1.6171	6.03	540
Mean Left Fk. Blacksmith Fk.	8.6566	1.4419	6.01	455
	(2.2520)	(.3830)	(.05)	(92)
Mean (SD) Non-LFBF Sites	.1799	.0291	6.28	15
	(.2596)	(.0423)	(.19)	(19)
Mean (SD) Utah Streams	2.2990	.3823	6.19	125
	(4.2437)	(.7072)	(.20)	(221)

Table 27. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for *Ephemerella inermis* (Ephemeroptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0268	.0052	5.19	14
Goff Creek	.0472	.0080	5.91	141
Kitty Creek	.0808	.0121	6.68	234
Gunbarrel Creek (L)	.0142	.0034	4.17	4
Gunbarrel Creek (M)	.0045	.0006	7.47	1
Gunbarrel Creek (U)	.0210	.0037	5.71	6
Mean Gunbarrel Creek	.0132 (.0083)	.0026 (.0017)	5.78 (1.65)	4 (3)
Mean (SD) Non-Gunbarrel Sites	.0516 (.0273)	.0084 (.0035)	5.93 (.75)	130 (110)
Mean (SD) Wyoming Streams	.0420 (.0294)	.0070 (.0041)	5.89 (.61)	98 (110)
Curtis Creek	.4026	.0549	7.33	1150
Logan River	.0101	.0013	7.47	14
Temple Fork	.1414	.0213	6.63	242
Left Fk. Blacksmith Fk. (L)	.8749	.1285	6.81	3395
Left Fk. Blacksmith Fk. (M)	2.5286	.3606	7.01	5426
Left Fk. Blacksmith Fk. (U)	1.2633	.1782	7.09	2819
Mean Left Fk. Blacksmith Fk.	1.5556 (.8647)	.2224 (.1222)	6.97 (.14)	3880 (1370)
Mean (SD) Non-LFBF Sites	.1847 (.1998)	.0258 (.0271)	7.14 (.45)	469 (601)
Mean (SD) Utah Streams	.5274 (.7046)	.0750 (.1007)	7.10 (.38)	1322 (1775)

Table 28 . Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for Baetidae (Ephemeroptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.3500	.0355	9.86	518
Goff Creek	.6896	.0768	8.98	643
Kitty Creek	.5562	.0525	10.60	1051
Gunbarrel Creek (L)	.5220	.0492	10.62	783
Gunbarrel Creek (M)	.5166	.0485	10.66	1056
Gunbarrel Creek (U)	.5282	.0495	10.70	1027
Mean Gunbarrel Creek	.5223 (.0058)	.0491 (.0005)	10.66 (.04)	955 (150)
Mean (SD) Non-Gunbarrel Sites	.5319 (.1711)	.0549 (.0208)	9.81 (.81)	737 (279)
Mean (SD) Wyoming Streams	.5295 (.1398)	.0535 (.0172)	10.03 (.79)	792 (252)
Curtis Creek	9.3102	.8757	10.64	17104
Logan River	10.0864	.9664	10.44	14775
Temple Fork	11.3544	1.0912	10.40	10560
Left Fk. Blacksmith Fk. (L)	10.2192	1.0141	10.08	16515
Left Fk. Blacksmith Fk. (M)	10.5242	1.1925	8.82	15564
Left Fk. Blacksmith Fk. (U)	9.6124	.8616	11.16	16795
Mean Left Fk. Blacksmith Fk.	10.1186 (.4641)	1.0227 (.1656)	10.02 (1.17)	16291 (645)
Mean (SD) Non-LFBF Sites	10.2503 (1.0319)	.9778 (.1082)	10.49 (.13)	14046 (3480)
Mean (SD) Utah Streams	10.2174 (.8451)	.9890 (.0912)	10.38 (.26)	14683 (2913)

Table 29. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Siphlonuridae (Ephemeroptera) for the Wyoming low alkalinity (<50 mg/1) sites and the Utah high alkalinity (>150 mg/1) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0075	.0016	4.56	2
Goff Creek	.0032	.0004	7.31	1
Kitty Creek	.0416	.0072	5.74	6
Gunbarrel Creek (L)	.0115	.0033	3.50	4
Gunbarrel Creek (M)	.0574	.0096	5.98	10
Gunbarrel Creek (U)	.0214	.0029	7.27	11
Mean Gunbarrel Creek	.0301 (.0242)	.0053 (.0038)	5.58 (1.92)	8 (4)
Mean (SD) Non-Gunbarrel Sites	.0174 (.0210)	.0031 (.0036)	5.87 (1.38)	3 (3)
Mean (SD) Wyoming Streams	.0206 (.0183)	.0036 (.0032)	5.80 (1.14)	4 (3)
Curtis Creek	0	0	---	0
Logan River	.0290	.0040	7.28	4
Temple Fork	0	0	---	0
Left Fk. Blacksmith Fk. (L)	0	0	---	0
Left Fk. Blacksmith Fk. (M)	0	0	---	0
Left Fk. Blacksmith Fk. (U)	0	0	---	0
Mean Left Fk. Blacksmith Fk.	0	0	---	0
Mean (SD) Non-LFBF Sites	0	0	---	1 (1)
Mean (SD) Utah Streams	.0073	.0010	---	1 (1)

Table 30. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Paraleptophlebia (Ephemeroptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0001	0	5.45	1
Goff Creek	0	0	---	0
Kitty Creek	.0001	0	12.38	1
Gunbarrel Creek (L)	0	0	---	0
Gunbarrel Creek (M)	0	0	---	0
Gunbarrel Creek (U)	0	0	---	0
Mean Gunbarrel Creek	0	0	---	0
Mean (SD) Non-Gunbarrel Sites	.0001	0	---	1
Mean (SD) Wyoming Streams	.0001 (.0000)	0	---	1 (0)
Curtis Creek	.0825	.0124	6.68	656
Logan River	0	0	---	0
Temple Fork	.0156	.0024	6.56	107
Left Fk. Blacksmith Fk. (L)	.2143	.0385	5.56	960
Left Fk. Blacksmith Fk. (M)	.2745	.0514	5.34	890
Left Fk. Blacksmith Fk. (U)	.4022	.0702	5.73	1706
Mean Left Fk. Blacksmith Fk.	.2970 (.0959)	.0534 (.0159)	5.54 (.20)	1185 (452)
Mean (SD) Non-LFBF Sites	.0327 (.0438)	.0049 (.0066)	6.62 (.08)	254 (352)
Mean (SD) Utah Streams	.0988 (.1369)	.0171 (.0248)	6.26 (.63)	487 (547)

