1979

Deep Creek Validation Study Report

G. W. Minshall

C. Y. Manuel

R. W. Dunn

R. K. Pace

M. R. McSorley

D. A. Andrews

FINAL REPORT

DEEP CREEK VALIDATION STUDY REPORT

G. W. Minshall
C. Y. Manuel, R. W. Dunn, R. K. Pace,
M. R. McSorley, and D. A. Andrews

Idaho State University

US/IBP DESERT BIOME
RESEARCH MEMORANDUM 77-6

in

FINAL PROGRESS REPORTS
Validation Studies, pp. 145-175

1976 Proposal No. 2.3.6.

Printed 1979

Citation format: Author(s). 1979. Title.
US/IBP Desert Biome Res. Memo. 77-6.
Utah State Univ., Logan. 31 pp.

Ecology Center, Utah State University, Logan, Utah 84322

ABSTRACT

The results of the 1975 and 1976 validation studies are presented. In 1975, light and nutrient levels (nitrogen, phosphorus) were manipulated in order to permit testing of the Desert Biome Aquatic Model; during 1976, routine sampling was done to follow recovery from the light manipulation and to provide an independent validation of the model. In the course of these studies, additional insight was obtained into the structure and function of the Deep Creek ecosystem (Curlew Valley, Idaho-Utah).

Coverage of the stream with plastic sheets eliminated all of the light from Station 3C (black plastic) and 70% from Station 3B (white plastic). Station 3A served as a control. In general, the predicted reductions in plant biomass were obtained. All of the vegetation within the black-covered section died and floated away within 1 mo after the stream was treated. Covering with white plastic caused a shift from a *Potamogeton*- to a *Chara*-dominated community. The impact of the light alterations on the plants extended through 1976. No change was detected in organic matter storage or transport as a result of the manipulation. A greater percentage of fish was found under the white plastic than under either the control or black plastic. Apparently, the white plastic provided additional "cover" over that of the control, but still allowed plant growth and the persistence of food organisms. Under the black plastic no plant growth occurred, and few invertebrates or fish were found there.

The addition of NH_4NO_3 (approximately 2.19 mg/l NH_3-N and 3.38 mg/l NO_3-N) to the water at Station 2 had little effect on the biomass of periphyton or macrophytes (*Cladophora*) in the stream. But the addition of PO_4 (approximately 2.49 mg/l PO_4-P) and PO_4 plus NH_4NO_3 (approximately 2.62 mg/l PO_4-P, 4.19 mg/l NH_3-N and 4.41 mg/l NO_3-N) resulted in measurable increases in plant biomass, with the latter showing the most dramatic changes.

Study of the sediment dynamics at Station 3 revealed organically rich debris extending from 0.5 to over 1.25 m in depth. Aerobic conditions appear to be confined to the upper few centimeters of sediment. This is a zone of recent deposition and frequent reworking by the stream and benthic organisms. Below this is a layer about 10 cm in depth which, although anaerobic, appears to be biologically active and which may be reworked by the stream at least annually. Sediments deeper than about 15 cm do not appear to be biologically active and probably are reworked by the stream only infrequently. Measurements of undisturbed sediments gave respiration values ranging from 98.7-152.3 mg $O_2 \cdot m^{-2} \cdot hr^{-1}$. A series of measurements showed that the rates of erosion and deposition of sediments at Station 3 are about equal, and that the storage component is in dynamic equilibrium with the relatively constant flow regimen.

Dissolved organic carbon was similar at Deep Creek Stations 1-3 and showed no important variation between up- and downstream locations. The mean concentrations of dissolved organic carbon and fine particulate organic carbon at Station 3 for 1975 were 1.7 and 1.8 g C/m^3, and for 1976 were 1.5 and 0.7 g C/m^3. Values followed discharge patterns at Stations 2 and 3, but not at Station 1. Particulate matter was highest at Station 1 and lowest at Station 2. The lack of variation in upstream-downstream and between-site concentrations of dissolved and fine particulate organic carbon indicates a steady state condition and that the system is efficient in processing or storing these materials. Import of coarse particulate organic matter usually exceed export; lack of accrual of these materials in the sediments indicates that they too are actively processed. The mean distances traveled by dislodged *Potamogeton* and *Cladophora* were 49.5 and 33.3 m, respectively.

INTRODUCTION

This report contains the results of two field seasons. During 1975 the primary goal was to impose two separate perturbations on the Deep Creek ecosystem (light reduction and nutrient addition) and to monitor the effects. During 1976 the primary objective was to obtain a set of measurements from Deep Creek Station 3 comparable to those collected during 1970-72 and during 1976. The purpose of the activities in 1975 was to provide a test of the Desert Biome Aquatic Model; the 1976 activities were to provide an independent validation of the model. In the course of the two-year study period, additional process studies also were carried out to further enhance understanding of the structure and function of the Deep Creek ecosystem.

Light and nutrients were chosen for manipulation because of their basic nature and ease of regulation, and because preliminary computer runs indicated that the Aquatic Model was particularly sensitive to these variables. In addition, both perturbations offered the potential for crossbiome comparison. Light, in particular, is hypothesized to be responsible for major differences between desert and forest streams (Minshall 1975). Since both light intensity and nutrient content of the water exert their principal influence at the level of the primary producers, the manipulations were timed to correspond closely to the main growth period for aquatic plants (about May 1 through mid-October). The nutrient addition experiment also provided the opportunity to obtain more complete

information on the dynamics of the *Cladophora glomerata* (filamentous algal) community at Station 2.

Three light regimes were imposed on the stream: 1) full sunlight; 2) 30% of incident (shaded); and 3) no incident radiation (dark). A curvilinear relationship between primary production and light intensity was postulated, with a plateau in production being reached at about 50% of full light. This part of the study was performed at IBP Station 3 where an especially lush and relatively uniform growth of macrophytes (*Chara* and *Potamogeton*) were known to occur. The effect of all three light levels was studied simultaneously on three adjacent sections of the stream, each approximately 100 m long. The control section (full sunlight) was located immediately upstream of the shaded section. But the latter was separated from the downstream, fully darkened section by a buffer zone of 180 m in order to avoid possible modifying effects from the perturbed, upstream section.

The nutrient manipulation part of the study was to determine the effects of increased levels of phosphorus and nitrogen on the growth energy pathways of a stream *Cladophora glomerata* community, and the interactions between the *Cladophora* community and the overall stream ecosystem. Station 2, Deep Creek, presented a unique situation for the study of the growth and dynamics of *Cladophora glomerata*. Two-week periods of irrigation diversion of water reduce the stream flow and allow a large growth of *Cladophora* to accumulate. When normal stream flows are reestablished, the flushing action removes most of the *Cladophora* and allows development of another *Cladophora* community during the next 2-wk diversion of irrigation water. During the spring and summer there are seven or eight 2-wk diversions of irrigation water separated by 2-day intervals of normal water flows. Thus, nearly every two weeks a "new" community of *Cladophora* was available for study.

METHODS

Solar Radiation

Solar radiation was recorded in kilocalories multiplied by an instrument constant 0.369 for the period April 26 through September 14 (DSCODE A3UMLJ6). Instrument: pyrheliograph (actinometer), range 360-2000 μ, continuous recording, 7-day clock (Weathermeasure Corp. No. 401). Instrument was located 3 m above ground at the stream side. Solar radiation values for May 30 to June 13 and June 22 to July 19, 1975, are missing due to machine malfunction. Vandalism was responsible for some missing data in August 1975.

Air and Water Temperatures

Continuous temperatures and maximum-minimum temperatures were recorded in °C (A3UMLJ2,3).

Air: measured by thermograph, dual pen, continuous recording, 7-day clock (Weathermeasure Corp. No. T601-S-W), located in metal shelter. Temperature was taken from a probe located 1 m above ground.

Water: measured by thermograph (same as preceding). Probe was set 1 m from the bank in stream. Maximum and minimum registering thermometer was placed in the middle of the stream to calibrate the thermograph.

Field Measurements

Data recorded: depth, width, current velocity, stage height, discharge, temperature from April through October 1975 and 1976 (A3UMLL3).

Depth was recorded every 10 cm across the stream each week. Width was measured at the same spot each week and recorded in meters. Stage height was read from a meter stick placed in the stream at the point where discharge is measured. Current velocity was measured weekly at five points across the stream with an OTT C-1 current meter using propeller number one. The OTT was inoperative in the latter part of the summer of 1975, so a Model 2030 Digital Flowmeter (General Oceanics, Inc., Miami, Florida) was used. Discharge was calculated from mean depth, width and current velocity.

Water Chemistry

Water from Stations 2 (1975 only) and 3 (1975 and 1976) was analyzed monthly from April through October for calcium, magnesium, silica, iron, chloride, carbonate and bicarbonate alkalinity, sulfate, hardness, ortho- and total phosphate, ammonia, nitrate and nitrite nitrogen, pH and specific conductance. In addition, weekly determinations of ammonia, nitrate and nitrite nitrogen, ortho- and total phosphate and alkalinity were made for Station 2 and for each section of Station 3 (A up, A down, B up, B down, C up, C down) during 1975 and at Station 3 (A up, A down) in 1976 (A3UMLM2, 3).

Experimental methods for water analyses are described in an earlier report (Minshall et al. 1972).

Periphyton and Macrophytes

Data were recorded for periphyton—chlorophyll *a* in mg/m^2; macrophytes—ash free dry weights (AFDW) in g/m^2 by species (A3UMLF3, H3).

To determine the effect of light on the primary-producer component, both the periphyton community and the macrophytes were sampled. Redwood trays (1/16 m^2) containing small rocks were placed into the stream to estimate the standing crop of periphyton. When sections of the stream were covered with plastic, boxes were placed under the plastic. Introduction of the trays into the stream was timed so that at each of the monthly sampling dates, the trays removed would have had a 6-wk residence time. Generally two trays were removed each time. But in 1976 limited space under the white plastic precluded putting in two boxes, especially in the last half of the season. To sample, the trays were removed from the stream and the rocks were placed into polyethylene jars covered with foil to exclude light. Chlorophyll was extracted with acetone and the samples refrigerated. After 24 hr the samples were either measured spectrophotometrically or (in 1975) decanted into 120-ml glass jars and stored at 0 C for later

analysis. The latter was necessary because of an unanticipated malfunctioning of the spectrophotometer.

Macrophytes (aquatic vascular plants and macrophytic algae) were collected monthly from June through October 1975 and from May through October 1976, using a Hess Sampler (1/16 m^2). On each sampling date two samples were taken from the channel and the margin in the three treatment sections; that is, the unshaded control section, the section 70% shaded and the 100% shaded section, designated A, B and C, respectively. Exceptions to this procedure were: 1) by July 1975, macrophytes were absent from the C section; therefore samples were not taken in August, September and October 1975; 2) sample size was doubled for the August 1975 sampling; and 3) when the October 1975 samples were taken, the substrate within the Hess Sampler was stirred up to a depth of approximately 5 cm. The current was sufficient to carry this resuspended material into the sleeve of the sampler, thus including "stored organic matter" in the sample. Later, at the time of analysis, this fraction was separated from the regularly collected, above-the-substratum plant parts. Two of the three major taxa, *Chara vulgaris* and *Cladophora glomerata*, are macrophytic algae and consequently are rootless. The third taxon, *Potamogeton pectinatus*, has shallow, loosely anchored roots, and these roots were included in the 1975 and 1976 samples. Samples were placed in jars, preserved with 10% formalin and transported to the laboratory where they were separated into species, dried at 60 C for at least 24 hr, then ashed at 550 C for 3 hr to obtain the AFDW.

Primary Production

Hourly dissolved oxygen and temperature recordings were taken over a 24-hr period at Deep Creek Station 3 only.

In 1975, duplicate water samples were collected each hour from upstream and downstream stations beginning at midnight and continuing for a 24-hr period. Collections were taken in standard BOD bottles and fixed immediately with 2 ml each of $MnSO_4$ and KOH-KI. Later the samples were acidified (conc. H_3PO_4) and titrated with phenyl arsene oxide to determine oxygen content. Stream metabolism was estimated by the two station diel oxygen technique and by the single curve method (Odum 1957; McDiffett et al. 1972; Slack et al. 1973). Diffusion was determined by means of the stream morphology method. Calculations were done by hand and by use of a computer program written by J. T. Brock (Idaho State University). In 1976, productivity of the macrophytes was estimated on the basis of changes in standing crops. In 1975, the length (m) of the study sections at Station 3 varied as follows:

	Sec A	*Sec B*	*Sec C*
May	390	380	350
Jun	100	180	97
Jul	100	97	97
Aug	164	97	97

Dissolved and Particulate Organic Carbon in Transport

Data were recorded for particulate carbon and dissolved carbon converted to cal/m^3 of stream water (A3UMLF5-7).

Water samples were taken from midstream and placed in the dark under refrigeration for transport to the laboratory, where they were stored under the same conditions. Particulate matter was removed by filtering the water through 0.8 μ membrane filter and dissolved material determined from the filtered water. Determinations were made within 48 hr using the semimicro method of quantitative dichromate oxidation (Maciolek 1962).

Drift (CPOM in Transport)

Data were recorded for depth and width of water column (cm), current velocity, duration of sampling (min), stream discharge, numbers (by size classes) of invertebrates and ash free dry weights (at 525 C for 4 hr) of plant material. In 1974, Stations 1, 2 and 3 were sampled at up- and downstream locations from February through December, and the data are included here because they have not been reported previously (A3UMLD5-7). In 1975 only three sections at Station 3 (A up, A down, B up, B down, C up, C down) were sampled from April through October. No drift collections were made in 1976.

Drift was sampled at monthly intervals at selected times of the year. Samples of 15-min duration were collected at noon and midnight from sites upstream and downstream of the study section, with the downstream site sampled first and located 15 min in flow time below the upstream site.

The sampling device used was conical net (90 cm long, 273 μ mesh), fitted to a 20 x 50 cm support frame, inserted vertically into the stream and supported a few centimeters off the bottom. In this manner, the entire column of water (20 cm wide by x cm deep) from the center of the stream was sampled. Depth of the water column (x) was determined each time with a meter stick; middepth current velocity at the mouth of the net was measured for the entire period with a digital flowmeter (Gen. Oceanics, Inc., Model 2030). From knowledge of the cross-sectional area of the submerged portion of the frame, current velocity and duration of collection time, it was possible to determine the volume of water sampled. This, in turn, permitted calculation of numbers and weights of organisms by size classes and dry weights of living and dead plant material per m^3 of stream flow.

Benthic Invertebrates and Detritus

Numbers were recorded by 1-mm-size groups for each taxon. Collections were made in conjunction with the drift samples. In 1974, collections were obtained from Stations 1, 2 and 3 at monthly intervals beginning in February and ending in December. In 1975 and 1976, samples were taken at Station 3 only from April through October. The 1975 samples included duplicate collections from each of the experimental sites (A, B, C). Data for invertebrates are stored under A3UMLD1-3, detritus under A3UMLE1-3.

Samples were collected with a modified Hess, 1/16-m^2 sampler (0.390 mm mesh), preserved with 10% formalin and returned to the laboratory for processing. Samples were washed through a series of sieves (3.36, 1.68, 0.841, 0.351 mm), identified and sorted to the lowest taxonomic cagegory practicable (usually species), measured and counted under a binocular microscope.

Two representative samples from each station or experimental subsite were collected monthly. One sample from each pair was collected from the center of the stream; the other was taken halfway between the center and the shore.

Fish

Data were recorded on numbers collected by species. During the three summer months of 1975, fish populations were estimated under two light intensities controlled by light and dark plastic sheeting over the stream. The fish were trapped using specially built minnow traps made by the Cuba Specialty Manufacturing Co., Houghton, New York. Mesh size was 3.2 mm; the inlet opening was 25 mm in diameter. Fish captured ranged in length from 12-62 mm. Two species were prevalent, speckled dace (*Rhinichthys osculus*) and Utah chub (*Gila atraria*). A third species, rainbow trout (*Salmo gairdneri*), was found in the study section of the stream but only as adults.

Three traps were placed under each of the sheets and three more were set in the control. The traps were placed at points along the section that were accessible through seams in the plastic. They were checked every hour for 3 hr during the day except in August, when they were set during the night (2000 to 0600 hr). Fish were counted, measured and returned to the stream after each sampling check.

Population estimates during 1976 were based on the Multiple Mark-Recapture method outlined by Robson and Regier (1971). Six traps were baited with bread and placed at approximately 30-m intervals in the control section in August. The next day the fish in each trap were counted, marked by clipping the caudal fin and immediately released. The traps were baited and replaced in the stream in the same locations. The following day the fish were again collected from the traps, marked fish were counted, unmarked fish were counted and marked, and then all were returned to the stream. The traps were again baited and fish collected 24 hr later. After the marked or unmarked status of the fish collected on the last day was determined, the fish were preserved and returned to the laboratory. In early September, and again in late October, six baited traps were put into the stream in the same places as before. In addition, one trap each was placed 25, 50 and 75 m upstream from the control section. Three traps were also placed in the recolonized section, which is approximately 200 m downstream from the control. After 24 hr, the fish were recovered from the traps, and the numbers of marked and unmarked fish were recorded.

Table 1. Light manipulation study. Parameters measured in each of the three study sections at Station 3 during the main period of aquatic plant growth (April-October) 1975

Parameter	Frequency
Solar radiation, incoming	continuous
streambed	occasional
Temperature	continuous
	weekly max-min
Discharge, study reach	weekly
drift sites	monthly
Water chemistry, incoming	monthly
leaving each section	irregular
Periphyton (Chl a, species comp.)	monthly
Macrophytes (standing crop, growth, loss)	monthly
Primary production - community respiration	April, May, June, July, August
Organic carbon (input-output budget for each station)	monthly
Drift	monthly
Benthic invertebrates and detritus	Monthly
Fish	June, July, August

Light Manipulation Experiment

Three light regimes were imposed on the stream: 1) full sunlight; 2) 30% of incident; and 3) no incident radiation. All three levels were studied simultaneously on three adjacent sections of Deep Creek Station 3, each approximately 100 m in length. The sections were arranged with the naturally lighted Section A upstream, followed immediately by a section shaded with white plastic, B. The latter was separated from the completely darkened Section C by a 180-m-long buffer zone.

Monitoring of a standard set of parameters (Table 1) began in April 1975, prior to the initiation of plant growth, and continued through October. The experimental sections of the stream were covered with reinforced polyethylene (Poly-Scrim, milky white and black, respectively) on June 21, 1976. One set of measurements was made just prior to covering the stream and another set was obtained a few weeks later. The plastic was removed from the stream in November 1975 and, on May 12, 1976, a 12-m length of the shaded section was again covered with white plastic. Coverage continued through September 20, 1976, at which time all aquatic vegetation was absent.

Nutrient Addition Experiment

For the ammonium nitrate addition, a riffle of the stream (30-m length) was divided into two channels of roughly equal area by constructing a partition using corrugated fiberglass panels and steel fence posts. Ammonium nitrate (NH_4NO_3) was added to one channel using a 20-liter bucket suspended from a steel fence post. One-liter container full of NH_4NO_3 (974 g) was dissolved in 20 liters of water to yield a .6 molar stock solution. Three milliliters per minute of the stock solution were allowed to drip into the channel through a series of tubes with the flow rate controlled using pinchcock clamps. The other channel was used as a control.

