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Biotic Responses to
Sediment Removal in a Tributary of Silver Creek, Idaho

by

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IN

BIOLOGY

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INTRODUCTION

doesn't intensive agr & grazing imply a lack of buffer zones?

Intensive agriculture, grazing and a lack of riparian buffer zones have led to increasing levels of sediment deposition in lotic systems throughout the Intermountain West. Aquatic biota can be adversely affected because of the potential loss of available habitats. Some aspects of the presence of substantial quantities of sediment in streams have been studied extensively, especially the effects on reproductive success of salmonids (e.g. Cooper 1956; Peters 1967; Hausle and Coble 1976). However, sediment may also reduce the amount of living space for fish and decrease the production of aquatic macroinvertebrates.

suggest you delete this

Sediment may regulate fish populations indirectly by modifying available habitats. A primary result of sediment being deposited in streams is the loss of deeper water for fish (Hunt 1969; King and Ball 1964). Reduced water depths may limit the standing crop of fish present in streams by making habitats unsuitable for larger individuals (Saunders and Smith 1965). The use of particular habitats by trout species may decrease substantially as water depth decreases (Bovee 1978). Sediment also decreases the availability of prey for fish (Farnworth et al. 1979; Lotrich 1973).

reword

citing same thing here?

too vague

The production of aquatic macroinvertebrates can be adversely affected by sediment (Cordone and Kelley 1961). In some cases, sediment reduces the number of benthic organisms through burial of sessile forms and alteration of the substrate (Hynes 1970; Harman 1972; Minshall and Minshall 1977). Sediment can increase migration, drift, and mortality; it may also reduce reproduction (Farnworth et al. 1979). Recolonization by mobile invertebrates is generally rapid if pre-disturbance conditions are resumed (Kennedy 1955; Waters 1964).

The accumulation and erosion of sediment in streams may change species composition of submersed, rooted aquatic macrophytes through alteration of sediment type or composition (Farnworth et al. 1979). Suspended sediment can reduce photosynthetic rates of submersed macrophytes, but few studies (e.g. Meyer and Heritage 1941) have been conducted regarding this effect.

The deposition of sediment can pose unique problems in streams located in areas where gradient changes are gradual. Sufficient flows and turbulence needed to flush accumulated sediment are not generated ~~because of the minimal changes in elevation.~~ The Silver Creek drainage, located in southcentral Idaho, is primarily spring-fed and has a low gradient. Flows throughout this system typically are not sufficient to flush sediment deposited on the stream substrate.

Silver Creek and tributaries have received an increased sediment load in recent years due to an expansion of agricultural practices in the basin. The increase in sediment may decrease the productivity of Silver Creek and its value ~~as a premier~~ in supporting a trout fishery.

Data collected in several tributaries of Silver Creek suggest that, because of sediment, overwintering habitat for trout is inadequate. Sediment has accumulated to depths in excess of one meter in several of these streams (Griffith et al. 1982, unpublished data). In addition to the general lack of physical space, there is a low standing crop of aquatic macroinvertebrates (Griffith et al. 1982, unpublished data), which are the primary source of food for salmonids in Silver Creek. T~~hese conditions cause~~ trout ~~to~~ leave the tributaries during the winter, appar. because of these conditions

The Nature Conservancy, a nonprofit conservation agency, owns a 517 ha ~~area~~ portion of the Silver Creek drainage, including the headwaters. Sediment inputs into the system have gradually been reduced because of an aggressive program to acquire land and secure riparian easements. However, the transport of previously deposited sediment in Silver Creek is hampered by the low stream gradient and insufficient flows. Thus, sediment movement out of the system is likely to occur at a slow rate, and may continue to adversely affect aquatic organisms for a substantial period of time.

Recent innovations in habitat improvement of degraded streams has included the development of equipment for removing sediment from ~~gravel~~ spawning beds of salmon (Mih 1978; ~~U. S. Forest Service 1980, unpublished data~~). The success of gravel cleaning machinery has been variable; however, a vacuum cleaner-type unit developed by the Forest Service has shown promise in restoring spawning gravel at Lolo Creek, Montana (~~unpublished data~~). The use of this equipment to remove substantial amounts of sediment has not been previously examined.

To test the feasibility of using dredging equipment in streams as a method of rehabilitating trout habitat, sediment was removed from experimental sections of a tributary to Silver Creek. The specific objectives of this study were to: (1) assess the abundance of trout and nongame fish in an experimental stream section, (2) assess the winter-holding capacity for trout in an experimental stream section, (3) assess the diversity, abundance, and composition of aquatic macroinvertebrates in an experimental stream section, and (4) assess changes if any, in the species composition and coverage of the substrate by submersed, rooted aquatic macrophytes after sediment removal.

STUDY AREA DESCRIPTION

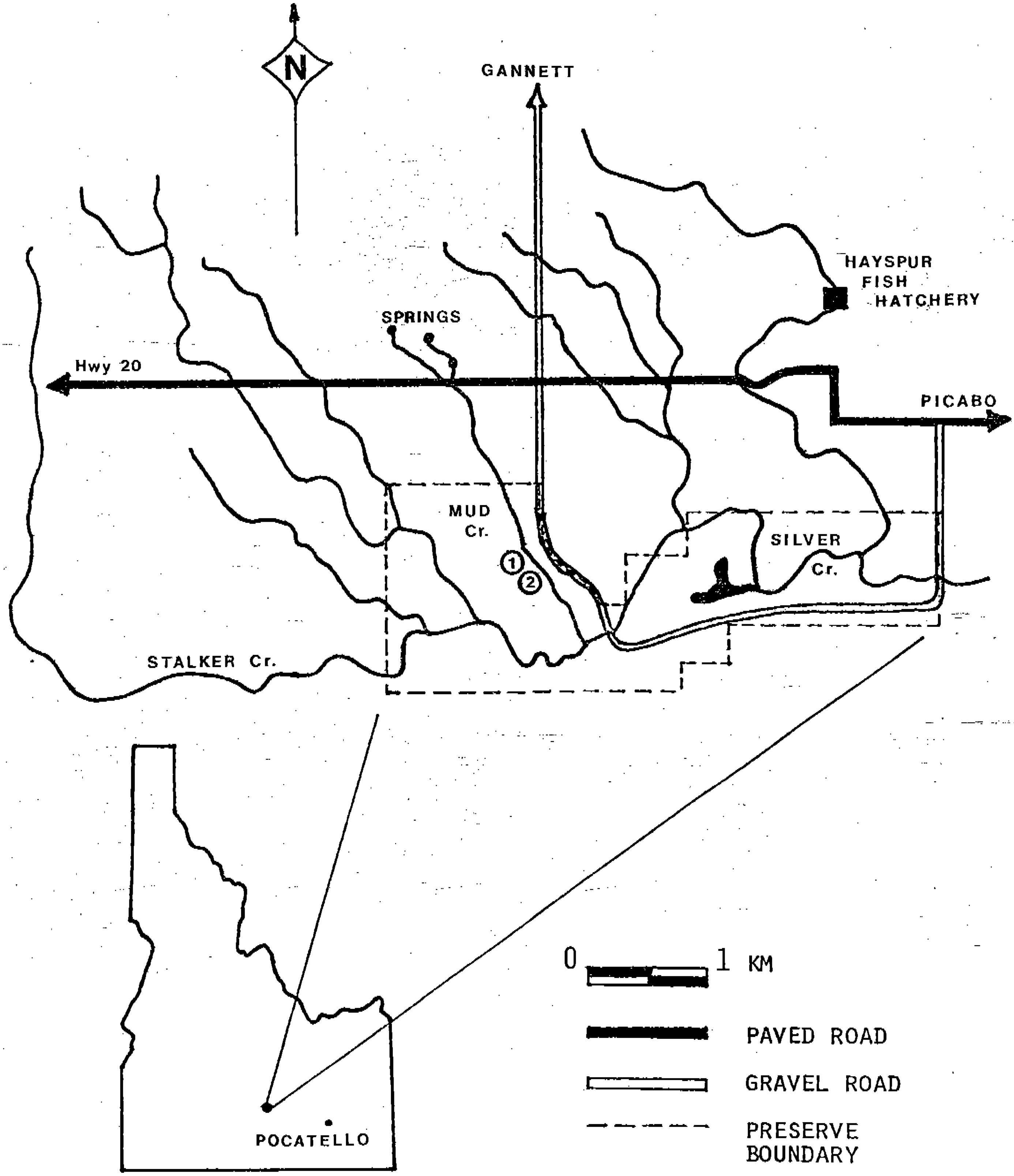
This study was conducted on the Silver Creek Preserve located approximately 10 km west of Picabo, Idaho, in Blaine County (Figure 1). The area is situated in a cool semidesert valley and receives an average annual precipitation of 35 cm. The tributary of Silver Creek studied, Mud Creek, flows approximately 2.5 km from springs downstream to a confluence with Stalker Creek. Mud Creek originates at an elevation of 1490 m, and has a gradient of less than one percent. The stream drains an area of approximately 4.2 km^2 and it has an average width of 4.5 m in the study area.

The hydrograph pattern of Mud Creek has not been measured over the period of a water year; however, the pattern of annual discharge is probably similar to Silver Creek. The lowest flows occur during late spring following spring runoff. The flows increase gradually throughout the summer, reach a peak in October, and then decrease until spring runoff.

The greatest amount of suspended sediment in Mud Creek occurs in early spring with values of about 10 mg/l recorded (Griffith et al. 1982). This is considered to be a minimal value in the Silver Creek system when compared to the larger tributaries such as Stalker and Grove Creeks, where values approximating 100 mg/l have been measured (Manuel et al. 1979).

Figure 1. ~~Map showing~~ Location of the Silver Creek Preserve in Idaho, and the location of study sites (numbers 1 & 2) on Mud Creek. ~~Number 1 = upper study site, and Number 2 = lower study site.~~

also label Grove & Loving Crks


N
GANNETT
HAYSPUR
FISH
HATCHERY
SPRINGS
Hwy 20
PICABO
MUD
Cr.
1
2
SILVER
Cr.
STALKER Cr.
POCATELLO
0
1 KM
PAVED ROAD
GRAVEL ROAD
PRESERVE
BOUNDARY

The substrate is primarily silt, sand, and organic detritus which reaches depths of greater than 1.0 m, and is generally covered to some degree by aquatic macrophytes. There are few areas where exposed gravel exists; much of this gravel is partially imbedded with sediment.

Fish species present in Mud Creek are brook trout (*Salvelinus fontinalis*), rainbow trout (*Salmo gairdneri*), longnose dace (*Rhinichthys cataractae*), speckled dace (*R. osculus*), piute sculpin (*Cottus beldingi*), Wood River sculpin (*C. leiopomis*), and bridgelip sucker (*Catostomus columbianus*). *Cottus leiopomis* was first identified in Mud Creek in 1982, but had previously been identified in Loving Creek near the Hayspur Fish Hatchery (Dick Wallace, personal communication).

The aquatic macroinvertebrate community is typical of streams with a largely depositional substratum. The predominant taxa is generally Diptera (true flies) with Ephemeroptera (mayflies) and Trichoptera (caddisflies) being uncommon (Griffith et al. 1982).

Vegetation growing in Mud Creek is primarily stonewort (*Chara vulgaris*), Sago pondweed (*Potamogeton pectinatus*), and horned pondweed (*Zannichellia palustris*), with species of minor importance being watercress (*Rorippa nastertium-aquaticum*), and mare's tail (*Hippuris vulgaris*).

The riparian area is dominated by grasses (*Poa* spp.), wildrose (*Rosa* sp.), and cinquefoil (*Potentilla* spp.).

The general sparseness of overhanging shrubs and trees facilitates the growth of submersed, rooted aquatic vegetation.

The land adjacent to Mud Creek is largely agricultural. Exposed fields, channelization, and drainage canals have modified this stream basin probably causing increases in sediment.

Two sections of Mud Creek were chosen to be dredged. The first section was located above a road culvert on the Stalker Creek Road and is designated with the number 1 on Figure 1. This experimental section was 35 m long, with sections of equal length immediately upstream and downstream as controls. The length of sections in this study site were selected to take advantage of rock dams placed in the stream in the mid-1950's to create pools. The dams were present at 35 m intervals. A second experimental section (number 2, Figure 1) was situated approximately 40 m downstream from the culvert. It was a gravel area approximately 12 m long which was one-fourth to three-fourths imbedded with sediment.

METHODS AND MATERIALS

Sediment was removed from two experimental sections of Mud Creek using a suction dredge designed by the U. S. Forest Service Missoula Equipment Development Center (MEDC) for cleaning salmonid spawning gravel. A Pacific Pumper Model Mark 3 pump was used. ~~It is an efficient lightweight unit~~ having a capacity of 4.4 l/sec. The pump is driven by a two-cycle air-cooled engine rated at 8.5 horsepower. A 7.5-cm diameter suction nozzle was coupled to a PVC Pardee eductor. Separators were available to remove sediment from water discharge but were not used because infrequent cleaning of the separators was unavoidable.

At both sites, transects were randomly established perpendicular to the stream channel to standardize collection of benthic macroinvertebrate samples with a Hess net. Metal fence posts were placed at the ends of each transect approximately 5 m from the stream bank.

Dredging was initiated at the head of both experimental sections and progressed downstream. Water discharge was pumped onto adjacent land approximately 30 m from the stream where dense vegetation filtered out sediment without problems of it returning to the creek.