Table 31 . Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Hydropsychidae (Trichoptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.3824	.0474	8.07	13
Goff Creek	.5187	.0652	7.96	36
Kitty Creek	1.0243	.1317	7.78	40
Gunbarrel Creek (L)	.8699	.1078	8.07	39
Gunbarrel Creek (M)	.2195	.0258	8.51	18
Gunbarrel Creek (U)	.4084	.0512	7.98	17
Mean Gunbarrel Creek	.4993	.0616	8.19	25
	(.3346)	(.0420)	(.28)	(12)
Mean (SD) Non-Gunbarrel Sites	.6418	.0814	7.94	30
	(.3382)	(.0444)	(.15)	(15)
Mean (SD) Wyoming Streams	.6062	.0765	8.00	29
	(.2852)	(.0376)	(.17)	(12)
Curtis Creek	2.8398	.3079	9.22	213
Logan River	2.8224	.3180	8.87	88
Temple Fork	.6310	.0699	9.03	26
Left Fk. Blacksmith Fk. (L)	12.6484	1.3978	9.05	716
Left Fk. Blacksmith Fk. (M)	5.3554	0.5958	8.99	431
Left Fk. Blacksmith Fk. (U)	2.0811	.2286	9.10	220
Mean Left Fk. Blacksmith Fk.	6.6950	.7407	9.05	456
	(5.4095)	(.5979)	(.06)	(249)
Mean (SD) Non-LFBF Sites	2.0977	.2319	9.04	109
	(1.2703)	(.1404)	(.18)	(95)
Mean (SD) Utah Streams	3.2471	.3591	9.04	196
	(2.5218)	(.2790)	(.14)	(190)

Table 32 . Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Rhyacophilidae (Trichoptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0096	.0025	3.82	9
Goff Creek	.1194	.0286	4.17	54
Kitty Creek	.2618	.0530	4.94	266
Gunbarrel Creek (L)	.1070	.0227	4.72	149
Gunbarrel Creek (M)	.0756	.0138	5.47	111
Gunbarrel Creek (U)	.0547	.0141	3.87	19
Mean Gunbarrel Creek	.0791 (.0263)	.0169 (.0051)	4.69 (.80)	93 (67)
Mean (SD) Non-Gunbarrel Sites	.1303 (.1265)	.0280 (.0253)	4.31 (.57)	110 (137)
Mean (SD) Wyoming Streams	.1175 (.1064)	.0253 (.0214)	4.41 (.50)	106 (112)
Curtis Creek	.9598	.1702	5.64	299
Logan River	2.0419	.5248	3.89	185
Temple Fork	2.3238	.4378	5.31	466
Left Fk. Blacksmith Fk. (L)	.2089	.0326	6.41	28
Left Fk. Blacksmith Fk. (M)	.0358	.0060	5.95	2
Left Fk. Blacksmith Fk. (U)	.0220	.0028	7.77	32
Mean Left Fk. Blacksmith Fk.	.0889 (.1042)	.0138 (.0164)	6.71 (.95)	21 (16)
Mean (SD) Non-LFBF Sites	1.7752 (.7201)	.3776 (.1848)	4.95 (.93)	317 (141)
Mean (SD) Utah Streams	1.3536 (1.0279)	.2867 (.2363)	5.39 (1.16)	243 (188)

Table 33. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for Glossosomatidae (Trichoptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	0	0	---	0
Goff Creek	0	0	---	0
Kitty Creek	.0008	.0001	7.85	3
Gunbarrel Creek (L)	0	0	---	0
Gunbarrel Creek (M)	0	0	---	0
Gunbarrel Creek (U)	0	0	---	0
Mean Gunbarrel Creek	0	0	---	0
Mean (SD) Non-Gunbarrel Sites	.0003	0	---	1
Mean (SD) Wyoming Streams	.0002	0	---	1
Curtis Creek	.1816	.0239	7.60	375
Logan River	.4308	.0684	6.30	358
Temple Fork	.3182	.0432	7.37	291
Left Fk. Blacksmith Fk. (L)	.0067	.0007	9.46	47
Left Fk. Blacksmith Fk. (M)	.0801	.0106	7.52	85
Left Fk. Blacksmith Fk. (U)	.0424	.0056	7.52	65
Mean Left Fk. Blacksmith Fk.	.0431 (.0367)	.0056 (.0050)	8.17 (1.12)	66 (19)
Mean (SD) Non-LFBF Sites	.3102 (.1248)	.0452 (.0223)	7.09 (.69)	341 (44)
Mean (SD) Utah Streams	.2434 (.1680)	.0353 (.0269)	7.36 (.78)	273 (142)

Table 34. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for Brachycentridae (Trichoptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0020	.0003	7.04	0
Goff Creek	.0000	.0	---	0
Kitty Creek	.0188	.0027	7.04	9
Gunbarrel Creek (L)	.0010	.0001	7.07	0
Gunbarrel Creek (M)	.0013	.0002	7.04	0
Gunbarrel Creek (U)	.0000	.0000	0	0
Mean Gunbarrel Creek	.0008	.0001	7.06	0
	(.0007)	(.0001)	(.02)	(0)
Mean (SD) Non-Gunbarrel Sites	.0069	.0010	7.04	3
	(.0103)	(.0015)	(.00)	(5)
Mean (SD) Wyoming Streams	.0054	.0008	7.05	2.25
	(.0090)	(.0013)	(.01)	(5)
Curtis Creek	.0526	.0075	7.04	29
Logan River	.0012	.0002	7.04	1
Temple Fork	.2587	.0476	5.43	76
Left Fk. Blacksmith Fk. (L)	.2729	.0392	6.97	376
Left Fk. Blacksmith Fk. (M)	.1965	.0279	7.04	257
Left Fk. Blacksmith Fk. (U)	.2344	.0365	6.43	167
Mean Left Fk. Blacksmith Fk.	.2346	.0345	6.81	267
	(.0382)	(.0059)	(.33)	(105)
Mean (SD) Non-LFBF Sites	.1042	.0184	6.50	35
	(.1363)	(.0255)	(.93)	(38)
Mean (SD) Utah Streams	.1368	.0225	6.58	93
	(.1290)	(.0223)	(.77)	(120)