For the phosphate and phosphate plus ammonium nitrate addition experiments, a relatively uniform 45-m section of stream was selected. The upstream 15-m section was used as a control section. Phosphate was added at the upstream end of the second 15-m section by placing two trays of commercial phosphate fertilizer (47-0-0, J. R. Simplot Co.) in the stream. The trays were refilled every other day. At the upstream end of the third 15-m section, NH_4NO_3 was added at a flow rate of 5 ml/min using the above method. Another tray of phosphate fertilizer was also placed in the stream at this point.

Both experiments were conducted during 2-wk periods of irrigation water diversion from the stream. The NH_4NO_3 addition experiment was conducted for 9 days from July 4 through July 12, 1975, and the PO_4 and PO_4 plus NH_4NO_3 addition was conducted for 11 days from July 23 through August 2, 1975.

Biological and chemical sampling was conducted every other day beginning with day 1 of the experiment. At noon and midnight, 15-min drift samples were taken at the downstream and upstream ends of both channels during the NH_4NO_3 addition experiment, and at the upstream and downstream ends of the three sections in the PO_4 and PO_4 plus NH_4NO_3 addition experiment. Discharge also was measured. During the NH_4NO_3 addition experiment, noon and midnight water samples (1 liter) for chemical analyses were collected at upstream and downstream ends of both channels. Because no consistent differences in water chemistry values were noted between upstream and downstream samples taken during the NH_4NO_3 addition experiment, only downstream water samples were taken at the end of all three sections during the PO_4 and PO_4 plus NH_4NO_3 addition experiment. During the PO_4 and PO_4 plus NH_4NO_3 addition experiment, daily maximum-minimum temperatures were also recorded. During the NH_4NO_3 addition experiment, three 46-cm^2 areas of substratum were sampled randomly in each channel for *Cladophora glomerata* by pushing a metal cylinder into the gravel substratum and removing all enclosed *Cladophora*. Three 46-cm^2 areas of the gravel substratum were also sampled in each channel by pushing the cylinder into the substratum and removing all gravel to a depth of 4-5 cm. During the PO_4 and PO_4 plus NH_4NO_3 addition experiment, four samples of *Cladophora* (or *Spirogyra* sp.) and three substratum samples were taken from each section in the same manner. Small samples of *Cladophora* and *Spirogyra* sp. also were taken from each channel of the NH_4NO_3 addition experiment and all three sections of the PO_4 and PO_4 plus NH_4NO_3 addition experiment for further analysis.

Drift samples were preserved in 10% formalin and later were sorted into five basic categories: aquatic animal, aquatic plant, terrestrial animal, terrestrial plant and an unidentifiable component. In addition, the aquatic plant component was sorted to remove *Cladophora* and *Spirogyra* sp. Oven dry weight (ODW) and ash free dry weight (AFDW) estimates were obtained for each component, plus *Cladophora* and *Spirogyra* sp., by placing samples in tared crucibles, drying in an oven at 60 C for 3 days, weighing, then burning the samples in a muffle furnace at 550 C and reweighing.

The water samples were analyzed within 24 hr for the following components: nitrate nitrogen by the NitraVer II method; ammonium nitrogen by the direct Nesslerization method; orthophosphate phosphorus by the StannaVer method (Hach Chemical Co. 1969); carbonate, bicarbonate alkalinities and hardness, using standard methods (American Public Health Association 1970).

The invertebrates and all large particle detritus were picked from the 46-cm^2 samples of *Cladophora* and *Spirogyra* and preserved in 95% ethanol. The invertebrates were later counted and grouped into size classes, and ODW and AFDW estimates were obtained using appropriate conversion factors. ODW and AFDW estimates of *Cladophora* and *Spirogyra* and large particle detritus were obtained employing the same methods used on the drift samples.

The invertebrates were also picked from the 46-cm^2 substratum samples and processed in the same manner. The gravel substratum was then placed in small glass jars containing 50 ml of 90% acetone and allowed to extract in the dark at 0 C. Later, spectrophotometric analyses, following the methods of Strickland and Parsons (1968), were used with a Beckman DB-G spectrophotometer to determine chlorophyll *a* and phaeo-pigments.

To determine the ratio of chlorophyll *a* to ODW and AFDW, small samples of *Cladophora* and *Spirogyra* were cleaned rigorously under a faucet, rinsed in distilled water, blotted dry, ground in 50 ml of 90% acetone with a mortar and pestle, allowed to extract in the dark at 0 C, and analyzed for chlorophyll *a* and phaeo-pigments, using the methods described above. The acetone then was recombined with the algal residue in a tared crucible, evaporated at 60 C, and ODW and AFDW estimates were obtained.

To determine the amount of fine particulate detritus the *Cladophora* community contributed to the stream, small aluminum pans were placed beneath clumps of *Cladophora* and Nitex nets (290 μm) were placed immediately downstream from the same clumps. After 24 hr, the pans, net and clump of *Cladophora* were removed from the stream. Invertebrates and large particle detritus were removed from the *Cladophora* and preserved in 95% ethyl alcohol. The *Cladophora* was then washed vigorously in distilled water to remove the standing crop of fine particle detritus, blotted dry, placed in an aluminum pan and allowed to dry. The distilled water containing the fine particle detritus was preserved with 10% formalin and later filtered onto tared membrane filters. Invertebrates were removed from the pans and nets and preserved, and the fine particle detritus was removed and preserved in 10% formalin and later filtered onto membrane filters. Small filaments of *Cladophora* and other larger particles of detritus were placed in small vials and allowed to dry.

ODW and AFDW estimates were obtained for all components using previously described methods. A total of 40 samples of *Cladophora* was analyzed.

To further enable the rate processes of *Cladophora* detrital dynamics to be analyzed, small clumps of *Cladophora* were cleaned by picking out all invertebrates and large particle detritus and washing vigorously in distilled water and briefly in 70% ethanol to remove fine particle detritus. These clumps of *Cladophora* were tied to small stones and replaced into the stream. After 24 hr they were removed; invertebrates, fine particle detritus and large particle detritus were analyzed as described for the previous experiment. A total of 22 samples of *Cladophora* was analyzed in this manner.

RESULTS

Physical-Chemical Conditions

The spring and summer of 1975 were notably cool and cloudy. The growing season for terrestrial plants (based on dates of the latest and earliest killing frost) extended from June 26 to August 24. Spring runoff started at the end of May and lasted until the week of June 13 (Fig. 1), whereas in previous years, and in 1976, it occcured in March and April. Solar radiation values in 1975 were lower than in previous years (Table 2), totaling some 3000 to 3300 kcal/m^2 less for the period shown; those in 1976 were similar to 1971 and 1972, except for August (A3UMLJ2, J3, J6, L3, M2, M3). The August 1976 values are based on incomplete records, and this may have lowered the mean substantially. The maximum water temperatures of 24.6 C on July 5, 1975, and 26.7 C on August 7, 1976, and the minimums of 2.8 C on May 24, 1975, and 3.8 C on May 9, 1976 (Fig. 1), are similar to those recorded in 1971 (Minshall et al. 1973, Fig. 4C, p. 32).

Table 2. Comparison (mean and range) of solar radiation climate (kcal·m^{-2}·day^{-1}) for 1971 and 1972, and 1975 and 1976

Month	Solar radiation			
	1971	1972	1975	1976
May	4640 (2159 - 7306)	5048 (830 - 6642)	4965 (1578 - 7638)	5338 (2823 - 6891)
June	3554 (3321 - 7721)	5327 (3736 - 7389)	4055 (2657 - 5812)	5632 (1744 - 6725)
July	5694 (1661 - 7057)	5737 (3819 - 6808)	4456 (2076 - 5811)	5223 (2159 - 6559)
August	4955 (1328 - 6642)	5051 (2989 - 6559)	4357 (2241 - 5396)	3767 (2408 - 6144)
TOTAL	2,563,389	2,603,020	2,193,459	2,455,080

The 1975 and 1976 values for water chemistry are summarized in Table 3. The pH and ion concentrations at Station 3 in 1975 and 1976 were consistent with values reported for 1970-72 (Minshall et al. 1973, Table 5), and values were also similar between Stations 2 and 3. Notable exceptions are chloride and sulfate, which reached very high concentrations at Station 3. As can be seen from Figure 2, in 1975 the change in concentration of chloride paralleled the change in sulfate at Station 3, and low concentrations in August were followed by rapid increases. However, in 1976, chloride increased steadily from April through November, and the August depression did not occur. Figure 3 compares the values for orthophosphate, nitrate and ammonia. The concentration of NO_3 was highest in April (0.10 mg/l), decreased steadily during the summer, then increased sharply between September and October. With the exception of one high value (0.71 mg/l in October 1976), there was little fluctuation in the concentration of

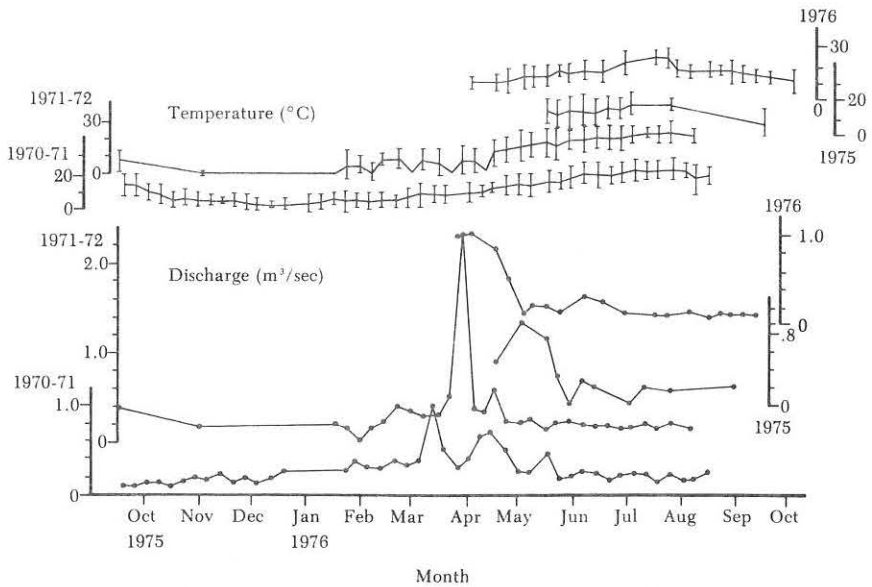

Figure 1. Discharge (measured weekly) and weekly maximum and minimum temperatures (°C), with a line connecting the mean values, for Deep Creek Station 3, 1970-72, 1975 and 1976.

Table 3. Comparison of water chemistry conditions (range and mean) April-October 1975 and April-November 1976. All values, except for pH, expressed as mg/l

	pH	Calcium	Magnesium	Bicarbonate (as $CaCO_3$)	Chloride	Sulfate	Silica	Iron	Ortho-P	NH_3-N	NO_3-N	TDS
1975												
Station 2												
Max.	8.6	81	73	214	180	170	22	0.10	0.38	0.85	0.18	679
Min.	8.1	25	14	182	69	14	6	0.02	0.08	0.18	0.00	536
Mean	8.4	49	34	200	133	48	14	0.06	0.22	0.44	0.08	598
N = 7												
Station 3												
Max.	8.7	155	87	245	550	400	27	0.16	0.33	1.65	0.11	1138
Min.	8.0	55	21	150	126	22	8	0.13	0.14	0.30	0.03	660
Mean	8.4	91	47	189	292	157	17	0.07	0.23	0.87	0.06	859
N = 7												
1976 *												
Station 3												
Max.	8.2	152	70	261	462	320	36	0.11	0.71	1.21	0.10	1530
Min.	7.9	36	45	124	172	56	15	0.08	0.08	0.30	0.05	512
Mean	8.0	101	55	221	321	178	24	0.09	0.33	0.70	0.07	1081
N = 8												

*All 1976 values are means of upstream - downstream samples taken 200 m apart.

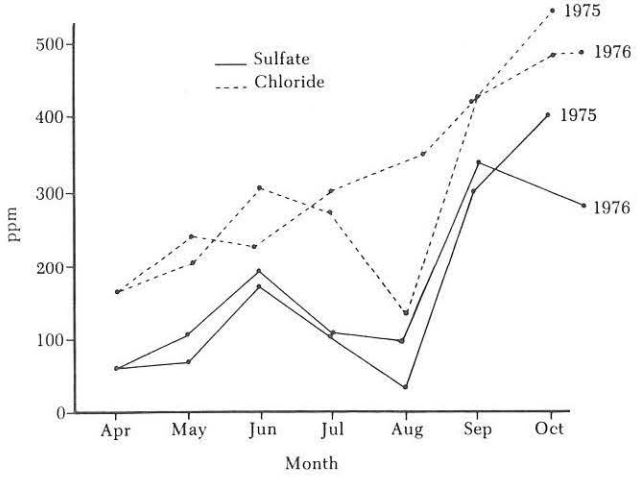

Figure 2. Chloride and sulfate concentrations at Deep Creek Station 3, Curlew Valley, Idaho, 1975 and 1976.

Table 4. Results for intensive analysis of inorganic carbon, nitrogen and phosphate from Stations 2 and 3, Deep Creek, 1975. Differences in upstream and downstream concentrations evaluated by the pairing design test of significance

	Ortho Phosphate (mg/l)	Ammonia (mg/l)	Bicarbonate (mg/l)	Nitrate (mg/l)
Station 2				
Upstream $\bar{X}$	.22	.43	195	.10
Downstream $\bar{X}$	.23	.41	198	.09
Level of Significance	N.S.	N.S.	N.S.	-.20
Station 3				
Control				
Upstream $\bar{X}$	.26	.71	190	.052
Downstream $\bar{X}$	.27	.75	199	.045
Level of Significance	N.S.	+.40	+.01	-.20
Shaded				
Upstream $\bar{X}$	.27	.86	196	.05
Downstream $\bar{X}$	.24	.93	191	.05
Level of Significance	N.S.	+.20	N.S.	N.S.
Black				
Upstream $\bar{X}$	.19	.92	196	.05
Downstream $\bar{X}$	.20	.84	196	.05
Level of Significance	N.S.	-.50	N.S.	N.S.

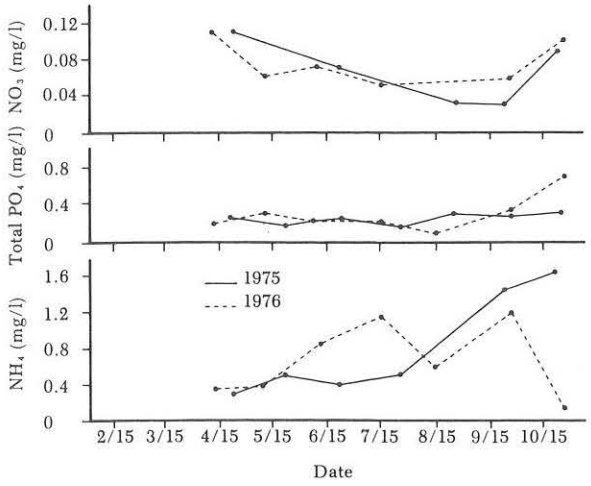

Figure 3. Concentrations of NH_4, ortho-PO_4 and NO_3 in Deep Creek Station 3, 1975 and 1976.

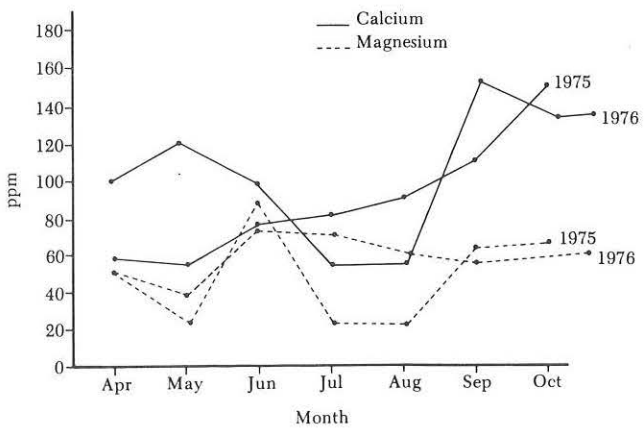

Figure 4. Calcium and magnesium concentrations at Deep Creek Station 3, Curlew Valley, Idaho, 1975 and 1976.

Table 5. Comparison of monthly upstream and downstream chemical values in the control section at Deep Creek Station 3, April to November 1976, using paired *t*-test

	Upstream Mean (mg/l)	Downstream Mean (mg/l)	Degrees Freedom	t - value	Level of Significance
Ca^{++}	111.88	90.50	8	2.56	.05
Mg^{++}	54.13	55.25	8	- .84	
Si	24.45	24.26	8	.15	N.S.
HCO_3	221.00	221.50	8	- .14	N.S.
Cl^-	323.63	319.25	8	.73	.50
SO_4^{--}	187.00	169.38	8	1.53	.20
NH_4	.71	.68	8	.41	N.S.
NO_3	.073	.059	8	1.16	.40
PO_4	.46	.40	6*	2.08	.10
pH	7.96	8.03	6*	-2.50	.05
Conductivity	1645	1648	8	- .06	N.S.

*April through Oct. In Nov., PO_4 goes up, and pH goes down between the two sampling sites.

orthophosphate, and no seasonal trend was observed. In 1975, ammonia levels remained constant until late July when they began to increase, reaching a maximum of 1.65 mg/l in October. This pattern was not repeated in 1976, however, when the concentration of ammonia fluctuated widely. Figure 4 shows that at Station 3 the calcium level increased from May through October, while magnesium remained relatively constant. Table 4 gives the results of the pairing design (two samples) test for significance for the differences between upstream-downstream concentrations of orthophosphate, nitrate, ammonia and bicarbonate, based on weekly samples collected June through September 1975. The only species that showed a highly significant change was the bicarbonate ion, which increased downstream in the control section at Station 3. On several sampling dates, ammonia increased downstream in the control and shaded sections, but the level of significance was low (0.40 and 0.20, respectively). Nitrate decreased slightly at Station 2 and in the control section of Station 3, but most of the changes in ion concentrations were subtle and the stream appeared to be in steady state in most sections for most of the ions tested.

Upstream and downstream water samples, collected monthly from the control section at Station 3, were analyzed and the results of the paired *t*-test are given in Table 5. Calcium showed a significant decrease downstream, while pH increased. On the basis of the 1975 analysis, it was expected that bicarbonate would increase downstream. In 1976, however, there was no change in the concentration between up- and downstream locations; PO_4 decreased (level of significance = 0.10) in 1976, in contrast to 1975 when it showed no upstream-downstream change. The trend (with the exception of magnesium) was toward a decrease in concentration of ions downstream, but for most species these changes were slight.

Dissolved (DOC) and particulate organic carbon were analyzed at frequent intervals during 1975 to determine the effect of the two experimental manipulations on organic transport. However, the measurements also were made to complete a series begun in 1974 for the purpose of documenting the levels and seasonal variations of organic carbon in Deep Creek. Consequently, water from Station 1 was analyzed along with that from Stations 2 and 3. Evaluation of procedures used during 1970-72 raised doubts as to the accuracy of the values obtained and led to the new series of measurements. The results obtained (Table 6) are one to several orders of magnitude lower than those reported previously (Minshall et al. 1973) and fully invalidate the earlier measurements.

Figure 5 shows upstream and downstream values for DOC and FPOC (fine particulate organic carbon) at Substations A (control), B (shaded) and C (black plastic) in 1975. The frequency of sampling, internal consistency of the data and number of sampling sites in the 1975 study have provided a set of curves that can be considered as typical for Deep Creek Station 3. Substation A was sampled again in 1976 and the values, while more erratic, are consistent with those in 1975.