Dredging began at the upper experimental section on 9 June 1982 and was completed on 15 June. Sediment was removed down to a firm claypan layer. Gravel was present below this layer; however, it was still 0.6 to 1.0 m down, and dredging deeper was not feasible. Eighty man-hours were required for a two person crew to dredge this 170-m^2 area.

On 29 June, three man-hours were needed to remove sediment from the lower experimental section using a specially adapted gravel cleaning head. Sediment was removed from half of the stream channel and designated as an experimental section; the remaining half of the channel was left unaltered and used as a control.

Physical Measurements

At the upper study site, the experimental and control sections were further divided in order to create a grid system to facilitate the recording of physical measurements. Wooden garden stakes were driven into the banks at every 5.0 m mark on either side of the stream channel. A ~~plastic~~ measuring tape was stretched between stakes and then water and sediment depths were recorded to the nearest centimeter at each 0.5 m ~~mark across the channel~~. Water velocities were also taken at each point using a Marsh-McBirney Model 201 ~~water current~~ meter. These measurements were collected before dredging on 9-10 June, and immediately after on 17-18 June. ~~Physical measurements~~ were ~~further collected~~ on 12 February 1983, 21-22 June 1983, and ~~[illegible]~~ 12 September 1984.

Aquatic Vegetation

A measuring tape was stretched across the stream channel at each set of wooden stakes to assess species composition of aquatic macrophytes. The plant species present directly beneath the tape at every 0.5 m mark was recorded. These data were used to estimate the percentage of stream bottom covered by each plant species.

Before dredging, plant coverage was not systematically measured because vegetation was patchily distributed. However, coverage was estimated visually in the experimental and control sections for each species. On 11 July, plant coverage was recorded in both control sections but not at the experimental section, because dredging had removed all vegetation. On 7 August, cover data were collected in each section since exceptional vegetative growth was present. These data were again collected in the experimental section on 2 October 1982, and final measurements were taken in each section on 13 August 1983.

Aquatic Macroinvertebrates

Benthic macroinvertebrates were quantitatively sampled using a modified Hess net with an area of 0.06 m^2 and a mesh size of 0.39 mm. The net was used to sample the upper 8 to 10 cm of substrate. Before sediment removal at the upper study site, benthic samples were collected from the experimental section, and one of the two control sections. Samples were collected from both sections following dredging on 11 August 1982, 21 November 1982, and 13 February 1983. Four samples per section were collected for a total of 32 samples.

Benthic macroinvertebrate samples were taken at the lower study site before dredging; afterwards, samples were taken every two weeks during July-August 1982. Benthic samples were also taken from the lower study site in October and November 1982, and in February and March 1983. A total of 64 benthic samples were collected at the lower study site.

Drift nets with 0.05 mm mesh size were set on 1 October and 20 November 1982 immediately above both experimental sections to assess abundance of invertebrate species available for colonization of the substrate, and to assess the availability of food organisms for trout. Drift nets were secured to iron bars imbedded in the substratum. Nets were set once during the evening, left in the stream for three hours, and then removed.

All samples were preserved with a 10% formalin solution in the field, and were sorted in the laboratory to separate invertebrates from debris. Organisms were identified to the genus level when feasible using keys by Merritt and Cummins (1978) and Pennak (1978). Data were organized into functional feeding groups (Cummins 1973) using information summarized by Merritt and Cummins (1978) and that found in unpublished reports by aquatic ecologists at Idaho State University (e.g.

Reviews by Elliot (1971) and Resh (1979), and unpublished reports by investigators at Idaho State University on the Silver Creek drainage, were used to establish the sampling scheme and to develop the statistical design. The unpublished reports contained valuable information concerning the seasonal variability inherent in certain invertebrate taxa of the drainage.

Aquatic macroinvertebrate data collected at the lower study site were analyzed with respect to sampling date and sampling station (experimental and control), on the basis of total numbers, individual taxa, and functional feeding group. Analyses of these data were performed using the SAS computer program for two-way analysis of variance (ANOVA). The program for a non-balanced design was utilized because one of the four replicate samples collected from the control area on 20 November 1982 was lost.

Statistical analyses were performed on log (x + 1) transformed abundance data to normalize the data for ANOVA (Elliot 1971).

Fish

Fish populations were monitored before dredging at the upper study site in experimental and control sections using electroshocking gear. Nets were set across the stream channel at the upstream end of each section to block fish movement upstream. A single pass was made through each section with a backpack electroshocking unit producing 250 volts DC that attracted fish to the positive electrode.

Electroshocking samples were collected ~~in~~ two-week intervals during June through August 1982. Fish were also sampled in October and November 1982, and February and March 1983. The weight and total length of trout collected were recorded and scale samples were taken.

Snorkeling was also used to estimate trout abundance. A single count was made in each section at the upper study site ~~in~~ two-week intervals during ~~July~~ through August ~~1982~~. ~~Counts were also done in November 1982, and during the summer of 1983~~.

Friedman's non-parametric two-way analysis of variance by ranks was utilized to test for significant differences in young-of-the-year (YOY) and older (~~age I+ to maximum age group~~) brook trout abundance between sections (Zar 1974). Statistical tests were performed ~~separately for~~ data collected by electroshocking ~~and snorkeling~~. If a significant X^2 value was detected, a non-parametric multiple comparison among rank sums was used to determine which sections were different (Zar 1974). The significance level set for the analyses was 0.05.

Age and Growth

Aging of trout was accomplished by scale analysis using a modified Bausch and Lomb Tri-Simplex projector

(Phillips 1974). Wet mounts of scales were viewed at 93x magnification. Body-scale regressions and back-calculations of body lengths at annuli were performed using the Applesoft program DISBCAL (Frie 1982). For brook trout scale data, the traditional Lee option with a 30 mm constant correction factor was used for all back-calculations (Carlander 1981). For rainbow trout scale data, the correction factor used was ~~estimated~~ obtained from the body-scale regression.

RESULTS

Upper Study Site

Physical Changes

Mean water depth was doubled to 58 cm and mean sediment depth decreased by 66% in the experimental section after dredging (Table 1). Sediment was removed until a firm claypan layer was exposed. This layer was virtually impenetrable by the suction dredge and no attempt was made to remove additional material. Undercut banks which were imbedded with sediment were restored to create additional cover for fish.

Before dredging, water depth was less than 50 cm in about 88% of the experimental section. This area had little cover or space for larger trout throughout the entire 35 m length. After dredging, water depth was less than 50 cm in only 24% of the section.

Maximum water depth did not increase after dredging. The deepest point of the experimental section had sediment depths in excess of 1.0 m prior to dredging. This area quickly filled in with surrounding material during dredging, and no additional effort was expended at this point of the stream. However, total water volume of the entire experimental section was increased by 100%.

Table 1. Physical characteristics of the upper Mud Creek experimental section before and after dredging.

	Mean Sediment Depth (cm)	Mean Water Depth (cm)	Maximum Water Depth (cm)	Mean Water Velocity (cm/sec)	Volume (m^3)
Before	73	29	84	19	50
After	25	58	84	12	100

Dredging did not expose gravel but instead a compacted clay was found. Underneath this clay was marl interspersed with silt and sand and then another claypan layer. Organic matter present was primarily dead plant material.

Changes in the flow of ground water or springs emerging into this section after dredging were not directly measured. However, there was no evidence that ground water flow and spring seepage increased.

Sediment Redeposition

No appreciable amount of redeposition of sediment occurred up to 12 February 1983. The longevity of the project was contingent upon the rate of refilling and length of time before the section reverted to predevelopment conditions. This trend of no significant redeposition continued during a very gradual spring runoff in 1983.

A major storm event occurred on 3 June 1983 with a series of severe thunderstorms passing through the Picabo Valley. Total precipitation for the Picabo area is not available for this date; however, in Ketchum, amounts ranging from 2.5 to 4.0 cm were measured. Stream flow and water turbidity were unusually high in Mud Creek after the storms. The stream was bank full with water flowing over the road culvert located between the two study sites.

An estimated 13 cm of sediment was redeposited ~~in~~ throughout the experimental section during June 1983. Mean sediment depth in the experimental section increased from 25 cm to 38 cm. Mean sediment depth in the upper and lower controls was 47 cm and 58 cm respectively, a decrease from predredging values of 8 cm and 5 cm respectively.

Approximately 25 cm of sediment was redeposited during a two year period after dredging~~, or about 12.5 cm/yr.~~ Sediment depths in the upper and lower controls averaged 37 cm and 51 cm respectively by 12 September 1984.

Aquatic Vegetation

Dredging completely eliminated all macrophytes in the experimental section and regrowth afterwards was slow. Substantial growths of aquatic vegetation were present in the experimental section by August 1982. Cover data for the three dominant plant species at the upper Mud Creek study site, 1982-1983, are found in Table 2.

Potamogeton was the predominant plant species present in the experimental section before dredging. Afterwards, *C. vulgaris* grew rapidly and was the most abundant species by October. Both *P. pectinatus* and *Z. palustris* declined by a large percentage (Table 2).

By November, nearly all rooted aquatic vegetation was absent from Mud Creek except for scattered beds of *Chara*. The high flows present at this time washed all dead plant material downstream.

Table 2. Percent of stream bottom covered by aquatic plant species in the experimental and control sections at the upper Mud Creek study site, 1982–1983.

Date	Percent of Section Covered		
	Upper Control	Experimental	Lower Control
Aug 1982			
C. vulgaris	45	3	70
P. pectinatus	18	73	24
Z. palustris	37	23	6
Oct 1982[a]			
C. vulgaris	—	61	--
P. pectinatus	—	39	--
Z. palustris	—	0	--
Aug 1983			
C. vulgaris	85	99	100
P. pectinatus	15	1	0
Z. palustris	0	0	0

[a] Cover data not collected from control sections

Chara growth in the experimental section was dense by mid-April with no other vegetation present. *Potamogeton* appeared in late May, but not in the dense stands seen in 1982. *Zannichellia* was completely absent from the experimental section in 1983.

Fish

Brook trout were numerically the most abundant fish species present in Mud Creek. Before dredging, the numerical density of fish other than trout was in the following order from highest to lowest: speckled dace, longnose dace, bridgelip sucker, piute sculpin, and Wood River sculpin.

Nongame Fish Species

Sediment removal had a temporary negative effect on the numbers of nongame fish species (Table 3). The immediate results of dredging were not seen since densities between sections were not very different. However, nongame species did not increase in number in the experimental section as they did in the control sections. By late July, densities of nongame fish were approximately 9 to 14 times greater in the lower and upper control respectively, than ~~they were~~ in the experimental section. Numbers declined drastically during the winter with the die off of aquatic vegetation.

Table ?. Density of nongame fish species in upper Mud Creek study site collected by electrofishing, 1982-1983.

	Nongame Fish Density (no./35 m)											
	Lower Control				Experimental				Upper Control			
Date	Dace	Sculpin	Sucker	Tot.	Dace	Sculpin	Sucker	Tot.	Dace	Sculpin	Sucker	Tot.
10 Jun 1982	57	6	7	70	23	4	0	27	18	4	0	22
DREDGING												
26 Jun 1982	48	3	2	53	70	2	5	77	85	1	3	89
14 Jul 1982	79	12	13	104	76	1	5	82	124	3	5	132
30 Jul 1982	125	7	36	168	6	1	5	12	90	1	12	103
2 Oct 1982	7	5	13	25	0	1	0	1	28	2	14	44
21 Nov 1982	4	3	2	9	0	0	0	0	0	0	0	0
12 Feb 1983	11	5	1	17	6	0	0	6	0	0	0	0
16 Mar 1983	3	0	3	6	0	0	1	1	2	1	0	3

Nongame fish were abundant in the experimental section during the late spring ~~through~~ and summer of 1983, and were strongly associated with the dense growths of macrophytes. No attempt was made to count them while snorkeling.

Brook Trout

The density of brook trout declined by 60% in the experimental section immediately following dredging (Table 4). Densities remained low through the summer and were similar between sections. In October, brook trout numbers increased, particularly the numbers of larger fish in the experimental section. Sixty-six brook trout were collected in the experimental section in late November, while only six and nine were collected in the lower control and upper control respectively. Approximately 100 to 150 brook trout were observed from the bank in the experimental section in January 1983 (Guy Bonnivier, personal communication). However, the non-parametric ANOVA ~~revealed~~ indicated no significant difference in brook trout abundance between sections (X^2=3.62, 2 df).

Numbers of YOY brook trout declined by almost two-thirds in the experimental section following dredging (Table 4). Young-of-the-year brook trout were not abundant in any section after dredging. Brook trout YOY were not significantly different in abundance between sections (X^2=2.24, 2 df) from July 1982 to March 1983.

Numbers

Table 4. Density of brook trout in upper Mud Creek study site collected by electrofishing, 1982-1983.

	Lower Control			Experimental			Upper Control		
Date	≤109 mm	>109 mm	Tot.	≤109 mm	> 109 mm	Tot.	≤109 mm	>109 mm	Tot.
10 Jun 1982	10	3	13	24	6	30	24	2	26
DREDGING									
26 Jun 1982	16	1	17	9	3	12	9	0	9
14 Jul 1982	25	1	26	9	9	18	28	1	29
30 Jul 1982	20	3	23	12	8	20	21	0	21
2 Oct 1982	21	6	27	12	20*	32	22	7	29
21 Nov 1982	5	1	6	18	48	66	8	1	9
12 Feb 1983	3	0	3	3	0	3	0	0	0
16 Mar 1983	1	2	3	0	2	2	1	0	1

* Number of brook trout > 109 mm total length underestimated by 25-30 because fish escaped collection by electrofishing gear.

