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Effects of Alterations to Low Gradient Reaches of Utah Streams

Fish and Wildlife Service

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EFFECTS OF ALTERATIONS TO LOW GRADIENT REACHES OF UTAH STREAMS

by

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PREFACE

Stream channels in the semi-arid Intermountain West have been modified for many years by agricultural interests, primarily to provide flood protection. Little information has been available on the long-term physical and biological consequences of channel modification in this unique geographic region. Of special concern is the relationship between stream channel modification and the high value recreational fishery resource. This report describes an investigation of the physical and biological effects of stream channelization in northern Utah. The study was conducted by the Utah Cooperative Fishery Research Unit (Utah State University and Utah Division of Wildlife Resources, Cooperators).

Any suggestions or questions regarding this report should be addressed to:

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SUMMARY AND CONCLUSIONS

Erosion and deposition of streambed gravel were directly correlated with the percentage of stream reach that was altered. The greatest erosion and deposition resulted in reaches with a high proportion of alteration whereas reaches with a lower proportion of alteration were less affected. Pools occurred less frequently in bulldozed than in backhoe altered areas, although this may have been due to stream characteristics rather than the type of alteration. Shape and integrity of stream banks differed distinctly between the two types of alteration. Banks were left relatively unchanged in shape during dredging, except that in some places they were nearly covered with material removed from the streambed. Some of the riparian vegetation survived. Stream banks and riparian vegetation in bulldozed areas were eliminated, as banks were either tapered back or completely covered, with no deep water left in close proximity.

High stream flows in spring appeared to be required to maintain the depth and frequency of pools. Normal spring flows through altered reaches removed streambed materials deposited in pools by the alteration process, restoring them to near pre-alteration depths. Although the location of pools may have been changed somewhat as a result of channelization and subsequent restoration by fluvial processes, the number of pools was essentially the same. Low spring flows did not restore many altered pools, and left some pools in unaltered areas shallower than usual. While about equal amounts of erosion occurred during the low flows of fall and the high flows of spring in altered stream reaches, most deposition occurred during the high flows in spring.

In all bulldozed sites the trout populations were not self-sustaining, either because of few spawning adults or little recruitment and survival of age 0 trout. No long term differences in growth rates were observed for trout in altered or unaltered reaches.

During the study, dredging had less affect than bulldozing on survival of age 0 fish, but there were indications that dredging would reduce spawning in the future.

During low streamflows brown trout and whitefish used deep pools. Since such pools were absent from severely channeled areas fish moved from these altered areas into areas which contained pools, but returned when streamflows were normal. Although the biomass and production of brown trout were adversely affected by stream channel alterations, these measurements failed to show that trout from severely channeled areas depend on more natural reaches for survival during low streamflows and for recruitment of young.

Production of brown trout and mountain whitefish was directly related to the proportion of a reach in pools, being highest in the reach with the most pools and least in the reach with the fewest. Biomass followed this same trend.

Growth of whitefish was faster in both altered and unaltered areas of the Blacksmith Fork and Logan Rivers than has been reported in the literature for most other locations. Production was greater than previously found for a reach that was the lower limit of their occurrence in the Logan River.

Trout and whitefish population estimates, biomass, and production over a year's time fluctuated widely in both natural and altered sites, indicating the necessity to measure these parameters seasonally to adequately describe the ecology of the population.

Mean annual densities and standing crops of invertebrates showed no significant differences between sites, reflecting the heterogeneity of the stream habitat and its resultant sampling variability, as well as seasonal changes and the relatively short-term effects of alterations on these parameters.

Shannon diversity indices for invertebrates increased slightly immediately following stream channel alterations, but decreased as recolonization began by the more mobile families such as Chironomids, Simuliids, and Baetids.

All of the stream channel perturbations had the same type of effect on the macroinvertebrates--lowered standing crops (numbers and weight), slightly lower Shannon diversity index, and an adverse effect on production.

The duration of the impact by the perturbation on the benthic community was largely dependent upon the rate of return of substrate stability.

Irrigation diversions coupled with stream channel alterations produced a greater detrimental effect on fish and macroinvertebrates than occurred from either of these alterations alone.

RECOMMENDATIONS

In the flood plains of streams in the Intermountain West, reduced stream flows during the summer result from irrigation diversions on all major streams. Therefore, the effect of stream alterations on physical conditions and fish and macroinvertebrate populations must be considered jointly with reduced streamflows.

Although landowners in the flood plains of rivers alter stream channels to prevent flooding, their short reach alterations do not last long--usually less than one year. Landowners are frustrated by upstream activities that produce stream erosion and deposition, and the lack of comprehensive programs to stabilize the entire stream system. Three programs are needed to prevent continued damage to and destruction of streams: Comprehensive basin-wide plans to regulate stream channel changes so as to minimize damages to other landowners and to the streams; research to identify methods of controlling the height of the water table under agricultural land with minimal effects on streams; and an effective information and education program to educate owners of river bottom land about the hydraulics of the river in a flood plain, the consequences of altering streams and producing unstable conditions in the altered area and downstream, and alternative ways to prevent flood damage to crops.

Between 1955 and 1970, fishing increased 37 percent in the Mountain States, and this trend is expected to continue. It is believed that over 80 percent of prime trout stream habitat has been severely degraded or eliminated in Utah. Because channel alterations may be irreversible or cause unstable streambeds, engineers and biologists should work jointly so that the necessary changes to the stream environment would result in the least damage to fish and wildlife habitat. Perhaps, through this kind of interaction, stream alterations could be made that would sometimes improve habitat for fish and wildlife.

This study demonstrated that pools were vital to survival of brown trout and mountain whitefish during low streamflows. Alternatives to channelization must be evaluated so that pool environments are not completely eliminated as happens with typical stream channeling practices.

Dewatering which results in loss of pools, or ineffective scouring of pools during spring runoff, has an effect similar to channel alteration. Minimum streamflow regulations are needed to protect fish populations.

Improvement of the law regarding alteration of stream environments is desperately needed in the Intermountain West where streams are not plentiful and are being damaged by various kinds of water resource development. A single agency or a coordinating council should review permit applications for stream alterations and should monitor and evaluate channel modifications so that control of the accumulated effects can be managed on a watershed basis. Land use planning that involves the entire river system should be manditory.

Descriptions of the microhabitat requirements of key fish species should cover the various life stages during various seasons. This critical information should include the responses of the fish to changes in cover and streamflow. Such knowledge is needed to accurately predict the impact of alterations on stream environments.

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INTRODUCTION

Streams are altered for highway construction, flood control, mining, land reclamation, navigation, and other reasons. These alterations are often engineering answers to problems that clearly are interdisciplinary. Stream channelization is a form of alteration which usually results in straightening the channel, thereby reducing the length of the original channel and increasing the gradient and water velocity. In addition, streambed substrate is removed, pools are usually converted into riffles or runs, and vegetation along the streambank is removed. Following channelization, streambeds are known to remain unstable for some time (Campbell, Kumar, and Johnson 1972). Unstable substrate is believed to be the most significant factor related to changes in fish and invertebrate populations following channelization (Etnier 1972). Environmental changes of this kind have been shown to be detrimental to the habitats of both aquatic and terrestrial organisms.

Public awareness of man's detrimental effects to the environment has received much interest recently (McEvoy 1973) and people will demand more ecological and environmental considerations in water project planning in the future (McCloskey 1973). McCloskey has pointed out that the public environmental movement has had a great impact in the planning of water projects, particularly in the West.