Dissolved organic carbon was similar at all three stations and showed no important variation between up- and downstream locations (Table 6). The pairing design *t*-test was applied to upstream and downstream values for both 1975 and 1976, and there was no statistical difference. Furthermore, although the concentrations varied between sampling dates, there was no seasonal trend. The mean concentrations of DOC and FPOC at Station 3 for 1975 were 1.7 and 1.8 g C/m^3 and for 1976 were 1.5 and 0.7 g C/m^3. Values followed discharge patterns at Stations 2 and 3 but not at Station 1. Particulate matter was highest at Station 1 (mean 3.9-4.2) and lowest at Station 2 (mean 0.5); those at Station 3 were intermediate between the other two. Mean dissolved and particulate levels were quite similar, although dissolved showed a smaller spread than particulate. In other streams in which organic content has been measured, the dissolved fraction is frequently at least twice as high as the particulate portion (Table 7).

Light Manipulation at Deep Creek Station 3

Macrophytes

Coverage of the stream with plastic eliminated all of the light from Section C (black plastic) and 70% of the light from Section B (Table 8). From preliminary tests, a reduction of 83% had been anticipated in the latter. In general, the predicted reductions in plant biomass were obtained (Table 9, Fig. 6), but the apparent initial enhancement of plant growth under the white-covered section was not expected. The only taxa which occurred in regular, measurable amounts were *Potamogeton pectinatus*, *Chara vulgaris* and *Cladophora glomerata*. Of these, *Potamogeton* and *Chara* were the most important in terms of biomass.

Table 6. Dissolved (A) and fine particulate (B) organic carbon (mg/l) in Deep Creek water

A. Dissolved organic carbon

1975	DEEP CREEK STATION					
	1		2		3	
Date	DOC Up	DOC Dn	DOC Up	DOC Dn	DOC A Up	DOC C Dn
18 Jan	1.9	1.4	1.0	1.3	1.5	2.0
16 Feb	1.9	2.0	1.6	1.4	2.4	2.1
15 Mar	1.7	1.7	2.2	2.4	3.1	2.9
18 Apr	2.5	2.5	1.1	1.2	2.0	2.0
23 May	1.8	2.0	0.4	0.6	0.9	1.5
31 May	1.9	1.9	1.1	1.3	2.2	1.7
13 Jun	2.0	2.1	2.0	1.9	1.6	3.1
27 Jun	2.4	2.5	0.6		1.5	1.1
19 Jul			0.5	1.4	1.4	1.7
2 Aug	2.2	1.8	1.2	1.2	1.8	1.6
16 Aug	1.4	1.3	.8	.8	1.6	1.0
30 Aug	2.2	1.5	1.0	1.2	2.1	1.1
14 Sep			0.8	1.0	1.1	0.6
2 Nov			1.0	0.4	1.2	1.4
Mean	2.0	1.9	1.1	1.2	1.7	1.7
S.D.	±0.3	±0.4	±0.5	±0.5	±0.6	±0.7

B. Fine particulate organic carbon

	DEEP CREEK STATION					
	1		2		3	
Date	FPOC Up	FPOC Dn	FPOC Up	FPOC Dn	FPOC A Up	FPOC C Dn
1974						
I 16 Nov	1.0	0.8	0.5	0.5	2.6	2.7
I 19 Dec	2.1	2.3	0.3	0.5	2.5	2.9
1975						
18 Jan	2.4	2.5	0.2	0.3	4.7	5.8
16 Feb	7.4	7.9	0.3	0.3	2.8	3.4
15 Mar	5.4	7.4	0.7	0.8	1.8	1.9
1, 2 & 3 17/19 Apr	6.2	6.3	0.4	0.4	1.9	2.0
22 May			0.5	0.8	2.1	2.6
25 May	5.0	5.3				
31 May	5.6	5.9	0.5	0.5	1.6	1.2
13 Jun	4.1	4.0	0.6	0.6	0.8	1.1
27 Jun	2.6	3.3	0.7	0.6	0.7	0.5
19 Jul			0.8	0.8	0.5	1.5*
2 Aug	4.3	5.5	0.5	0.5	0.6	0.7
16 Aug	3.0	2.4	0.5	0.4	0.5	0.6
30 Aug	1.2	0.9	0.4	0.2	0.3	0.5
14 Sep			0.3	0.2	0.8	1.4
2 Nov			0.3	0.3	0.7	1.2
Mean	3.9	4.2	0.5	0.5	1.6	1.9
S.D.	±2.0	±2.4	±0.2	±0.2	±1.2	±1.4

*Bottle froze and broke.

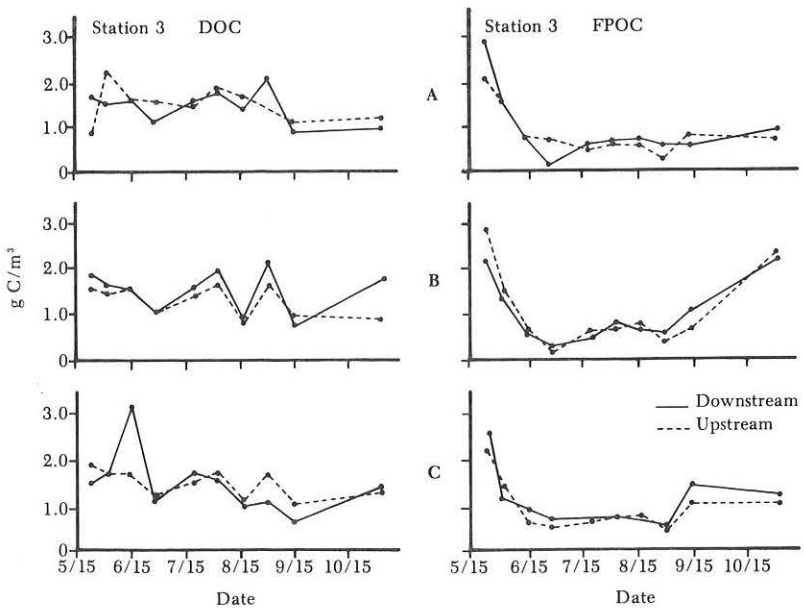

Figure 5. Upstream and downstream concentrations of dissolved organic carbon and fine particulate organic carbon in g C/m³, May through October 1975.

Table 7. The concentration of DOC and the ratio of DOC:FPOC in streams and rivers

DOC g C/m^3	DOC:FPOC	Stream or river	Reference
1 to 7	---	Roaring Creek	McDowell and Fisher (1976)
2 to 3	---	Hubbard Brook	Fisher and Likens (1973)
--	2.3:1	Bear Brook	Fisher and Likens (1973)
2.5 to 12.5	2.65:1	Little Miami River	Weber and Moore (1967)
1 to 24	2:1 to 10:1	Middle Oconee	Nelson and Scott (1962)
3 to 4	2.2:1	Tecopa Bore	Naiman (1976)
1 to 6	3.5:1 to 8:1	Two inlet streams to Lawrence Lake	Wetzel and Otsuki (1974)
.5 to 5	---	Austrian rivers and streams	Einsele (1960)
6 to 8*	---	Woodland streams in Germany	Hüll (1955)
3 to 10*	---	Lowland rivers in USSR	Shadin (1956)
.5 to 3.5	1:1 to 2:1	Deep Creek	This study

*Includes FPOC.

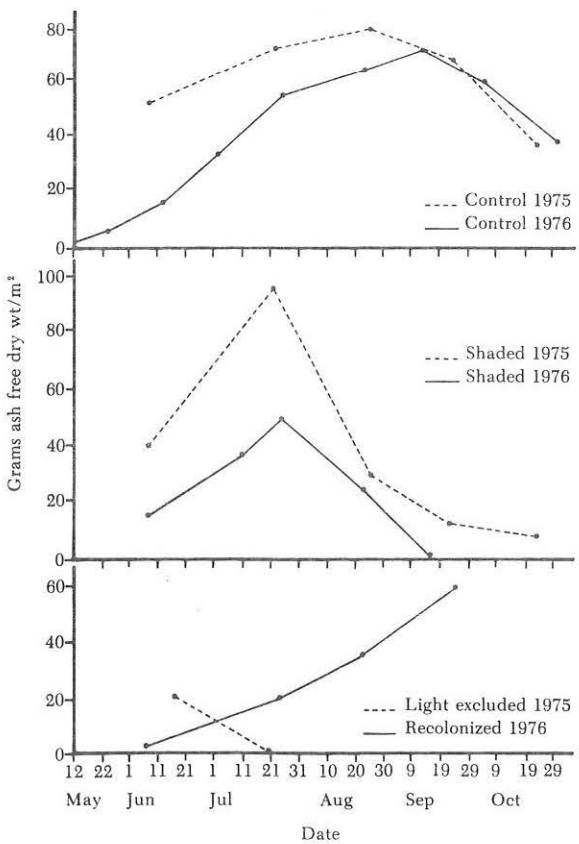

Figure 6. Total macrophyte standing crop in the control and experimental sections, Deep Creek Station 3, 1975 and 1976.

Table 8. Reduction of light brought about by covering Deep Creek Station 3 with white and black plastic. Data were collected July 21, 1975

Time	Place	cal·cm^{-2}·min^{-1}	Ratio	Sky Conditions
0945	Bank beside St. 3 B	0.785	.30	clear
0945	Under white plastic	0.235		clear
1000	Bank beside St. 3 C	0.810		clear
1000	Under black plastic*	0.000		clear
1410	Bank beside St. 3 B	1.345	.24	clear
1410	Under white plastic	.325		clear
1740	Bank beside St. 3 B	.235	.30	overcast
1740	Under white plastic	.075		overcast

*Although several light leaks were noted, they were not enough to register on a pyranometer, or to promote any plant growth.

Table 9. Monthly variations in biomass of macrophytes from the control and shaded sections, and the section covered with black plastic, Deep Creek, 1975. Mean values in g AFDW/m²; M + C = Margin + Channel; ± SE. Plastic was put on shaded and black sections on June 21

Date (1975)	Species	Sampling location	No. of samples	Experimental section: Control	Shaded	Black Plastic
6/17	P. pectinatus	Margin	2	20.2	8.2	21.3
	"	Channel	2	61.8	61.6	14.7
	"	M + C	4	41.0 ± 25.0	34.9 ± 27.7	18.0 ± 12.4
	C. vulgaris	Margin	2	0.1	0.3	0.0
	"	Channel	2	0.0	7.7	1.9
	"	M + C	4	0.0	4.0 ± 2.2	1.0 ± 0.8
	C. glomerata	Margin	2	5.4	1.4	0.0
	"	Channel	2	17.0	0.0	0.8
	"	M + C	4	11.2 ± 5.8	0.6 ± 0.6	0.4 ± 0.4
7/21	P. pectinatus	Margin	2	45.8	81.5	---
	"	Channel	2	58.4	94.5	---
	"	M + C	4	52.1 ± 26.1	88.3 ± 9.2	---
	C. vulgaris	Margin	2	6.8	0.0	---
	"	Channel	2	17.1	14.3	---
	"	M + C	4	12.0 ± 7.3	7.1 ± 6.9	---
	C. glomerata	Margin	2	0.4	0.0	---
	"	Channel	2	16.8	0.8	---
	"	M + C	4	8.6 ± 6.0	0.4 ± 0.4	---
8/26	P. pectinatus	Margin	4	84.4 ± 19.6	28.5 ± 5.1	---
	"	Channel	4	39.4 ± 14.3	27.9 ± 14.0	---
	"	M + C	8	62.2 ± 14.1	28.1 ± 3.6	---
	C. vulgaris	Margin	4	1.3 ± 1.3	1.3 ± 1.3	---
	"	Channel	4	34.6 ± 10.6	7.0 ± 6.4	---
	"	M + C	8	18.0 ± 8.0	4.2 ± 1.5	---
	C. glomerata	Margin	4	0.4 ± 0.4	0.0	---
	"	Channel	4	0.3 ± 0.2	0.0	---
	"	M + C	8	0.3 ± 0.2	0.0	---
9/22	P. pectinatus	Margin	2	37.2	16.8	---
	"	Channel	2	35.9	5.8	---
	"	M + C	4	36.5 ± 9.0	11.3 ± 7.2	---
	C. vulgaris	Margin	2	0.0	0.0	---
	"	Channel	2	62.0	2.8	---
	"	M + C	4	31.0 ± 23.0	0.7 ± 0.7	---
	C. glomerata	Margin	2	0.0	0.0	---
	"	Channel	2	0.9	0.0	---
	"	M + C	4	0.5 ± 0.2	0.0	---
10/22	P. pectinatus	Margin	2	4.5	3.5	---
	"	Channel	2	2.3	2.9	---
	"	M + C	4	3.4 ± 1.9	3.0 ± 0.4	---
	C. vulgaris	Margin	2	0.2	3.2	---
	"	Channel	2	67.8	6.3	---
	"	M + C	4	34.0 ± 19.8	4.7 ± 1.4	---
	C. glomerata	Margin	2	0.3	0.0	---
	"	Channel	2	0.5	0.0	---
	"	M + C	4	0.4 ± 0.3	0.0	---

The water level of the stream was high throughout most of April and May 1975. When it dropped, it was observed that *Potamogeton* shoots were about 15 cm long. By extrapolation, May 15 was taken as the date of the initiation of growth. New flooding in early June delayed the stream manipulation until June 21. Four days prior to the manipulation, samples were taken from the control section and from the sections to be covered with plastic. Some of the shoots of *Potamogeton* were 80 cm long and many terminated in floral spikes. On the initial sampling date the mean biomass of *Potamogeton* in the channel was 61.8 g/m^2 (AFDW) in Section A (control) and 61.6 g/m^2 in Section B (to be covered with white plastic), but only 14.7 in Section C (to be covered with black plastic; Table 9). Although care had been taken to select sections which were very nearly alike in all morphological parameters, Section C was deeper than Sections A and B. It was observed that in the deeper channels of the stream, *Potamogeton* grew less luxuriantly; therefore, the smaller biomass in Section C may be attributed to water depth.

The most obvious result of the stream manipulation was the absence of macrophytes from Station C on the July sampling date, 1 mo after the stream was covered with black plastic. Not only had the vegetation died, but it also had broken loose from the substratum and been swept away. The result was a bare, sandy or silty substratum.

A second noteworthy result was the development of the aquatic plant community in the control section, and the modification of this development in the section covered with white plastic. Prior to manipulation, most of the growth of *Potamogeton* occurred as colonies of vegetation and was more pronounced in the channel. Some of the individual strands of the colonies were over 80 cm long, but many were shorter. The initiation of flowering, which occurred at the apical tip, marked an end to the elaboration of additional internodes. However, new shoots developing from rhizomes, or from the lower internodes of existing shoots, extended the colonies both in thickness and in the area of stream bottom covered. At no time, however, was the entire surface of the stream covered in the control section. Distribution of the vegetation was spotty, with dense colonies randomly scattered over the substratum. The plants closest to the surface were reddish-brown, while the shaded lower shoots were green. By July, the channel colonies of *Potamogeton*-dominated vegetation included *Chara*; by August, *Chara* was codominant with *Potamogeton*. The September samples indicate that, in the channel, *Chara* had become the dominant species. This resulted not only from increased growth of *Chara* but also from sloughing of *Potamogeton*. As *Potamogeton* became more sparse in the channel, it increased in the margin of the stream, and by August the biomass of *Potamogeton* in the margin exceeded that in the channel. Therefore, in the control section of the stream there was a change from a *Potamogeton*-dominated flora, localized primarily in the channel, to *Chara*-dominated colonies, and *Potamogeton* colonies on the margins. These visual observations are supported by data presented in Table 9 and Figure 7.

At the time of the manipulation, the plant community in Section B was comparable to that found in the control section. Colonies of *Potamogeton* contained shoots of varying degrees of maturity. Flower spikes were found at the tips of many strands. One month later, the entire length of Section B, including both the channel and margin, appeared to be covered with a uniform stand of long, thin, delicate strands of *Potamogeton*. The reddish-brown pigments characteristic of the plants of the open stream were not present, and the leaves and stems were bright green. It is doubtful if the size of the colonies at the substratum surface was actually any greater than in the control area. The illusion of luxuriance was probably a result of an elongation of internodes of individual strands, a phenomenon characteristic of plants grown in the shade. The stand was not dense and the adaptation to shade, through internodal and leaf elongation, resulted in a maximum utilization of the reduced light. Although the light reaching the water surface was only 30% of incident

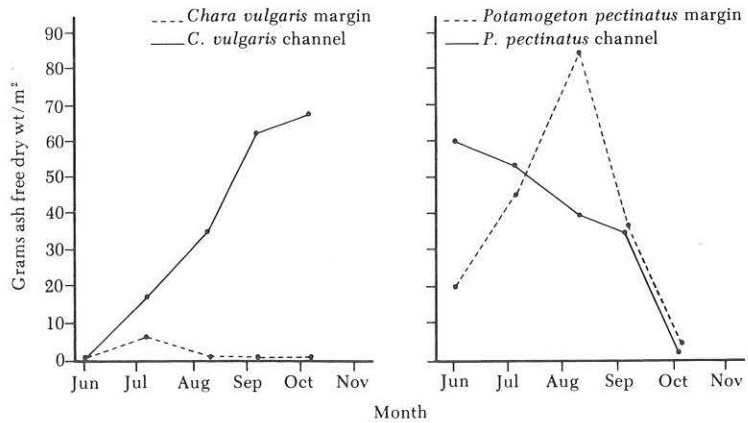

Figure 7. Biomass of *Chara vulgaris* and *Potamogeton pectinatus* in the channel and margin of the control section at Deep Creek Station 3, 1975.

solar radiation, in June and early July this illumination was sufficient for a substantial rate of photosynthesis, and the mean biomass of *Potamogeton* increased from 34.90 g/m² (AFDW) to 88.36 g/m². This increase of 1.6 $g \cdot m^{-2} \cdot day^{-1}$ for the pooled values of margin and channel is significantly greater than the 0.33 $g \cdot m^{-2} \cdot day^{-1}$ increase in the control section.

Although *Chara* was present in the July samples from the shaded section, it was drastically reduced by August and never approached the level of biomass found in the control section. *Potamogeton* also had decreased by August and, although flowering had been initiated prior to the manipulation, fruit failed to mature. Decreasing day length, coupled with shading, reduced the amount of light reaching the plants to a point where photosynthesis was less than the combined losses due to respiration and sloughing. A modified spectral quality imposed by the white plastic may have been responsible for the prevention of fruit development. Also, it has been suggested that intensity of illumination may influence the development of reproductive primordia, with higher intensities permitting higher rates of photosynthesis and thus, the maturation of a greater number of reproductive organs, but there is little evidence to support or refute this suggestion (Sculthorpe 1967).

By August, the total plant biomass in the manipulated section was less than in the control (Table 9; Fig. 6). The total biomass for the channel and margin are pooled. The assumption is made that the margin and channel samples estimate equal parts of the stream surface. The group comparison *t*-test showed that the difference in the mean of biomasses of plants from Sections A and B is highly significant (3.13; $df = 14$; confidence level = 99%).

A portion of the shaded section was covered with white plastic again in 1976 and the same three sections at Station 3 were sampled during the growth season. The section that had been covered with black plastic in 1975 was not covered in 1976, and the recolonization of that section was documented. Figure 8 compares biomass of *Potamogeton* in each of the three sections for the two years. The seasonal changes, as well as the maximum biomass in the control, are approximately the same for the two years. In the shaded section, the absolute amounts are less in 1976 than in 1975, but the time of maximum biomass and the shapes of the curves are similar. *Potamogeton* was not successful in the recolonization section and the maximum biomass, which was achieved in late August, was less than 5 g AFDW/m².