Abundance of age-I and older brook trout was significantly different between sections (X^2=12.08, 2 df). Significantly greater numbers of these larger fish were present in the experimental section than in either control (multiple comparison test for ranked data in a randomized block).

Snorkeling counts performed in the summer of 1983 revealed very few larger fish (Table 5). Most fish observed were YOY brook trout which, except for 5 June, were most abundant in the experimental section.

Snorkeling also revealed distinct habitat differences between YOY and larger brook trout. Young-of-the-year generally preferred shallow areas with overhead streambank cover or submerged vegetation, while the larger trout were generally associated with deeper, more open areas.

Rainbow Trout

Rainbow trout were not abundant in Mud Creek and never comprised a significant part of any sample. There was a trend for rainbow trout numbers to increase in the fall and winter but not substantially. Infrequently, large (254 mm to 381 mm) rainbow trout were observed while snorkeling the experimental section. These fish were generally in the deeper water of the experimental section.

Age and Growth

Back-calculated lengths at age for brook trout using the 30 mm body-scale constant are found in Table 6. The

Table 5. Numbers of brook trout per 35-m stream section in the upper Mud Creek study site observed by snorkeling, 1983.

	Number of Brook Trout		
Date	Lower Control	Experimental	Upper Control
5 Jun	21	46	59
30 Jun	14[a]	41	41[a]
14 Jul	30[a]	31[a]	31[a]
28 Jul	39	61	13
13 Aug	34	61	37[a]

[a]one to several fish larger than 109 mm observed

Table 6. Back-calculated total lengths and increments of growth for brook trout collected in 1982 and 1983 from the upper Mud Creek study site.

Age Group	No. fish	Mean length at capture (mm)	Computed mean length at each annulus (mm)		
			1	2	3
I	53	149.11	106.54		
II	14	197.71	116.02	165.24	
III	3	269.00	122.12	194.75	247.35
Weighted mean length			109.10	170.44	247.35
Mean growth increment			109.10	53.34	52.60
Number of fish			70	17	3

brook trout sampled ranged from 84 mm to 327 mm total length. Brook trout exceeding 300 mm in length were difficult to capture, necessitating the use of a small sample of larger fish in back-calculations.

Rainbow trout growth data are found in Table 7. The rainbow trout sampled ranged in size from 80 mm to 242 mm.

Aquatic Macroinvertebrates

Invertebrate abundance

Chironomidae was the most abundant taxa present at either section before dredging (Table 8), comprising 83% and 57% of total abundance at the experimental and control sections respectively. Seventeen invertebrate taxa were identified from benthic samples collected at the upper study site.

Approximately two months after dredging, the invertebrate fauna at the experimental section was almost nonexistant except for chironomids, which made up nearly 95% of total abundance. By November, the mean abundance of macroinvertebrates rose to almost 3,300 organisms/m^2, approximately two and one-half times that found in August. Of this figure, chironomids comprised 90%, and *Baetis parvus/tricaudatus* comprised about eight percent. Invertebrate numbers peaked in February at approximately 4,100/m^2. Chironomids were again the predominant taxa and comprised 93% of

Table 7. Back-calculated total lengths and increments of growth for rainbow trout collected in 1982 and 1983 from the upper Mud Creek study site.

Age Group	No. fish	Mean length at capture (mm)	Computed mean length at each annulus (mm)		
			1	2	3
I	18	98.28	89.12		
II	3	172.00	94.99	139.54	
III	3	224.66	102.86	150.92	197.64
Weighted mean length			91.58	145.23	197.64
Mean growth increment			91.58	46.30	46.71
Number of fish			24	6	3

Table 8 . Mean ($\bar{x}$) and standard deviation (SD) of benthic invertebrate abundance (no./m^2) arranged by functional feeding group as collected from the experimental and lower control section of the upper Mud Creek study site, 1982-1983.

	Experimental		Control	
	$\bar{x}$	SD	$\bar{x}$	SD
9 Jun 1982				
Scrapers				
Baetis parvus/tricaudatus	28	35	68	98
Helicopsyche borealis	--	--	8	16
Fluminicola	4	8	4	8
Gyraulus	8	16	16	32
Hydroptila	--	--	4	8
Total	40		100	
Gatherers				
Paraleptophlebia debilis	--	--	--	--
Tricorythodes minutus	--	--	8	16
Total	--		8	
Miners				
Chironomidae	1808	944	2856	2884
Tubificidae	16	22	724	526
Total	1824		3580	
Filterers				
Simulium	--	--	--	--
Pisidium	40	53	716	1180
Total	40		716	
Shredders				
Gammarus lacustris	223	253	496	673
Haliplus	--	--	--	--
Total	223		496	

This can go on a single table - will need a fold-out page

9 June 1982 11 Aug 21 Nov 13 Feb

taxon expt control

28(35) 68(98) ← put SD in ( )

Table 8 . Continued

Predators				
Oecetis	8	9	36	42
Ischnura	16	22	4	8
Sialis	--	--	--	--
Hirudinea	28	27	88	154
Total	44		92	
Grand Total	2171		4992	
11 Aug 1982				
Scrapers				
Baetis parvus/tricaudatus	--	--	728	760
Helicopsyche borealis	--	--	--	--
Fluminicola	--	--	--	--
Gyraulus	--	--	--	--
Hydroptila	--	--	--	--
Total	--		728	
Gatherers				
Paraleptophlebia debilis	--	--	24	28
Tricorythodes minutus	16	32	508	330
Total	16		532	
Miners				
Chironomidae	1348	398	680	117
Tubificidae	40	9	264	143
Total	1388		944	
Filterers				
Simulium	--	--	4	8
Pisidium	--	--	--	--
Total	--		4	
Shredders				
Gammarus lacustris	--	--	248	433
Haliplus	4	8	24	28
Total	4		272	

Table 8 . Continued

Predators				
Oecetis	--	--	--	--
Ischnura	--	--	--	--
Sialis	8	9	4	8
Hirudinea	4	8	176	148
Total	12		180	
Grand Total	1420		2660	
21 Nov 1982				
Scrapers				
Baetis parvus/tricaudatus	264	194	888	482
Helicopsyche borealis	4	8	16	13
Fluminicola	--	--	--	--
Gyraulus	--	--	--	--
Hydroptila	8	16	--	--
Total	278		904	
Gatherers				
Paraleptophlebia debilis	--	--	--	--
Tricorythodes minutus	4	8	--	--
Total	4		--	
Miners				
Chironomidae	2868	1929	4412	2120
Tubificidae	96	132	664	261
Total	2964		5076	
Filterers				
Simulium	4	8	40	42
Pisidium	12	24	48	39
Total	16		88	
Shredders				
Gammarus lacustris	--	--	84	110
Haliplus	8	16	28	27
Total	8		112	

Table 8. Continued

Predators				
Oecetis	--	--	4	8
Ischnura	12	24	160	140
Sialis	4	8	8	9
Hirudinea	--	--	204	162
Total	16		372	
Grand Total	3286		6552	
13 Feb 1983				
Scrapers				
Baetis parvus/tricaudatus	124	46	1082	768
Helicopsyche borealis	--	--	8	9
Fluminicola	--	--	--	--
Gyraulus	--	--	8	16
Hydroptila	--	--	--	--
Total	124		1098	
Gatherers				
Paraleptophlebia debilis	--	--	--	--
Tricorythodes minutus	--	--	--	--
Total	--		--	
Miners				
Chironomidae	3868	604	4076	1831
Tubificidae	56	50	152	158
Total	3924		4228	
Filterers				
Simulium	16	18	36	52
Pisidium	40	48	124	88
Total	56		160	
Shredders				
Gammarus lacustris	8	16	60	110
Haliplus	4	8	36	27
Total	12		96	

Table 8. Continued

Predators				
Oecetis	--	--	--	--
Ischnura	12	24	52	54
Sialis	16	22	72	134
Hirudinea	--	--	76	66
Total	28		200	
Grand Total	4144		5782	

total abundance, while *Baetis* made up roughly three percent.

Functional feeding groups

you don't use term "collectors" in Table 8

Collectors were the predominant functional feeding group present before dredging (Table 8). Miners were the most abundant subgroup of collectors comprising 84% of the invertebrate community, while shredders made up 10%. Scrapers and filterers were absent from samples nearly two months after dredging. Except for miners, other functional groups were poorly represented in August.

Miners continued to be the predominant group of invertebrates present at the experimental area into November and February, while scrapers comprised no greater than eight percent of total abundance.

Lower Study Site

Aquatic Macroinvertebrates

Taxonomic richness and total abundance

A total of 32 taxa were identified in benthic samples collected from the lower Mud Creek study site (~~Table~~ Appendix 1). Of these, representatives from two families (Chironomidae, Corixidae) and one order (Hirudinea) were not keyed to genus.

Richness values were generally higher for control samples (Table 9), but several genera were represented by only a few individuals. There was no discernible trend for the number of taxa to increase in the experimental area after dredging. Seasonally, fewer taxa were present in both areas during the late summer than in fall or winter.

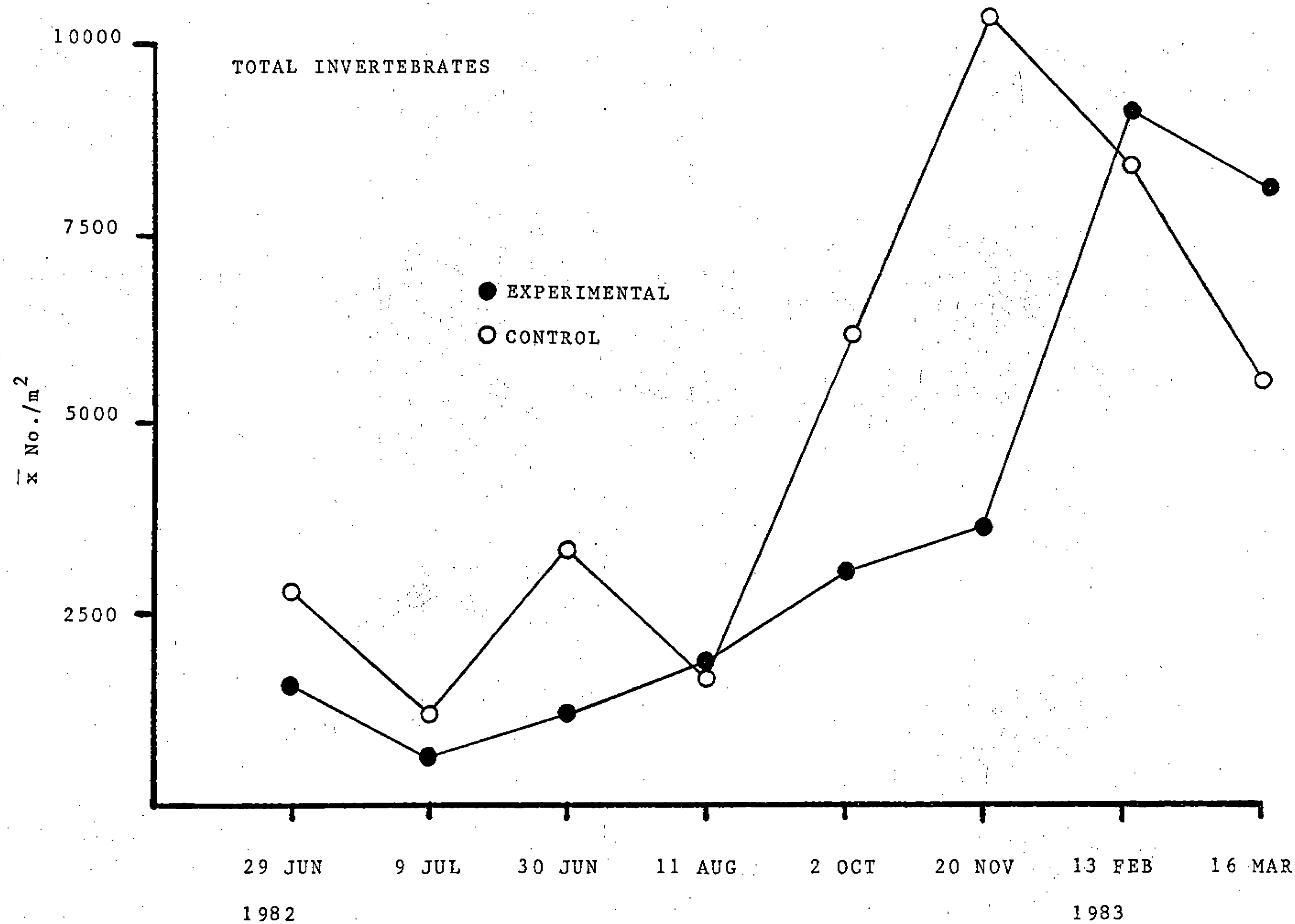
Although it ~~was assumed~~ had been expected that the benthic community ~~was~~ would be virtually eliminated in the experimental area after dredging, a mean of almost 1000 organisms/m^2 was already present 10 days later. Total mean numbers of the benthic macroinvertebrate community sampled at the lower Mud Creek site are found in ~~Table~~ Appendix 1.

Macroinvertebrate numbers continued to increase on the experimental area after dredging (Figure 2). Numbers of macroinvertebrates were consistently lower

Table 9. Richness (number of macroinvertebrate taxa) values for the experimental and control halves of the lower Mud Creek study site, 1982-1983.

Date	Richness: Experimental	Richness: Control
29 Jun 1982	19	24
9 Jul 1982	15	20
30 Jul 1982	16	19
11 Aug 1982	16	15
2 Oct 1982	20	25
20 Nov 1982	19	23
13 Feb 1983	17	21
16 Mar 1983	25	22

Figure 7. Mean densities of aquatic macroinvertebrates per sampling date at the experimental and control sections at the lower Mud Creek study site, 1982-1983.