Table 35. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for Limnephilidae (Trichoptera) for the Wyoming low alkalinity (<50 mg/1) sites and the Utah high alkalinity (>150 mg/1) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0007	.0001	8.07	5
Goff Creek	.0082	.0015	5.32	10
Kitty Creek	.1684	.0279	6.03	359
Gunbarrel Creek (L)	.0011	.0002	6.53	5
Gunbarrel Creek (M)	.0016	.0002	6.56	6
Gunbarrel Creek (U)	.0086	.0014	6.38	34
Mean Gunbarrel Creek	.0038 (.0042)	.0006 (.0007)	6.49 (.10)	15 (16)
Mean (SD) Non-Gunbarrel Sites	.0591 (.0947)	.0098 (.0157)	6.47 (1.43)	125 (203)
Mean (SD) Wyoming Streams	.0453 (.0821)	.0075 (.0136)	6.48 (1.17)	97 (175)
Curtis Creek	.6010	.0934	6.43	1695
Logan River	.0638	.0156	4.10	113
Temple Fork	.2927	.0480	6.10	437
Left Fk. Blacksmith Fk. (L)	.7092	.1151	6.16	1514
Left Fk. Blacksmith Fk. (M)	3.1664	.5244	6.04	4234
Left Fk. Blacksmith Fk. (U)	1.7029	.2919	5.83	3019
Mean Left Fk. Blacksmith Fk.	1.8595 (1.2361)	.3104 (.2053)	6.01 (.17)	2922 (1363)
Mean (SD) Non-LFBF Sites	.3192 (.2696)	.0523 (.0391)	5.54 (1.26)	748 (836)
Mean (SD) Utah Streams	.7042 (.8010)	.1169 (.1329)	5.66 (1.06)	1292 (1283)

Table 36. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Tipulidae (Small) (Diptera) for the Wyoming low alkalinity (< 50 mg/l) sites and the Utah high alkalinity (> 150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0046	.0017	2.77	9
Goff Creek	.0116	.0041	2.80	28
Kitty Creek	.0170	.0039	4.37	55
Gunbarrel Creek (L)	.0067	.0016	4.08	20
Gunbarrel Creek (M)	.0124	.0042	2.98	34
Gunbarrel Creek (U)	.0079	.0030	2.63	16
Mean Gunbarrel Creek	.0090 (.0030)	.0029 (.0013)	3.23 (.76)	23 (9)
Mean (SD) Non-Gunbarrel Sites	.0111 (.0062)	.0032 (.0013)	3.31 (.92)	31 (23)
Mean (SD) Wyoming Streams	.0106 (.0052)	.0032 (.0011)	3.29 (.75)	29 (19)
Curtis Creek	.1564	.0311	5.03	208
Logan River	.1613	.0347	4.65	108
Temple Fork	.5610	.1115	5.03	801
Left Fk. Blacksmith Fk. (L)	.3368	.0668	5.04	437
Left Fk. Blacksmith Fk. (M)	.3666	.0724	5.06	437
Left Fk. Blacksmith Fk. (U)	.3211	.0651	4.94	399
Mean Left Fk. Blacksmith Fk.	.3415 (.0231)	.0681 (.0038)	5.01 (.06)	424 (22)
Mean (SD) Non-LFBF Sites	.2929 (.2322)	.0591 (.0454)	4.90 (.22)	372 (375)
Mean (SD) Utah Streams	.3051 (.1911)	.0614 (.0374)	4.93 (.19)	385 (307)

Table 37. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Tipulidae (Large) (Diptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0143	.0063	2.26	3
Goff Creek	.0117	.0053	2.22	2
Kitty Creek	.0071	.0030	2.35	2
Gunbarrel Creek (L)	.0046	.0022	2.13	1
Gunbarrel Creek (M)	.0079	.0043	1.84	2
Gunbarrel Creek (U)	.0021	.0010	2.16	1
Mean Gunbarrel Creek	.0049 (.0029)	.0025 (.0017)	2.04 (.17)	1 (0)
Mean (SD) Non-Gunbarrel Sites	.0110 (.0036)	.0049 (.0017)	2.28 (.07)	2 (1)
Mean (SD) Wyoming Streams	.0095 (.0043)	.0043 (.0019)	2.22 (.13)	2 (1)
Curtis Creek	.6120	.4385	1.40	3
Logan River	.6501	.1935	3.36	4
Temple Fork	.2647	.0716	3.69	4
Left Fk. Blacksmith Fk. (L)	1.4709	.4595	3.20	6
Left Fk. Blacksmith Fk. (M)	3.4028	1.1144	3.05	12
Left Fk. Blacksmith Fk. (U)	1.2509	.3981	3.14	5
Mean Left Fk. Blacksmith Fk.	2.0415 (1.1841)	.6573 (.3971)	3.13 (.08)	8 (4)
Mean (SD) Non-LFBF Sites	.5089 (.2124)	.2345 (.1869)	2.82 (1.24)	4 (1)
Mean (SD) Utah Streams	.8921 (.7857)	.3403 (.2607)	2.90 (1.02)	5 (2)

Table 38. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Athericidae (Diptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	0	0	---	0
Goff Creek	0	0	---	0
Kitty Creek	0	0	---	0
Gunbarrel Creek (L)	0	0	---	0
Gunbarrel Creek (M)	0	0	---	0
Gunbarrel Creek (U)	0	0	---	0
Mean Gunbarrel Creek	0	0	---	0
Mean (SD) Non-Gunbarrel Sites	0	0	---	0
Mean (SD) Wyoming Streams	0	0	---	0
Curtis Creek	.0474	.0043	---	3
Logan River	.0082	.0004	---	2
Temple Fork	0	0	---	0
Left Fk. Blacksmith Fk. (L)	.4364	.2350	1.86	15
Left Fk. Blacksmith Fk. (M)	.7707	.3453	2.23	23
Left Fk. Blacksmith Fk. (U)	1.9715	.8625	2.29	69
Mean Left Fk. Blacksmith Fk.	1.0595 (.8072)	.4810 (.3350)	2.13 (.23)	36 (29)
Mean (SD) Non-LFBF Sites	.0185 (.0253)	.0016 (.0024)	---	2 (2)
Mean (SD) Utah Streams	.2788 (.5209)	.1214 (.2397)	---	10 (17)

Table 39. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for Psychodidae (Diptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0003	.0000	5.97	0
Goff Creek	.0008	.0001	5.97	1
Kitty Creek	.0019	.0003	5.97	4
Gunbarrel Creek (L)	.0001	.0000	---	1
Gunbarrel Creek (M)	.0016	.0003	5.97	3
Gunbarrel Creek (U)	.0008	.0001	5.77	0
Mean Gunbarrel Creek	.0008 (.0008)	.0001 (.0002)	5.87 (.14)	1 (2)
Mean (SD) Non-Gunbarrel Sites	.0010 (.0008)	.0001 (.0002)	5.97 (.00)	2 (2)
Mean (SD) Wyoming Streams	.0010 (.0007)	.0001 (.0001)	5.95 (.05)	2 (2)
Curtis Creek	.1474	.0244	6.04	276
Logan River	.1630	.0291	5.60	214
Temple Fork	.2918	.0488	5.98	357
Left Fk. Blacksmith Fk. (L)	.4023	.0714	5.63	517
Left Fk. Blacksmith Fk. (M)	.8614	.1565	5.50	436
Left Fk. Blacksmith Fk. (U)	.6148	.1034	5.95	775
Mean Left Fk. Blacksmith Fk.	.6262 (.2298)	.1104 (.0430)	5.69 (.23)	576 (177)
Mean (SD) Non-LFBF Sites	.2007 (.0793)	.0341 (.0129)	5.87 (.24)	282 (72)
Mean (SD) Utah Streams	.3071 (.2224)	.0532 (.0396)	5.83 (.22)	356 (158)