The biomass of *Chara* in 1975 and 1976 in each of the three sections is shown in Figure 9. In each of the two years the biomass was much less in the shaded section than in the control; the highest values, however, were from the recolonized section where *Chara* literally blanketed the stream by late September. The contributions of *Potamogeton*, *Chara* and *Cladophora*, expressed as percentage of macrophyte standing crop, are depicted in Figure 10. It is evident that there is seasonal variation in relative species abundance in the control and in each of the experimental

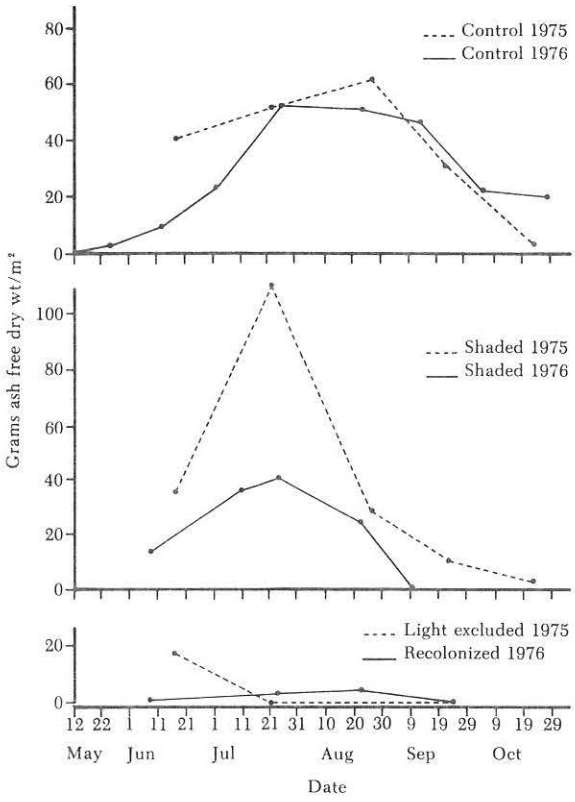

Figure 8. Standing crop of *Potamogeton pectinatus* in the control and experimental sections of Deep Creek Station 3, 1975 and 1976.

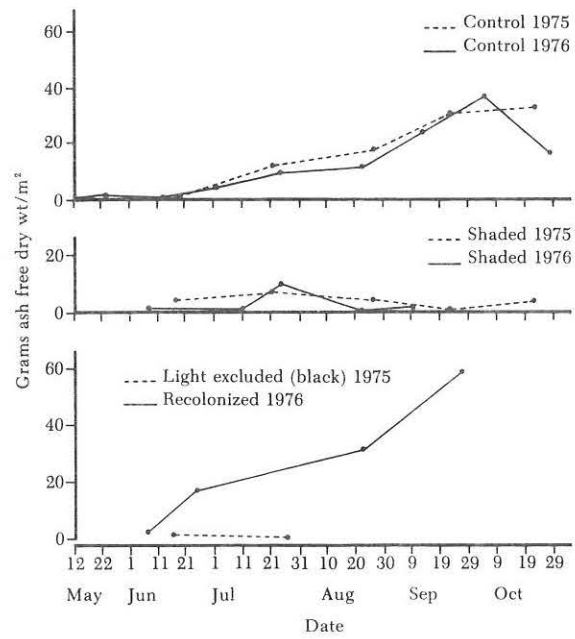

Figure 9. Standing crop of *Chara vulgaris* in the control and experimental sections of Deep Creek Station 3, 1975 and 1976.

sections. Shading favored the growth of *Potamogeton* over *Chara*. In the recolonized section, *Potamogeton* comprised only a small percentage of the total biomass and this fraction was steadily reduced to zero by September.

Periphyton

Chlorophyll *a* concentrations of the periphyton on artificial substrata were determined in 1975 and 1976. Study sections in 1975 included the control, shaded and darkened sections, while the 1976 study was of the control, shaded and recolonized sections. The recolonized section had been covered with black plastic the previous year. Unfortunately, difficulties associated with the spectrophotometer in 1975 caused some of the values for that year to be suspect. The midsummer concentrations (Fig. 11), in particular, appear to be too low.

Sagging of the plastic due to accumulated rain water prevented the recovery of the trays under the black plastic for the August and September 1975 samples. The June samples were taken prior to stream manipulation. Although the chlorophyll *a* estimates for the control section fluctuated, they were consistently higher at any given sampling date following manipulation than the corresponding estimate for the covered sections. The periphyton which colonized this slow-moving section of Deep Creek was largely *Cladophora*, and therefore not readily comparable to the diatom-dominated communities of periphyton characteristic of the faster-moving stretches of the creek.

During 1976 in the control sections, the lowest value (4 mg/m^2) occurred in late June, and the September high of 111 mg/m^2 was followed by a drop in October. The change in chlorophyll *a* concentration in the shaded and the recolonized sections closely paralleled the changes in the control. The correlation coefficient between the control and the shaded is 0.96, and between the control and recolonized is 0.80. The mean values for the control and shaded from May through September are 36.8 and 34.4 mg/m^2, respectively, and the paired *t*-test shows they are not different. In contrast to this, the mean value for the recolonized section from June through October is about 1.5 times that of the control (65 mg/m^2 to 43 mg/m^2), and the paired *t*-test shows them to be different at the 0.50 level.

Productivity of Macrophytes

The influence of shading on macrophyte productivity varied with the species, as shown in Table 10. For this analysis, it was assumed that the growth of *Potamogeton* and *Cladophora* was initiated on May 1 in 1976 but not until May 15 in 1975, for reasons given earlier. Measurable production in *Chara* began about one month later. Productivity was calculated by dividing the maximum biomass by the number of days from the initiation of growth to the date of maximum biomass, with the results expressed as g AFDW$\cdot m^{-2}\cdot day^{-1}$. Productivity is underestimated in these calculations by the amount of material lost or consumed prior to the date of maximum biomass plus any production that occurred after that date.

The productivity of *Potamogeton* in 1975 and 1976 in the control section was 0.57 and 0.54 $g\cdot m^{-2}\cdot day^{-1}$, respectively. In 1975, shading apparently enhanced productivity, resulting in 0.81 $g\cdot m^{-2}\cdot day^{-1}$. In 1976, however, *Potamogeton* productivity was reduced. This possibly was caused by a failure in the production of seeds and/or overwintering stem tubers in 1975, resulting in a reduction in the number of individual plants established in 1976. In both years, maximum biomass occurred at least a month sooner in the shaded section and then was quickly reduced. Therefore, the mean standing crop for the season on the shaded section was less than in the control.

Cladophora reached a maximum biomass early in the season in both the control and the shaded sections. In the control, productivity in 1975 and 1976 was 0.30 and 0.17 $g\cdot m^{-2}\cdot day^{-1}$, respectively, but in the shaded section it was only about 10% of these values. The reduction in *Cladophora* production cannot be attributed to shading because maximum biomass occurred in both the control and the shaded sections prior to the manipulation (Table 10). Although the study sections at Deep Creek were selected for uniformity between sections, the control section is situated just downstream from a riffle area. In May and June, *Cladophora* production in the riffle was high and large clumps of *Cladophora* were imported into the control section when they became established, and were subsequently sampled as a part of the standing crop.

In the control section, *Chara* had a productivity of about half that of *Potamogeton* and, although the growing season for *Chara* was longer, the net production was still much less than that of *Potamogeton*. Shading reduced both the productivity of *Chara* ($g\cdot m^{-2}\cdot day^{-1}$) and the number of days during which production occurred, resulting in a maximum biomass of only about 25% of that of the control.

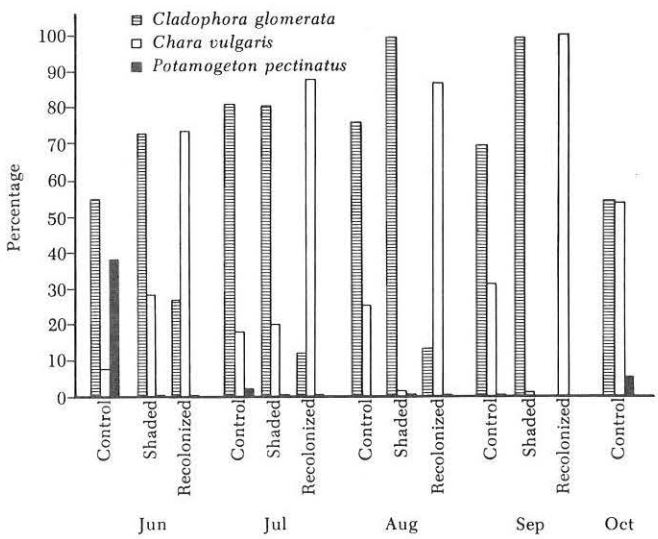

Figure 10. *Potamogeton pectinatus*, *Chara vulgaris* and *Cladophora glomerata* as percentage of total macrophyte biomass in control, shaded and recolonized sections of Station 3.

Table 10. Net productivity and maximum net production of macrophytes at Deep Creek Station 3, 1975 and 1976

Genera	Treatment	Date Growth initiated	Date of Max. Biomass	No. Days to Max. Biomass	Max. Net Production (g/m^2)	Productivity ($g \cdot m^{-2} \cdot day^{-1}$)
Potamogeton	Control	May 11, 1975	Sept. 9, 1975	108	62	.57
Potamogeton	Control	May 1, 1976	Aug. 10, 1976	101	55	.54
Potamogeton	Shaded	May 11, 1975	July 21, 1975	71	88	.81
Potamogeton	Shaded	May 1, 1976	July 24, 1976	95	40	.42
Potamogeton	Black plastic	Max. biomass occurred prior to covering - then production went to zero.				
Potamogeton	Recolonized	May 1, 1976	Aug. 22, 1976	115	45	.04
Chara	Control	June 11, 1975	Oct. 22, 1975	133	34	.26
Chara	Control	June 1, 1976	Oct. 4, 1976	125	37	.30
Chara	Shaded	June 11, 1975	July 21, 1975	40	7	.18
Chara	Shaded	June 1, 1976	July 24, 1976	53	10	.19
Chara	Black plastic	Max. biomass occurred prior to covering - then production went to zero.				
Chara	Recolonized	June 1, 1976	Sept. 26, 1976	117	59	.50
Cladophora	Control	May 11, 1975	June 17, 1975	37	11	.30
Cladophora	Control	May 1, 1976	June 12, 1976	42	7	.17
Cladophora	Shaded	May 11, 1975	June 17, 1975	37	.57*	.02
Cladophora	Shaded	May 1, 1976	July 9, 1976	70	.6	.01
Cladophora	Black plastic	Max. biomass occurred prior to covering - then production went to zero.				
Cladophora	Recolonized	May 1, 1976	Aug. 22, 1976	113	.02	.00

*prior to covering (Cladophora).

As had been anticipated, the exclusion of light in the section covered with black plastic resulted in total removal of plants in 1975. When this 100-m section was recolonized in 1976, *Chara* was the dominant macrophyte. The productivity of *Chara* was 0.59 $g \cdot m^{-2} \cdot day^{-1}$, or 167% that of *Chara* in the control. In contrast, the productivity of *Potamogeton* was only 0.04 $g \cdot m^{-2} \cdot day^{-1}$, and *Cladophora* production was close to zero. Thus, these data show that the influence of light on macrophyte productivity varies with the species and, because of this, total net macrophyte production, as well as relative species composition, is modified.

Benthos and Drift

A comparison of benthic invertebrate standing crops and production at the control site of station 3 in the year of the manipulation (1975) and the years immediately preceding and following it is given in Table 11. None of these data have been reported previously. The taxa are arranged in order of decreasing mean standing crop during 1975. The ten most abundant ($\overline{B}$) taxa in 1975 also were among the top ten in 1976 although not necessarily in the same order of importance; only two of the top ten in 1974 (*Erpobdella, Helobdella*) are missing from the 1975 top ten list. Total mean standing crop was similar in 1974 and 1975 but was

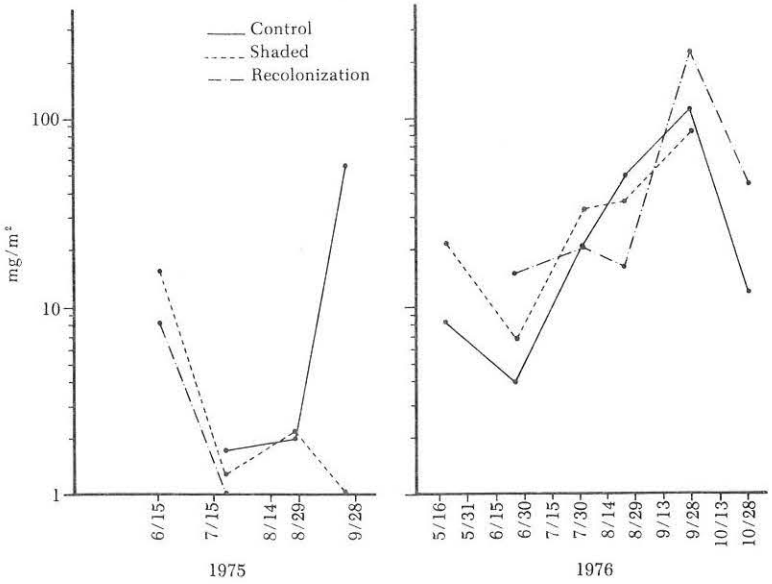

Figure 11. Chlorophyll *a* concentrations, 1975 and 1976.

Table 11. Benthic invertebrate mean standing crop ($\bar{B}$), production (P) (both in mg DW/m²) and turnover rates (T) at Deep Creek station 3 for 1974, 1975 and 1976. For direct comparability the calculations for all three years are based on the same 5 months of data (May-September). The values in parentheses following each taxon are the relative rankings in each year according to biomass

Taxa	1974			1975			1976		
	$\bar{B}$	P	T	$\bar{B}$	P	T	$\bar{B}$	P	T
Flumenicola nuttaliana (1, 1, 1)	1883.84	619.74	0.33	1863.97	717.60	0.38	4958.62	899.35	0.18
Ballagma anna (10, 2, 5)	68.64	80.84	1.18	417.46	177.12	0.42	255.78	119.96	0.47
Gammarus lacustris (2, 3, 2)	1476.48	420.88	0.28	257.12	144.60	0.56	1809.92	791.38	0.44
Physa gyrina (5, 4, 4)	272.91	245.22	0.90	209.01	168.95	0.81	277.71	233.31	0.84
Hyalella azteca (3, 5, 3)	969.22	590.49	0.61	195.74	110.73	0.57	402.45	285.50	0.71
Chironomidae (7, 6, 9)	143.39	98.21	0.68	142.30	107.43	0.75	68.38	56.61	0.83
Dubiraphia giulianii (--, 7, 10)	5.20	1.31	0.25	79.34	54.14	0.68	47.94	27.79	0.58
Hydropsyche occidentalis (6, 8, 6)	220.11	296.48	1.35	68.18	14.63	0.21	132.13	156.73	1.19
Pisidium casertanum (--, 9, 8)	36.48	26.62	0.73	60.86	51.77	0.85	84.88	93.09	1.10
Optioservus divergens (4, 10, 7)	312.64	257.14	0.82	55.65	10.04	0.36	91.12	44.80	0.49
Helobdella elongata (8, --, --)	94.51	74.80	0.79	52.90	71.04	1.34	1.46	3.64	2.50
Argia vivida	---	---	---	39.04	97.60	2.50	---	---	---
Erpobdella punctata	80.64	167.20	2.07	36.37	67.72	1.86	---	---	---
Tricorythodes minutus	30.83	43.51	1.41	30.54	---	---	3.41	5.08	1.49
Baetis tricaudatus	8.27	7.94	0.96	14.74	17.96	1.22	9.22	21.02	2.28
Gyraulus parvus	5.76	1.81	0.31	8.32	3.90	0.47	17.86	---	---
Haliplus immaculicollis	0.72	0.80	1.11	6.72	7.20	1.07	---	---	---
Hydroptila sp.	12.48	19.91	1.59	2.50	4.00	1.60	1.92	2.40	1.25
Ceratopogonidae	3.66	6.44	1.76	2.13	2.56	1.20	---	---	---
Agabus intersectus	---	---	---	1.12	2.80	2.50	---	---	---
Simulium sp.	0.80	0.52	0.65	0.43	0.36	0.83	0.45	1.28	2.86
Hydracarina	5.76	25.52	4.43	0.29	0.72	2.50	0.61	0.76	1.25
Ferrissia sp.	0.24	0.60	2.50	0.24	0.60	2.50	---	---	---
Lymnaea sp.	38.32	36.08	0.94	0.19	0.48	2.50	1.81	4.52	2.50
Limnephilus frijole	---	---	---	0.19	0.24	1.25	---	---	---
Cleptelmis sp.	---	---	---	0.10	0.08	0.83	---	---	---
Brychius sp.	---	---	---	0.02	0.04	2.50	---	---	---
Chewatopsyche analis	6.50	19.80	3.05	---	---	---	12.08	20.24	1.67
Sigara	---	---	---	---	---	---	22.46	136.24	6.06
Callibaetis nigritus	---	---	---	---	---	---	0.46	1.16	2.50
Dytiscidae	24.64	40.00	1.62	---	---	---	---	---	---
Totals	5702.04	3081.86	---	3545.47	1834.31	---	8200.67	2904.86	---

nearly a third higher in 1976. In contrast, total production was considerably lower in 1975 than in 1974 or 1976.

Shading and darkening the stream had pronounced effect on the benthic invertebrates. Most taxa decreased in amount in both treatment sections from that found in the control (Table 12). A couple (*Flumenicola*, *Cleptelmis*) decreased in the shaded section relative to the control but increased in the darkened section. *Hyalella azteca* and Hydracarina increased in the shaded section over that of the control but decreased in the darkened section relative to both the control and shaded sections. Only *Simulium* showed a progressive increase with decreasing light conditions.

The April, May and June drift samples were taken before the manipulation of the stream and showed no significant difference between the control and experimental sites (Table 13). However, as shown by samples collected during the final four months, reduction of light had a marked effect on the amounts of plants and animals exported from the two experimental sections. The effect was most pronounced at the peak of the growing season; by October, when ambient light levels began to decline as a result of normal seasonal trends, the differences between the sites became less distinct. Both plant and animal abundances in the drift were reduced as a result of the manipulation. Presumably the decreased light levels reduced the amount of plant material available for export and this reduction of food and substratum for the invertebrates in turn decreased the numbers of animals entering the drift.

Storage

Most of the organic matter produced by aquatic macrophytes is converted to detritus before being utilized. Part of this material is exported from its site of production by the current. The remainder becomes incorporated into the sediments where it is stored prior to consumption or decomposition. No difference in the amount of detritus in the top 5 cm of the sediments was found between the three study sections during 1975. This probably was due to the large amount of material that has accumulated since the construction of Curlew Reservoir in the 1920's. Therefore, even though there may have been some loss of detritus from Section C due to the removal of the vegetative shield, it was not sufficient to be detected. Samples collected throughout the 1976 study period gave mean values of 172 g AFDW/m² for the control, 191 g for the shaded and 141 g for the recolonized (formerly blackened) sections. These values may be compared with a mean of 250.74 g AFDW/m² ($\pm$97.3) collected from the control section in October 1975. However, the values for the three sites are not significantly different. The detrital content of the sediments was relatively constant during the period of active plant growth, but seemed to increase in the late summer-early autumn as the plants began to die off (Table 14). On any given date the absolute amounts of detritus generally were greater than the macrophyte standing crops.