In the early 1970s, the public questioned the use of federal and state funds for stream channelization because of the detrimental impacts to the environment. As a result, hearings were held on stream channelization during the 1st session of the 92nd U.S. Congress in May and June, 1971. After the hearings, several in depth reviews were made of the environmental impacts to natural resources from stream alteration projects (Little 1973, U.S. House of Representatives 1973). The report to the U.S. Council on Environmental Quality stated that at least 320,000 kilometers (200,000 miles) of waterways have been developed or modified in the United States since the early 1800s without proper planning, engineering, or financing (Little 1973). The report also stated that about 56,000 kilometers (35,000 miles) of stream channels have been modified by small watershed programs since 1940 by the Corps of Engineers and Soil Conservation Service. The larger federal flood control and navigation projects of the Corps of Engineers and Bureau of Reclamation are not included in this mileage. In 1972, the Western Association of State Game and Fish Commissioners adopted a resolution that vigorously opposes publicly funded stream channelization programs until natural resource values and recreation opportunities are comprehensively evaluated.

In the Intermountain West, stream channelization has been inventoried in Montana and Idaho. Altered stream channels in 13 Montana streams produced only one-fifth of the number and one-seventh of the weight of game fish as natural channels (Peters and Alvord 1964). Undisturbed sections of 45 streams in Idaho contained an average of 8 times the weight of game fish as channeled reaches (Gebhards 1970, Irizarry 1969). Invertebrates are similarly affected in altered stream reaches. For example, the standing crop of invertebrates was 8 times greater in unaltered portions of the Missouri River (Morris et al. 1968).

Most streams in the Intermountain West are channelized during road and railroad construction. For example, road and railroad construction accounted for 66 percent of the channel alterations in 45 Idaho streams (Gebhards 1970, Irizarry 1969) and for 51.5 percent of 403 kilometers (251 miles) of 13 streams in Montana (Peters and Alvord 1964). In these studies, flood control accounted for 19 percent of the channel alterations in Idaho and agricultural activities including flood control accounted for 36.3 percent of the stream miles that were altered in Montana. A number of studies have been made to determine the impacts of stream channelization that are associated with highway construction projects usually in canyon areas (Barton and Winger 1973, Elser 1968, Etnier 1972, Utah Division of Wildlife Resources 1972, Lewis 1969, Peters 1974, Whitney and Bailey 1959, Winger 1972).

Estimates that were made by the Utah Division of Wildlife Resources indicate that over 80 percent of prime trout habitat has been severely degraded or eliminated in Utah. Approximately 97 kilometers (60 miles) of Class 1 streams are all that remain in Utah today. Since data are available on the effects of stream alterations made during highway construction in canyon areas of the West, this study was designed to determine the impact of stream alterations on the fish and macroinvertebrates in the floodplain reaches of streams in the Intermountain West. The specific objectives of the study were: (1) To follow physical changes in the streambed after various types of alterations; (2) To estimate populations and production of fish and invertebrates in altered and unaltered reaches after different intervals of time; (3) To relate physical and biotic changes; and (4) To provide suggestions that will minimize the effects on fish and wildlife if alterations to the aquatic environment are necessary.

DESCRIPTION OF AREA AND STUDY SITES

GENERAL DESCRIPTION OF THE AREA

The Blacksmith Fork and Logan Rivers in northern Utah (Figure 1) were chosen for the study since these rivers are characteristic of the rivers in the Intermountain West. Both rivers originate as mountain streams that flow through canyons with a steep gradient, but open into widely meandering streams with a low gradient in the floodplain of Cache Valley. The Blacksmith Fork and Logan Rivers have national reputations as fine trout streams and are still important Class 1 waters in the State of Utah. In 1937, an 83 kg (37 3/4 pounds) brown trout was taken from the lower impoundment on the Logan River. Today, brown trout exceeding 22 kg (10 pounds) are still found in both rivers.

Cache Valley is a narrow elongate basin about 1,455 m (4,775 ft) above sea

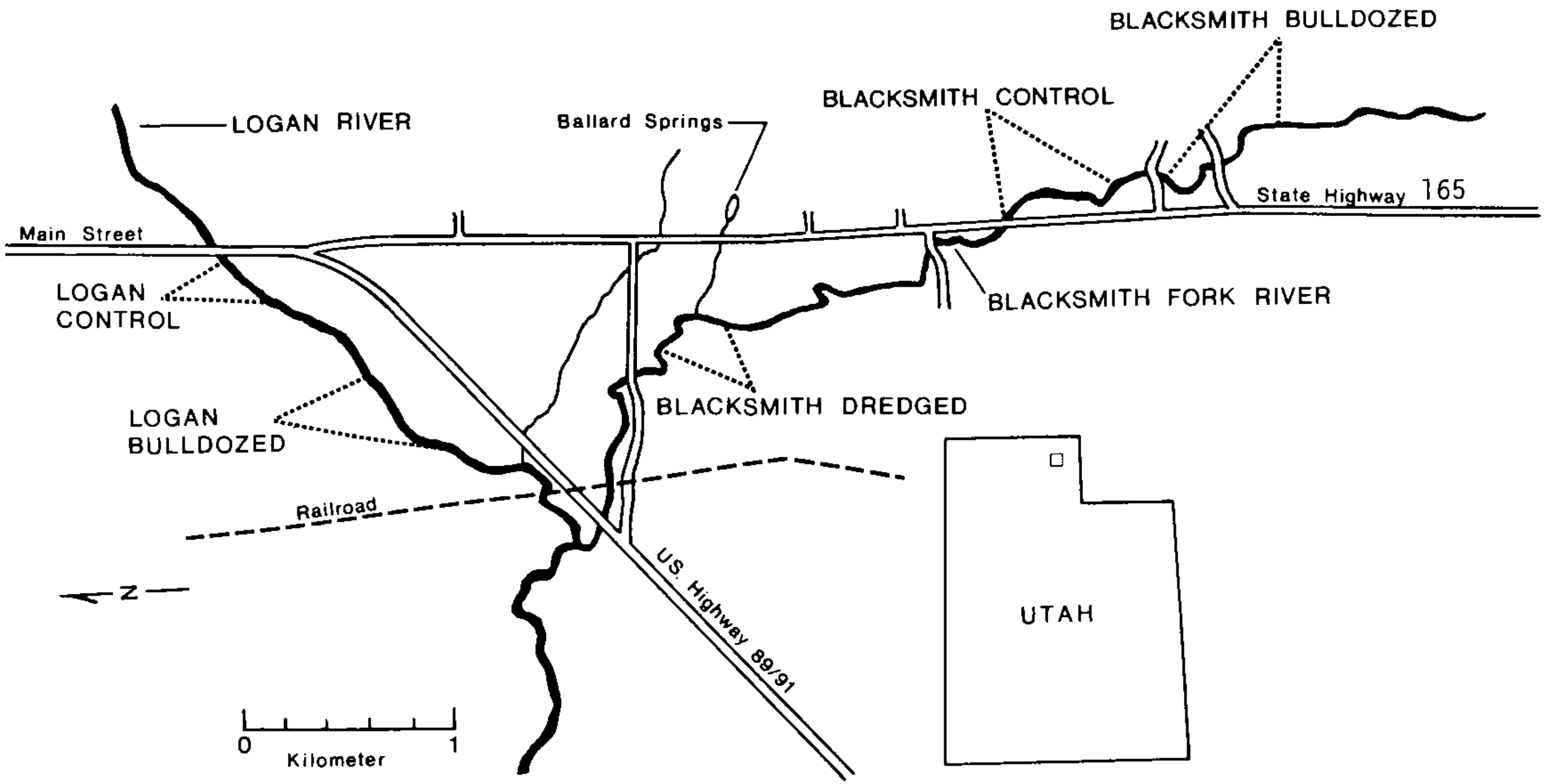


Fig. 1. Location of stream alteration study sites on the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

level in the northeast corner of the Great Basin that is covered by fertile sedimentary deposits of ancient Lake Bonneville. Tertiary rocks of the Salt Lake Formation are fairly well exposed in the foothill areas of the valley and Paleozoic rocks are found in the higher mountains bordering the valley (Williams 1962). Much of the sandstone is calcareous and about 95 percent of the rocks are of marine origin. Broad terraces of silt, clay, sand, and gravel were formed as ancient Lake Bonneville receded and these alluvial deposits are still conspicuous today between the canyons of the Blacksmith Fork and the Logan Rivers. At least 35 percent of the farmland is irrigated by canals in Cache Valley, and produces about 75 percent of the total crop value in the area (Williams 1962).