Table 40. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio (P/$\overline{SC}$) and density (# m^{-2}), by site, for Simuliidae (Diptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0266	.0018	14.78	80
Goff Creek	.0246	.0022	11.18	36
Kitty Creek	.0876	.0060	14.60	286
Gunbarrel Creek (L)	.0092	.0008	11.50	12
Gunbarrel Creek (M)	.0032	.0002	16.00	14
Gunbarrel Creek (U)	.0068	.0005	13.60	13
Mean Gunbarrel Creek	.0064 (.0030)	.0005 (.0003)	13.70 (2.25)	13 (1)
Mean (SD) Non-Gunbarrel Sites	.0463 (.0358)	.0033 (.0023)	13.50 (2.03)	134 (133)
Mean (SD) Wyoming Streams	.0363 (.0354)	.0026 (.0024)	13.57 (1.66)	104 (125)
Curtis Creek	.8420	.0749	11.24	1239
Logan River	.0984	.0092	10.70	147
Temple Fork	.6592	.0654	10.08	460
Left Fk. Blacksmith Fk. (L)	3.0298	.2594	11.68	4435
Left Fk. Blacksmith Fk. (M)	4.8788	.5500	8.87	4320
Left Fk. Blacksmith Fk. (U)	1.2732	.1044	12.20	2430
Mean Left Fk. Blacksmith Fk.	3.0606 (1.8030)	.3046 (.2262)	10.92 (1.79)	3728 (1126)
Mean (SD) Non-LFBF Sites	.5332 (.3875)	.0498 (.0355)	10.67 (.58)	615 (562)
Mean (SD) Utah Streams	1.1651 (1.3027)	.1135 (.1306)	10.74 (.49)	1394 (1623)

Table 41. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$), and density (# m^{-2}), by site, for Empididae (Diptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0279	.0076	3.65	128
Goff Creek	.0106	.0035	3.01	38
Kitty Creek	.0055	.0014	3.82	26
Gunbarrel Creek (L)	.0158	.0052	3.05	63
Gunbarrel Creek (M)	.0151	.0054	2.80	59
Gunbarrel Creek (U)	.0154	.0058	2.66	70
Mean Gunbarrel Creek	.0154 (.0004)	.0055 (.0003)	2.84 (.20)	64 (6)
Mean (SD) Non-Gunbarrel Sites	.0147 (.0117)	.0042 (.0032)	3.49 (.43)	64 (56)
Mean (SD) Wyoming Streams	.0149 (.0096)	.0045 (.0027)	3.33 (.48)	64 (46)
Curtis Creek	.0133	.0040	3.32	64
Logan River	.0390	.0153	2.55	141
Temple Fork	.0193	.0060	3.22	67
Left Fk. Blacksmith Fk. (L)	.1000	.0316	3.16	421
Left Fk. Blacksmith Fk. (M)	.0816	.0280	2.92	376
Left Fk. Blacksmith Fk. (U)	.0845	.0243	3.48	408
Mean Left Fk. Blacksmith Fk.	.0887 (.0099)	.0280 (.0037)	3.19 (.28)	402 (23)
Mean (SD) Non-LFBF Sites	.0239 (.0134)	.0084 (.0060)	3.03 (.42)	91 (44)
Mean (SD) Utah Streams	.0401 (.0342)	.0133 (.0110)	3.07 (.35)	169 (160)

Table 42. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Chironomidae (Diptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.2598	.0203	12.80	1340
Goff Creek	.2896	.0277	10.45	845
Kitty Creek	.1416	.0105	13.49	756
Gunbarrel Creek (L)	.3644	.0340	10.72	1361
Gunbarrel Creek (M)	.3582	.0282	12.70	1865
Gunbarrel Creek (U)	.4012	.0351	11.43	1860
Mean Gunbarrel Creek	.3746 (.0232)	.0324 (.0037)	11.62 (1.00)	1695 (290)
Mean (SD) Non-Gunbarrel Sites	.2303 (.0783)	.0195 (.0086)	12.25 (1.59)	980 (315)
Mean (SD) Wyoming Streams	.2664 (.0964)	.0227 (.0096)	12.09 (1.34)	1159 (440)
Curtis Creek	.4944	.0393	12.58	2334
Logan River	1.0868	.0966	11.25	4101
Temple Fork	.4286	.0357	12.01	1906
Left Fk. Blacksmith Fk. (L)	3.5446	.3100	11.43	13644
Left Fk. Blacksmith Fk. (M)	3.2646	.2917	11.19	11338
Left Fk. Blacksmith Fk. (U)	2.9986	.2561	11.71	12369
Mean Left Fk. Blacksmith Fk.	3.2693 (.2730)	.2859 (.0274)	11.44 (.26)	12450 (1155)
Mean (SD) Non-LFBF Sites	.6699 (.3625)	.0572 (.0342)	11.95 (.67)	2784 (1162)
Mean (SD) Utah Streams	1.3198 (1.3330)	.1144 (.1177)	11.82 (.60)	5200 (4925)

Table 43. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$), and density (# m^{-2}), by site, for Elmidae (Coleoptera) for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0005	.0001	5.79	1
Goff Creek	.0012	.0002	5.23	3
Kitty Creek	.0003	.0001	5.23	1
Gunbarrel Creek (L)	.0024	.0005	5.23	2
Gunbarrel Creek (M)	0	0	---	0
Gunbarrel Creek (U)	.0005	.0001	5.08	1
Mean Gunbarrel Creek	.0010 (.0013)	.0002 (.0003)	5.16 (.11)	1 (1)
Mean (SD) Non-Gunbarrel Sites	.0007 (.0005)	.0001 (.0001)	5.42 (.32)	2 (1)
Mean (SD) Wyoming Streams	.0008 (.0004)	.0002 (.0001)	5.35 (.29)	2 (1)
Curtis Creek	.5613	.1057	5.31	1009
Logan River	.2301	.0423	5.44	529
Temple Fork	.5232	.0970	5.39	1014
Left Fk. Blacksmith Fk. (L)	.0508	.0108	4.69	83
Left Fk. Blacksmith Fk. (M)	.1113	.0227	4.91	128
Left Fk. Blacksmith Fk. (U)	.0677	.0130	5.19	147
Mean Left Fk. Blacksmith Fk.	.0766 (.0312)	.0155 (.0063)	4.93 (.25)	119 (33)
Mean (SD) Non-LFBF Sites	.4382 (.1812)	.0817 (.0344)	5.38 (.07)	851 (279)
Mean (SD) Utah Streams	.3478 (.2336)	.0651 (.0434)	5.27 (.23)	668 (431)

Table 44. Summary of annual production (afd gm m^{-2} yr^{-1}), mean annual standing crop (afd gm m^{-2}), annual turnover ratio ($P/\overline{SC}$) and density (# m^{-2}), by site, for Hydracarina for the Wyoming low alkalinity (<50 mg/l) sites and the Utah high alkalinity (>150 mg/l) sites, 1978-1979. Numbers in parentheses are one standard deviation.