TOTAL INVERTEBRATES
EXPERIMENTAL
CONTROL
10000
7500
5000
2500
x̄ No./m²
29 JUN
9 JUL
30 JUN
11 AUG
2 OCT
20 NOV
13 FEB
16 MAR
1982
1983

at the experimental area than at the control area; however, this trend was reversed in late winter when macroinvertebrate abundance dropped precipitously in the control area from a mean of over 10,000 organisms/m^2 in Noverber 1982, to less than 6,000/m^2 by mid-March 1983. During this same period, densities of macroinvertebrates supported on the experimental area peaked at approximately 9,400 organisms/m^2 in February, and dropped slightly to over 8,600 organisms/m^2 by March.

Results of the ANOVA procedures performed on log (x + 1) transformed density data, indicated significant differences between locations and among seasons. There were significantly fewer organisms/m^2 present at the experimental area than at the control area during the study (F= 8.11, df =1,6). There were also significant differences in total macroinvertebrate abundance among seasons within both the experimental and control areas. Mean densities of benthic invertebrates were significantly higher during the fall through winter period than in the summer (SNK multiple range test).

Composition

Composition of the macroinvertebrate community at the lower Mud Creek site are found in Table .

Diptera (primarily Chironomidae) was the dominant order present at the lower study site before dredging, comprising 54% and 57% of the total numbers of macroinvertebrates at the experimental and control areas respectively. Following dredging, dipterans remained the dominant group in both areas, while ephemeropterans and trichopterans made up small percentages. By October 1982, dipterans comprised less than 10% of the total number of invertebrates present at the experimental area, while making up nearly 37% of control area densities. Dipteran abundance remained low at the experimental area during all subsequent sampling. Conversely, dipterans generally comprised a substantial percentage of total numbers in the control area.

Ephemeropterans increased in abundance at the the control area in about late July through August, yet lagged behind at the experimental area until early October, at which time they increased. Ephemeroptera and Trichoptera became the dominant orders present at the experimental area in fall through winter samples, making up 25% to 70% and 14% to 46% respectively of the total number of macroinvertebrates. Concurrently, at the control area, the percentage of total numbers comprised of ephemeropterans was only 13% to 54% and 3% to 12% respectively.

Individual taxa abundance

Six of the 10 major taxa analyzed with ANOVA exhibited significant differences in abundance between sites only, and ~~seven~~ eight of 10 showed significant differences among sampling dates (Table 10). Only one taxa, Optioservus quadrimaculatus, exhibited no significant difference in abundance. In ~~five~~ six of the analyses, a significant interaction between variables existed, suggesting a possible synergistic effect of site and season. Mean abundance values for individual taxa are found in ~~Table~~ Appendix 1.

Functional feeding groups

Predators and shredders were significantly different in abundance between sites; filterers, gatherers, and scrapers were significantly different among sampling dates, and miners exhibited significant differences within both variables (Table 11). No significant interaction between variables was detected in any case. Totals of mean densities for functional feeding groups are found in ~~Table~~ Appendix 1.

Collectors predominated the macroinvertebrate community before dredging, followed by scrapers, predators, and shredders (Table 12). Collectors remained the predominant functional group in both areas until November, ~~where~~ when scrapers were predominant in the experimental area followed by collectors. Except

Table . Results of the two-way analysis of variance procedures for the 10 most abundant taxa of benthic macroinvertebrates from the lower Mud Creek study site, 1982-1983. Significant differences (P=0.05) are denoted by an asterisk (*).

Taxon	Source	Degrees of Freedom	F Value	P>F
Baetis parvus/*tricaudatus*	Site	1	0.37	0.5466
	Date	6	14.20	0.0001*
	Interaction	6	0.69	0.6622
Chironomidae	Site	1	25.78	0.0001*
	Date	6	2.12	0.0710
	Interaction	6	2.34	0.0493*
Fluminicola sp.	Site	1	13.82	0.0006*
	Date	6	8.70	0.0001*
	Interaction	6	12.13	0.0001*
Gammarus lacustris	Site	1	27.64	0.0001*
	Date	6	1.86	0.1111
	Interaction	6	0.54	0.7752
Helicopsyche borealis	Site	1	1.70	0.2000
	Date	6	16.42	0.0001*
	Interaction	6	2.97	0.0169*
Hirudinea	Site	1	9.23	0.0042*
	Date	6	5.08	0.0006*
	Interaction	6	2.88	0.0200*
Hydropsyche sp.	Site	1	9.95	0.0030*
	Date	6	2.68	0.0275*
	Interaction	6	3.61	0.0057*

Table 10. Continued

<u>Optioservus quadrimaculatus</u>	Site	1	0.01	0.9134
	Date	6	3.42	0.0079*
	Interaction	6	1.09	0.3836
<u>Tricorythodes minutus</u>	Site	1	1.00	0.3224
	Date	6	3.86	0.0039*
	Interaction	6	2.59	0.0321*
<u>Tubifex tubifex</u>	Site	1	6.56	0.0142*
	Date	6	2.59	0.0320*
	Interaction	6	0.57	0.7504

Table 11. Results of the two-way analysis of variance procedures for functional feeding groups of benthic macroinvertebrates from the lower Mud Creek study site, 1982-1983. Significant differences (P=0.05) are denoted by an asterisk (*).

Functional Group	Source	Degrees of Freedom	F Value	P>F
Collectors:				
Filterers	Site	1	0.01	0.9224
	Date	6	4.93	0.0007*
	Interaction	6	0.77	0.5979
Gatherers	Site	1	2.73	0.1062
	Date	6	2.90	0.0185*
	Interaction	6	1.73	0.1377
Miners	Site	1	39.10	0.0001*
	Date	6	2.50	0.0376*
	Interaction	6	2.16	0.0671
Scrapers	Site	1	0.01	0.9049
	Date	6	26.01	0.0001*
	Interaction	6	0.79	0.5834
Predators	Site	1	19.79	0.0001*
	Date	6	1.74	0.1357
	Interaction	6	1.70	0.1448
Shredders	Site	1	11.36	0.0016*
	Date	6	1.48	0.2103
	Interaction	6	1.18	0.3378

Modify this as suggested for Table 8

Table 12. Functional feeding group composition (percent of total abundance) of the benthic macroinvertebrate community collected from the experimental and control areas of the lower Mud Creek study site, 1982-1983.

	Experimental	Control
29 Jun 1982		
Collectors	(77)	(76)
Filterers	6	5
Gatherers	7	9
Miners	64	62
Scrapers	20	19
Predators	2	3
Shredders	1	2
9 Jul 1982		
Collectors	(63)	(67)
Filterers	10	3
Gatherers	6	9
Miners	47	55
Scrapers	34	28
Predators	1	2
Shredders	1	3
30 Jul 1982		
Collectors	(77)	(70)
Filterers	5	4
Gatherers	3	7
Miners	69	59
Scrapers	20	28
Predators	2	1
Shredders	1	1
11 Aug 1982		
Collectors	(64)	(49)
Filterers	6	3

Table 12. Continued

Gatherers	1	2
Miners	57	44
Scrapers	35	46
Predators	0.5	2
Shredders	0.5	2
2 Oct 1982		
Collectors	(52)	(60)
Filterers	36	20
Gatherers	3	6
Miners	13	34
Scrapers	46	31
Predators	1	4
Shredders	1	5
20 Nov 1982		
Collectors	(31)	(54)
Filterers	17	31
Gatherers	2	1
Miners	12	22
Scrapers	68	41
Predators	0.1	3
Shredders	0.9	1
13 Feb 1983		
Collectors	(20)	(39)
Filterers	8	3
Gatherers	4	2
Miners	8	34
Scrapers	79	57
Predators	0.5	2
Shredders	0.5	1

Table . Continued

16 Mar 1983		
Collectors	(20)	(54)
Filterers	8	13
Gatherers	3	1
Miners	9	40
Scrapers	82	34
Predators	< 0.5	2
Shredders	< 0.5	10

for February, the collectors were the most abundant group present at the control area. Scrapers increased in abundance at the experimental area from late July up until the final sampling period in March, where they comprised 82% of the invertebrate community. Shredders and predators typically comprised no greater than 5% of total abundance.

Among the collectors, the miners constituted the main subgroup at the control area except for November. Miners were ~~also~~ the dominant subgroup of collectors present at the experimental area until October, when filterers assumed predominance.

Drift

A total of 13 invertebrate taxa were identified from drift samples taken in October and November 1982 (Table 13). Approximately three times as many invertebrates were collected in the drift in early October, as opposed to late November.

Baetis spp. were the predominant macroinvertebrate drifting downstream in October and November, comprising 87% and 79% of total abundance respectively of drift samples.

Diptera, including the family Chironomidae, made up 10% of total abundance in the October drift sample. However, in November, dipterans were scarce in the drift and comprised less than one percent of total abundance.

Simulium sp. increased in the drift more than four-fold in November. Other taxa were uncommon in drift samples.

Table 15. Abundance of aquatic macroinvertebrate taxa collected from the drift in Mud Creek, 1 October and 20 November, 1982.

Taxa	October Total No.	November Total No.
Coleoptera	3	2
Corixidae	1	1
Euparyphus sp.	3	--
Trichoptera	8	4
Hirudinea	1	--
Simulium sp.	25	113
Diptera	211	4
Collembola	1	--
Baetis spp.	1750	492
Tricorythodes sp.	1	--
Paraleptophlebia sp.	6	1
Hyalella sp.	2	2
Hydracarina	--	3
Unknown	2	2
Totals	2014	620

DISCUSSION

This study was initiated to quantify the responses of stream organisms to sediment removal, and to assess the utility of hydraulic dredging in streams as a method of rehabilitating salmonid habitat. No previous investigators have assessed changes in the biotic community of a fluvial system following sediment removal with dredging equipment. Carline and Brynildson (1977) studied the effects of hydraulic dredging on the aquatic biota and the physico-chemical characteristics of Wisconsin spring ponds. Andersson et al. (1975) and Wilbur and Langford (1972) documented changes in lake benthos after dredging. Complete and reliable data on the biotic component of lotic systems are lacking in dredging projects. Hopefully, results from this study will prompt further investigation and the development of more refined and efficient dredging equipment for use in lotic environments.

Upper Study Site

Aquatic Macrophytes

One of the major physical effects of hydraulic dredging was the temporary elimination of aquatic macrophytes. Potamogeton was the only vegetation directly affected because it was the only species present during dredging. Although Potamogeton was removed by dredging, it grew back in approximately two months as did Chara and Zannichellia.

The removal of the majority of fine sediment from the substrate did not have a detrimental effect on growth of Chara. Chara responded by increasing the percentage of substrate covered. Although Chara generally grows better in shallow water (Carline and Brynildson 1977), the increase in mean water depth at the experimental section did not adversely affect Chara growth. Chara spp. can grow in water reaching 20 m in depth (Prescott 1978).

Submersed macrophytes tend to stabilize sediment, both by the presence of roots, and by reducing water velocity, which causes an acceleration of sediment deposition (Davis and Brinson 1980). Francis and Bjornn (1979) suggested that sediment may be necessary in certain amounts for Chara to establish good root systems and form large beds. Chara did not grow well on exposed claypan until minor amounts of sediment were redeposited; it then readily established itself on the substrate of the experimental section.

By decreasing water velocity and thereby creating a pool environment, optimum conditions for Chara were established. Chara spp. are found primarily in hard water or alkaline lakes and slowly-flowing streams where calcium is abundant (Prescott 1978). The total hardness in the Silver Creek system, or the amount of magnesium and calcium carbonate ions in solution, generally is around 200 mg/l (Francis and Bjornn 1979).

Carline and Brynildson (1977) reported increases in magnesium concentrations after dredging in two Wisconsin spring ponds. Although this would be difficult to monitor in flowing water, dredging may have caused a local release of ions which were incorporated in the sediment and that may have been beneficial to *Chara* growth.

Potamogeton pectinatus is a tolerant species normally dominant or subdominant in disturbed systems (Davis and Brinson 1980). *Potamogeton* may also survive high levels of urban pollution. In Silver Creek, *Potamogeton* grows best in silted areas suggesting that sediment is necessary for a strong, healthy root system.

The observed decrease in area covered by *Potamogeton* following dredging indicates that removing most of the deep organic substrate was detrimental to *Potamogeton*. This plant has a fairly extensive rhizome system and may require the soft organic sediment for optimum growth.

Zannichellia palustris is a tolerant species normally present in low standing crops in disturbed systems (Davis and Brinson 1980). It can tolerate turbid conditions; however, even in undisturbed systems, it generally contributes minor amounts of biomass to the macrophyte community (Davis and Brinson 1980).

Zannichellia growth was minimal in the experimental section after dredging. This plant possesses a slender rhizome and the lack of a fine sediment substrate excluded this species from the experimental section.

Several factors may be responsible for the shift observed in the aquatic macrophyte community of Mud Creek following dredging. Firstly, photosynthesis generally responds to increases in light intensities with a rapid, nearly linear increase at low levels, followed by a leveling off at higher intensities (Davis and Brinson 1980). At higher intensities, the photosynthetic mechanism is "light saturated." No additional increases in photosynthetic rates result from additional light energy. In clear shallow waters, the photosynthetic mechanism of C. vulgaris may only be saturated at high light intensities. Chara vulgaris may therefore possess the potential for even higher photosynthetic rates, while other species have reached their maximum output. The rapid growth of Chara observed may have resulted in virtual control over such resources as nutrients and sunlight which would exclude competitors.