The climate of this area is semi-arid with about 41 cm (16 in) of precipitation occurring annually. The average monthly air temperature for the year is 8.6°C (47.3°F) with a low in January of about -4.1°C (24.6°F) and a high in July of 21.6°C (71.2°F) (Utah Department of Employment Security 1972).

The dominant vegetation of the area depends upon the altitude (Johnson 1970). Douglas fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), and sub-alpine fir (*Abies lasiocarpa*) are common species found on the north slopes above 2286 meters (7,500 ft) in elevation. Quaking aspen (*Populus tremuloides*) is common on the cool moist mountain slopes and canyon bottoms. Rocky Mountain juniper (*Juniperus scopulorum*) and mountain mahogany (*Cerocarpus ledifolius*) are found on the shallow, drier soils with bedrock outcroppings on the south-facing slopes. In the canyon bottoms along the streams, the water birch (*Betula occidentalis*) is found in scattered clumps. Box elder (*Acer negundo*), narrow leaf cottonwood (*Populus angustifolia*), red osier dogwood (*Cornus stolonifera*), sandbar willow (*Salix exigua*), velvet ash (*Fraxinus velutina*), and balsam poplar (*Populus balsamifera*) are trees that are characteristic to the floodplain areas at the study sites. Common plants found at the study sites are summarized in the Appendix.

DESCRIPTION OF STREAMS

Streamflows of the Blacksmith Fork and Logan Rivers are primarily governed by runoff from the snowpack as the air temperatures increase from mid-April to mid-July. The drainage area of the Blacksmith Fork River at U.S. Geological Survey Station 10113500 is 694 km^2 (268 mi^2). The average daily discharge for 62 years was 3.65 m^3/sec (129 ft^3/sec) with an annual production of 115 hm^3/yr (93,460 acre-feet/yr) (U.S. Geological Survey 1976). The drainage for the Logan River at U.S. Geological Survey Station 10109000 is 554 km^2 (214 mi^2). The average daily discharge for 62 years was 3.40 m^3/sec (120 ft^3/sec) with an annual production of 107 hm^3/yr (87,000 acre-feet/yr). These values do not include the irrigation diversion that occurs in the canyon. The average combined daily discharge of the Logan River and the major canyon diversion, the Logan, Hyde Park, and Smithfield Irrigation Canal, for 79 years was 7.79 m^3/sec (275 ft^3/sec) with an annual production of 246 hm^3/yr (199,200 acre-feet/yr).

Hydrographs of the average daily discharge and maximum-minimum values were plotted for 1975-76 for a selected U.S. Geological Survey station on the Logan River (Figure 2) and on the Blacksmith Fork River (Figure 3). In general,

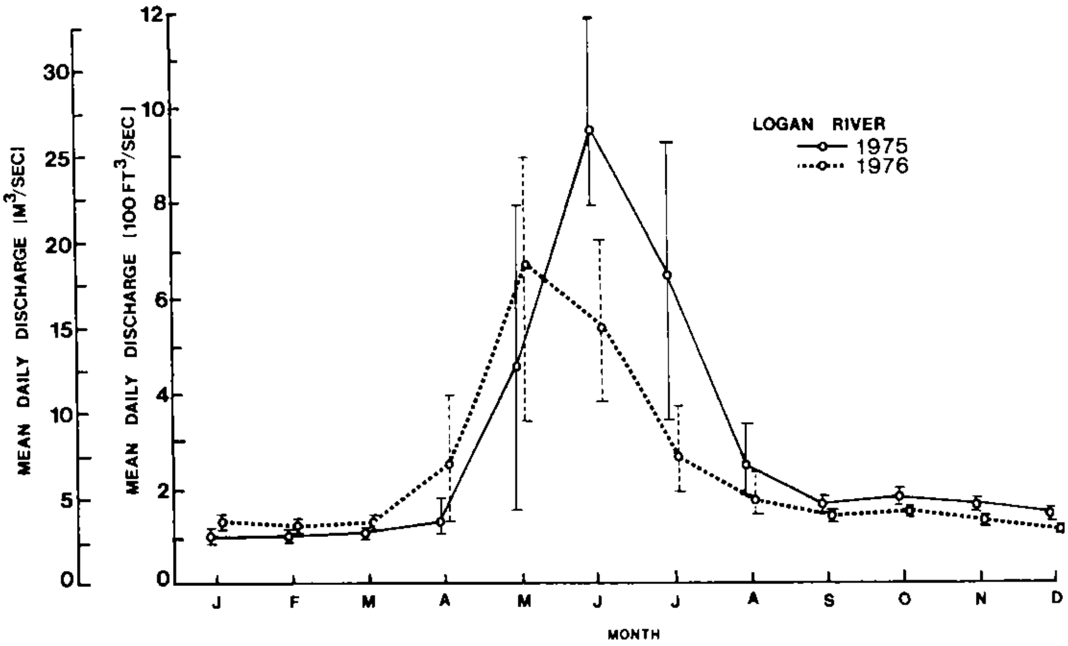


Fig. 2. Mean and range of daily discharge for the Logan River at the State Dam near Logan, Cache County, Utah, 1975-76 (USGS Station 1010900).

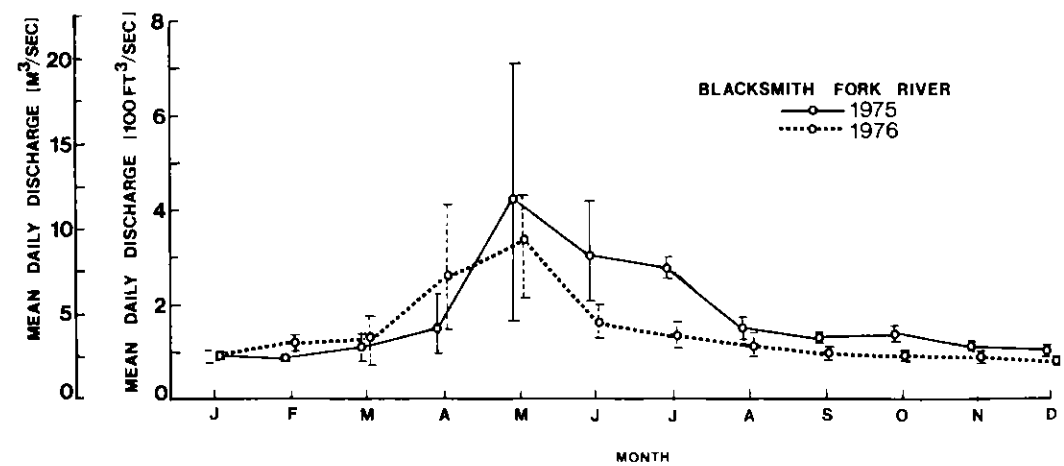


Fig. 3. Mean and range of daily discharge for the Blacksmith Fork River near Hyrum, Cache County, Utah, 1975-76 (USGS Station 10113500).

the Blacksmith Fork River had a lower flow than the Logan River and the flows for both rivers were lower in 1976 than in 1975 because of a lighter snowpack. Streamflow at the study sites in both rivers were much lower than at the survey stations because of irrigation diversions (Figures 4 and 5). Water temperatures averaged weekly and the maximum-minimum values in 1976 were plotted for the Logan River in Figure 6 and for the Blacksmith Fork River in Figure 7. The mean and range of daily water temperatures for both rivers are provided for selected dates to show daily fluctuations in temperature by season (Appendix A ; Figure 1). In general, the water temperature of the Blacksmith Fork River was slightly warmer than the Logan River and the greatest fluctuation in water temperature occurred during the warmer summer months. The chemical analyses of the water in different years are provided for the Blacksmith Fork River (Appendix A ; Table 1) and the Logan River (Appendix A ; Table 2). The average conductivity for eleven measurements in 1975 was 488 microhmos (range 430-500) and for fifty measurements in 1976 was 479 micromhos (range 345-645) for the Blacksmith Fork River. The range of selected water chemistry parameters was compared for both rivers in Appendix A ; Table 3. Waters with chemistry values such as these have been shown to be productive for brown trout, *Salmo trutta* (McFadden and Cooper 1964).