Stream Site	Production	SC	TR	Density
Clearwater Creek	.0214	.0056	3.82	205
Goff Creek	.0158	.0028	5.62	214
Kitty Creek	.0260	.0041	6.34	380
Gunbarrel Creek (L)	.0073	.0016	4.51	79
Gunbarrel Creek (M)	.0186	.0044	4.21	183
Gunbarrel Creek (U)	.0158	.0034	4.65	169
Mean Gunbarrel Creek	.0139	.0031	4.46	144
	(.0059)	(.0014)	(.22)	(56)
Mean (SD) Non-Gunbarrel Sites	.0211	.0042	5.26	266
	(.0051)	(.0014)	(1.30)	(99)
Mean (SD) Wyoming Streams	.0193	.0039	5.06	236
	(.0055)	(.0013)	(1.13)	(101)
Curtis Creek	.1287	.0250	5.16	1566
Logan River	.0651	.0115	5.68	940
Temple Fork	.0811	.0149	5.43	1071
Left Fk. Blacksmith Fk. (L)	.5320	.1411	3.77	4488
Left Fk. Blacksmith Fk. (M)	.3880	.1093	3.55	2955
Left Fk. Blacksmith Fk. (U)	.4883	.1159	4.21	4531
Mean Left Fk. Blacksmith Fk.	.4694	.1221	3.84	3991
	(.0738)	(.0168)	(.34)	(898)
Mean (SD) Non-LFBF Sites	.0916	.0171	5.42	1192
	(.0331)	(.0070)	(.26)	(330)
Mean (SD) Utah Streams	.1861	.0434	5.03	1892
	(.1908)	(.0528)	(.82)	(1425)

Appendix II

Coefficients of Variation for Production Values Between Replicate Sites and Remaining Streams for Each Region

Aquatic invertebrate samples were collected and analyzed at six sites on four streams from each region. Three of the streams in each region had a single study site while the fourth stream from each region had three similar study sites. Since only a single production value was calculated for each site, the replicate sites on one stream were analyzed to determine if between site differences for one stream were greater or less than differences between the remaining streams.

As seen in Table 45, most taxa in each region showed less variation between replicate sites on one stream than between the remaining three streams. For 17 of the 23 taxa in which coefficients of variation were calculated in the low alkalinity region, variation was lower between the replicate sites on Gunbarrel Creek. In the high alkalinity region, the coefficients of variation were lower between Left Fork Blacksmith Fork replicate sites for 17 of 27 taxa. For several of those taxa that had higher variation between replicate sites, production values were very low. At these very low values, very minor actual production differences could result in high coefficients of variation. An example is the calculation of a coefficient of variation of 176.9 percent for <u>Ephemerella</u> <u>coloradensis</u> between the Left Fork Blacksmith Fork replicate sites. This insect was very scarce in this stream, with no production calculated for two of the sites and only 0.0040 g/m^2 for the third (Table 24). These seemingly small differences resulted in a very high standard deviation of the sample mean, leading to the high coefficient of variation.

The coefficients of variation for all taxa summed for a total production value was lower between replicate sites on one stream than between the three remaining streams in both regions.

Table 45. Coefficients of variation (C.V.) for production values calculated for replicate Left Fork Blacksmith Fork (LFBF) and replicate Gunbarrel Creek (Gun) sites compared to remaining high alkalinity (Non-LFBF) and remaining low alkalinity (Non-Gun) stream sites.

Taxon	C.V., % LFBF Sites	C.V., % Non-LFBF Sites	C.V., % Gun Sites	C.V., % Non-Gun Sites
Nemouridae	22.7	23.6	14.3	47.8
Perlodidae	29.1	61.7	40.6	19.3
Chloroperlidae	27.3	92.6	23.5	52.5
Perlidae	17.4	151.7	----	----
Pteronarcidae	9.6	----	----	----
Rhithrogena	37.8	24.3	37.3	70.7
Cinygmula	57.0	50.1	15.8	79.7
Epeorus	42.8	40.6	24.4	61.7
Ephemerella coloradensis	176.9	99.1	4.8	58.4
E. doddsi	119.6	74.2	35.2	59.1
E. grandis	26.0	144.3	----	----
E. inermis	55.6	108.2	62.9	52.8
Baetidae	4.6	10.1	1.1	32.2
Siphlonuridae	----	----	80.2	120.9
Paraleptophlebia	32.3	134.0	----	----
Hydropsychidae	80.8	60.6	67.0	52.7
Rhyacophilidae	117.2	40.6	33.2	97.1
Glossosomatidae	85.2	40.2	----	----
Brachycentridae	16.3	130.8	87.5	149.3
Limnephilidae	66.5	84.5	110.5	160.2
Tipulidae (Small)	6.8	79.3	33.4	55.9
Tipulidae (Large)	58.0	41.7	59.6	32.8
Athericidae	76.2	136.9	----	----
Psychodidae	36.7	39.5	93.8	81.9
Simuliidae	58.9	72.7	47.2	77.3
Empididae	11.2	56.3	2.3	79.9

Table 45. Continued.

Taxon	C.V., % LFBF Sites	C.V., % Non-LFBF Sites	C.V., % Gun Sites	C.V., % Non-Gun Sites
Chironomidae	8.4	54.1	6.2	34.0
Elmidae	126.6	67.5	40.8	41.4
Hydracarina	15.7	36.1	42.4	24.2
All Taxa Summed	13.1	24.1	15.7	40.8

Appendix III

Regression Coefficients Used for Invertebrate Weight Estimation for Production Calculations

Table 46. Regression coefficients used for ash-free dry weight estimates per sieve size in production calculations. Regression equation used is $y=e^{(mx+b)}$, where y=weight in grams, m=slope, x=sequential position of each sieve size (x=1 for smallest sieve, x=11 for largest sieve), b=y intercept and r=correlation coefficient.