Secondly, the sediments in Mud Creek probably store elements critical to macrophyte growth. The temporary removal of this source by dredging may have retarded plant growth. As *Chara* grew more rapidly than the other species, it secured most of the remaining nutrients, and those deposited later.

Thirdly, the seeds and flowers of *Zannichellia* and *Potamogeton* are important food items for ducks (Prescott 1969; Fassett 1957). Silver Creek and tributaries are utilized year-round by waterfowl, which at times may number in the thousands. Although no quantitative evidence exists concerning the impact of waterfowl on aquatic plants in Silver Creek, it is suspected that large numbers of waterfowl could have a deleterious effect. Mallards (*Anas platyrhynchos*) and cinnamon teal (*Anas cyanoptera*), both dabbling ducks, were seen in moderate numbers on Mud Creek throughout the season. If ducks select for the more succulent plants such as *Potamogeton* and *Zannichellia*, then *Chara* may be given a competitive advantage.

Fish

Nongame Fish Species

The major factor limiting densities of nongame fish species after dredging ~~was~~ the initial lack of aquatic vegetation. All nongame species ~~inhabited~~ the dense growths of vegetation or ~~were associated with~~ the undercut banks. The decline in dace numbers observed following dredging indicates the importance of aquatic vegetation to their specific habitat ~~and~~

and food requirements.

Longnose dace are benthic fish and are usually associated with current velocities exceeding 45 cm/sec (Bartnik 1970). In Mud Creek, higher velocities are found where water is forced through narrow channels between vegetation beds. Longnose dace were observed near the substrate grazing macroinvertebrates off of vegetation.

Speckled dace prefer shallow, cool and quiet water (Simpson and Wallace 1978). This fish preferred regions near undercut banks and shallow water areas with dense vegetation. Deepening the water in the experimental section did not limit their distribution.

Bridgelip sucker, Piute sculpin, and Wood River sculpin numbers remained fairly stable after dredging. Suckers were generally found in aquatic vegetation, while sculpin tended to inhabit the shallow regions near undercut banks.

Temperature and flow are water quality parameters which indirectly limit the numbers of nongame fish species in Mud Creek because they have a direct effect on vegetation. Aquatic vegetation plays several important roles in the biology of nongame fish found in Mud Creek. The dense beds of vegetation serve as cover from possible predators, as substrate for food organisms, and as a determinant of water velocity near the substratum. Following the die off of aquatic vegetation, most nongame fish were overwintering in deep undercut banks restored by dredging. Rehabilitating this habitat was beneficial not only to trout, but to nongame fish species as well.

Trout

A primary objective of this study was to increase living space for trout in an experimental section of Mud Creek, particularly overwintering habitat, since this was a major factor limiting trout densities. This has been suggested by previous investigators (e.g. Everest 1969). ~~Suitable overwintering~~ habitat for trout in Mud Creek such as undercut banks, deep water, and a rubble-boulder substrate is generally lacking.

Trout densities increased substantially in the experimental section after dredging, particularly during the winter. The increased mean water depth and undercut bank cover made the area more suitable for wintering trout. Water depth has been shown to be one of the most important parameters relating to carrying capacity of salmonids in small streams (Hunt 1976; Lewis 1969). This parameter becomes increasingly important in winter when adult trout move into deeper water (Lewis 1969; Hunt 1974). Carline and Brynildson (1977) reported that in northern Wisconsin ponds with mean water depths of

Insert after Trout

Sampling efficiency

Electrofishing with a backpack unit in Mud Creek proved to be relatively ineffective at collecting trout. The exceptional clarity of the water, the dense vegetation, and the small electric field created by the shocker, all hampered efforts to capture fish. Although sampling with the backpack unit was successful in November, this generally was not the case. Trout usually avoided the positive electrode by swimming downstream around the individual wearing the shocking equipment.

Typically, trout were too abundant to prevent them from escaping capture. The stream was large enough so that a single individual could not effectively cover the entire width of the channel with the elecrode. However, to be consistent, electrofishing was conducted through March to allow for statistical analysis of abundance data.

Snorkeling was used in lieu of electrofishing from June through August 1983. A single observer could effectively view the entire width of the stream channel. Snorkeling has proven to be a valuable method in censusing fish populations in some situations (Northcote and Wilkie 1963; Goldstein 1978). Griffith (1981) demonstrated that an underwater observer with prior knowledge of the age and size distribution of a trout population, could effectively estimate the age-frequency distribution for that population. Young-of-the-year trout could be distinguished from older fish in Mud Creek because of minimal overlap in size between the few observed age classes present as determined from electrofishing data. However, underwater observations made from June through August 1983, revealed that the great majority of trout were juvenile fish.

Although the efficiency of the two methods to census trout populations ~~could~~ was not ~~be~~ directly compared, snorkeling appeared to be a more effective method of collecting abundance data ~~data on species composition and abundance~~ in a stream with water quality and physical dimensions such as Mud Creek.

less than 50 cm, living space appeared to be the major factor limiting trout populations. Shuck (1945) found that volume and depth of water were important factors determining population density of brown trout (Salmo trutta) in a section of stream. The number of fish species, including brook and brown trout, in sections of Owego Creek, New York, was most strongly correlated with stream depth (Sheldon 1968).

Suitability Index graphs developed by Raleigh (1982) for adult brook trout, suggest a significant increase in usage of areas with water depths greater than 15 cm (Figure 3). Wesche (1980) also reported that cover for adult brook trout is suitable in water depths greater than 15 cm.

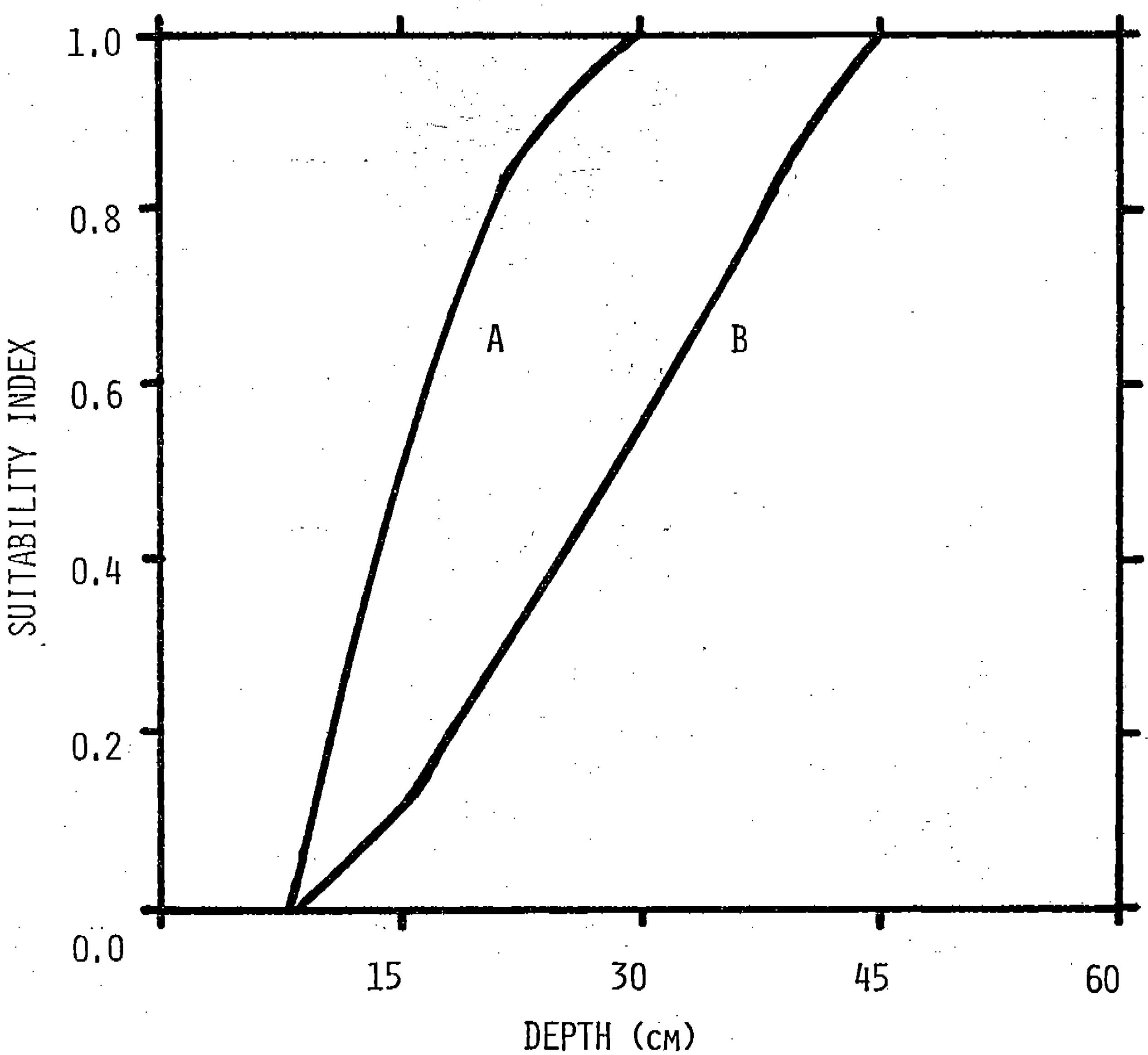
According to generalized probability of use curves developed for adult rainbow trout (Bovee 1978), usage drops from approximately 100% at water depths greater than 65 cm, to 20% or less at water depths less than 35 cm (Figure 4).

The area of the experimental section with water depths greater than 50 cm increased by 64% after dredging. The carrying capacity of this stream section for trout increased in response to the increase in available living space. There was also the greater capacity of this stream section to support wintering trout. Winter holding areas are often limiting to trout survival (Gard 1961a; Hunt 1976). Gard (1961b)

Figure 3. Suitability graph indicating the relationship between average thalweg depth during the late growing season low water period, and the presence of adult brook trout. From Raleigh (1982).

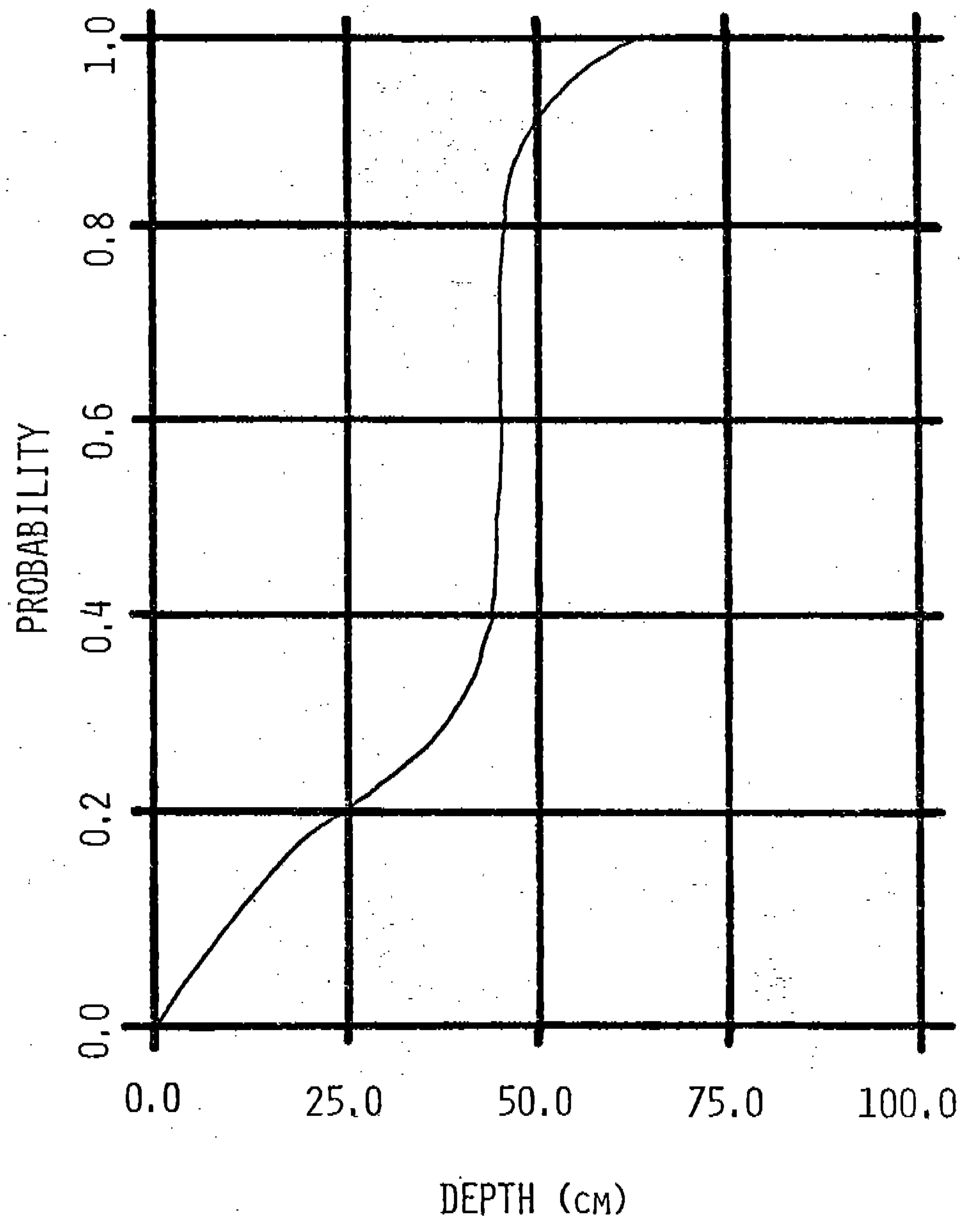
A = stream width ≤ 5 m
B = stream width > 5 m

insert inequality signs



1.0
0.8
0.6
0.4
0.2
0.0
SUITABILITY INDEX
A
B
15
30
45
60
DEPTH (CM)

Figure . Probability-of-use curve indicating the relationship between water depth and presence of adult rainbow trout. From Bovee (1978).