The principal fish that inhabit the Blacksmith Fork and Logan Rivers are the brown trout and mountain whitefish (*Prosopium williamsoni*). In addition, large numbers of the mottled sculpin (*Cottus bairdi*) are found in these rivers, but were not studied because of the problems involved in making quantitative population estimates of this species. Cutthroat trout (*Salmo clarki*), rainbow trout (*Salmo gairdneri*), and speckled dace (*Rhinichthys osculus*) are found occasionally in the study areas of these rivers. In early spring, large Utah suckers (*Catostomus ardens*) migrate into and through the study sites, sometimes in large numbers. These fish are believed to migrate into these sections of the rivers for spawning, but no young suckers were found after the migration was over. Either the juvenile suckers migrated out of the study area or spawning was not successful if, indeed, it did occur. During the summer, small numbers of carp (*Cyprinus carpio*) and the Utah chub (*Gila atraria*) were sampled from the study sites.

An ecological study of the mottled sculpin including age and growth, food habits, and reproduction was made on the Logan River east of Logan City, about 2.4 kilometers (1.5 miles) upstream from the Logan River control site (Zarbock 1951). This species may be important in the ecology of the rivers in the study area because it may compete with and provide forage for brown trout.

Other aspects of the ecology of these rivers were studied at various times. For example, Beers (1969), Clark (1958), and McConnell (1958) studied the algal components of the river biota and Erman (1968), Hales (1955), Meyers (1972), and Pearson and Kramer (1972) investigated the insect fauna. In addition, various aspects of the ecology of brown trout and mountain whitefish were studied at different times and in different parts of the rivers (Bernard 1976, Bergersen 1973, Bridges 1963, Brown 1972, Gosse 1977, Kimball 1972, Mathews 1966, Meyers 1972, Mongillo 1976, Salevurakis 1974, Sigler 1951, Sigler 1952).

Stream Alterations

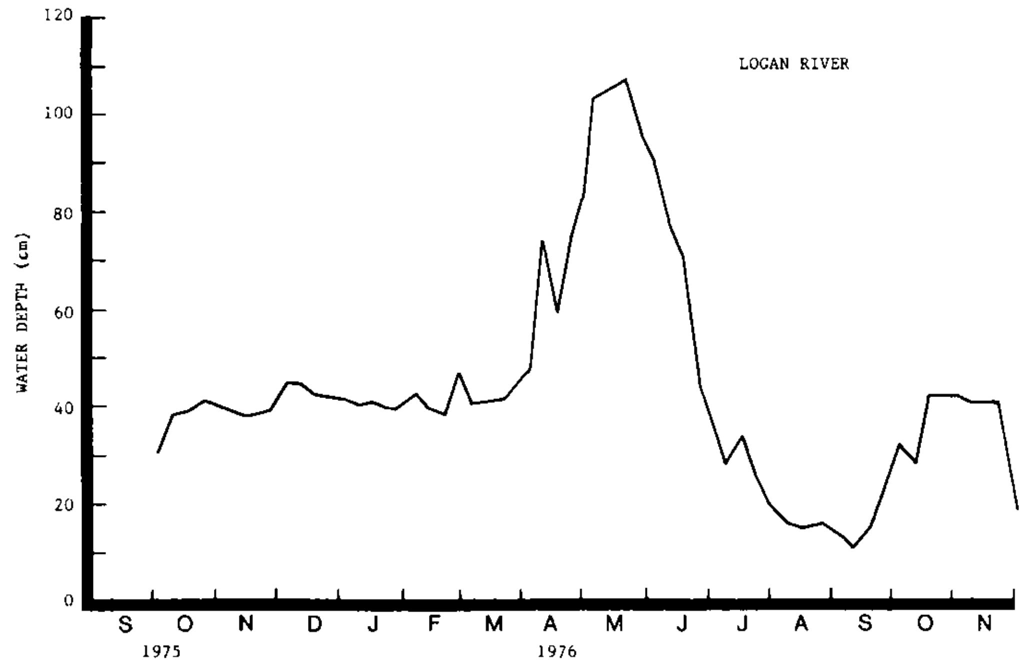


Fig. 4. Weekly readings of water depth at the stand gauge in the Logan River, Cache County, Utah, 1975-76.

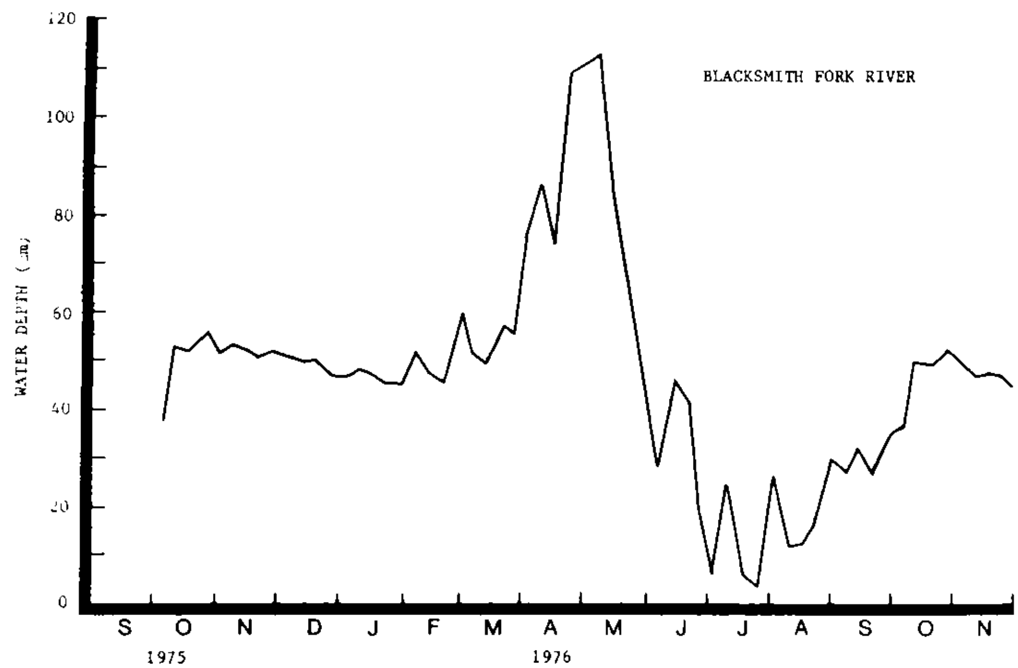


Fig. 5. Weekly readings of water depth at the stand gauge in the Blacksmith Fork River, Cache County, Utah, 1975-76.