Taxon	Slope	y Intercept	r
Nemouridae	.7074	-13.1303	.986
Perlodidae	.8673	-13.4278	.975
Chloroperlidae-Utah	.6665	-11.6983	.979
Chloroperlidae-Wyoming	.6218	-12.3112	.986
Perlidae	.8459	-12.3706	.989
Pteronarcidae	.6299	-10.5341	.994
Rhithrogena	.9645	-14.0366	.993
Cinygmula	.8797	-13.8043	.985
Epeorus	.8781	-14.0426	.978
Ephemerella coloradensis	1.0227	-14.5667	.987
E. doddsi	1.0363	-14.4513	.990
E. grandis	.9900	-14.4472	.991
E. inermis	1.0218	-14.4934	.989
Baetidae	.9126	-13.7126	.991
Siphlonuridae	.8817	-13.2207	.973
Paraleptophlebia	.7602	-13.1948	.987
Hydropsychidae	.9599	-13.6914	.994
Rhyacophilidae-Utah	.8727	-12.6109	.965
Rhyacophilidae-Wyoming	.7207	-12.2206	.971
Glossosomatidae	1.0216	-13.8166	.999
Brachycentridae	.8539	-13.4096	.979
Limnephilidae	.7115	-12.9441	.969

Table 46. Continued.

Taxon	Slope	y Intercept	r
Tipulidae (Small)	.4405	-11.0555	.845
Tipulidae (Large)		No Equation	
Athericidae		No Equation	
Psychodidae	.8293	-13.1958	.892
Simuliidae	.8573	-12.8355	.973
Empididae	.4852	-11.5932	.949
Chironomidae	.6942	-13.1985	.984
Elmidae	.7308	-12.6362	.980
Hydracarina	.8292	-12.9428	.992

Appendix IV

Minimum and Maximum Sieve Sizes Used for Production Calculation for Each Taxon

Table 47. Maximum and minimum sieve sizes used for production calculation for each taxon. Sizes 0.35 mm and 0.25 mm (U.S. Series 45 and 60) were combined.

Taxon	Maximum Opening in mm (U.S. Series)	Minimum Opening in mm (U.S. Series)
Nemouridae	2.80 (7)	0.25 (60)
Perlodidae	7.93 (2½)	0.50 (35)
Chloroperlidae	4.00 (5)	0.25 (60)
Perlidae	7.93 (2½)	1.00 (18)
Pteronarcidae	7.93 (2½)	1.00 (18)
Rhithrogena	4.00 (5)	0.25 (60)
Cinygmula	4.00 (5)	0.25 (60)
Epeorus	4.00 (5)	0.25 (60)
Ephemerella coloradensis	5.61 (3½)	0.25 (60)
E. doddsi	5.61 (3½)	0.25 (60)
E. grandis	5.61 (3½)	0.25 (60)
E. inermis	2.80 (7)	0.25 (60)
Baetidae	2.00 (10)	0.25 (60)
Siphlonuridae	4.00 (5)	0.25 (60)
Paraleptophlebia	2.80 (7)	0.25 (60)
Hydropsychidae	7.93 (2½)	0.25 (60)
Rhyacophilidae	4.00 (5)	0.25 (60)
Glossosomatidae	4.00 (5)	0.25 (60)
Brachycentridae	4.00 (5)	0.25 (60)
Limnephilidae	4.00 (5)	0.25 (60)
Tipulidae (Small)	4.00 (5)	0.25 (60)
Tipulidae (Large)	11.20 (11.20)	2.80 (7)
Athericidae	5.61 (3½)	0.25 (60)

Table 47. Continued.

Taxon	Maximum Opening in mm (U.S. Series)	Minimum Opening in mm (U.S. Series)
Psychodidae	2.80 (7)	0.25 (60)
Simuliidae	2.00 (10)	0.25 (60)
Empididae	2.00 (10)	0.25 (60)
Chironomidae	2.80 (7)	0.25 (60)
Elmidae	2.80 (7)	0.25 (60)
Hydracarina	1.00 (18)	0.25 (60)

Appendix V

Production Calculation Computer Program and Sample Production Calculation

Table 48. FORTRAN computer program formulated for the calculation of production estimates.

```
$RESET FREE
FILE  6(KIND=PRINTER)
FILE  5(KIND=PACK, FILETYPE=7,  TITLE="B13200.")
      DIMENSION SIZE(60)
      REAL MNNINE,MNEIGT,MNSEVN,MNSIX,MNFIVE,MNFOUR,MNTHRE,MNTWO
      REAL MNTEN,MNELVN
      REAL LOSSX,LOSSY,LOSSA,LOSSB,LOSSC,LOSSD,LOSSE,LOSSF
      REAL LOSSG,LOSSH
      NISITE = 0
      SLOPE = 0.9599
      B = -13.6914
      REGWTY = EXP(SLOPE * 11. + B)
      REGWTX = EXP(SLOPE * 10. + B)
      REGWTA = EXP(SLOPE * 9. + B)
      REGWTB = EXP(SLOPE * 8. + B)
      REGWTC = EXP(SLOPE * 7. + B)
      REGWTD = EXP(SLOPE * 6. + B)
      REGWTE = EXP(SLOPE * 5. + B)
      REGWTF = EXP(SLOPE * 4. + B)
      REGWTG = EXP(SLOPE * 3. + B)
      REGWTH = EXP(SLOPE * 1.5 + B)
      BETWTY = EXP(SLOPE * 11. + B)
      BETWTX = EXP(SLOPE * 10.5 + B)
      BETWTA = EXP(SLOPE * 9.5 + B)
      BETWTB = EXP(SLOPE * 8.5 + B)
      BETWTC = EXP(SLOPE * 7.5 + B)
      BETWTD = EXP(SLOPE * 6.5 + B)
      BETWTE = EXP(SLOPE * 5.5 + B)
      BETWTF = EXP(SLOPE * 4.5 + B)
      BETWTG = EXP(SLOPE * 3.5 + B)
      BETWTH = EXP(SLOPE * 2.25 + B)
    9 READ(5,100)ISITE,IDATE,IVISIT,ISTEVE,ISUB,ISOS,ID,ISORT
```

Table 48. Continued.

```
199 SIZE(5) = 0.0
    SIZE(7) = 0.0
    SIZE(10) = 0.0
    SIZE(14) = 0.0
    SIZE(18) = 0.0
    SIZE(25) = 0.0
    SIZE(35) = 0.0
    SIZE(45) = 0.0
    SIZE(60) = 0.0
  7 NISITE = NISITE + 1
    IF (ISITE .GT. 6) STOP
    IF (NISITE .GT. 12) STOP
    IF(ISITE .GT. NISITE)GO TO 7
    WRITE(6,21)
 21 FORMAT('1',10X,'PRODUCTION OF INSECT 13200, HYDROPSYCHIDAE')
    WRITE(6,22)NISITE
 22 FORMAT('0',5X,'SITE ',I2)
    WRITE(6,51)
 51 FORMAT('0',10X,'WYOMING SITES:  1=GUN-L, 2=GUN-M, 3=GUN-U, 4='
   1'CLEAR, 5=GOFF, 6=KIT')
    WRITE(6,52)
 52 FORMAT(' ',10X,'UTAH SITES:  7=LFBF-L, 8=LFBF-M, 9=LFBF-U, 10='
   1'CURTIS, 11=LOGAN, 12=TEMPLE')
 11 IF (ISUB .LT. 1) GO TO 10
    NUMTOT = ISORT * (8. / ISUB) + .5
    GO TO 20
 10 NUMTOT = ISORT * (64. / ISOS) + .5
 20 METSQU = NUMTOT * (10000. / 4140.) + .5
    SIZE(ISIEVE) = SIZE(ISIEVE) + METSQU
    READ(5,100)ISITE,IDATE,IVISIT,ISIEVE,ISUB,ISOS,ID,ISORT
100 FORMAT(I2,X,I3,X,I2,X,I2,X,I1,X,I1,X,I5,3X,I4)
    IF (ISITE .GT. NISITE) GO TO 99
    GO TO 11
 99 IF (ISITE .LT. 4) GO TO 97
    GO TO 96
 97 MNELVN = (SIZE (5) * .14) / 9.
```