Transport

There was no discernible difference in the amount of dissolved and particulate organic matter in the water

Table 12. Mean standing crop ($\bar{B}$), production (P) in mg DW/m² and turnover rate (T) of selected benthic invertebrates at Station 3 during the 1975 study period (5 mo). The values in parentheses following each taxon are the relative rankings for each treatment according to biomass

Taxa	Control			Shaded			Dark		
	$\bar{B}$	P	T	$\bar{B}$	P	T	$\bar{B}$	P	T
Fluvenicola nuttaliana (1, 1, 1)	1863.97	717.60	0.38	1791.17	586.70	0.33	1912.03	967.31	0.51
Enallagma anna (2, 2, 4)	417.46	177.12	0.42	337.42	184.39	0.55	63.92	73.52	1.15
Gammarus lacustris (3, 7, 7)	257.12	144.60	0.56	56.00	51.20	0.91	19.20	30.80	1.60
Physa gyrina (4, 6, 5)	209.01	168.95	0.81	56.88	68.60	1.21	30.50	28.48	0.93
Hyalella azteca (5, 3, 2)	195.74	110.73	0.57	229.78	130.33	0.57	141.14	166.73	1.18
Chironomidae (6, 4, 3)	142.30	107.43	0.75	130.43	80.47	0.62	99.98	100.49	1.00
Dubiraphia giulianii (7, 5, 8)	79.34	54.14	0.68	75.12	71.53	0.95	18.11	21.74	1.20
Hydropsyche occidentalis (8, 8, --)	68.18	14.63	0.21	36.54	91.36	2.50	2.72	6.80	2.50
Pisidium casertanum (9, 9, 9)	60.86	51.77	0.85	33.42	29.52	0.88	17.12	28.44	1.66
Optioservus divergens (10, --, 10)	55.65	10.04	0.36	0.70	1.76	2.50	8.06	19.84	2.46
Helobdella elongata	52.90	71.04	1.34	2.91	7.28	2.50	---	---	---
Argia vivida	39.04	97.60	2.50	---	---	---	---	---	---
Erpobdella punctata (--, --, 6)	36.37	67.72	1.86	2.56	6.40	2.50	28.80	72.00	2.50
Tricorythodes minutus (--, 10, --)	30.54	---	---	8.91	13.76	1.54	1.49	2.26	1.52
Baetis tricaudatus	14.74	17.96	1.22	5.41	3.92	0.72	5.79	8.18	1.41
Cyraulus parvus	8.32	3.90	0.47	5.71	6.97	1.22	1.58	0.0	0.0
Haliplus immaculicollis	6.72	7.20	1.07	---	---	---	0.32	0.80	2.50
Hydroptila sp.	2.50	4.00	1.60	1.62	3.58	2.22	---	---	---
Ceratopogonidae	2.13	2.56	1.20	1.74	2.68	1.54	1.63	2.83	1.73
Agabus intersectus	1.12	2.80	2.50	---	---	---	0.16	0.40	2.50
Simulium sp.	0.43	0.36	0.83	1.97	5.08	2.58	6.02	11.14	1.85
Hydracarina	0.29	0.72	2.50	1.07	2.20	2.05	---	---	---
Ferrissia sp.	0.24	0.60	2.50	---	---	---	---	---	---
Lymnaea sp.	0.19	0.48	2.50	---	---	---	---	---	---
Limnephilus fridgle	0.19	0.24	1.25	---	---	---	---	---	---
Cleptelmis sp.	0.10	0.08	0.83	---	---	---	---	---	---
Brychius sp.	0.02	0.04	2.50	---	---	---	---	---	---
Dytiscidae	---	---	---	0.24	0.60	2.50	---	---	---
Chematopsyche analis	---	---	---	---	---	---	3.38	9.44	2.80
Totals	3545.47	1834.31	---	2779.60	1348.33	---	2362.24	1551.56	---

Table 13. Invertebrate numbers and biomass (DW) and plant biomass per m³ drifting into (U) and out of (D) each study site (A = control, B = white plastic, C = black plastic) during 1975. Manipulation of the stream occurred after the June set of samples was collected

Taxon	Site	CONTROL						EXPERIMENTAL							
		April		May		June		July		August		September		October	
		U	D	U	D	U	D	U	D	U	D	U	D	U	D
Chironomidae	A	1.21	2.13	1.49	1.39	4.72	9.55	4.77	9.32	1.25	0.56	0.74	1.00	1.24	0.72
	B	2.13	0.88	1.39	0.51	9.55	3.46	9.32	2.49	0.74	0.97	0.74	0.58	0.77	0.64
	C	0.88	2.42	1.36	1.53	8.87	9.52	4.83	1.31	1.68	0.71	0.84	0.79	0.56	1.08
Hyalella azteca	A	0.40	0.45	0.12	0.06	0.10	0.34	1.09	1.46	0.22	0.26	0.70	0.68	0.10	0.17
	B	0.45	0.26	0.06	0.08	0.34	0.09	1.46	0.27	0.06	0.09	0.37	0.0	0.09	0.10
	C	0.26	0.37	0.07	0.36	0.54	0.37	2.30	0.23	0.13	0.23	0.05	0.13	0.04	0.19
Baetis tricaudatus	A	0.0	0.03	0.04	0.0	0.12	0.0	0.04	0.05	0.0	0.04	0.35	0.15	0.0	0.0
	B	0.03	0.02	0.0	0.0	0.0	0.06	0.05	0.05	0.0	0.05	0.12	0.0	0.04	0.0
	C	0.02	0.0	0.04	0.12	0.29	0.15	0.04	0.0	0.0	0.0	0.05	0.0	0.0	0.0
Simulium argus	A	0.02	0.03	0.0	0.0	0.12	0.15	0.0	0.09	0.0	0.0	0.0	0.04	0.10	0.05
	B	0.03	0.0	0.0	0.0	0.15	0.03	0.09	0.0	0.0	0.0	0.03	0.07	0.08	0.04
	C	0.0	0.06	0.04	0.09	0.0	0.0	0.0	0.0	0.0	0.0	0.11	0.0	0.0	0.0
Dubiraphia giulianii	A	0.0	0.0	0.04	0.0	0.07	0.0	0.0	0.08	0.0	0.04	0.06	0.0	0.07	0.06
	B	0.0	0.0	0.0	0.0	0.0	0.06	0.08	0.0	0.0	0.0	0.0	0.05	0.0	0.06
	C	0.0	0.0	0.0	0.0	0.10	0.47	0.29	0.04	0.0	0.0	0.0	0.0	0.0	0.0
Total number	A	2.32	3.52	2.05	2.15	5.48	10.44	7.47	12.09	2.23	1.32	3.25	3.05	2.85	1.75
	B	3.52	1.43	2.15	1.16	10.44	4.41	12.09	2.97	1.03	1.27	2.22	1.57	1.59	1.41
	C	1.43	3.02	1.84	2.62	11.26	11.41	8.63	1.74	2.82	0.94	1.76	2.67	0.99	1.59
Total weight (mg)	A	1.46	3.53	0.24	0.25	0.46	1.01	1.25	1.41	0.37	0.14	1.26	0.93	0.86	0.41
	B	3.53	0.65	0.25	0.06	1.01	0.68	1.41	0.22	0.42	0.16	0.28	0.82	0.19	0.51
	C	0.65	0.58	0.12	0.23	1.50	2.57	2.99	0.21	0.37	0.09	1.52	0.43	0.10	0.27
Aquatic plants (mg)	A	2.89	6.11	2.26	1.07	1.74	2.08	3.56	2.38	0.63	1.58	0.28	0.43	1.65	0.84
	B	6.11	5.08	1.07	1.10	2.08	0.79	2.38	0.27	0.08	0.13	0.40	0.28	0.69	0.83
	C	5.08	8.44	1.25	1.74	3.04	1.92	2.34	0.31	0.35	0.44	0.68	0.92	0.65	1.91
Terrestrial	xxxx	xx			xx				xx				xx		xxx
Terrestrial plants (mg)	A	0.0	0.0	0.0	0.0	0.0	0.0	0.16	0.09	0.07	0.03	0.0	0.04	0.31	0.19
	B	0.0	0.0	0.0	0.0	0.0	0.0	0.09	0.0	0.07	0.19	0.04	0.0	0.21	0.47
	C	0.0	0.0	0.0	0.0	0.0	0.22	0.22	0.0	0.12	0.27	0.0	0.0	0.18	0.54

Table 14. Storage of detrital organic matter in the sediments (g AFDW/m²) of 5 cm in Deep Creek during 1976

Date (1976)	Control		Shaded		Recolonized	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
May 12	105.5	± 132.2				
May 23	153.9	± 176.5				
June 12	190.0	± 323.0	185.0	± 242.0	129.9	± 86.2
July 1	197.6	± 78.6	37.5	± 19.7		
July 24	115.4		50.4	± 41.2	105.4	± 74.1
Aug. 22	181.0	± 109.9	278.6	± 110.1	168.2	± 162.8
Sept. 12	134.4	± 89.9	405.0	± 249.0	155.8	± 81.0
Oct. 4	269.0	± 108.9				
Oct. 27	208.2	± 30.0				
Mean	172		191		141	

column entering or leaving any study section (Table 15). Furthermore, there was no tendency for the amounts to increase downstream in response to the effects of the manipulation. This is contrary to what was expected since it was thought that removal of the vegetative shield would permit increased erosion. But this conclusion tends to be supported by the data for storage.

Fish

A greater percentage of fish was trapped under the white plastic than under either the control or black plastic (Table 16). Two to five times as many fish were trapped in the control section as in the black plastic section. Two to three times as many fish were caught in the shaded section as in the control.

A decrease in number of fish trapped from June to July may be due to normal mortality rates. The speckled dace spawned around the last week of June 1975. The increase in total numbers for August is due to the appearance of Utah chub in that section of the stream, probably to spawn although the largest chub trapped was only 62 mm long. There may have been immature chub mixed in with the dace in the June and July samples which were not distinguished from the larger dace. Larger numbers found in the white plastic section probably are due to the plastic shading the stream to some degree, but still allowing plant growth and the persistence of food (invertebrates). Under the black plastic almost no plant growth occurred, and few invertebrates or fish were found there.

The population of the western speckled dace, *Rhinichthys osculus*, was estimated for the control and the recolonized sections in 1976. (The small size of the shaded area in 1976, coupled with the mobility of the fish, precluded taking a meaningful sample from that section). The purpose of the study was to compare the population estimates for late summer 1976 with those for 1970 and to determine if there was a difference in the number of fish in the recolonized section, compared to the control.

In earlier investigations at Deep Creek, fish were collected by electrofishing. However, during the late summer months, a heavy growth of aquatic vegetation impeded the collection of fish (Minshall et al. 1973). It was determined that minnow traps were more effective; therefore, they were used in the 1976 study.

The August estimates are 1.2 and 2.2 fish/m², and the true value probably lies between these two (Table 17). On August 20 the marked fish were released adjacent to the

Table 15. Dissolved (A) and particulate (B) organic carbon (mg/l) entering and leaving each study section of Deep Creek Station 3

A. Dissolved

Date (1975)	Control up	Control dn	Shaded up	Shaded dn	Dark up	Dark dn
23 May	0.9	1.6	1.6	1.9	1.9	1.5
31 May	2.2	1.5	1.5	1.7	1.7	1.7
13 Jun	1.6	1.6	1.6	1.6	1.7	3.1
27 Jun	1.5	1.1	1.1	1.1	1.2	1.1
19 Jul	1.7	1.5	1.5	1.6	1.5	1.7
2 Aug	1.8	1.7	1.7	2.0	1.7	1.6
16 Aug	1.6	1.4	0.9	1.0	1.1	1.0
30 Aug	2.1	2.1	1.7	2.2	1.7	1.1
14 Sept	1.1	0.9	1.0	0.8	1.0	0.6
2 Nov	1.2	1.0	1.0	2.0	1.3	1.4
Mean	1.6	1.5	1.4	1.6	1.5	1.5
S.D.	±0.4	±0.4	±0.3	±0.5	±0.3	±0.7

B. Particulate

Date (1975)	Control up	Control dn	Shaded up	Shaded dn	Dark up	Dark dn
22 May	2.1	2.9	2.9	2.2	2.2	2.6
31 May	1.6	1.6	1.6	1.4	1.4	1.2
13 Jun	0.8	0.7	0.7	0.6	0.6	0.9
27 Jun	0.7	0.2	0.2	0.3	0.5	0.5
19 Jul	0.5	0.6	0.6	0.5	0.6	-
2 Aug	0.6	0.7	0.7	0.8	0.7	0.7
16 Aug	0.6	0.7	0.8	0.7	0.6	0.6
30 Aug	0.3	0.6	0.6	0.6	0.4	0.5
14 Sept	0.8	0.6	0.7	1.1	1.0	1.4
2 Nov	0.7	0.9	2.4	2.2	1.0	1.2
Mean	0.9	1.0	1.1	1.1	0.9	1.1
S.D.	±0.6	±0.8	±0.9	±0.7	±0.6	±0.7

Table 16. Number (A) and percentage (B) of fishes trapped under three light conditions and times of summer. Numbers in parentheses are those caught in each of three traps set in each section

A. Number

Date (1975)	Control	White Sheet	Black Sheet	Total
June 27	15 (7-4-4)	42 (12-14-16)	4 (0-1-3)	61
July 19	12 (4-5-3)	22 (6-8-8)	5 (1-2-2)	39
August	*11 (5-3-3)	*31 (12-11-8)	*2 (2-0-0)	44
	**11 (3-1-7)	**40 (9-16-15)	**6 (2-3-1)	57

* Daytime-approx. 1100 hr.
** Nighttime-approx. 0400 hr.

B. Percentage

Date (1975)	Control	White Sheet	Black Sheet
June	24.6%	68.9%	6.5%
July	30.8%	56.4%	12.8%
August	25%	70.4%	4.6%
	19.3%	70.2%	10.5%

Table 17. Estimation of the population of *Rhinichthys osculus* in the control section at Station 3, 1976

Date (1976)	Number of marked fish in section	Catch		Marked fish not caught	Marked fish released	Population estimate	
		marked	unmarked			200-m section	fish/m²
Aug 20	0	0	200	0	200	---	---
Aug 21	200	106	252	94	358	675	1.2
Aug 22	452	146	266	306	0	1276	2.2
Sep 6	306	98	194	208	0	1099	1.9

Table 18. *Rhinichthys osculus* caught in minnow traps in the control and recolonized sections and above the control at Deep Creek Station 3, September 1976

Sample Location		Caught with marks	Caught without marks	Total Catch	Ratio of marked fish to total fish
Control Section	1	4	12	16	.25
	2	24	52	76	.32
	3	16	64	80	120
	4	18	28	46	.39
	5	27	89	116	.23
	6	9	9	18	.50
Mean		12.8 ± 11.4 (SD)	40.5 ± 33.9	58.7 ± 39.2	.32 ± .11
Above Control					
	1	2	20	22	.09
	2	0	2	2	.00
	3	1	18	19	.05
Mean		1 ± 1	13.3 ± 9.9	14.0 ± 10.8	.05 ± .05
Recolonized					
	1	5	64	69	.07
	2	3	59	62	.07
	3	0	3	3	.05
Mean		2.7 ± 2.5	42.0 ± 33.9	44.7 ± 36.2	.06 ± .01

traps, and this possibly resulted in a concentration of marked fish, causing an underestimation of the population. The fish released on August 21 were evenly distributed within the control section, thus reducing the possibility of the error of concentration. By August 22 there may have been a dilution of marker through losses from emigration and/or death. This would cause an overestimation of the population. The mean of the two values, 1.7 fish/m², compares favorably with the July-August 1970 estimate of 1.9 fish/m².

The fish collected on August 22 were not returned to the stream and, therefore, the total number of marked fish, excluding losses, was 306. The population estimate for September, based on this number, and the recapture, is 1.9 fish/m². This number probably overestimates the August population since there was a dilution of marker. The presence of marked fish in the traps 75 m above and 200 m below the control section (Table 18) confirms the fact that emigration did occur. There were 15% fewer fish caught in September and approximately 90% fewer in October compared to August. These data support previous findings (Minshall et al. 1973) that the fish leave the main stream in the late fall.

Table 18 gives the number of marked and unmarked fish caught in traps in the control and recolonized sections in September 1976. There was no statistical difference in the number of fish between sections. However, the mean number of fish in the three traps in the recolonized section was 44.7, compared with a mean of 58.7 for six traps in the control. This difference of 31% suggests a habitat preference, which could possibly have been confirmed statistically with a larger sample size. At the time this sample was taken, the organic content of the living plants was about equal between the two sections, and the main differences were in species composition, with the recolonized section having a much greater percentage of *Chara* than the control.

NH_4NO_3 Addition Experiment

Morphometric parameters of both channels used in the NH_4NO_3 addition experiment were fairly similar (Table 19). Chemical parameters monitored in both channels remained fairly constant throughout the experiment (Table 20). No consistent variation could be detected between upstream and downstream samples (Table 5). However, some diel variation did occur. Total alkalinity and hardness values were higher at midnight than at midday in both channels on all sampling dates except the first, and all ammonium values recorded in the control channel occurred at midday. The addition of NH_4NO_3 did not cause any significant change in any chemical parameters measured except nitrate and ammonium. Phosphate concentrations were slightly higher in the experimental channel, but the difference was extremely small. The mean amount of NH_4^+ plus NO_3^- nitrogen was 5.57 mg/l in the experimental channel, while that of the control channel was 0.33 mg/l.

Table 19. Morphometric parameters of control and experimental areas

Parameter	Control Channel	NH_4NO_3 Addition Channel	Control Section	PO_4^{--} Addition Section	PO_4^{--} + NH_4NO_3 Addition Section
Length	26 m	26 m	15 m	15 m	15 m
$\bar{X}$ Width	1.4 m	1.4 m	2.9 m	3.1 m	3.0 m
$\bar{X}$ Depth	9.3 cm	10.6 cm	16.1 cm	16.5 cm	15.3 cm
Surface Area	36.4 m^2	36.4 m^2	43.5 m^2	46.5 m^2	45.0 m^2
Volume	3.4 m^3	3.9 m^3	7.0 m^3	7.7 m^3	6.9 m^3
Flow Time	5 min	5 min	5 min	5 min	5 min

Table 20. Range and mean of water chemistry parameters during NO_3 and PO_4-NO_3 addition experiments, Deep Creek Station 2. All values are in mg/l

		Total Alkalinity	Hardness	NO_3-N	NH_3-N	PO_4-P
NO_3 Experiment						
Control	Min.	208	240	0.18	0	0.03
Channel	Max.	228	259	0.44	0.32	0.08
n = 20	Mean	221	251	0.26	0.07	0.05
NO_3	Min.	209	242	1.45	0.89	0.04
Channel	Max.	250	261	4.71	3.57	0.12
n = 20	Mean	222	252	3.38	2.19	0.07
NO_3-PO_4 Experiment						
Control	Min.	203	229	0.18	0.45	0.04
Section	Max.	225	257	0.37	1.19	0.07
n = 12	Mean	217	246	0.26	0.73	0.05
PO_4	Min.	212	233	0.22	0.27	1.24
Section	Max.	227	268	0.31	0.85	4.03
n = 12	Mean	221	255	0.26	0.57	2.49
NO_3-PO_4	Min.	212	233	2.60	1.69	1.12
Section	Max.	227	274	6.25	8.36	3.97
n = 12	Mean	221	257	4.41	4.19	2.62

Biomass of *Cladophora glomerata* per m^2 was nearly equal in both channels on the first two sampling dates. However, on the third through fifth sampling dates the biomass of *Cladophora* in the experimental channel became greater than that in the control channel (Table 21). Benthic chlorophyll *a* and the phaeo-pigments very roughly show the same pattern of variation. But the differences between control and experimental channels are less clear except for the significantly higher concentrations of phaeo-pigments occurring on all sampling dates in the experimental channel.