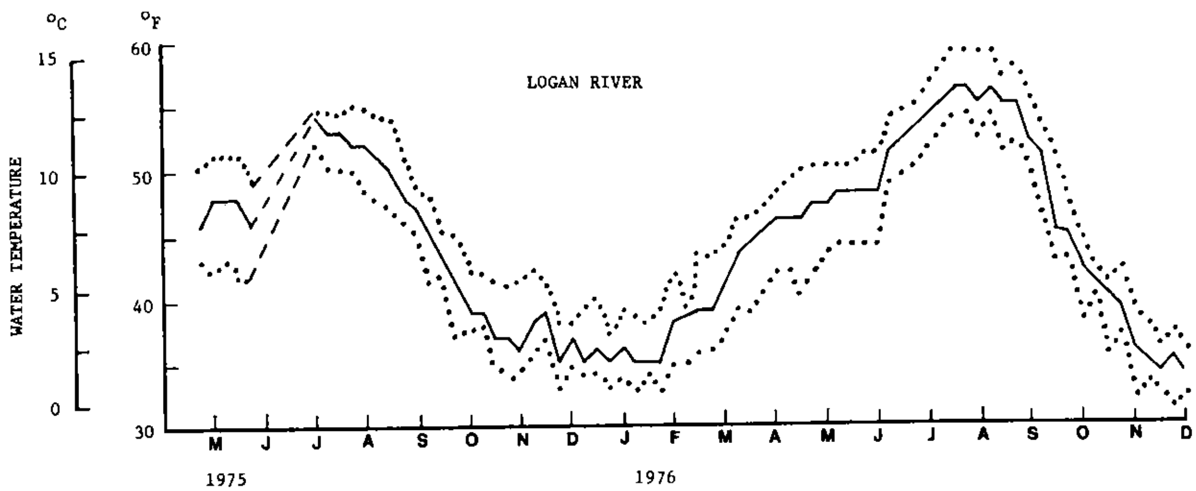


Fig. 6. Mean weekly water temperature and range for the Logan River, Cache County, Utah, May 1975 to December 1976.

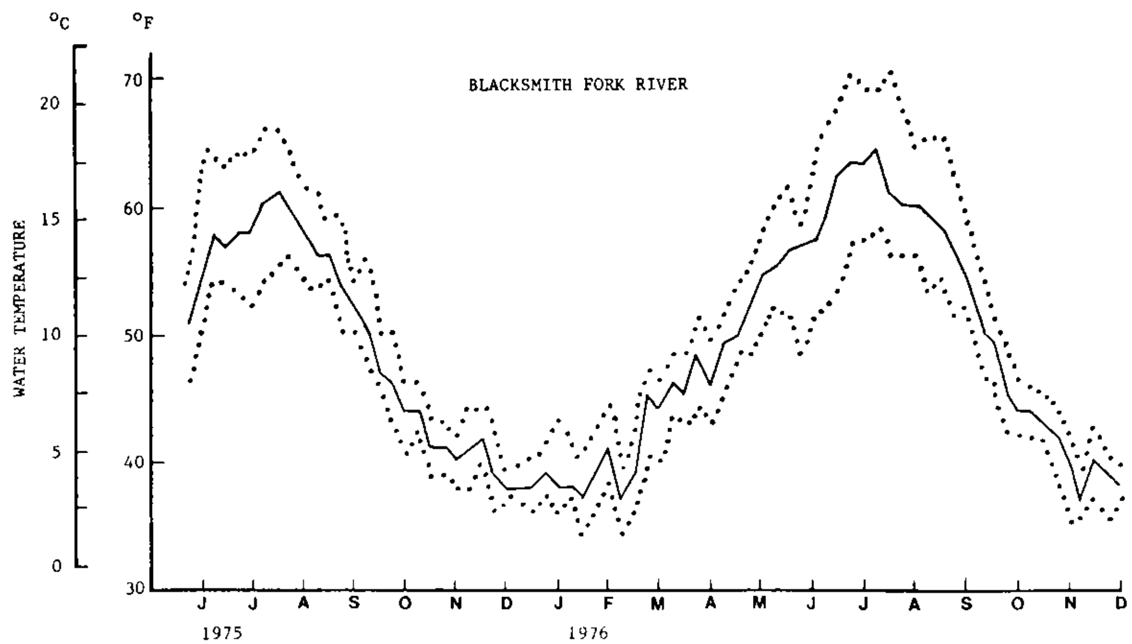


Fig. 7. Mean weekly water temperature and range for the Blacksmith Fork River, Cache County, Utah, June 1975 to December 1976.

Water development of the Logan River first began in 1860 when the first irrigation canal was built (Haws 1965). Today several large canals divert a large part of the Logan River flow. For example, the first diversion from the Logan River (Logan, Hyde Park and Smithfield Canal) above the State Dam diverted an average of 56.3 percent of the daily flow during the summer months and about the same percentage of the total annual runoff (U.S. Geological Survey 1976). The historical development of the Logan River, changes in water use, and legal controversies over water rights are documented in detail by Haws (1965).

The diversion of water from streams as they enter the floodplain reduces streamflows and is especially critical to aquatic life during the low flows of summer. Therefore, the effect of stream channel alterations on aquatic organisms must also include the effect of reduced streamflows as part of the man-influenced river systems for all larger rivers in the Intermountain West.

The maximum daily streamflow of the Logan River was recorded at 70.2 m^3/sec (2,480 ft^3/sec) on May 24, 1907 (Corps of Engineers 1973). Flood conditions have occurred fairly often in the Blacksmith Fork and Logan Rivers when rapid melting of the mountain snowpack occurred between April and June. Eight major floods have occurred since 1900 that damaged agricultural crops in the floodplain--mostly below the confluence of the Blacksmith Fork with the Logan River (Corps of Engineers 1976).

According to local landowners, channelization of the streambeds in both rivers began over 50 years ago when the ranchers shovelled the streambed gravel by hand and transported this gravel from the stream by horse-drawn wagons. Short reaches of the rivers have been altered ever since that time. Today short reaches of the rivers are altered periodically with backhoes and bulldozers by individual ranchers because of flooding in agricultural areas. Five study sites were selected that would provide information on three types of stream channel alterations (dredged, recently bulldozed, and old bulldozed) and two control areas in the floodplains of these rivers (Figure 1).

Logan Total Bulldozed Site

A flood control project conducted by the U.S. Army Corps of Engineers on the Logan River in 1971 was criticized by local residents and the Utah Division of Wildlife Resources and the project even brought national attention (Stroud 1972). This 1.69 km (1.05 mile) reach was deepened and widened by bulldozer into a cross-section that was shaped like a trapezoid (Utah Division of Wildlife Resources 1972). In addition, all understory vegetation was removed and large trees near the channel were either removed or cut back so that shade and cover were greatly reduced. A reach of this stream channel, altered by bulldozer in 1971, was selected as a study site (Figure 1). A view of this site in 1976 (5 years after the alteration) is provided in Figure 8. Most of this reach has remained relatively unchanged since 1971 except for the downstream end. In April 1975, about 100 m at the lower end of the altered area was rechanneled by bulldozer, but the remainder of this reach has not been altered by man since 1971. Logan total bulldozed refers to this entire reach, while Logan stable bulldozed refers to the portion not altered since 1971.

Blacksmith Fork River Control Site

Fig. 8. The total bulldozed study site that was altered in November 1971 on the Logan River, Cache County, Utah - January 1976.

Fig. 9. The control (unaltered) study site on the Blacksmith Fork River, Cache County, Utah - September 1975.

Although an unknown amount of channel alteration had occurred here sometime over 20-30 years ago, this reach (Figure 1) was selected as our primary control site since it was the most "typical" site on either river with natural conditions (Figure 9). This site contained much streambank vegetation which provided the stable undercut banks and overhanging cover that is required by brown trout, a key species in these rivers. Pools and riffles occurred alternately throughout the entire reach.

Blacksmith Fork River Recently Dredged Site

Gravel that was deposited at a sharp bend of this river formed a "dam" that created flooding problems for a local landowner. This landowner informed us that he was going to remove the gravel from the stream bottom, which gave us the opportunity to survey the entire reach before it was altered (Figure 1). This reach was altered for approximately 520 meters by backhoe on March 20 and 21, 1975 when the gravel was removed from the stream bottom and deposited on the streambanks (Figure 10). The backhoe was usually operated from one bank so that little change occurred to the opposite bank and there was minimal reduction in stream meander or sinuosity. Much of the gravel was redeposited in this reach during the spring runoff so the reach was dredged again by the landowner on August 28, 1975. This site was studied intensively since we were able to survey the reach before alterations were made, it contained a good pool-riffle ratio, and had good streambank cover. Estimates of the fish population were made before and after the reach was dredged, before and after spring runoff, and during selected conditions such as low streamflows to document the responses of the fish to various physical conditions.