Table 43. Continued.

```
      MNTEN = (SIZE (5) * .45) / 9.
      MNNINE = (SIZE(5)-(MNTEN*9)-(MNELVN*9)) / 9.
      MNEIGT = SIZE(7) / 9.
      MNSEVN = SIZE(10) / 9.
      MNSIX = SIZE(14) / 9.
      MNFIVE = SIZE(18) / 9.
      MNFOUR = SIZE(25) / 9.
      MNTHRE = SIZE(35) / 9.
      MNTWO = (SIZE(45)+SIZE(60)) / 9.
      MNTOT = MNELVN+MNTEN+MNNINE+MNEIGT+MNSEVN+MNSIX+MNFIVE
     1+MNFOUR+MNTHRE+MNTWO
      GO TO 98
   90 MNELVN = (SIZE(5) * .14) / 10.
      MNTEN = (SIZE (5) * .45) /10.
      MNNINE = (SIZE(5)-(MNELVN*10)-(MNTEN*10)) / 10.
      MNEIGT = SIZE(7) / 10.
      MNSEVN = SIZE(10) / 10.
      MNSIX = SIZE(14) / 10.
      MNFIVE = SIZE(18) / 10.
      MNFOUR = SIZE(25) / 10.
      MNTHRE = SIZE(35) / 10.
      MNTWO = (SIZE(45)+SIZE(60)) / 10.
      MNTOT = MNELVN+MNTEN+MNNINE+MNEIGT+MNSEVN+MNSIX+MNFIVE
     1+MNFOUR+MNTHRE+MTWO
   98 SCY = REGWTY * MNELVN
      SCX = REGWTX * MNTEN
      SCA = REGWTA * MNNINE
      SCB = REGWTB * MNEIGT
      SCC = REGWTC * MNSEVN
      SCD = REGWTD * MNSIX
      SCE = REGWTE * MNFIVE
      SCF = REGWTF * MNFOUR
      SCG = REGWTG * MNTHRE
      SCH = REGWTH * MNTWO
      SCT = SCY+SCX+SCA+SCH+SCC+SCD+SCE+SCF+SCG+SCH
      LOSSY = MNELVN
```

Table 48. Continued.

```
LOSSX = MNTEN - MNELVN
LOSSA = MNNINE - MNTEN
LOSSB = MNEIGT - MNNINE
LOSSC = MNSEVN - MNEIGT
LOSSD = MNSIX - MNSEVN
LOSSE = MNFIVE - MNSIX
LOSSF = MNFOUR - MNFIVE
LOSSG = MNTHRE - MNFOUR
LOSSH = MNTWO - MNTHRE
WTLOSY = LOSSY * BETWTY
WTLOSX = LOSSX * BETWTX
WTLOSA = LOSSA * BETWTA
WTLOSB = LOSSB * BETWTB
WTLOSC = LOSSC * BETWTC
WTLOSD = LOSSD * BETWTD
WTLOSE = LOSSE * BETWTE
WTLOSF = LOSSF * BETWTF
WTLOSG = LOSSG * BETWTG
WTLOSH = LOSSH * BETWTH
PRODY = WTLOSY * 10.
PRODX = WTLOSX * 10.
PRODA = WTLOSA * 10.
PRODB = WTLOSB * 10.
PRODC = WTLOSC * 10.
PRODD = WTLOSD * 10.
PRODE = WTLOSE * 10.
PRODF = WTLOSF * 10.
PRODG = WTLOSG * 10.
PRODH = WTLOSH * 10.
PRODT=PRODA+PRODB+PRODC+PRODD+PRODE+PRODF+PRODG+PRODH+PRODX+PRODY
IF(SCT .LE. 0.0) GO TO 450
TR = PRODT / SCT
GO TO 451
```

Table 48. Continued.

```
450 IR = 0.0
451 CONTINUE
    WRITE(6,61)
 61 FORMAT('0','.')
    WRITE(6,31)
 31 FORMAT('0',9X,'SIEVE SIZE |  45&60 |   35   |   25   |   18   |')
    WRITE(6,62)
 62 FORMAT('+',57X,'   14   |   10   |    7   |    5   | 3.5')
    WRITE(6,69)
 69 FORMAT('+',100X,'  |   2.5   |')
    WRITE(6,65)
 65 FORMAT(' ','_______________________________________________')
    WRITE(6,66)
 66 FORMAT('+',52X,'_____________________________________________')
    WRITE(6,63)
 63 FORMAT(' ',20X,'|',8X,'|',8X,'|',8X,'|',8X,'|',8X,'|',8X,'|',8X,
   1'|',8X,'|',8X,'|',8X,'|')
    WRITE(6,32)MNTWO,MNTHRE,MNFOUR,MNFIVE,MNSIX,MNSEVN,MNEIGT,
   1MNNINE,MNTEN,MNELVN
 32 FORMAT(' ',7X,'AVG #/METSQU |',F7.2,X,'|',F7.2,X,'|',F7.2,X
   1,'|',F7.2,X,'|',F7.2,X,'|'
   1,F7.2,X,'|',F7.2,X,'|',F7.2,X,'|',F7.2,X,'|',F7.2,X,'|')
    WRITE(6,63)
    WRITE(6,33)REGWTH,REGWTG,REGWTF,REGWTE,REGWTD,REGWTC,REGWTB
   1,REGWTA,REGWTX,REGWTY
 33 FORMAT(' ',9X,'AVG WEIGHT |',F7.6,X,'|',F7.6,X,'|',F7.6,X,
   1'|',F7.6,X,'|',F7.6,X,'|',F7.6,X,'|',F7.6,X,'|',F7.6,
   1X,'|',F7.6,X,'|',F7.6,X,'|')
    WRITE(6,63)
    WRITE(6,34)SCH,SCG,SCF,SCE,SCD,SCC,SCB,SCA,SCX,SCY
 34 FORMAT(' ',7X,'SC(G/METSQU) |',F7.5,X,'|',F7.5,X,'|',F7.5,X,'|',
   1F7.5,X,'|',F7.5,X,'|',F7.5,X,'|',F7.5,X,'|',F7.5,X,'|',F7.5
   1,X,'|',F7.5,X,'|')
    WRITE(6,64)
 64 FORMAT(' ',20X,'|',12X,'|',8X,'|',8X,'|',8X,'|',8X,'|',8X,'|',8X,
   1'|',8X,'|',8X,'|',8X,'|')
```