Differences in organic matter content and chlorophyll *a* content of *Cladophora* in the control and experimental channels were not large (Table 22). Surprisingly, the organic matter content of *Cladophora* in the experimental channel remained lower and much more stable than that of *Cladophora* in the control channel. Chlorophyll *a* as percentage of organic matter and ODW of *Cladophora* increased throughout the experiment in the experimental channel and became higher than that of *Cladophora* in the control channel which peaked, then decreased.

PO_4 and PO_4 plus NH_4NO_3 Addition Experiments

Morphometric parameters of the three 15-m sections used in the study were similar, with the $PO_4^{=}$ plus NH_4NO_3 showing slightly increased current velocities and shallowness over the other sections (Table 19). Total alkalinity, for one sample, and hardness were always higher at noon than at midnight, which was opposite the findings during the NH_4NO_3 addition experiment. Addition of the phosphate fertilizer caused a slight increase in total alkalinity and a more significant increase in water hardness. In the control and $PO_4^{=}$ addition sections, NO_3^{-} concentrations at noon were always higher than or equal to the midnight values. Ammonium concentrations, unlike those found during the NH_4NO_3 addition experiment, showed no consistent diurnal variation, but always showed reduced concentrations in the $PO_4^{=}$ addition section. The mean amount of phosphate phosphorus was 0.05, 2.49 and 2.62 mg/l in the control, $PO_4^{=}$ addition and $PO_4^{=}$ plus NH_4NO_3 addition sections, respectively. The mean amount of NH_4^{+} plus NO_3^{-} nitrogen was 0.99, 0.83 and 8.60 mg/l in the control, $PO_4^{=}$ addition and $PO_4^{=}$ plus NH_4NO_3 addition sections, respectively.

Table 21. Mean amounts of *Cladophora*, chlorophyll *a* and phaeo-pigments per m^2 in control and NH_4NO_3 addition channels

	Day					
	1	3	5	7	9	$\bar{X}$
Biomass of Cladophora (g ODW/m^2)						
Control	73.9	75.4	115.2	116.7	127.5	101.7
NH_4NO_3	69.5	74.6	122.5	143.5	144.9	111.0
Benthic chl *a* (mg/m^2)						
Control	--	16.70	29.91	18.29	33.01	19.58
NH_4NO_3	--	19.11	36.24	28.36	21.75	21.09
Phaoe-pigments (mg/m^2)						
Control	--	41.98	50.21	33.89	36.42	32.50
NH_4NO_3	--	49.87	66.66	41.10	50.78	41.68

Table 22. Chlorophyll *a* and organic matter content of *Cladophora* sampled from the control and NH_4NO_3 addition channels

	Day					
	1	3	5	7	9	$\bar{X}$
AFDW or % of ODW						
Control	49.3	56.7	55.4	58.3	55.6	55.1
NH_4NO_3	46.6	46.8	47.2	52.2	52.9	49.1
Chl *a* or % of ODW						
Control	0.24	0.29	0.30	0.29	0.26	0.28
NH_4NO_3	0.23	0.27	0.28	0.32	0.33	0.29
Chl *a* or % of AFDW						
Control	0.49	0.51	0.54	0.50	0.47	0.50
NH_4NO_3	0.50	0.58	0.60	0.61	0.63	0.58

Biomass of *Cladophora glomerata* per m^2 was nearly equal in all three sections on the first two sampling dates (Table 23). On the third sampling date, biomass of *Cladophora* in the $PO_4^{=}$ addition and $PO_4^{=}$ plus NH_4NO_3 addition sections showed increases over biomass occurring in the control section. On the last three sampling dates,

Table 23. Comparison of standing crops of *Cladophora glomerata*, *Spirogyra* sp., benthic chlorophyll *a* and phaeo-pigments in the control, PO_4 addition and NH_4NO_3 addition sections at Deep Creek Station 2

	Day						
	1	3	5	7	9	11	$\bar{X}$
Biomass of Cladophora glomerata g ODW/m²							
Control	36.4	23.4	29.9	92.4	112.0	118.3	68.7
PO_4	30.4	30.4	37.4	23.9	31.0	22.5	29.3
$PO_4 + NH_4NO_3$	34.8	28.8	49.5	58.2	20.7	15.7	34.6
Biomass of Spirogyra sp. g ODW/m²							
Control	0	0	0	6.0	14.2	2.0	3.7
PO_4	0	0	19.0	62.0	70.7	16.9	28.1
$PO_4 + NH_4NO_3$	0	0	18.5	47.3	77.7	18.8	27.1
Benthic chl a mg/m²							
Control	18.22	23.04	26.09	31.39	24.52	27.26	25.09
PO_4	23.78	24.44	31.48	33.35	26.87	29.52	28.24
$PO_4 + NH_4NO_3$	28.35	33.91	39.78	45.61	40.30	34.74	37.1
Phaeo-pigments mg/m²							
Control	65.48	69.52	51.44	33.96	34.35	34.91	48.28
PO_4	62.13	65.48	43.83	38.04	49.87	54.09	52.24
$PO_4 + NH_4NO_3$	54.75	59.26	39.57	22.78	36.78	43.13	42.71

Spirogyra sp. became dominant in the $PO_4^{=}$ addition and $PO_4^{=}$ plus NH_4NO_3 addition sections, and the standing crop biomass of *Cladophora* in these sections dropped drastically. The standing crop biomass of *Cladophora* continued to increase in the control section. The greatly reduced amounts of *Cladophora* and *Spirogyra* sp. in the $PO_4^{=}$ addition and $PO_4^{=}$ plus NH_4NO_3 addition sections on the last sampling date were a result of deterioration of the *Cladophora* mats and increased discharge from several intensive thunderstorms, which caused the export of large mats of *Cladophora* and *Spirogyra* sp. Export of *Cladophora* from the control section increased only slightly.

Benthic chlorophyll *a* concentrations increased in all three sections over the first four sampling dates and then showed decreases on the last two dates, probably as a result of scouring from increased discharge. The amount of benthic chlorophyll *a* per m^2 in the $PO_4^{=}$ addition section was higher than that of the control section, while benthic chlorophyll *a* concentrations in the $PO_4^{=}$ plus NH_4NO_3 addition section were highest (Table 23). Phaeo-pigment concentrations generally showed a pattern of variation opposite those of the chlorophyll *a* concentrations.

Unlike the results of the NH_4NO_3 addition experiment, differences in organic matter content and chlorophyll *a* content of *Cladophora* in control, $PO_4^{=}$ and $PO_4^{=}$ plus NH_4NO_3 addition sections were large and consistent (Table 24). Organic matter content of *Cladophora* increased from

Table 24. Chlorophyll *a* and organic matter content of *Cladophora* sampled from control, $PO_4^{=}$ addition and $PO_4^{=}$ plus NH_4NO_3 addition sections

	Day						
	1	3	5	7	9	11	$\bar{X}$
AFDW or % of ODW							
Control	60.1	58.4	60.7	43.6	40.2	48.0	51.8
PO_4	62.2	53.6	62.9	56.4	55.2	56.9	57.9
$PO_4 + NH_4NO_3$	62.7	58.1	65.6	61.2	62.7	63.3	62.3
Chl a or % of ODW							
Control	0.36	0.30	0.28	0.07	0.11	0.15	0.21
PO_4	0.36	0.34	0.44	0.19	0.24	0.27	0.31
$PO_4 + NH_4NO_3$	0.38	0.43	0.79	0.53	0.74	0.76	0.61
Chl a or % of AFDW							
Control	0.59	0.52	0.46	0.16	0.27	0.31	0.39
PO_4	0.60	0.64	0.70	0.33	0.44	0.48	0.53
$PO_4 + NH_4NO_3$	0.60	0.74	1.21	0.86	1.18	1.21	0.97

the control section to the $PO_4^{=}$ addition section and $PO_4^{=}$ plus NH_4NO_3 addition section. The differences in organic matter content were consistent but not extremely large. Chlorophyll *a* as percentage of organic matter and ODW of *Cladophora* showed an increase from the $PO_4^{=}$ addition section over that of *Cladophora* from the control section. But the increase in chlorophyll *a* as percentage of organic matter and ODW of *Cladophora* sampled in the $PO_4^{=}$ plus NH_4NO_3 addition is dramatic, nearly twice that of *Cladophora* sampled in the control section.

Cladophora glomerata *Detritus*

The standing crop of fine particle detritus per gram ODW of *Cladophora* was reasonably constant, but the amount of fine particle detritus that was measured as settling from *Cladophora* showed large variations (Table 25). The percent organic matter of the deposited component also was much smaller, indicating a much higher inorganic fraction. Only 0.21 g of *Cladophora* (ODW) per 100 g *Cladophora* per day was exported as small filaments.

Sediment Dynamics

Organically rich sediment is a conspicuous feature at Deep Creek Station 3. About 90% of the stream bed is blanketed with a loosely consolidated mixture of organic and inorganic material that responds readily to compression, releasing entrapped methane and hydrogen sulfide. While loose sediments are characteristic of the stream in general, they are especially noticeable on the inside of meanders, in developing point bars. It is not uncommon, when sampling these places, to sink up to 50 cm in muck. The muck consists of the remains of aquatic macrophytes which have sloughed off or died and become entrapped in the sediments. In 1976 a series of measurements was undertaken to determine the extent and composition of the sediments and to estimate their contributions to stream metabolism.

Table 25. Fine particle detritus data for the *Cladophora* community

Sample & No.		Standing Crop Fine Part. Det. (gODW/gODW Clad.)	Export (settle) Fine Part. Det. (g ODW ·g ODW Clad.$^{-1}$·day^{-1})	Export (Cladophora) Downstream (g ODW ·g ODW Clad.$^{-1}$·day^{-1})	Standing Crop Fine Part. Det. (% AFDW)	Export (settle) Fine Part. Det. (% AFDW)
1	n = 3	0.100	0.413	0.08	34.00	11.01
2	n = 3	0.140	0.148	0.15	27.41	12.61
3	n = 3	0.141	1.006	0.21	31.42	9.79
4	n = 3	0.103	0.114	0.06	21.64	13.94
5	n = 3	0.150	0.794	0.18	42.78	12.71
6	n = 3	0.162	0.828	0.14	23.52	11.02
7	n = 3	0.159	2.730	0.36	21.77	9.89
8	n = 3	0.112	1.191	0.19	31.11	6.83
9	n = 3	0.121	1.975	0.29	35.52	10.39
10	n = 3	0.136	3.123	0.44	22.95	5.59
$\bar{X}$	n = 30	0.132	1.232	0.21	29.21	10.38

The depth of the sediments at Station 3 was determined through coring (Wildco Model 2420 hand corer) to exceed 0.5 m and to extend beyond 1.25 m in at least some places. A core taken in an erosional area (shallow reach) showed no fine sediments in the first 60 mm and consisted entirely of mollusk shells and small bits of gravel. The next 20 mm was brown-grey muck which converted to fine-grained, black-colored material at a depth of abut 80 mm. In depositing sediments (eddy of a meander), the first 2 mm consisted of loose, coarse particulate detritus. Brown-grey-colored sediments persisted down to 40 mm and then changed to a black ooze.

Redox potential measurements (Fig. 12) decreased rapidly in the first 3 cm of the sediments, stabilized at low levels over the next 10 cm and then increased slightly before stabilizing again at levels which presumably persisted deep into the sediments. The data suggest that aerobic conditions are confined to the upper few centimeters of sediment at Station 3. This is a zone of recent deposition and frequent reworking by the stream and benthic organisms. Below this there is a layer of about 10 cm in depth which, though anaerobic, appears to be biologically active and which may be reworked by the stream at least annually. Sediments deeper than about 15 cm do not appear to be biologically active and probably are reworked by the stream only infrequently ("long-term storage").

In the eroding area, the coarse particles (>1 mm) predominated, whereas in the depositing area the finer particles (< 0.5 mm) made up the bulk of the material (Table 26). The organic fraction (AFDW) was a small (2-3%) but consistent proportion of the material in all size classes in the erosional substratum. But in the depositional area, the 1- and 0.5-mm-size fractions contained significantly larger proportions of organic matter (33 and 18%, respectively) than did the smaller-size fractions.

Benthic metabolism was measured at Station 3 in July, August and September 1976. Rectangular metal boxes, open at both ends, were inserted into the substrate and to this was attached a Plexiglas photosynthesis respiration chamber fitted with a submersible pump to circulate water within the chamber. The photosynthesis and respiration values were calculated from the change in oxygen concentration, determined by the Winkler method. The results, given in Table 27, show respiration values ranging from 98.7-152.3 mg $O_2 \cdot m^{-2} \cdot hr^{-1}$. These values are very close to respiration values for Station 3 in July and August 1974 (Minshall et al. 1975). In August, photosynthesis and respiration experiments were carried out on both a depositing and an eroding area. Although the respiration values in the depositing area were similar to those in the eroding area (143.3 and 152.3 mg $O_2 \cdot m^{-2} \cdot hr^{-1}$), photosynthesis was less than half (88.6 and 187.2 mg $O_2 \cdot m^{-2} \cdot hr^{-1}$, respectively).

In another respiration experiment, 1-cm cores were removed from the stream and placed in 500-ml bottles that had been covered to exclude light. The bottles were filled with stream water, fitted with magnetic stirrers and returned to the stream for approximately 2 hr. The change in oxygen concentration was determined by the Winkler method. The respiration rates in this experiment were 224.5 and 367.4 mg $O_2 \cdot m^{-2} \cdot hr^{-1}$ (Table 28) and are much higher than in the experiments where the substrate was not disturbed.

The question arises: Are the organic sediments increasing, or has the system reached a "steady state" with respect to sedimentation and erosion? The answer is important because it would indicate whether the stream is exporting or storing organic matter. Therefore, four sets of measurements were obtained from Station 3 in an effort to determine the extent of erosion and deposition.

In the first set of measurements, sedimentation and erosion were determined in reference to a fixed point. The fixed point was achieved by sinking two poles, 50 cm apart and joined by a crossbar, into the substrate. The poles were stabilized with a 15-cm-diameter collar that rested on the stream bed. The midpoint of the line connecting the top of the poles served as the reference point. Ten sets of poles were placed randomly within a 200-m section of the stream on May 18.

Table 26. Particle size composition of the top 10 cm of sediment from an eroding and a depositing area of Deep Creek Station 3, July 1, 1976

Sediment Sizes (mm)	% of Core (wet vol.)	Dry Wt. (g)	AFDW (g)	% organic
A. Eroding				
>1.00	54.0	111.86	2.17	1.94
<1.00 >0.50	12.5	17.43	0.56	3.22
<0.50 >0.25	20.5	29.46	0.87	2.94
<0.25 >0.10	5.5	7.25	0.25	3.49
<0.10 >0.05	7.5	3.37	0.07	2.09
B. Depositing				
>1.00	17.0	1.86	0.62	33.31
<1.00 >0.50	18.0	4.17	0.76	18.23
<0.50 >0.25	30.5	29.19	0.22	0.75
<0.25 >0.10	23.0	22.84	0.47	2.08
<0.10 >0.05	11.5	12.47	0.27	2.16

Table 27. In situ measurements of sediment metabolism at Station 3, 1976 compared with 1974 (Minshall et al. 1975)

Date	water temp, (°C)	respriation rate (mg $O_2 \cdot m^{-2} \cdot hr^{-1}$)	net photosynthesis rate (mg $O_2 \cdot m^{-2} \cdot hr^{-1}$)	Method
7/17/76	17	98.7	———	P/R chamber
8/21/76	17.5	143.3	88.57	" (depositing area)
8/21/76	17.5	152.3	187.2	" (eroding area)
9/5/76	17	116.4	———	"
5/12/74	11.7	37.6	———	stream stirred respiration chambers
5/25/74	19.5	178.2	———	
6/2/74	18.8	180.9	———	
6/16/74	21.3	213.1	———	
7/21/74	18.8	152.4	———	
8/12/74	17.6		———	

Table 28. Respiration of sediment cores placed in dark bottles and incubated in the stream at Deep Creek Station 3, 1976

Date	water temperature (° C)	Respiration rate (mg $O_2 \cdot m^{-2} \cdot hr^{-1}$)
8/12/76	20	224.5
9/6/76	18	343.3
10/4/76	15	367.4

Unfortunately, this experiment had to be abandoned in June when it became apparent that the poles were interfering with drift. Prior to the removal of the poles, two series of measurements were made. The data (Table 29) indicate that erosion exceeded sedimentation during the 34-day period between May 18 and June 21. The mean rate of erosion was 0.55 mm/day and the total depth of erosion was 1.88 cm.

In the next set of measurements, the poles and crossbars were replaced by fixed points of reference external to the stream. Six sets of stakes were driven into the stream bank on either side and were connected by nylon line perpendicular to stream flow. Each line was marked in three places, in the middle and halfway between the middle and either end. Initial measurements of the distance from the taut line to the stream bed were made August 7. Some of the lines were broken during the summer and complete data, from August 7 to December 11, were taken for only three locations, thus giving nine sets of measurements. The rate of sedimentation from August 7 to September 19 was 0.40 mm/day, but increased to 0.60 mm/day for the next time period (Table 30). By November there was a mean accrual of 4.8 cm, but the erosional processes of the next 9 days were great (4.0 mm/day) and 3.6 cm of sediment were removed. Between November 19 and December 11 sedimentation, which was large in some spots, was almost completely balanced by erosion elsewhere. When the entire time period between August 7 and December 11 is considered, the net deposition of sediment is 1.74 cm, and the overall rate is 0.14 mm/day.

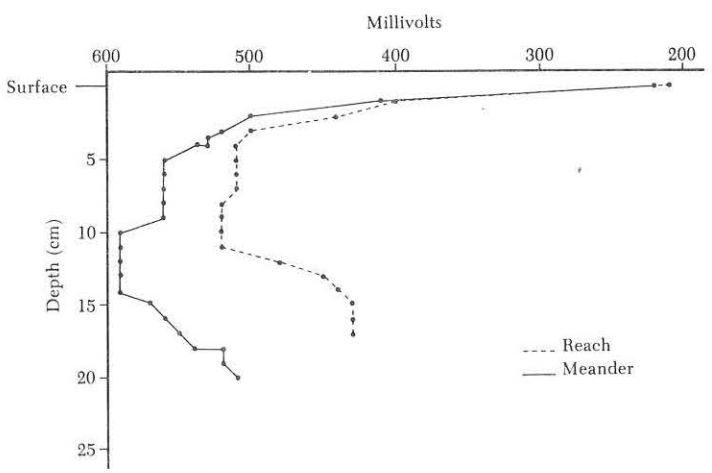

Figure 12. Redox potential of sediments at Deep Creek Station 3.