Blacksmith Fork River Recently Bulldozed Site

The flood plain of the Blacksmith Fork River as it meanders through Millville, Providence and Nibley, Utah and adjacent areas is being converted from agricultural uses to commercial and residential uses (Corps of Engineers 1976). In May 1971, the streamflow of the Blacksmith Fork River was 23.4 m^3/sec (825 ft^3/sec), a level exceeded only by the historical record of 45.9 m^3/sec (1,620 ft^3/sec) of May 1917. The Corps of Engineers channeled a reach of the Blacksmith Fork River near Nibley and Millville, Utah in the Fall of 1971 as a measure to prevent future flood damage in this area. On September 6, 1975, the landowners rechanneled a part of this reach (about 300 meters) by bulldozer (Figure 11). This site (Figure 1) was chosen because it provided an opportunity to compare the effects of an old bulldozed with a recently bulldozed reach. This site was subdivided into a recently bulldozed portion (1975) and an old bulldozed section (1971) immediately upstream.

Logan River Control Site

This reach (Figure 1) was chosen to provide supplementary information to the primary control site on the Blacksmith Fork River. This reach did not contain conditions as natural as the primary control site, but the information from this site on the larger river - the Logan - could be compared with similar data from the more intensively studied site on the smaller Blacksmith Fork River. This reach was altered several times in the past, most recently about 30 years ago, but is believed to be relatively stable now. Because of the

Fig. 10. The recently dredged study site on the Blacksmith Fork River, Cache County, Utah - March 1975. Upper photograph shows the study site immediately before it was altered by a backhoe. Lower photograph shows the site immediately after it was altered by the backhoe.

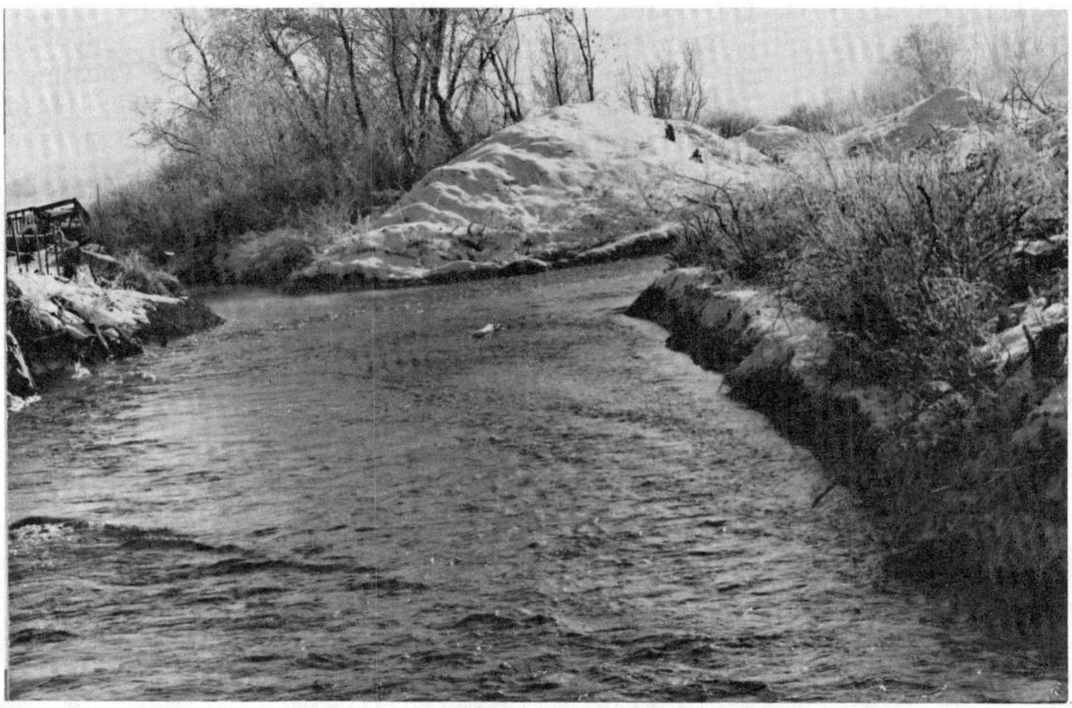
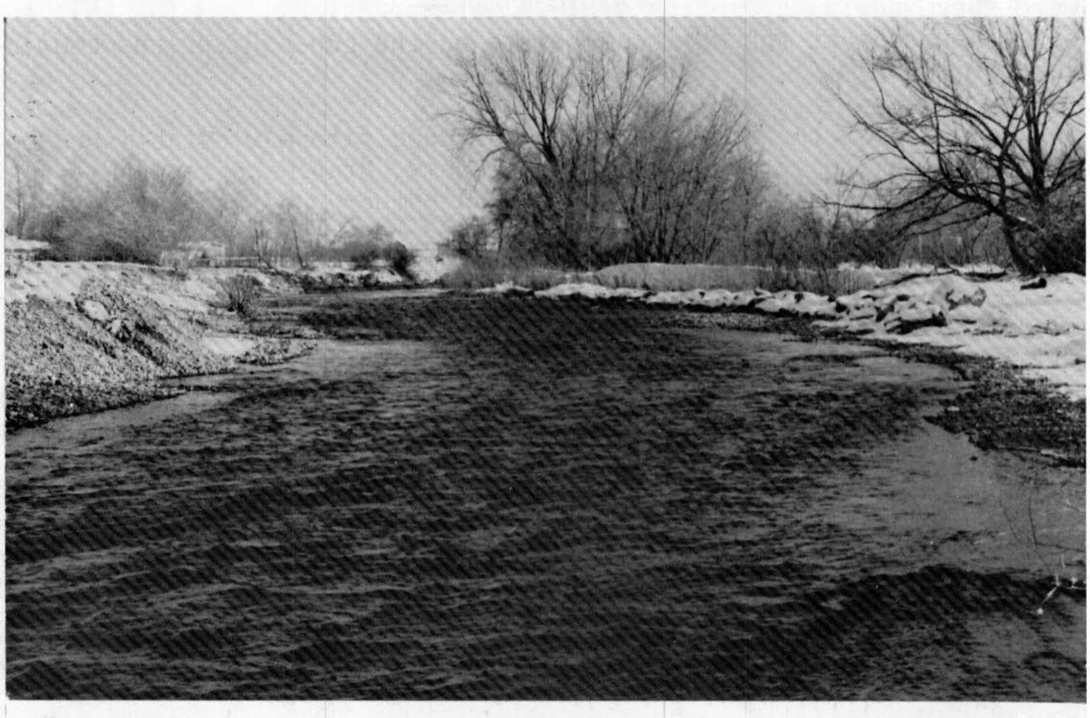


Fig. 11. The recently bulldozed study site on the Blacksmith Fork River, Cache County, Utah. Upper photograph is the study site immediately before it was bulldozed in September 1975. Lower photograph is the study site after it was bulldozed in November 1975.



constraints of time and budget, macroinvertebrates were not studied at this site.

METHODS

PHYSICAL PARAMETERS

Baseline and Cross Sections

A baseline was surveyed with an optical transit parallel to the river and between the high water mark and cultivated or pasture lands at all five study sites. The azimuth of the line was recorded from compass readings to the nearest fifteen minutes, angles in the line were recorded to the nearest minute, and all distances were measured along the baseline to the nearest 0.03 m (0.1 foot). Cross section stations were marked with numbered wooden stakes at intervals of 15.2 m and numbered according to the distance from the origin of the line (i.e., station 131 was 131 m from the origin of the line (see Figure 12). In most cases, the cross sections were surveyed perpendicular to the baseline. In instances where they were taken at an angle to the baseline, the angle was measured with a field compass to the nearest degree. In each case the placement of the cross section was marked on the bank opposite the baseline with a stake or some natural marker. Elevations to the nearest 0.03 m and width to the nearest 0.3 m were taken at the cross sections where there was some change in the contour, at the shoreline and at the place where the water velocity was strongest.