PROBABILITY
0.0
0.2
0.4
0.6
0.8
1.0
0.0
25.0
50.0
75.0
100.0
DEPTH (CM)

reported increased survival of trout when such areas were created. Winter holding areas for fish are often limited in the Intermountain West because stream flows are lowest at this time of year (Wydoski and Duff 1982). Wydoski and Duff (1982) suggested that the construction of pools for winter cover in western regions can be vital for fish survival. Jester and McKirdy (1966) found increased overwinter survival of rainbow trout when pools were created by stream habitat improvement.

In addition to increasing mean water depth, undercut bank cover was restored. All age groups, but particularly YOY trout, used undercut banks to a great extent during the study. This habitat proved especially important during the winter when vegetation was lacking.

Stream bank cover is an important variable in optimal brook trout habitat (Raleigh 1982). Boussu (1954) demonstrated that removal of undercut banks from a section of stream caused a decrease in the number and weight of resident trout, especially larger fish. The sloughing off and collapse of streambanks from cattle grazing probably affects fish populations most importantly (Platts 1978). Saunders and Smith (1965) speculated that low population numbers of brook trout in Ellerslie Brook were strongly associated with loss of suitable habitats, particularly undercut banks. They found that as silt was scoured away and banks became undercut, older trout (age I+ and older) quickly utilized them.

Undercut banks are important and often essential habitat for trout, especially fish seeking cover from adverse winter conditions.

The declines in fish densities in February and March 1983, were unexpected and are attributed to the lack of a sufficient food supply. Griffith (unpublished data) observed similar declines in trout densities in Mud Creek during winter, and also suggested that the food supply for trout during this period was inadequate.

Effects of temperature on trout

Thermal conditions in the experimental section were not altered by dredging. Water temperatures during the summer often approached 20 C; however, this did not appear to stress trout. Optimal temperatures for growth and survival of brook trout are 11 to 16 C (Baldwin 1951). Mid-day (1200 hr) summer water temperatures were usually in this range and temperature was not considered as a limiting factor. Carline and Brynildson (1977) observed no appreciable effect of dredging on the thermal regime of spring ponds.

Water temperatures in winter at mid-day were ~~always~~ higher than 5 C; however, a temperature of 2.5 C was recorded at 0800 hr on 19 November 1982. Salmonids seek cover during the winter when ambient water temperatures drop to 4-8 C (Bustard and Narver 1975). Low water temperatures probably trigger movement in trout to more favorable conditions in Mud Creek or in the larger tributaries. The deeper water in the experimental section afforded temporary cover for migrating fish. However, with the decreasing water temperatures came the rapid die off of aquatic macrophytes, which resulted in shallower water, loss of instream cover for fish, and the loss of habitat for aquatic macroinvertebrates.

Effects of water velocity on trout

Since water velocity decreased in the experimental section after dredging, it was assumed beneficial to brook trout. Brook trout prefer moderate flows (Elson 1939), and Griffith (1972) reported that focal point velocities for adult brook trout in Idaho ranged from 7-11 cm/sec. Wesche (1974) observed that the majority of brook trout in a Wyoming stream were associated with point velocities of less than 15 cm/sec. Water velocities in control sections were approximately 20 cm/sec, which approaches the maximum focal point velocity of 25 cm/sec documented by Griffith (1972).

Spawning by trout

Trout did not spawn in the upper experimental section after dredging. Spawning was not anticipated because no suitable gravel was uncovered by removing sediment. The lower experimental section was more conducive to spawning by trout but no redds were seen

Food abundance

The decline in trout abundance observed in February and March 1983, was unexpected and in part can be attributed to the lack of a sufficient food supply. Griffith ~~(unpublished data)~~ et al. (1982, unpub. data) reported similar declines in trout numbers in Mud Creek during the winter, and suggested an inadequate food supply as the cause.

Invertebrates were abundant in the drift in October, but not in November. The status of invertebrate abundance in the drift at Mud Creek in late winter is unknown, but if benthic abundance is associated with abundance of drifting organisms (McLay 1970), it may be substantial. Francis and Bjornn (1979) reported the greatest numbers of drifting invertebrates at Silver Creek in late winter and late summer, and the smallest numbers in spring and fall.

The lack of suitable habitats for invertebrates in Mud Creek probably induces drift, particularly in those organisms needing firm attachment sites such as mayflies and caddisflies. This supply of food for trout may decline in winter as the upstream pool of invertebrates, which generally replenishes drift, is depleted. Drift from autochthonous sources is probably minimal because of the general lack of instream habitat to support large populations of those species preferred by trout as food items. Allochthonous sources of invertebrates may provide a limited pool of food organisms.

after dredging during the spawning season. It is likely that the intergravel environment may not have been suitable for the hatching and survival of trout embryos and fry.

Aquatic Macroinvertebrates

Invertebrate abundance

The benthic community was much reduced after dredging and recolonization ~~commenced~~ slowly. Only chironomids showed a steady increase in density after dredging. Although vegetative growth in August was fairly dense and comprised primarily of Potamogeton, invertebrates other than chironomids were scarce. This trend continued through February after the cessation of plant growth.

The suppression of vegetative growth in the experimental section resulted in much reduced densities of macroinvertebrates. Carline and Brynildson (1977) observed drastic declines in invertebrate abundance after dredging two spring ponds in Wisconsin. The area of pond bottom covered by Chara was much reduced after dredging, and the authors suggested that certain invertebrate taxa were adversely affected as a result. Chara growth was dense in the lower control and invertebrate abundance and diversity were greater than at the experimental area.

Since chironomid densities increased consistently through time, it was surprising that *Tubifex tubifex* also did not increase. Both taxa are tolerant of organic sediment where concentrations of dissolved oxygen are often critical. Tubificids can reach high densities, often in excess of $10,000/m^2$ in waters receiving organic enrichment (Carline and Brynildson 1977). Removal of most of the organic sediment possibly caused a reduction in tubificid numbers. Dredging also resulted in fewer invertebrate predators, particularly *Sialis* sp. and leeches, which may prey upon oligochaetes. However, though predation by sialids and leeches was probably reduced, Loden (1974) demonstrated that six species of chironomids preyed upon oligochaetes. Therefore, the low densities of *Tubifex* following dredging may have been due to increased predation by expanding chironomid populations.

It is likely that standing crops of benthic macroinvertebrates increased in 1983 at the experimental section as *Chara* growth developed. The benthic community may have been in a transition phase in 1982 and into early 1983. Rooted macrophytes provide cover, a substrate for attachment, and possibly a source of food for certain benthic organisms. However, as macrophyte growth ceases in winter, suitable habitats for invertebrates are generally lacking.

Functional feeding groups

Apparently, the functional feeding group composition of macroinvertebrates found in Mud Creek is dictated by the depositional nature of the substrate and by aquatic macrophytes. The miner subgroup was found to be exceptionally resilient to alteration of the substrate. Other groups appeared to be particularly sensitive to such a drastic disturbance of the environment. Even though the importance of functional groups such as scrapers and gatherers certainly increased in 1983 due to greater macrophyte growth, in all likelihood, miners probably remained the predominant trophic category.

Lower Study Site

Aquatic Macroinvertebrates

The interpretation of data obtained from collections of benthic macroinvertebrates are confounded by factors such as physical features of the environment, and life history characteristics of the benthic organisms. Platts et al. (1983), Hynes (1970), and Resh (1979) have discussed these and other factors, and addressed ways to deal with them in sampling designs.

To lessen the effect of seasonal variation, benthic samples were collected on identical dates at each section. Since the full community makeup and life cycle variations of all taxa from Mud Creek were not entirely known, at least one collection per season was taken.

Four benthic samples per section were collected because this was deemed adequate to sample the benthos of Mud Creek with reasonable statistical accuracy. In the analyses of samples collected at the lower study site, subtle, but statistically significant differences were considered acceptable for the purpose of this study.

Taxonomic richness and total abundance

The 32 taxa found in Mud Creek ~~is~~ approximately half of the total found in Silver Creek (Minshall ~~et al.~~ and Minshall-Falter 1982, unpublished data). Silver Creek provides a more heterogeneous environment for macroinvertebrates and supports a greater diversity of species than Mud Creek. Most of the stream bottom of Mud Creek is covered by a layer of sediment, which in late spring through fall, supports dense growths of rooted macrophytes. The presence of vegetation often results in the greatest invertebrate biomass and this may be related to increased surface area (Harrod 1964) or a sheltered habitat (Minckley 1963). Francis and Bjornn (1979) found greater numbers of macroinvertebrates on vegetation than on gravel substrate in main Silver Creek. Both types of substrate were sampled at the lower study site after sediment removal, and total number of macroinvertebrates was generally higher on vegetation than on gravel.

Generally, gravel substrates are more productive in terms of macroinvertebrate diversity and biomass than are sand or muck bottoms (Tarzwell 1937; Sprules 1947). This type of stream bottom is fairly stable, has an abundant number of small interstices between stones to provide shelter for invertebrates, and provides a large surface area for growth of microscopic plants, which often are an important food source for aquatic macroinvertebrates (Smith and Moyle 1944). Gravel substrates are more efficient in collecting detritus than are substrates composed of smaller- or larger-sized particles (Rabeni and Minshall 1977), and thus retain a greater amount of food for benthic organisms.

Sediment was exposed in the control area following the cessation of macrophytic growth in winter. Sediment substrates do not support a wide variety of benthic macroinvertebrates (Cordone and Kelley 1961). Only a few taxa such as genera of Chironomidae are physically adapted to conditions found in this type of environment. Continually shifting organic substrates prevent the establishment of attached algae and rooted plants, and the instability of this bottom type excludes most species of benthic organisms (King and Ball 1964), especially those requiring a firm surface for attachment. The decline in macroinvertebrate numbers observed at the control area in November, was linked to the cessation of macrophytic growth and the exposure of sediment.

Abundance data provides very basic information about the biological condition of a stream, the extent of environmental disturbance, and the potential for stream improvement (Platts et al. 1983). However, Wydoski and Helm (1980) stated that using total number of invertebrates per unit area as an index can be misleading, because it is a relatively crude index composed of a summation of many overlapping and fluctuating populations representing many different life cycles. Differences in total number of benthic organisms per unit area between sections may be the result of sampling variability.

A number of factors may explain the greater densities of macroinvertebrates present at the control area. The macroinvertebrate fauna is ecologically adapted to conditions found in Mud Creek, and may exhibit a strong preference for aquatic macrophytes as colonizing substrate.

Dispersal of invertebratees between areas in a random or directional fashion may have caused fluctuation in numbers. Movement in search of food, cover, or areas for attachment may have resulted in population fluctuations. Macroinvertebrates can migrate or drift between areas in search of protected habitats or to avoid adverse conditions (Farnworth et al. 1979). The edge effect created by removing sediment from half of the stream channel, could have initiated greater movement between areas. Hargrave (1970) observed that Hyalella azteca, a motile amphipod, frequently moves as much as ~~one meter~~ 1 m between habitats in search of food.

Periphyton growth on the gravel substrate may not have been sufficient to support large numbers of grazing invertebrates. The periphyton present may have been exploited at a greater rate than it could be replenished. Hart (1981) found that that the grazing caddisfly, Dicosmoecus gilvipes, spent less time in areas that were recently grazed. Epiphyton present on aquatic vegetation may have been a more abundant and recyclable food source than the microflora present on the gravel.

Lastly, benthic invertebrates will migrate from those areas which are at greater than equilibrium density or overcolonized, in favor of low-density areas of substrate which are of comparable physical-chemical quality (Peckarsky 1979). The carrying capacity of the experimental area may have been reached at about 10,000 organisms/m^2, and as additional invertebrates attempted to colonize the gravel, the attrition (emigration) rates of attached organisms increased, or migrating organisms colonized other suitable areas.

Composition

That Diptera was the most abundant group of invertebrates present in benthic samples prior to dredging was not unexpected. The sediment substrate of Mud Creek is conducive to supporting most members of this order. Minshall and Andrews (1973) found that Diptera comprised over 70% of the macroinvertebrate community in sections of the Portneuf River, Idaho, that had been affected by sedimentation. They concluded that the stream was in a state of biological imbalance and therefore was polluted. A similar contention is proposed for Mud Creek where nearly 60% of the total number of invertebrates was comprised of dipterans before dredging. A relatively small percentage was comprised of Ephemeroptera and Trichoptera.

The observed decline in dipterans and the substantial increases in both ephemeropterans and trichopterans on the experimental area, is attributable to removing sediment from the previously imbedded gravel. The increase in abundance of the latter two orders to a state of predominance, is a condition typical of a number of Rocky Mountain streams not influenced by sediment from agricultural practices (Platts et al, 1983). Removing sediment and exposing gravel can directly influence the composition and state of biological balance of macroinvertebrate communities present in streams.