Table 48. Continued.

```
      WRITE(6,35)LOSSH,LOSSG,LOSSF,LOSSE,LOSSD,LOSSC,LOSSB,LOSSA
     1,LOSSX,LOSSY
   35 FORMAT(' ',7X,'#LOSS/METSQU |',F11.2,X,'|',F7.2,X,'|',F7.2
     1,X,'|',F7.2,X,
     1'|',F7.2,X,'|',F7.2,X,'|',F7.2,X,'|',F7.2,X,'|',F7.2,X,'|'
     1,F7.2,X,'|')
      WRITE(6,64)
      WRITE(6,36)BETWTH,BETWTG,BETWTF,BETWTE,BETWTD,BETWTC,BETWTB
     1,BETWTA,BETWTX,BETWTY
   36 FORMAT(' ',9X,'WT AT LOSS |',F11.6,X,'|',F7.6,X,'|',F7.6,X,'|',
     1F7.6,X,'|',F7.6,X,'|',F7.6,X,'|',F7.6,X,'|',F7.6,X,'|',F7.6,X,'|'
     1,F7.6,X,'|')
      WRITE(6,64)
      WRITE(6,37)WTLOSH,WTLOSG,WTLOSF,WTLOSE,WTLOSD,WTLOSC,WTLOSB
     1,WTLOSA,WTLOSX,WTLOSY
   37 FORMAT(' ',12X,'WT LOSS |',F11.5,X,'|',F7.5,X,'|'F7.5,X,'|',F7.5,
     1X,'|',F7.5,X,'|',F7.5,X,'|',F7.5,X,'|',F7.5,X,'|',F7.5,X,'|'
     1,F7.5,X,'|')
      WRITE(6,64)
      WRITE(6,38)PRODH,PRODG,PRODF,PRODE,PRODD,PRODC,PRODB,PRODA
     1,PRODX,PRODY
   38 FORMAT(' ',9X,'PRODUCITON |',F11.5,X,'|',F7.5,X,'|',F7.5,X,'|',
     1F7.5,X,'|',F7.5,X,'|',F7.5,X,'|',F7.5,X,'|',F7.5,X,'|',F7.5,X,'|'
     1,F7.5,X,'|')
      WRITE(6,61)
      WRITE(6,39)PRODT,SCT,TR,MNTOT
   39 FORMAT('0',10X,'TOTAL PRODUCTION =',F8.4,3X,'MEAN STANDING CROP='
     1,F8.4,3X,'TURNOVER RATIO =',F5.2,3X,'MEAN #/METSQU =',F8.2)
      WRITE(6,57)
   57 FORMAT(' ',28X,'GMS/METSQU',21X,'GMS/METSQU')
      WRITE(6,41)
   41 FORMAT('0','****************************************************')
      WRITE(6,42)
   42 FORMAT('+',52X,'************************************************')
      GO TO 199
      END
```

Table 49. Sample computer output of FORTRAN program formulated for calculation of production estimates.

```
        PRODUCTION OF INSECT 13200, HYDROPSYCHIDAE

   SITE  8

        WYOMING SITES:  1=GUN-L, 2=GUN-M, 3=GUN-U, 4=CLEAR, 5=GOFF, 6=KIT
        UTAH SITES:  7=LFHF-L, 8=LFHF-M, 9=LFHF-U, 10=CURTIS, 11=LOGAN, 12=TEMPLE

 .

      SIEVE SIZE |  45&60 |    35    |   25    |    18    |    14    |    10    |    7    |    5    |  3.5     |   2.5  |
-----------------------------------------------------------------------------------------------------------------
                 |        |          |         |          |          |          |         |         |          |        |
    AVG #/METSQU |  89.90 |   58.00  | 103.10  |   52.10  |   52.20  |   33.40  |    5.90 |  15.05  |   19.45  |   2.20 |
                 |        |          |         |          |          |          |         |         |          |        |
      AVG WEIGHT |.000005 |.000020   |.000053  |.000137   |.000359   |.000938   |.002449  |.006395  |.016699   |.043609 |
                 |        |          |         |          |          |          |         |         |          |        |
    SC(G/METSQU) |0.00043 |0.00117   |0.00543  |0.00716   |0.01874   |0.03132   |0.01445  |0.09622  |0.32481   |0.09603 |
                 |             |          |          |          |          |          |         |         |          |        |
    #LOSS/METSQU |        31.90 |  -45.10 |   51.00  |   -0.10  |   18.80  |   27.50  |  -9.15  |  -4.40  |   17.25  |   2.20 |
                 |             |          |          |          |          |          |         |         |          |        |
      WT AT LOSS |     0.000010 |.000033   |.000085  |.000222   |.000580   |.001515   |.003957  |.010334  |.026986   |.043609 |
                 |             |          |          |          |          |          |         |         |          |        |
         WT LOSS |      0.00031 |-.00147   |0.00434  |-.00002   |0.01091   |0.04167   |-.03620  |-.04551  |0.46548   |0.09603 |
                 |             |          |          |          |          |          |         |         |          |        |
      PRODUCTION |      0.00313 |-.01469   |0.04339  |-.00022   |0.10909   |0.41670   |-.36195  |-.45509  |4.65475   |0.96026 |

 .

        TOTAL PRODUCTION =  5.3554    MEAN STANDING CROP=  0.5958    TURNOVER RATIO = 8.99    MEAN #/METSQU =  341.00
                          GMS/METSQU                          GMS/METSQU

*****************************************************************************************************
```

VITA

Thomas G. Osborn

Candidate for the Degree of

Doctor of Philosophy

Dissertation: Stream Insect Production as a Function of Alkalinity and Detritus Processing Rates.

Major Field: Wildlife Science

Biographical Information:

Personal Data: Born at Hart, Michigan, June 7, 1951, son of Gordon C. and Anna M. Osborn.

Education: Graduated from Hart High, Michigan; received Bachelor of Science in Resource Development from Michigan State University in 1973; received Master of Science in Water Resource Development in 1975; completed requirements for a Doctor of Philosophy in Wildlife Science at Utah State University in 1981.

Professional Experience: 1975-1980, Teaching and Research Assistant, Wildlife Science, Utah State University; 1974-1975, Teaching and Research Assistant, Resource Development, Michigan State University.