At the Logan River bulldozed site, the baseline and cross section stations that were surveyed in the spring of 1972 were re-established for this survey. This baseline began at the railroad bridge on the Logan River and continued upstream for 1,692 m.

The baseline at the Blacksmith Fork dredged site was established beginning at the 1700 South Street bridge in Cache County, Utah, and continued upstream 1,247 m. This site contained cross sections numbered 335 to 847.

At the Blacksmith Fork control site, the baseline began at the bridge on Utah State Highway 165 and continued upstream 550 m. Dense bank vegetation at this site made surveying with an optical level impractical because of poor visibility. Therefore, cross sections in this area were surveyed with the following technique. Fixed stations were established on both sides of the river along the baseline, and the elevations of these stations were measured to the nearest 0.03 m. Cross sections were surveyed by holding the surveyor's chain taut between the two stations. The stadia rod was held vertically against the chain at the point where the reading was to be taken, and the elevation was recorded to the nearest 0.03 m at the point where the chain crossed the rod. The location of the rod along the chain was recorded to the nearest 0.3 m.

The baseline at the Blacksmith Fork bulldozed site began at the 1st South Street bridge in Millville, Utah and continued upstream for 592 m. The baseline of the Logan River control site began 15 m below the Main Street bridge and continued downstream for 92 m.

Estimation of Sand and Gravel Transport and Deposition

Cross sections measured just after dredging were compared to those measured just after spring high flows, and areas of erosion and deposition of the streambed were measured with a polar planimeter. The amount of erosion (in m^2) in two adjacent cross sections was averaged ($\frac{A+B}{2}$) and multiplied by the distance between cross sections to obtain the volume of material (in m^3) eroded. Deposition was calculated in the same way. Summing all erosion and all deposition values for a site yields a total volume for sediments moved, but this value may not be comparable from one site to another because of the different lengths of stream involved. For this reason the totals were divided by the number of 100 m intervals contained in the study reach, yielding values in m^3/100 m of stream. These values may then be compared to gain an indication of the dynamics of a streambed. These values probably underestimate the actual amount of erosion and deposition, especially if the time interval between surveys is very long.

BIOLOGICAL PARAMETERS

Fish

Collections. Whitefish and brown trout populations were sampled in the study area between February 1975 and December 1976 (Appendix B, Tables 1 & 2). Fish were collected with two 500 watt DC backpack electro-shockers. Crews of six to fourteen people (depending on fish density, mean river width, and volume of flow) sampled the rivers in 100 m invervals. Captured fish were held in 100 l plastic buckets, then anesthetized in a solution (0.14 ml/l) of MS-222/Quinaldine mixture (Schoettger and Steucke 1970).

Fork and total lengths (to the nearest mm) were recorded for all fish collected. Fish between 10 and 500 g and fish over 500 g were weighed on 500 g and 5 kg capacity dietary scales, respectively. Brown trout less than 10 g were subsampled, returned to the lab and weighed to the nearest 0.1 g on an electric top-loading balance. Weights for whitefish less than 10 g were estimated from a length-weight regression for young-of-the-year whitefish from the Logan River (Brown 1972).

Fish over 50 g were marked with numbered dart tags (Dell 1968). Fish less than 50 g were marked by removal of fins (adipose or pelvic) or by punching holes in fins. Freeze brands (Everest and Edmundson 1967) and numbered fingerling dangler tags were used on occasion to obtain some information on movement for young-of-the-year.

All fish were held until fully revived and then released in the section where they were captured. Visual inspections of sampling areas were made at various intervals after electrofishing to check for delayed mortality.

Movement. Movement of individual fish over 50 g could be determined during this study since each fish was marked with a numbered tag and the section of capture was always recorded. A limited amount of movement data for fish under 50 g was obtained using freeze brands and dangler tags. Movement data were obtained during all sampling for population estimates as well as sampling for data on fecundity and growth. Several special collections were made outside the boundaries of study sites to obtain movement data for the entire study area (Appendix A; Table 2).

There were two objectives for obtaining information on fish movement: (1) To check assumptions made in making population estimates, and (2) for a better understanding of the ecology and life history of brown trout and whitefish. Data were stratified by size group of fish and time between recaptures and then analyzed to determine the number of fish moving, direction of movement (upstream or downstream), mean distance moved, and number remaining stationary. The distance the fish traveled was determined to the nearest 100 m since movement within sections could not be followed. Movement into adjacent sections may reflect a change in locality of only a few meters across an imaginary boundary; consequently, movement between adjacent sections was treated separately in data analysis. These data were used to determine whether any immigration had occurred between mark and recapture sampling for population estimates. Fish movement was also analyzed by size group for different streamflows (including a separate season for spawning) to determine the effects of changes in streamflow on fish movement.

Age Composition. Scale impressions were made in cellulose acetate and examined on a scale projector at 80X. At least two independent readings were made of the scales from each fish. The number of annuli, fork length of fish, and date and location of sampling were recorded and analyzed. The scale method of age determination was validated by comparison with length frequencies of the fish and other information on fish from the Logan River (Sigler 1951, Bergersen 1973) and Blacksmith Fork River (Gosse 1977). The final age divisions were drawn on length frequency histograms by date of collection.

Population Estimates. Whitefish and brown trout populations were estimated using Chapman's (1951) modification of the Petersen population estimator (equation 1):

$$\hat{N} = \frac{(M + 1)(C + 1)}{R + 1} - 1 \qquad (1)$$

where: N = estimated number of fish in the population
M = number of fish marked on the first sampling
C = number of fish captured on the second sampling
R = number of fish in the second sampling that were marked during the first sampling.

When fish movement into a study site occurred between the mark and capture dates, it was incorporated into the estimator (equation 2):

$$N^* = \frac{(M + 1)\{C - am(Q) + 1\}}{R + 1} - 1 \qquad (2)$$

where: N* = revised estimate of the number of fish in the population

M = number of fish marked in the first sampling
C = number of fish captured in the second sampling
am = number of marked fish which have moved into the study site between mark and capture sampling
Q = estimated ratio of the total number of fish/number of marked fish in the area where immigrants originated
R = number of fish in second sampling that were marked during the first sampling.

(See Appendix B; Table 4 for derivation of equation 2). Estimates were made at approximately two-month intervals for length groups approximating the year classes 1976 through 1972 and 1971 and older (Appendix B; Table 5+). Fish populations in Logan control were estimated on 9 October 1975 and 5 February 1976. Confidence intervals (95%) were calculated for individual estimates treating the ratio of recaptures to captures (R:C) as a binomial variable (Davis 1964, Seber 1973) and obtaining intervals from the tables of Crow (1956) and graphs of Clopper and Pearson (1934).

The first population estimate for Blacksmith bulldozed (11 August 1975) was made using the "two-catch" method of Zippin (1958) (equation 3):

$$N = \frac{C_1^2}{C_1 - C_2} \tag{3}$$

where: N = estimated number of fish in the population
C_1 = number of fish in first catch
C_2 = number of fish in second catch

The estimate was made by grouping the fish by size class and calculating the 95% confidence intervals (N±2 SE) with a normal distribution. The standard error (SE) was calculated using (equation 4):

$$SE = \frac{C_1 C_2}{(C_1 - C_2)^2} \; (C_1 + C_2) \tag{4}$$

The two-catch estimate was used for the first sampling period because of the possibility that the proposed alteration by bulldozer at this site would occur before the recapture sampling could be made using the Petersen estimator.