Individual taxa abundance

Individual taxa generally followed delayed but expected trends in abundance on the experimental area after dredging. Densities of chironomid larvae were lower at the experimental area than control densities because of the general lack of sediment and vegetation typically associated with genera of this group. Carline and Brynildson (1977) observed declines in chironomid populations at Krause and Sunshine Springs, Wisconsin, of 29% and 59% respectively of total abundance, six years after dredging. They also documented changes in generic composition of chironomids following dredging, while such trends could not be reported in this study because of the absence of absolute species identification.

Baetis parvus/*tricaudatus* densities were greater on the control area through November because of the presence of vegetation. Francis and Bjornn (1979) found greater numbers of *Baetis* spp. present on vegetation than on gravel in Silver Creek. Macrophytes afforded shelter for these small mayflies from invertebrate and fish predators. Because this species feeds upon the microflora present on stones, it was surprising not to observe greater densities at the experimental area in summer when production of microscopic plants is high. Instead, greatest densities of *B. parvus/ tricaudatus* on gravel were found in winter when primary production is comparatively low. The gravel and associated interstices between stones provided shelter in the absence of macrophytes, and stable sites for attachment.

In addition to *B. parvus/tricaudatus*, the other three taxa in the scraper category which were analyzed statistically, exhibited similar trends. The colonization of the gravel by *Fluminicola* sp., *Helicopsyche borealis*, and *Optioservus quadrimaculatus* in winter, was probably in response to a lack of vegetation for attachment, which is generally the preferred habitat (*see* Francis and Bjornn 1979).

The amphipod, *Gammarus lacustris*, generally prefers vegetation or sand substrates (Carline and Brynildson 1977). Although *G. lacustris* densities were initially higher at the experimental area, dredging altered the environment, and afterwards this species was significantly greater in abundance at the control area. When vegetation died off, *G. lacustris* densities were still higher on the control than on the experimental area. Apparently, the organic sediment provides the preferred food source of *G. lacustris*, and the soft substrate is easier to burrow into than gravel. Also, the brownish color of *Gammarus* closely matched the coloration of the sediment, which would serve to conceal this organism from predators.

The leeches, Hirudinea, preferred the organic sediment/macrophyte substrate of the control area, as did *Tubifex tubifex*. Both taxa are generally associated with such substrates (Carline and Brynildson 1977). Francis and Bjornn (1979) found greater densities of these two taxa in vegetation samples than in gravel samples. Hirudinea and *T. tubifex* both possess high tolerance quotients (TQ) of 108, which indicates their selectivity for fine substrate materials and low stream gradients (Winget and Mangum 1979).

Tricorythodes minutus and *Hydropsyche* spp. also possess high TQ values of 108 (Winget and Mangum 1979), and would therefore have been expected to be in greater densities at the control area. *Tricorythodes* was generally more abundant in control samples than experimental samples, but not significantly. *Hydropsyche* spp. were significantly more abundant in experimental area samples. Francis and Bjornn (1979) found greater densities of *T. minutus* in vegetation samples than in gravel samples, while the opposite was found with *Hydropsyche* spp. *Hydropsyche* spp. are net-spinning caddisflies and rocky substrates generally provide the major attachment sites for nets (Wallace et al. 1977).

Functional feeding groups

Sediment removal caused a shift in dominance of the functional feeding group composition from a community predominated by collectors, to one predominated by scrapers. This was expected since the majority of the decomposing organic matter fed upon by the collector subgroups was removed by dredging. The exposed gravel substrate was made suitable for colonization by periphyton, the primary food source of scrapers (Cummins 1973).

Generally, scrapers are most common in summer, correlated with the highest primary production: community respiration (P:R) estimate and warmest temperatures (Cummins and Klug 1979); however, scrapers were most abundant at the experimental area in late fall through winter. These periods are associated with low P:R ratios and cold temperatures. The increase in numbers and the relative dominance assumed by the scraper category, was possibly a function of the increased relative importance of non-feeding stages in the spring (Cummins and Klug 1979), and was not food-related.

The observed increase in filtering collectors at the experimental area in October and November, was comprised primarily by the net-spinning trichopteran, *Hydropsyche* spp. This genera increased in abundance in possible association with deposition of particulate organic matter (POM) between interstices of stones. Wallace et al. (1977) have demonstrated partitioning of the fine-ultrafine detritus food source by particle size according to the mesh size of nets spun by trichopteran net-spinners. Although most evidence suggests that these species of caddisflies feed on fine particulate organic matter (FPOM)-ultrafine particulate organic matter (UPOM) in suspension (eg. Wallace et al. 1977), some of this organic matter may be in the form of deposited sedimentary organics which continues to move by saltation (Cummins and Klug 1979). No measure of bed load movement was undertaken; however, in a largely depositional system such as Mud Creek, it could be substantial and may supply an adequate food source to net-spinning trichopterans.

Drift

Abundance of invertebrates in the drift was generally not indicative of abundance in benthic samples at the lower study site. The density of aquatic macroinvertebrates in benthic samples was greater in November than in October; however, more invertebrates were present in the drift in October than in November. The latter observation may have been due to overcrowded conditions on preferred habitats, inducing migration downstream via drift (Peckarsky 1979).

Species abundance in drift samples also were not indicative of abundance in benthic samples at the lower study site. Generally, the proportional occurrence of species in the drift is similar to that in the bottom fauna (McLay 1970). *Baetis* densities in benthic samples taken in November, were greater than densities present in October; however, abundance of *Baetis* in the November drift sample was less than October abundance. A similar trend was observed for dipterans.

Simulium abundance in the drift was highest in November and corresponded with the greatest densities of *Simulium* found in benthic samples collected at the lower study site. The abundance of *Simulium* in the drift seen in November, was probably related to the lack of suitable attachment sites as vegetative surface area was lost.

Project Costs

Total project cost for both sites was approximately $660.00. Project costs include fuel and labor only since dredging equipment was on loan to The Nature Conservancy by the U. S. Forest Service MEDC. It cost approximately $7.95 per cubic meter to dredge the upper experimental section. If rental of dredging equipment were included (Guy Bonnivier, personal communication), the cost per unit volume would have been about $13.00.

Costs are considerably higher than those reported by Carline and Brynildson (1977); however, their equipment was larger and more efficient. A 7.5-cm intake was used in this study. The project would have been less costly if a larger intake of 10 cm or 15 cm was utilized. Costs were somewhat inflated by time delays which arose because hoses frequently became clogged with debris and rocks. Wisconsin Department of Natural Resources (DNR) personnel used dredges having 15 cm and 20 cm intakes of which the latter was more cost efficient on a per unit volume basis.

Unit costs of dredging spring ponds less than 0.4 ha are usually highest (Carline and Brynildson 1977). Carline and Brynildson speculated that if the development area is one hectare or greater, dredging to depths of maximum fish productivity seems realistic, because unit costs would not greatly increase. The cost of dredging a relatively small area (0.02 ha) of stream in this study was relatively high. A more cost-effective approach may have been to dredge several longer stream sections (50 m or more), or a single section of 150 m in length.

Benefits of Dredging

Maximum benefits from habitat rehabilitation by dredging can be acheived by creating a more heterogeneous environment, not only by increasing summer and winter cover for trout, but also by stimulating increased benthic production through cleaning gravel imbedded with sediment. This approach would not only provide trout with needed winter cover, but also would supply them with a food source through winter. Dredging would improve the aesthetic qualities of streams by removing unsightly sediment and restoring the natural gravel substrate.

Hydraulic dredging is a viable technique in streams, particularly in situations where sediment inputs have been controlled and redeposition is gradual. Sediment inputs into the Silver Creek drainage have stabilized because of an aggressive management program undertaken by The Nature Conservancy. This program has successfully reduced sediment inputs at the source in several cases. However, in low gradient streams like Mud Creek, sufficient flows do not exist to scour sediment, and there remains the need for new technology to rejuvenate such systems. Direct removal of sediment in addition to a form of prevention is required. Dredging provides one method for habitat restoration and should be considered for future use in stream management.

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Appendix /. Mean ($\bar{x}$) and standard deviation (SD) of benthic invertebrate abundance (no./m^2) arranged by functional feeding group as collected from the experimental and control halves of the lower Mud Creek study site, 1982-1983.

	Experimental		Control	
	$\bar{x}$	SD	$\bar{x}$	SD
29 Jun 1982				
Scrapers				
Baetis parvus/tricaudatus	12	15	92	163
Helicopsyche borealis	32	29	12	24
Fluminicola	284	182	208	218
Physa	0	0	8	16
Gyraulus	56	91	52	63
Hydroptila	44	38	96	0
Optioservus quadrimaculatus	12	8	20	15
Euparyphus	4	8	12	8
Total	440		500	
Gatherers				
Ephemerella inermis	56	28	116	126
Paraleptophlebia debilis	0	0	0	0
Tricorythodes minutus	80	88	88	114
Optioservus quadrimaculatus	12	8	20	15
Euparyphus	4	8	12	8
Total	152		236	
Miners				
Chironomidae	1324	620	1468	529
Tubificidae	64	43	144	34
Lumbriculus	4	8	4	8
Total	1392		1616	
Filterers				
Simulium	0	0	4	8
Hydropsyche	116	74	56	50
Pisidium	32	64	72	62
Total	148		132	
Shredders				
Gammarus lacustris	300	363	96	26

Appendix . Continued

Hyalella azteca	0	0	8	16
Haliplus	0	0	0	0
Limnephilus	0	0	32	64
Hesperophylax	0	0	0	0
Onocosmoecus	0	0	0	0
Tipula	4	8	24	38
Total	4		64	
Predators				
Oecetis	16	22	32	26
Ophiogomphus occedentis	0	0	4	8
Ischnura	0	0	0	0
Corixidae	0	0	0	0
Isoperla	0	0	0	0
Sialis	0	0	0	0
Hirudinea	16	22	4	8
Bezzia	16	22	20	15
Total	48		60	
Grand Total	2184		2608	

9 Jul 1982

Scrapers				
Baetis parvus/tricaudatus	64	84	136	152
Helicopsyche borealis	4	8	12	8
Fluminicola	120	103	292	62
Physa	0	0	0	0
Gyraulus	44	33	44	40
Hydroptila	0	0	4	8
Optioservus quadrimaculatus	8	9	4	8
Euparyphus	0	0	12	8
Total	240		504	
Gatherers				
Ephemerella inermis	12	24	36	53
Paraleptophlebia debilis	0	0	0	0
Tricorythodes minutus	24	28	108	134
Optioservus quadrimaculatus	8	9	4	8
Euparyphus	0	0	12	8
Total	44		160	

Appendix . Continued

Miners				
Chironomidae	284	152	876	516
Tubificidae	48	34	116	62
Lumbriculus	0	0	4	8
Total	332		996	
Filterers				
Simulium	52	94	0	0
Hydropsyche	16	22	48	75
Pisidium	0	0	4	8
Total	68		52	
Shredders				
Gammarus lacustris	8	9	68	59
Hyalella azteca	0	0	0	0
Haliplus	0	0	0	0
Limnephilus	0	0	0	0
Hesperophylax	0	0	0	0
Onocosmoecus	0	0	0	0
Tipula	0	0	0	0
Total	8		68	
Predators				
Oecetis	4	8	12	8
Ophiogomphus occedentis	0	0	0	0
Ischnura	0	0	0	0
Corixidae	0	0	0	0
Isoperla	0	0	0	0
Sialis	0	0	0	0
Hirudinea	4	8	20	20
Bezzia	0	0	4	8
Total	8		36	
Grand Total	700		1816	

30 Jul 1982

Scrapers				
Baetis parvus/tricaudatus	108	81	300	418
Helicopsyche borealis	4	8	8	9
Fluminicola	182	146	364	24
Physa	4	8	4	8

Appendix . Continued

Gyraulus	64	98	104	70
Hydroptila	0	0	84	89
Optioservus quadrimaculatus	4	8	20	20
Euparyphus	0	0	0	0
Total	366		884	
Gatherers				
Ephemerella inermis	0	0	0	0
Paraleptophlebia debilis	0	0	0	0
Tricorythodes minutus	52	35	204	270
Optioservus quadrimaculatus	4	8	12	8
Euparyphus	0	0	0	0
Total	56		216	
Miners				
Chironomidae	1184	1163	1796	437
Tubificidae	70	105	84	86
Lumbriculus	20	15	4	8
Total	1274		1884	
Filterers				
Simulium	0	0	0	0
Hydropsyche	84	102	100	68
Pisidium	12	24	44	38
Total	96		144	
Shredders				
Gammarus lacustris	4	8	36	53
Hyalella azteca	0	0	0	0
Haliplus	0	0	0	0
Limnephilus	0	0	0	0
Hesperophylax	0	0	0	0
Onocosmoecus	4	8	0	0
Tipula	20	15	0	0
Total	28		36	
Predators				
Oecetis	0	0	8	9
Ophiogomphus occedentis	0	0	0	0

Ischnura	0	0	0	0
Corixidae	0	0	0	0
Isoperla	0	0	0	0
Sialis	0	0	0	0
Hirudinea	36	20	20	20
Bezzia	0	0	8	16
Total	36		28	
Grand Total	1856		3192	

11 Aug 1982

Scrapers				
Baetis parvus/tricaudatus	344	188	592	555
Helicopsyche borealis	108	102	152	117
Fluminicola	328	122	284	164
Physa	0	0	4	8
Gyraulus	36	42	8	9
Hydroptila	0	0	0	0
Optioservus quadrimaculatus	4	8	4	8
Euparyphus	0	0	0	0
Total	820		1044	
Gatherers				
Ephemerella inermis	0	0	0	0
Paraleptophlebia debilis	0	0	0	0
Tricorythodes minutus	4	8	44	68
Optioservus quadrimaculatus	4	8	4	8
Euparyphus	0	0	0	0
Total	8		48	
Miners				
Chironomidae	1302	912	984	462
Tubificidae	30	31	20	20
Lumbriculus	4	8	0	0
Total	1336		1004	
Filterers				
Simulium	4	8	0	0
Hydropsyche	124	198	44	60
Pisidium	16	18	20	40
Total	144		64	