Table 29. Sedimentation and erosion of the streambed relative to fixed points, midway between two poles, Deep Creek Station 3, 1976; sedimentation = +, and erosion = —

Sample no.	May 18 to June 12	June 12 to June 21
1	+ 0.0 cm	+ 0.4 cm
2	- 0.8	- 0.6
3	+ 1.6	- 0.1
4	- 7.1	+ 2.2
5	- 2.2	+ 0.1
6	+ 0.5	+ 0.7
7	- 1.9	- 1.1
8	+ 2.2	- 11.4
9	- 1.0	0.0
10	- 2.5	+ 2.2
mean	- 1.1	- 0.8
mean rate	- 0.45mm/day	- 0.84 mm/day

mean erosion for entire 34 day period = 1.8 cm

mean erosional rate for 34 day period = .55

Sedimentation rate, as well as percent organic matter, was estimated in a third set of measurements. On June 6, 12 plastic trays, 5 cm deep and with a surface area of 1/32 m^2 (313 cm^2), were filled with substrate material and placed in the stream in depressions created by the substrate removal. They were positioned so that the tops of the trays and the substrate material within were flush with the stream bed. Six trays were put in a section of the stream that appeared to be in the process of sedimenting, and six were put in an eroding section. After 155 days the trays were retrieved, the vegetation was removed and preserved for separate analyses, and the depth of the newly deposited material was recorded. The trays were transported to the laboratory where dry weight and ash free dry weight were determined. The mean sedimentation rate, as shown in Table 31, was 0.22 mm/day, giving a net accrual of 3.4 cm.

The rate of erosion was more difficult to estimate with this method. Two of the trays were lost, presumably lightened by erosion within, dislodged by erosion around them and floated away by the current. The material in the remaining four trays showed varying degrees of erosion, which was more pronounced in the downstream end of each tray. Because the trays themselves tended to influence the erosional process, this portion of the experiment failed to provide meaningful data for estimating erosion.

A fortuitous circumstance provided an additional set of measurements of erosion. In the summer of 1974, a number of cylinders had been placed in the stream in connection with another study. Those in a depositing section have since been obscured by the sediment, but three were located in an eroding section. The portion of the cylinders that stood above the stream bed was measured and taken as a rough estimate of erosion. The mean value was 8.3 cm, which, over a 878-day period, would give a rate of 0.09 mm/day. It

Table 30. Sedimentation and erosion of the streambed relative to fixed positions on lines external to the stream at Deep Creek Station 3, 1976; sedimentation = +, and erosion = —

Line	Position	Aug. 7 to Sept. 19 (43 days)	Sept.19 to Nov. 8 (50 days)	Nov. 8 to Nov. 19 (11 days)	Nov. 19 to Dec 11 (22 days)	Net for the period (126 days)
1	lateral	- 5.6 cm	+ 6.4 cm	- 20.9 cm	+ 22.1 cm	+ 1.7 cm
	center	+ 3.9	+ 9.1	- 2.0	- 1.8	+ 9.2
	lateral	+ 6.5	+ 1.1	+ 0.6	- 2.5	+ 5.7
2	lateral	+ 1.1	+ 10.6	- 10.7	- 13.3	- 12.3
	center	+ 4.4	+ 0.6	+ 2.0	- 3.4	+ 3.6
	lateral	+ 8.8	- 7.6	- 0.5	+ 8.5	+ 9.2
3	lateral	+ 1.2	+ 0.9	0.0	- 1.6	+ 0.5
	center	+ 2.1	+ 2.5	- 0.8	- 3.4	+ 0.4
	lateral	- 6.6	+ 3.3	- 0.1	+ 1.1	- 2.3
Mean		+ 1.8	+ 3.0	- 3.6	+ 0.6	+ 1.7
Rate (mm/day)		+ 0.40	+ 0.60	- 4.00	+ 0.29	+ 0.14

Table 31. Sedimentation on trays placed in Deep Creek Station 3, June 6, 1976, and removed November 8, 1976 (155 days)

Tray No.	Depth of sediment (cm)	Rate of deposition (cm/day)	Dry wt. (g/m^2)	AFDW (g/m^2)	(AFDW/DW) X 100	Rate of deposition of organic material (g AFDW·m^{-2}·day^{-1})
1	4.0	0.022	9860	1567	15.9 %	10.2
2	3.0	0.017	7375	940	12.8	6.1
3	5.0	0.028	11511	1480	12.9	9.6
4	3.0	0.017	6296	722	12.2	5.0
5	2.5	0.014	4220	552	13.1	3.6
6	3.0	0.017	5231	699	13.4	4.5
Mean	3.4	0.021	7416	1002	13.4	6.5

Table 32. Organic fraction of the sediment profile, Deep Creek Station 3, 1976

Sample depth and source	Number of samples	Percent organic matter (AFDW/DW) X 100
0 - 3.4 cm sedimentation trays, includes recently deposited detritus	6	13.4%
0 - 1 cm substrate from respiration experiment, with plants removed	18	6.4
0 - 7 cm substrate from experiment with P/R chambers, plants removed	7	4.1
from a 125 cm core:		
0 - 31 cm	1	4.2
31- 62	1	3.5
62 - 94	1	2.4
94 - 125	1	2.5

should be noted, however, that the sections of the stream that appear to be steadily eroding are few and comprise only about 10% of the whole.

In the tray experiment, there was heavy colonization by *Chara vulgaris* and the sediment was rich in organic material, either derived from or trapped by the vegetation. The percent organic matter (as ash free dry weight) was 13.4% (Table 31). This value is compared with others from independent measurements of Deep Creek sediment in Table 32. The 125-cm core was removed from an area of deep sediment on the inside curve, or point bar, of a meander. From Table 32 it can be seen that the percent organic matter in sediment decreased with depth until a depth of about 62 cm and then stabilized at 2.5%.

Import-Export

Macrophytes enter and leave a section of stream via transport in the water column and the effect of this process may vary, not only with the physical parameters of the system but also between taxa. To determine the magnitude of import and export, samples were taken periodically from May 1976 through December 1976. On each sampling date, a 6-mm mesh net was placed across the stream at the downstream end of a 200-m section and left in for 15 min. The net was then removed and cleaned, and the entrapped material was put into a container. The net was then placed in the stream at the beginning of the 200-m section for 15 min. After the upstream sample had been collected, both samples were preserved in 10% formalin. In the laboratory, each sample was separated into species, dried for at least 24 hr at 60 C, weighed and then ashed at 550 C for 3 hr in a muffle furnace to obtain organic weight (AFDW). The time between sampling periods varied, but was generally 2-3 wk. Because the variance between the values obtained in early samples was great, samples were taken daily on each of three days in mid-August to determine if samples taken close together in time would have a lower variance.

Earlier studies at Deep Creek Station 2 (Minshall et al. 1975) and additional observations at Station 3 indicated that macrophytes normally do not remain in transport long. To determine the mean distance traveled, and the length of time in transport of *Potamogeton*, *Cladophora* and *Chara*, samples of each plant were introduced into the water column at Station 3, and the time and distance they traveled were recorded. Data from the import-export net samples are given in Table 33 and Figure 13; data from 1974 (Minshall et al. 1975) are included for comparison. *Chara* was absent from most samples and never present in large amounts. The values for *Cladophora* for import ranged from a high of 1054 g/day on May 23 to zero on August 8. The amount of *Cladophora* exported was less than the amount imported on each sampling date except July 1 (and August, when both were zero). *Potamogeton* was present in every export sample and all but one import sample. The variance between samples was much less than that for *Cladophora*, and export exceeded import about 50% of the time.

The mean distance traveled and time in transport for *Potamogeton* and *Cladophora* were calculated from the experimental values as shown in Table 34 and are 49.5 m and 33.3 m, respectively. These values are consistent with the observations of Minshall et al. (1975) that most plants remained in transport for a distance of less than 50 m. Because of $CaCO_3$ deposits on *Chara*, which greatly increase its density, the distance traveled by *Chara* was insignificant.

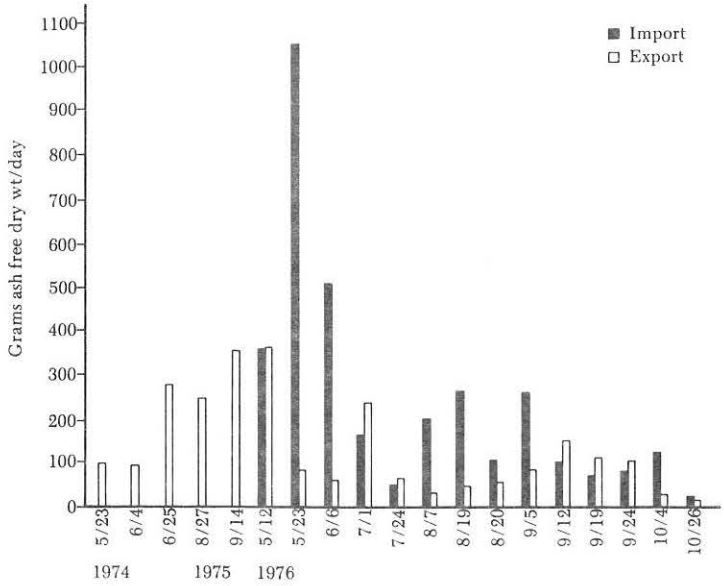

Figure 13. Total import and export of macrophytes from control section of Deep Creek Station 3.

Table 33. Import (I) and export (E) of aquatic macrophytes and detritus (both aquatic and terrestrial in origin) from the control section of Deep Creek Station 3, May through October 1976. Export only, May and June 1974, and August and September 1975. Values given in grams organic matter per day

Date	Potamogeton pectinatus		Cladophora glomerata		Chara vulgaris		Nostoc		Detritus	
	I	E	I	E	I	E	I	E	I	E
5-23-74	-*	14.4	-	52.8	-	0.0	-	-	-	79.2
6-4-74	-	21.6	-	120.0	-	2.4	-	-	-	28.8
6-25-74	-	84.0	-	264.0	-	4.8	-	-	-	124.8
8-27-75	-	88.0	-	34.8	-	0.0	-	-	-	36.0
9-14-75	-	298.6	-	3.3	-	0.0	-	-	-	54.8
5-12-76	Sample not separated into taxa and considered to be detritus								360.1	363.0
5-23-76	0.0	37.9=	1054.0	37.9	0.0	0.0	0.0	0.0	0.0	0.0
6-6-76	24.4	22.4	447.7	24.4	0.0	trace	0.0	0.0	38.5	17.7
7-1-76	23.2	18.9	75.1	137.4	8.1	2.9	0.0	0.0	61.1	82.2
7-24-76	15.8	24.2	trace	trace	0.0	0.0	0.0	0.0	34.5	42.6
8-7-76	93.9	16.5	0.0	0.0	2.6	0.0	0.0	0.0	lost	17.3
8-19-76	12.1	48.6	105.6	0.0	1.1	0.0	255.9	0.0	3.4	trace
8-20-76	35.1	41.1	3.2	0.0	2.1	0.0	4.5	0.0	18.2	14.1
9-5-76	189.9	61.4	4.5	0.0	0.0	0.0	6.5	21.6	59.9	0.0
9-12-76	75.4	145.1	7.2	0.0	0.0	0.0	1.9	0.0	16.8	5.0
9-19-76	58.6	85.2	7.7	0.0	0.0	0.0	4.6	4.5	0.0	23.4
9-24-76	33.2	93.1	41.5	trace	1.3	0.0	2.4	0.0	3.4	10.9
10-4-76	47.4	18.8	trace	trace	trace	trace	0.0	0.0	38.9	10.3
10-20-76	9.6	8.8	1.7	0.0	trace	trace	0.0	0.0	10.6	6.1

*not measured.
=this sample was not separated into species, but estimated to be approximately 50-50 Cladophora and Potamogeton.

Table 34. Distance traveled and time in transport, *Potamogeton* and *Cladophora*

Genera	Distance (m)	Time (sec)	Rate (m/sec)
Cladophora	18.0	90	0.20
	26.5	90	0.29
	9.5	45	0.21
	2.0	25	0.08
	56.0	180	0.31
	90.0	450	0.20
$\bar{X}$	33.67	146.7	0.22
S.D.	33.33	2.44	3.00
Potamogeton	12.5	75	0.17
	17.0	45	0.38
	94.0	285	0.33
	41.0	180	0.23
	83.0	1080	0.08
$\bar{X}$	49.5	333.3	0.24
S.D.	37.14	7.14	7.27

Decomposition Rates of *Cladophora* and *Potamogeton*

In each of eight nylon hair nets, 10 g (dry wt) of heat-killed *Cladophora glomerata* were placed, after which one net was tied to half of a brick and placed on the substrate at Station 3. Two of the nets were removed after 5 min and taken back to the laboratory to be processed as controls to see what amount was lost in breakage in transit. The same was done with eight samples of heat-killed *Potamogeton pectinatus*. A section of chicken netting was placed upstream to prevent drifting plants from depositing on the "leaf packs."

The results are given in Table 35. Dry weight losses for *Cladophora* were higher than for *Potamogeton* on every occasion. Initially, the *Cladophora* decomposed more rapidly but, by the end of a month, similar amounts of the two plants had disintegrated. The 31-day loss rate of 2.8% is faster than the 1.5% per day value reported by Cummins (1974) for fast terrestrial leaf litter, such as ash and alder leaves.

DISCUSSION

Light Manipulation

The section of Deep Creek selected for this study has been intensively studied for the past several years. The dominant components of the macrophyte community, *Chara vulgaris* and *Potamogeton pectinatus*, were the same as reported in previous years. In 1970 and 1971 the maximum values for biomass were 140 g AFDW/m² and 178 g AFDW/m², respectively (Minshall et al. 1973). The maximum biomass for the control section in this study was only 75.1 g/m², calculated by pooling channel and margin samples for August. The low production in 1975 probably resulted from the unusually late spring. Development of terrestrial vegetation was about a month later than in previous years; therefore it is reasonable to expect a concomitant reduction in production in the stream.

Deep Creek Station 3 resembles, in certain attributes, an enriched stream studied by Westlake (1961). He describes

Table 35. Decomposition of *Cladophora glomerata* and *Potamogeton pectinatus* in Deep Creek Station 3

Day	Date	Sample	Dry Wt. (g)	$\bar{X}$	AFDW (g)	$\bar{X}$	% Loss	Decay Rate (g/day)
0	24 June 1976	Potamogeton (control)	9.6231		2.7037		3.8	
		Cladophora (control)	9.3231		4.5229		6.8	
7	1 July 1976	Potamogeton	7.6100	8.2759	3.6100	3.9949	17.2	0.2463
		Potamogeton	8.9417		4.3797			
		Cladophora	6.2815	6.0662	0.8609	1.2984	39.3	0.5620
		Cladophora	5.8508		1.7358			
31	24 July 1976	Potamogeton	2.3150	1.7041	1.2630	0.7637	83.0	0.2676
		Potamogeton	1.0932		0.2593		89.7	0.2837
		Cladophora	1.2060		0.1345			
		Cladophora	sample lost in transit					
58	20 Aug. 1976	All of the remaining six packs had no plant material left.					100	unable to calculate

*The following invertebrates were collected in the packs: CLADOPHORA - Chironomus, Limnephilus, Lynmaea, Hyalella; POTAMOGETON - Chironomus, Lymnaea, Hyalella, Caenis, Baetis, Gammarus, Physa. Also several crayfish (Pacifastacus) were observed feeding on the material in the bags.

the stream as having a uniform, gravelly bottom, overlain with sludge and scarcely shaded by trees. The dominant component of the macrophyte community was *Potamogeton pectinatus*, and associated taxa included *Cladophora* sp. (no mention is made of *Chara*). Westlake reported a macrophyte biomass value of 96 g AFDW/m². This is within the range of values obtained for Deep Creek. Westlake's values, as well as ours, are much lower than those for streams or rivers studied by Edwards and Owens (1960), Odum (1957) and Hannan and Dorris (1970).

Owens and Edwards (1961) reported that production of macrophytes was less in a shaded than in an unshaded section of the River Ivel (incident light ranging from 45-92% of that in the unshaded area). In the present study, there was a greater reduction of light (incident light being only 30% of that in the open area) under the plastic canopy, and very probably the spectral distribution differed from that of light filtering through a leaf canopy. Nevertheless, our results are similar to those of Owens and Edwards (1961) in that: 1) there was a reduction in production in the shaded area and 2) the community structure was modified. The ultimate structure of the community, should the plastic canopy remain for several seasons, cannot be predicted since "little is known of the precise influence of changes in light intensity and quality on the distribution of life forms and species" (Sculthorpe 1967).

At Deep Creek Station 3 the most conspicuous forms of aquatic vegetation are the macrophytes. Not all of the stream bed is covered with them, however, and even at the height of macrophyte biomass, there are many patches of stream bottom that appear bare, but are, in fact, covered with periphyton. Furthermore, the macrophytes themselves provide surface area for periphyton colonization. Thus, periphyton is an important component of the ecosystem.

Chlorophyll *a* concentration has been used by many investigators as a measure of periphyton biomass and/or productivity. This study indicates that at Station 3 the biomass of periphyton is low in early summer and increases until late September, and that this pattern is consistent even when the absolute values vary, as between the control and recolonized sections. The reason for the increase in the recolonized section is not clear, especially when the available nutrients and the solar radiation are the same.

The 1976 data for chlorophyll *a* have been compared to those of 1971 and 1972 for Station 3 of Deep Creek. The 1972 data are erratic, but the 1971 values are quite similar to those of 1976, with a low concentration in May 1971, less than 2 mg/m², followed by steadily increasing concentrations to a high of 106 mg/m² in late August. The close agreement of the 1971 and 1976 values would suggest that they may be representative of Station 3. The Deep Creek data are lower than, but in the same order of magnitude of those reported in some other studies. For example, Swanson and Bachmann (1976) found the mean concentration of chlorophyll *a* in the Skunk River to be 160 mg/m², and Hannan and Dorris (1970) reported that, after dredging, the concentration of chlorophyll *a* in the San Marcos River increased from 120 mg/m² in May to 320 mg/m² in August.

Nutrient Manipulation

Results of the addition of ammonium nitrate on algal growth at Deep Creek Station 2 are somewhat inconclusive. Addition apparently increased the amount of *Cladophora* and benthic chlorophyll *a*. The benthic chlorophyll *a* values must be viewed critically, however, as a breakdown in equipment necessitated storage of the chlorophyll *a* for a long period of time during which some degradation could have occurred. This could account for the erratic variation in chlorophyll *a* and the large amounts of phaeo-pigments.