Appendix . Continued

Shredders				
Gammarus lacustris	12	14	40	20
Hyalella azteca	4	8	8	9
Haliplus	0	0	0	0
Limnephilus	0	0	0	0
Hesperophylax	0	0	0	0
Onocosmoecus	0	0	0	0
Tipula	0	0	0	0
Total	16		48	
Predators				
Oecetis	0	0	0	0
Ophiogomphus occedentis	0	0	0	0
Ischnura	0	0	0	0
Corixidae	0	0	0	0
Isoperla	0	0	0	0
Sialis	0	0	0	0
Hirudinea	12	8	48	54
Bezzia	0	0	0	0
Total	12		48	
Grand Total	2336		2256	

2 Oct 1982

Scrapers				
Baetis parvus/tricaudatus	732	382	772	622
Helicopsyche borealis	324	56	48	29
Fluminicola	204	68	764	224
Physa	0	0	8	16
Gyraulus	32	29	76	51
Hydroptila	4	8	0	0
Optioservus quadrimaculatus	56	38	244	213
Euparyphus	24	20	72	92
Total	1376		1984	
Gatherers				
Ephemerella inermis	8	16	0	0
Paraleptophlebia debilis	0	0	4	8
Tricorythodes minutus	4	8	60	44
Optioservus quadrimaculatus	56	38	244	213
Euparyphus	24	20	72	92
Total	92		380	

Appendix . Continued

Miners				
Chironomidae	256	65	1832	1412
Tubificidae	132	141	332	141
Lumbriculus	12	8	0	0
Total	400		2164	
Filterers				
Simulium	12	24	436	519
Hydropsyche	1036	634	284	328
Pisidium	14	14	584	296
Total	1062		1304	
Shredders				
Gammarus lacustris	12	15	180	114
Hyalella azteca	0	0	32	64
Haliplus	0	0	24	38
Limnephilus	0	0	0	0
Hesperophylax	0	0	0	0
Onocosmoecus	0	0	0	0
Tipula	20	23	72	94
Total	32		308	
Predators				
Oecetis	0	0	28	27
Ophiogomphus occedentis	4	8	4	8
Ischnura	0	0	20	30
Corixidae	0	0	4	8
Isoperla	0	0	0	0
Sialis	0	0	0	0
Hirudinea	24	20	220	75
Bezzia	4	8	16	18
Total	32		292	
Grand Total	2994		6432	

20 Nov 1982

Scrapers				
Baetis parvus/tricaudatus	1356	1514	3909	1559
Helicopsyche borealis	528	140	314	306
Fluminicola	268	94	96	115

Appendix . Continued

Physa	4	8	5	9
Gyraulus	4	8	0	0
Hydroptila	4	8	10	9
Optioservus quadrimaculatus	32	45	37	51
Euparyphus	16	32	0	0
Total	2212		4371	
Gatherers				
Ephemerella inermis	0	0	0	0
Paraleptophlebia debilis	0	0	5	9
Tricorythodes minutus	40	53	53	51
Optioservus quadrimaculatus	32	45	37	51
Euparyphus	16	32	0	0
Total	88		95	
Miners				
Chironomidae	288	312	2282	2415
Tubificidae	84	127	170	98
Lumbriculus	9	8	0	0
Total	381		2452	
Filterers				
Simulium	128	178	3146	3487
Hydropsyche	424	354	170	240
Pisidium	0	0	21	24
Total	552		3337	
Shredders				
Gammarus lacustris	0	0	74	76
Hyalella azteca	8	9	32	32
Haliplus	0	0	10	9
Limnephilus	0	0	5	9
Hesperophylax	0	0	0	0
Onocosmoecus	0	0	0	0
Tipula	0	0	0	0
Total	8		121	
Predators				
Oecetis	0	0	32	42
Ophiogomphus occedentis	0	0	0	0
Ischnura	0	0	90	143

Appendix . Continued

Corixidae	0	0	58	102
Isoperla	0	0	0	0
Sialis	0	0	5	9
Hirudinea	28	20	122	66
Bezzia	4	8	0	0
Total	32		307	
Grand Total	3273		10683	

13 Feb 1983

Scrapers				
Baetis parvus/tricaudatus	6280	4690	4496	1364
Helicopsyche borealis	804	644	212	208
Fluminicola	252	248	96	150
Physa	0	0	0	0
Gyraulus	0	0	8	16
Hydroptila	0	0	12	24
Optioservus quadrimaculatus	100	138	24	38
Euparyphus	24	30	0	0
Total	7460		4848	
Gatherers				
Ephemerella inermis	0	0	48	41
Paraleptophlebia debilis	0	0	0	0
Tricorythodes minutus	308	295	108	174
Optioservus quadrimaculatus	100	138	24	38
Euparyphus	24	30	0	0
Total	432		180	
Miners				
Chironomidae	580	291	2512	2918
Tubificidae	112	112	356	169
Lumbriculus	16	13	0	0
Total	708		2868	
Filterers				
Simulium	92	76	256	372
Hydropsyche	668	316	40	33
Pisidium	0	0	0	0
Total	760		296	

Appendix . Continued

Shredders				
Gammarus lacustris	0	0	32	45
Hyalella azteca	8	16	48	34
Haliplus	0	0	28	38
Limnephilus	4	8	0	0
Hesperophylax	4	8	0	0
Onocosmoecus	0	0	0	0
Tipula	0	0	0	0
Total	16		108	
Predators				
Oecetis	0	0	28	35
Ophiogomphus occedentis	0	0	0	0
Ischnura	0	0	56	83
Corixidae	0	0	0	0
Isoperla	0	0	4	8
Sialis	0	0	4	8
Hirudinea	16	13	88	71
Bezzia	0	0	0	0
Total	16		180	
Grand Total	9392		8480	

16 Mar 1983

Scrapers				
Baetis parvus/tricaudatus	5776	6347	1764	1389
Helicopsyche borealis	580	378	180	297
Fluminicola	328	108	4	8
Physa	4	8	0	0
Gyraulus	0	0	0	0
Hydroptila	0	0	0	0
Optioservus quadrimaculatus	160	260	40	60
Euparyphus	16	18	12	15
Total	6864		2000	
Gatherers				
Ephemerella inermis	100	128	0	0
Paraleptophlebia debilis	0	0	0	0
Tricorythodes minutus	60	76	0	0
Optioservus quadrimaculatus	160	260	40	60

Appendix . Continued

Euparyphus	16	18	12	15
Total	276		52	
Miners				
Chironomidae	648	478	1992	994
Tubificidae	116	62	364	243
Lumbriculus	8	16	4	8
Total	772		2360	
Filterers				
Simulium	92	136	308	256
Hydropsyche	564	488	456	912
Pisidium	4	8	0	0
Total	660		764	
Shredders				
Gammarus lacustris	10	15	404	369
Hyalella azteca	0	0	156	165
Haliplus	8	9	16	22
Limnephilus	4	8	4	8
Hesperophylax	4	8	32	64
Onocosmoecus	0	0	12	24
Tipula	0	0	0	0
Total	26		624	
Predators				
Oecetis	20	24	8	16
Ophiogomphus occedentis	0	0	0	0
Ischnura	4	8	32	45
Corixidae	0	0	0	0
Isoperla	4	8	0	0
Sialis	0	0	4	8
Hirudinea	12	8	72	123
Bezzia	0	0	0	0
Total	40		116	
Grand Total	8638		5916	

Appendix 2. Total numbers and composition (percent of total numbers) of the macroinvertebrate community of the experimental and control halves of the lower Mud Creek study site. Data obtained from four benthic samples (each 1/16 m^2 in area), except for 20 November 1982, where only three were used due to a laboratory accident.

	Experimental		Control	
	Total No.	Percent of Total	Total No.	Percent of Total
29 Jun 1982				
Diptera	5392	54.3	6160	57.4
Ephemeroptera	592	6.0	1184	11.0
Trichoptera	848	8.5	912	8.5
Odonata	0	0.0	16	0.1
Coleoptera	48	0.4	80	0.7
Hymenoptera	16	0.2	0	0.0
Amphipoda	1200	12.0	416	4.0
Hydracarina	0	0.0	0	0.0
Haplotaxida	256	2.6	576	5.4
Oligochaeta	16	0.2	16	0.1
Hirudinea	64	0.6	16	0.1
Unionoidea	128	1.2	288	2.7
Basommatophora	1360	14.0	1072	10.0
Hemiptera	0	0.0	0	0.0
Plecoptera	0	0.0	0	0.0
Grand Total	9920		10736	
9 Jul 1982				
Diptera	1344	48.6	3680	50.0
Ephemeroptera	400	14.4	1136	15.4

Appendix 7. Continued

Trichoptera	96	3.4	320	4.3
Odonata	0	0.0	0	0.0
Coleoptera	32	1.2	16	0.2
Hymenoptera	0	0.0	0	0.0
Amphipoda	32	1.2	272	4.0
Hydracarina	0	0.0	0	0.0
Haplotaxida	192	6.9	464	6.3
Oligochaeta	0	0.0	16	0.2
Hirudinea	16	0.6	80	1.0
Unionoidea	0	0.0	16	0.2
Basommatophora	656	23.7	1360	18.4
Hemiptera	0	0.0	0	0.0
Plecoptera	0	0.0	0	0.0
Grand Total	2768		7360	
30 Jul 1982				
Diptera	4816	62.2	7296	57.0
Ephemeroptera	640	8.2	2032	16.0
Trichoptera	368	4.8	800	6.2
Odonata	0	0.0	0	0.0
Coleoptera	16	0.2	80	0.6
Hymenoptera	0	0.0	0	0.0
Amphipoda	16	0.2	144	1.0
Hydracarina	0	0.0	0	0.0
Haplotaxida	288	3.7	336	2.6
Oligochaeta	80	1.0	16	0.1

Appendix 2. Continued

Hirudinea	144	2.0	80	0.6
Unionoidea	48	0.6	176	1.3
Basommatophora	1328	17.1	1888	14.6
Hemiptera	0	0.0	0	0.0
Plecoptera	0	0.0	0	0.0
Grand Total	7744		12848	
11 Aug 1982				
Diptera	5236	55.3	3872	43.0
Ephemeroptera	1408	14.8	2544	28.2
Trichoptera	928	10.0	784	9.0
Odonata	0	0.0	0	0.0
Coleoptera	16	0.2	16	0.1
Hymenoptera	0	0.0	0	0.0
Amphipoda	64	0.6	192	2.1
Hydracarina	96	1.0	64	0.7
Haplotaxida	128	1.4	80	0.9
Oligochaeta	16	0.2	0	0.0
Hirudinea	48	0.5	192	2.1
Unionoidea	64	0.6	80	0.9
Basommatophora	1456	15.4	1184	13.0
Hemiptera	0	0.0	0	0.0
Plecoptera	0	0.0	0	0.0
Grand Total	9460		9008	

Appendix 2. Continued

2 Oct 1982				
Diptera	1184	9.8	9712	36.5
Ephemeroptera	2976	24.8	3536	13.3
Trichoptera	5456	46.0	1440	5.4
Odonata	16	0.1	96	0.3
Coleoptera	224	1.8	1072	4.0
Hymenoptera	16	0.1	0	0.0
Amphipoda	48	0.4	848	3.0
Hydracarina	368	3.0	400	2.0
Haplotaxida	528	4.4	1328	4.9
Oligochaeta	48	0.4	0	0.0
Hirudinea	96	0.8	880	3.3
Unionoidea	64	0.5	2336	8.8
Basommatophora	944	7.8	4928	18.5
Hemiptera	16	0.1	0	0.0
Plecoptera	0	0.0	0	0.0
Grand Total	11984		26576	
20 Nov 1982				
Diptera	1824	14.0	16480	51.0
Ephemeroptera	5584	43.0	11936	37.0
Trichoptera	3664	28.2	1600	5.0
Odonata	0	0.0	272	0.8
Coleoptera	128	1.0	144	0.4
Hymenoptera	0	0.0	16	0.04
Amphipoda	32	0.2	320	1.0

Appendix 2. Continued

Hydracarina	144	1.1	112	0.3
Haplotaxida	336	3.0	512	1.6
Oligochaeta	32	0.2	0	0.0
Hirudinea	112	0.8	368	1.1
Unionoidea	0	0.0	64	0.2
Basommatophora	1104	8.5	320	1.0
Hemiptera	0	0.0	176	0.5
Plecoptera	0	0.0	0	0.0
Grand Total	12960		32320	
13 Feb 1983				
Diptera	2832	7.5	11248	33.0
Ephemeroptera	26352	70.0	18608	54.4
Trichoptera	5920	16.0	1168	3.4
Odonata	0	0.0	224	0.6
Coleoptera	400	1.0	208	0.6
Hymenoptera	0	0.0	0	0.0
Amphipoda	32	0.08	320	0.9
Hydracarina	368	1.0	208	0.6
Haplotaxida	576	1.5	1424	4.2
Oligochaeta	64	0.2	0	0.0
Hirudinea	64	0.2	352	1.0
Unionoidea	0	0.0	0	0.0
Basommatophora	1008	2.6	416	1.2
Hemiptera	0	0.0	0	0.0