Results of the addition experiments of $PO_4^{=}$ and $PO_4^{=}$ plus NH_4NO_3 on algal growth are much more conclusive. Initially, the addition of $PO_4^{=}$ and $PO_4^{=}$ plus NH_4NO_3 stimulated the growth of *Cladophora*. The shift to a *Spirogyra* sp.-dominated community was sudden and unexpected. Several factors were investigated in an attempt to explain the change. No conclusive evidence indicating the factor or factors responsible has yet been discovered. No trace elements (such as heavy metals) known to be inhibitory to the growth of *Cladophora* were found in significant quantity in the phosphate fertilizer. Addition of the phosphate fertilizer may have reduced the pH enough to inhibit growth of *Cladophora*. This hypothesis has not yet been tested using Deep Creek water; however, the effect of adding concentrations of phosphate fertilizer, equivalent to those used in the experiment, to tap water appears to have relatively little effect on pH. At present it is believed that the shift to a *Spirogyra*-dominated community was a result of several factors. *Spirogyra* remained dominant in slow-water

Table 36. Standing crop and sloughing rates of *Cladophora glomerata* at Deep Creek Station 3, May and June 1974, August and September 1975 and May 1976

Date	Standing Crop (g AFDW/m^2)	Sloughing Rate per m^2 (g·m^{-2}·day^{-1})	Sloughing Rate Standing Crop (%/day)
May 23, 1974	6.44	0.48	7.5
June 4, 1974	13.00	1.10	8.5
June 25, 1974	26.40	2.42	9.1
June 17, 1975	11.22	*	*
July 21, 1975	8.65	*	*
Aug. 27, 1975	.34	.32	94.1
Sept. 14, 1975	.42	.03	7.1
May 23, 1976	1.9	.35	18.42
June 6, 1976	4.6	.22	4.74
June 12, 1976	6.7	*	*
July 1, 1976	5.1	1.26	24.71
July 24, 1976	.6	trace	
Aug. 22, 1976	.4	0.0$^+$	
Sept. 12, 1976	.3	0.0	
Oct. 4, 1976	.2	trace	
Oct. 27, 1976	.5	0.0$^+$	

*Indicates that no data on sloughing are available on this date.

areas of Deep Creek above the diversion weir at Station 2 throughout the summer. The only differences between those waters and Station 2 were lower water temperatures and slightly higher nitrate concentrations. It is believed that lowered water temperatures plus the increased nutrients allowed the shift to a *Spirogyra*-dominated community. Mean water temperatures during the experiment were 23.1 C, day 1; 23.9 C, day 3; 22.5 C, day 5; 16.4 C, day 7; 18.6 C, day 9; 20.0 C, day 11. The lowering of water temperatures on days 5 and 7 (a result of lowered air temperatures and increased discharge caused by thunderstorms) coincides with the appearance and increasing growth of *Spirogyra* in the $PO_4^{=}$ and $PO_4^{=}$ plus NH_4NO_3 addition sections. Further evidence of the effect of temperature on the growth of *Spirogyra* was observed. Near the middle of the 15-m $PO_4^{=}$ addition section, a small amount of seepage water from the irrigation canal entered the stream. Testing revealed no differences in chemical parameters, but the water temperature at the point of entry was 5-7 C below that of the stream water. Growth of *Spirogyra* was much more dense in the seepage area and downstream to a point where only a 1-2 C difference in water temperature was detectable. Addition of fluorescein dye to the seepage water showed that the increased growth of *Spirogyra* followed exactly the plume of cooler seepage water. That lowered waater temperatures and higher nutrient concentrations would lead to a shift in community dominance from *Cladophora* to *Spirogyra* is surprising, as *Cladophora* is an alga favored by high concentrations of nutrients and intermediate water temperatures, but the results of this experiment indicate that these two factors may prevent *Spirogyra* from becoming the dominant summer alga at Station 2, Deep Creek.

Another observation was the deterioration of *Cladophora* mats in proximity to the growth of *Spirogyra*. *Spirogyra* often grew intermingled with mats of *Cladophora*, "using" holdfasts of *Cladophora* for increased stability. In these cases the amount of *Spirogyra* seemed to increase at the expense of the mat of *Cladophora*. The drastic reduction in standing crop biomass of *Spirogyra* and *Cladophora* in the $PO_4^{=}$ and $PO_4^{=}$ plus NH_4NO_3 addition sections was a result of the deterioration of the holdfast filaments of *Cladophora* which allowed the current to remove extensive mats of algae. Initially, deterioration of the holdfast filaments of *Cladophora* was attributed to shading. However, basal filaments undergo higher degrees of shading in the extensive mats of *Cladophora* that develop in the stream without deteriorating, which leads to the conclusion that a possible antagonistic reaction between *Spirogyra* sp. and *Cladophora glomerata* may exist. The fact that in the stream *Spirogyra* sp. and *Cladophora glomerata* tend to grow in pure stands, even when in close conjunction, lends support to this hypothesis.

The relationship of various morphological characteristics of *Cladophora glomerata*, such as chlorophyll *a* content and organic matter content, may provide a better indication of the effects of the addition of nutrients to the stream on the algal community, as these parameters should remain relatively unaffected by morphometric differences in the study sections. Changes in chlorophyll *a* and organic matter content of *Cladophora* during the NH_4NO_3 addition experiment were slight, consisting mainly of a very slight increase in chlorophyll *a* per biomass of *Cladophora*. Changes occurring in the $PO_4^{=}$ and $PO_4^{=}$ plus NH_4NO_3 addition experiment were dramatic and consistent. Organic matter content of the *Cladophora* increased in the $PO_4^{=}$ addition section and further increased in the $PO_4^{=}$ plus NH_4NO_3 addition section. But the most pronounced change occurred in chlorophyll *a* content, which showed the same pattern but with more dramatic increases. The mean amount of chlorophyll *a* per gram ODW or AFDW *Cladophora* in the $PO_4^{=}$ plus NH_4NO_3 addition section was nearly three times that of *Cladophora* in the control section. Several authors (Eppley 1968, 1972; Eppley and Renger 1974; Holm-Hansen 1970; Thomas, 1970a, b) have noted lowered concentrations of chlorophyll *a* in various types of algae occurring in nitrogen-deficient waters. This is usually accompanied by reduced assimilation numbers and productivity. The original idea for these experiments had occurred after noting the yellow-green, "bleached-out" *Cladophora* in Deep Creek, which contained very small amounts of chlorophyll *a* and the reduced amounts of NO_3^{-} that occurred during irrigation water diversions. This indicated possible NO_3^{-}-limited *Cladophora* production. With the addition of $PO_4^{=}$ plus NH_4NO_3, the change in the morphological condition of *Cladophora* was readily apparent. *Cladophora* occurring in the $PO_4^{=}$ plus NH_4NO_3 addition section was a dark green, while *Cladophora* occurring in the control section remained a light yellow-green. *Cladophora* occurring in the $PO_4^{=}$ addition section appeared only slightly darker than that in the control section. The increase in chlorophyll *a* as percentage of biomass of *Cladophora* in the $PO_4^{=}$ addition section might

indicate a relationship between chlorophyll *a* and $PO_4^{=}$. However, it is more likely that the increased availability of $PO_4^{=}$ stimulated increased uptake and use of available forms of nitrogen. The reduced amounts of NH_4^{+} in the $PO_4^{=}$ addition section and the extreme increase of chlorophyll *a* as percentage of biomass in the $PO_4^{=}$ plus NH_4NO_3 addition experiment, while the addition of NH_4NO_3 alone caused only small increases in chlorophyll *a* as percentage of biomass, support this conclusion. From the accumulation of biomass, it is unclear whether nitrogen was limiting growth of *Cladophora*. The change to a *Spirogyra*-dominated community during the $PO_4^{=}$ and $PO_4^{=}$ plus NH_4NO_3 addition experiments made determinations on the growth of *Cladophora* inconclusive. *Cladophora* growth apparently was increased by addition of NH_4NO_3 alone, but the increase was relatively small.

Thus the effects of nutrients and temperature on the algal community at Deep Creek Station 2 may be rather complex, with only relatively small changes causing not only varying rates of algal production, but shifts in the dominant algal species as well.

Detrital Dynamics

Standing crop of fine particle detritus per gram ODW *Cladophora* remained relatively constant, while export of fine particle detritus per gram ODW varied greatly. This may indicate that *Cladophora* serves as a processing site for detritus with amounts exported as a result of the size of the invertebrate community occurring in the *Cladophora*, or it could simply indicate a filtering effect of *Cladophora*. The lowered percent AFDW of the settled detritus indicates the latter as the more likely possibility. Interestingly, only an extremely small amount of *Cladophora* was exported as detritus; thus the major pathways for *Cladophora* biomass to enter into the detrital web of the stream appear to be through bacterial decomposition of large masses of *Cladophora* that have accumulated on submerged objects, or possibly to a much lesser extent, by consumption of live filaments by invertebrates.

Data from this study are still being analyzed. Drift and invertebrate data are being analyzed to further determine the dynamics of the *Cladophora* community. It is hoped that these data will allow quantitative mapping of the fate of *Cladophora* biomass and accurate assessment of the importance of the *Cladophora* community to the summer invertebrate community. At present, it is believed that *Cladophora* supports the major portion of invertebrate biomass at Station 2 during the summer. Only one invertebrate, a riffle beetle (Elmidae) has been found to be more abundant on the natural substratum. Further analyses are being conducted to determine what effects the nutrient additions had on the epiphytes of *Cladophora glomerata* and *Spirogyra* sp.

Import-Export

The lack of variation in upstream-downstream, and between-site concentrations of DOC and FPOC, suggests that this is a steady state variable and that the system is efficient in processing or storing these materials. The range

Table 37. Ratio of export of macrophytes to macrophyte standing crop at Deep Creek Station 3

Date	Standing Crop	Export ($g \cdot m^{-2} \cdot day^{-1}$)	(Export/Standing Crop) x 100 (%/day)
May 1974	16.35	.91	5.56
June 1974	50.60	2.03	4.02
Aug. 1975	79.50	.77	.97
Sept. 1975	68.99	1.88	2.74
May 1976	4.35*	.47	10.80
June 1976	16.50	.40	2.42
July 1976	50.35*	.96*	1.91
Aug. 1976	63.50	..29*	.46
Sept. 1976	71.10	.70*	.98
Oct. 1976	49.95*	.14*	.?9

*Mean of two or more sampling dates.

of DOC (0.5-3.5 g C/m^3) in Deep Creek is within the range of published values for DOC in streams and rivers (Table 7). Although most studies have been carried out on heterotrophic systems, one stream, Tecopa Bore, with a DOC concentration of 3-4 g C/m^2, is autotrophic. Ratios of DOC:FPOC were included in Table 7 and, in every reported case, the concentration of DOC was at least twice that of FPOC. A ratio of about 2:1 also was found for Deep Creek for all stations and all dates with the exception of May and early June 1975, which coincided with high discharge. The particulate organic fraction also exceeded DOC in the Middle Oconee River (Nelson and Scott 1962) and the Little Miami River (Weber and Moore 1967) during periods of storm discharge.

Two prominent features of the import-export data (Fig. 13) are that import of coarse particulate organic matter (CPOM) is usually greater than export, and that both are bimodal with the peaks in import preceding the peaks in export. These spatial and temporal variations, together with differences among samples in percent contribution of each macrophyte species, suggest differences in growth strategies and warrant closer examination.

Swanson and Bachmann (1976), in their study of algal export in Iowa streams, found that the amount of algae per m^2 in export samples increased downstream with the increase in the drainage basin area. However, accrual of algal material does not seem to occur at Station 3 of Deep Creek. Data in Table 34 show that *Cladophora glomerata* is removed from transport within 34 m of the point of introduction and, since it is continuously being sloughed, it seems reasonable to expect it to be in steady state with respect to transport. Our data on import and export do not support this, however, but instead show that import usually exceeds export and, on some sampling dates, is many times greater. Examination of the stream reveals that the stream section just upstream from the control section supports a more lush stand of *Cladophora glomerata* than does the 200-m control section. The difference in import and export can be accounted for because the upstream or import-net-caught material generated in this more productive section, while the downstream or export-net-caught material

Table 38. Sedimentation and erosion rates based on four different methods of measurement at Deep Creek Station 3; sedimentation = +, and erosion = —

Method	Date	number of days	rate
Measurements made midway between two poles	May 18 to June 21, 1976	34	- 0.55 mm/day
Measurements made relative to fixed positions on lines external to the stream	August 7 to December 11, 1976	126	+ 0.14 mm/day
Sedimentation on trays	June 6 to November 8, 1976	155	+ 0.22 mm/day
erosion around cylinders	June 1974 to November 1976	878	- 0.09 mm/day

generated within the last 30-50 m of the control section. Apparently, little or none of the material entering the 200-m study section remained in transport to be collected in the export net, since Minshall et al. (1975) found that, of 525 g of dyed *Cladophora glomerata* introduced into transport, only 2 g reached a net 100 m downstream.

Both the export and the import of *Cladophora glomerata* were greatest in late spring and early summer, and the amount in export decreased to zero in August. Although the amount of *Cladophora glomerata* in transport is influenced by other variables such as current, temperature and day length, it is most closely related to standing crop. Assuming a mean transport distance of 34 m and a mean stream width of 3.2 m, the amount of material collected in the export net can be used to calculate the amount introduced into transport per m^2 per day. This value, divided by standing crop, gives the sloughing rate. These calculations were used to develop Table 36 which shows that the standing crop, as well as sloughing per m^2, increases from May through late June or early July. As the water velocity decreases and the temperature increases, *Cladophora glomerata* begins to die off. The ratio of sloughing to standing crop increases (June 25, 1974, and July 1, 1976, Table 37), and by July the standing crop of *Cladophora* is greatly reduced.

Sediment Dynamics

A summary of the several sedimentation and erosion experiments is given in Table 38. It appears that both sedimentation and erosion are active processes in Deep Creek, and that the system is probably at, or near, equilibrium. Within the boundary of the stream, and to a depth of 5 to 10 cm, the position of equilibrium is one at which there is a large amount of organic matter present in storage. This concept is supported by data from standing crop measurements that indicate the detritus is almost constant throughout the year. Sedimentation can, at times, result in the accrual of up to 1000 g organic material per m^2 in one season. The system is kept in balance by subsequent erosion and/or decomposition of this material. Data presented in Table 38 indicate that organic material decreases with depth to a concentration of about 2.5%, which is very close to the concentration of organic matter reported for soils of the region (Buckman and Brady 1969, Table 6:1). This suggests that the meandering of the stream, accompanied by erosion and deposition, does not significantly modify the organic content of the landscape, that import and production of organic matter is balanced by export and processing and that the stream approximates a steady state regime.

ACKNOWLEDGMENTS

We wish to extend our best thanks to John Adekalu, Jim Brock, Polly Chang, Mike Mallea, Judy Allen, Sharon Manuel, Curt Nimz, Walt Poole, Caryl Tickner, Joe Wlosinski and others who have helped in various ways to ensure the success of this project.

LITERATURE CITED

American Public Health Association. 1970. Standard methods for the examination of water and wastewater. 12th ed. APHA, New York. 769 pp.

Buckman, H. O., and N. C. Brady. 1969. The nature and properties of soils. 7th ed. The MacMillan Co., New York. 653 pp.

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

Edwards, R. W., and M. Owens. 1960. The effects of plants on river conditions. I. Summer crops and estimates of net productivity of macrophytes in a chalk stream. J. Ecol. 49:151-160.

Einsele, W. 1960. Die Stromungsgeschwindigikeit als beherrschender Faktor bei der limnologischen Gestaltung der Gewasser. Osterreichs Fischerei Suppl. 1, 2. 40 pp.

Eppley, R. W. 1968. An incubation method for estimating the carbon content of phytoplankton in natural samples. Limnol. Oceanogr. 13:574-582.

Eppley, R. W. 1972. Temperature and phytoplankton growth in the sea. Fish. Bull. 70:1063-1085.

Eppley, R. W., and E. H. Renger. 1974. Nitrogen assimilation of an oceanic diatom in nitrogen-limited continuous culture. J. Phycol. 10:15-23.

Fisher, S. G., and G. W. Likens. 1973. Energy flow in Bear Brook, New Hampshire: an integrative approach to ecosystem metabolism. Ecol. Monogr. 42:421-439.

Hach Chemical Company. 1969. Colorimetric procedures for water and wastewater analysis. Hach Chemical Co. 102 pp.

Hannan, H. H., and T. C. Dorris. 1970. Succession of a macrophyte community in a constant temperature river. Limnol. Oceanogr. 15:442-453.

Höll, K. 1955. Chemische Untersuchungen and kleinen Fliessgewässern. Verh. int. Verein. Theor. Angew. Limnol. 12:360-372.

HOLM-HANSEN, O. 1970. ATP levels in algal cells as influenced by environmental conditions. Plant Cell Physiol. 11:689-700.

MACIOLEK, J. A. 1962. Limnological organic analyses by quantitative dichromate oxidation. Fish. Wildl. Serv. Res. Rep. 60. 61 pp.

MCDIFFETT, W. F., A. E. CARR, and D. L. YOUNG. 1972. An estimate of primary productivity in a Pennsylvania trout stream using a diurnal oxygen curve technique. Amer. Midl. Natur. 87:565-570.

MCDOWELL, W. H., and S. G. FISHER. 1976. Autumnal processing of dissolved organic matter in a small woodland stream ecosystem. Ecology 57:561-569.

MINSHALL, G. W. 1975. Autotrophy in stream ecosystems. AIBS Symp., Corvallis, Ore.

MINSHALL, G. W., coordinator, et al. 1972. Validation studies at Deep Creek, Curlew Valley. US/IBP Desert Biome Res. Memo. 72-5. Utah State Univ., Logan. 59 pp.

MINSHALL, G. W., coordinator, et al. 1973. Validation studies at Deep Creek, Curlew Valley. US/IBP Desert Biome Res. Memo. 73-48. Utah State Univ., Logan. 99 pp.

MINSHALL, G. W., J. T. BROCK, D. A. MCCULLOUGH, R. DUNN, M. R. MCSORLEY, and R. PACE. 1975. Process studies related to the Deep Creek ecosystem. US/IBP Desert Biome Res. Memo. 75-46. Utah State Univ., Logan. 31 pp.

NAIMAN, R. J. 1976. Primary production, standing stock, and export of organic matter in a Mohave Desert thermal stream. Limnol. Oceanogr. 21:60-73.

NELSON, D. S., 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.

ODUM, H. T. 1957. Trophic structure and productivity of Silver Springs, Florida. Ecol. Monogr. 27:55-112.

OWENS, M., and R. W. EDWARDS. 1961. The effects of plants on river conditions. II. Further crop studies and estimates of net productivity of macrophytes in a chalk stream. J. Ecol. 49:119-126.

ROBSON, D. S., and H. A. REGIER. 1966. Estimates of tag loss from recoveries of fish tagged and permanently marked. Trans. Amer. Fish. Soc. 95:56-59.

SCULTHORPE, C. D. 1967. The biology of aquatic vascular plants. Edward Arnold Ltd., London.

SHADIN, V. I. 1956. Life in rivers. Fizni presnih vod S.S.S.R. 3:113-256.

SLACK, K. V., R. C. AVERETT, P. E. GREESON, and R. G. LIPSCOMB. 1973. Methods for collection and analysis of aquatic biological and microbiological samples. Chapter A-4 *in* U.S. Geological Survey techniques of water-resources investigations. Book 5. 165 pp.

STRICKLAND, J. D. H., and T. R. PARSONS. 1968. A manual of sea water analysis. Fish. Res. Bd. Can. Bull. No. 167. 217 pp.

SWANSON, C. D., and R. W. BACHMANN. 1976. A model of algal exports in some Iowa streams. Ecology 57:1076-1080.

THOMAS, W. H. 1970a. On nitrogen deficiency in tropical Pacific oceanic phytoplankton: photosynthetic parameters in poor and rich water. Limnol. Oceanogr. 15: 380-385.

THOMAS, W. H. 1970b. Effect of ammonium and nitrate concentration on chlorophyll increases in natural tropical Pacific phytoplankton populations. Limnol. Oceanogr. 15:386-394.

WEBER, C. I., and D. R. MOORE. 1967. Phytoplankton, seston and dissolved organic carbon in the Little Miami River at Cincinnati, Ohio. Limnol. Oceanogr. 12:311-318.

WESTLAKE, D. F. 1961. Aquatic macrophytes and the oxygen balance of running water. Verh. Internat. Verein. Limnol. 14:499-504.

WETZEL, R. G., and A. OTSUKI. 1974. Allochthonous organic carbon of a Marl lake. Arch. Hydrobiol. 73:31-56.