Growth. Growth rates for the time intervals between population estimates in a study site were calculated for each year class from mean weights. Growth was assumed to be an exponential function and was calculated by following Chapman (1968) (equation 5):

$$G = \frac{\ln \overline{W}_2 - \ln \overline{W}_1}{\Delta t} \tag{5}$$

where: G = instantaneous growth rate
$\overline{W}_1, \overline{W}_2$ = mean weights of an age group at times t_1 and t_2, respectively

Δt = time interval $(t_1 - t_2)$

For the Logan and Blacksmith bulldozed sites mean weights were calculated for the entire study site as were growth rates because of low numbers of fish in these areas.

Population change rate. Changes in population numbers between successive estimates result from either movement or mortality or a combination of these changes. Population change rates were calculated using both components since there was no way nor need to effectively distinguish between them. This rate was assumed to be exponential and was calculated as follows (equation 4):

$$Y = \frac{\ln N_1 - \ln N_2}{\Delta t} \tag{6}$$

where: Y = instantaneous population change rate
N_1, N_2 = population estimates for a year class at times t_1 and t_2
$\ln$ = natural logarithm
Δt = time interval between estimates $(t_2 - t_1)$

Production. Biomass (standing crop) of a year class was calculated as follows (equation 7):

$$B = \bar{w}N \tag{7}$$

where: $\bar{w}$ = mean weight for a year class
N = estimated number for a year class

Mean biomass of a year class $(\bar{B}_1)$ between collections was obtained by following Chapman 1968 (equation 8):

$$B_i = \frac{B_o \{e^{(G - Y)} - 1\}}{(G - Y)} \tag{8}$$

where: B_o = biomass of a year class at the beginning of the time interval between samplings
G,Y = instantaneous growth and population change rates, respectively, for the period between samplings

Production (P) is calculated for a cohort (i) over a time interval (t) using equation 9:

$$P_{it} = G_{it}\bar{B}_{it} \tag{9}$$

where: G_{it} = instantaneous growth rate for cohort (i) during time interval (t)
$\bar{B}_{it}$ = mean biomass of cohort (i) during time interval (t)

For dates when mean weights were available, but population estimates were not (e.g. during spring floods), the production was calculated for the time interval by following equation 9 using the nearest population estimates on either side of the time period. Although this technique produces no new information on population size, it provides a more reliable estimate of production over long periods of time by providing more accurate growth rates.

Macroinvertebrates

Two types of sampling devices were employed: a Hess sampler (total area 1380 cm^2) with a 0.25 mm mesh net, and basket-type samplers. The basket samplers have been proven to be effective in small streams in this region (Israelson et al. 1975). They are easy to use and less subject to sampling technicians variability than most methods. Their disadvantages are the time necessary for colonization by macroinvertebrates, their vulnerability to loss by vandalism, and loss due to substrate movement.

The baskets (total area 225 cm^2) were 15 cm cubes constructed of 1.2 mm hardware cloth with 0.25 mm mesh nitex cloth in the bottom. This design allows lateral movement of invertebrates, but prevents vertical movement out of the sampler, especially during retrieval. The baskets were installed by digging a narrow trench perpendicular to stream flow, filling the baskets with some of the removed substrate, placing the baskets in the trench and replacing substrate around them. They remained in the stream for a minimum of two months prior to sampling. This period of time was found to be adequate for the macroinvertebrate community to become re-established (Brooks 1971). Basket samples were taken by grasping the edges of the basket, rapidly lifting it straight up out of the water, and depositing it in a 12 l plastic tub.

The Hess sampler (total area 1380 cm^2) with a 0.250 mm mesh net was used for comparison with the basket samplers and to obtain samples when basket samplers were no longer in place. The Hess samples were taken in the vicinity of baskets (± 10 m of stream). The substrate was loosened to a depth of 10-15 cm if the material was not compacted and washed thoroughly. The sample was then transferred to a 12 l plastic wash tub.

The original sampling schedule was to collect two samples monthly with each sampler at each site. However, the loss of basket samplers reduced the number of samples that were collected by this method (Appendix E ; Table 3).

All samples were processed by the following method. Large pieces of substrate were carefully washed off and removed from the tub. The sample was then sugar floated three times to separate the invertebrates and organic matter from the gravel and sand (Anderson 1959). The gravel and sand were discarded and the sample was washed with fresh water through a 0.25 mm diameter mesh sieve and placed in a clean tub. The sample was then washed through a US #5 sieve (4.0 mm diameter openings) into another tub and the fraction retained was placed in a separate bottle. This process was repeated for the entire sieve series (US #s 5, 7, 10, 14, 18, 25, 35, 45, 60 with corresponding mesh openings of 4.0, 2.80, 2.00, 1.50, 1.00, 0.710, 0.500, 0.355, 0.250 mm). This series corresponded to alternate sieves in the test sieve aperture series recommended by the International Standards Organization, Geneva, Switzerland. (The log of the opening in mm is highly correlated with sieve size (each sieve = 1 x axis unit and can be described by the regression $y = -.150104311x + .749940750$; $r = -.999988$.) The samples were preserved in 10% formalin and returned to the laboratory. While invertebrates preserved in formalin lose weight (Howmiller 1972; Winberg

1971), this loss is due mainly to dehydration, rather than the loss of soluble lipids as when specimens are preserved in alcohol. This was more desirable in the present study as dry, rather than wet, weights were used in weight calculations.

In the laboratory, invertebrates were sorted from detritus by hand. The samples obtained from larger sieve sizes (5-10 or 14) were sorted under an illuminated magnifier (2x) in their entirety. Samples from smaller sieve sizes (14 or 18-60) were mechanically sub-sampled (Waters 1969b). The sub-sampler has been shown to give statistically random samples (Appendix C ; Table 3; Elliott 1971). Sub-samples were sorted until the total number of invertebrates examined was ≥50 (Elliot 1971, Cummins 1975). The samples from the smallest sieve sizes (35-60) were sorted under a dissecting microscope (10-30x). Identification was made to family, or to genus when possible.

The total lengths of all invertebrates from one sampling station were measured with an ocular micrometer. The data provided a means of analyzing the efficiency of size sorting by the sieves (Appendix E ; Figures 1-3) and allowed comparison with data from the literature based on total lengths.

Composite samples, by taxa and sieve size, were used for the determination of average wet, dry (85°C, 12 hr), and ash (500°C, 2 hr) weights of the insects (Winberg 1971). Further calculations based on weight were made from linear regressions of log normalized ash free weights (Appendix F ; Table 1); sieve sizes with inadequate sample sizes were omitted from these regressions. A weighted mean ash free dry weight for each sieve size, regardless of taxa, was calculated from the same data for use in estimates of mean total biomass standing crop and total production (Appendix F ; Figures 1-4).

Estimates of the mean density (number of individuals of each taxa per m^2) were made by sieve size for each date at each site. Each sample was treated equally, and corrected for sample area and number of sub-samples. Estimates of the mean standing crop (gm/m^2) were calculated from estimates of density ($no./m^2$) and average weights.

Estimates of the mean total standing crop (number of individuals per m^2 by sieve regardless of taxa, and totals regardless of taxa) were also made for each date at each site. In these cases, the total number of insects in each sample was treated as the sample attribute, and the means were calculated as above. Mean total biomass was calculated by treating the total biomass of each sample (calculated as above) as the sample attribute.

Total production estimates following Hynes' method (Hynes and Coleman 1968, Hamilton 1969, Waters and Crawford 1973) were made from mean standing crops and average weights using data for total invertebrates.

A Shannon diversity index was determined following the description of Wilhm and Dorris (1968). Diversity index values were calculated for each date at each site using mean standing crop estimates.

When seasonal values are used in comparisons, the seasons are based on the water year and are:

Fall: October, November, December
Winter: January, February, March
Spring: April, May, June
Summer: July, August, September

Significance of differences between seasons and sites was determined by analysis of variance and least significant difference.

RESULTS AND DISCUSSION

PHYSICAL PARAMETERS

Three type of illustrations are used to depict changes in the river over time: (1) a series of plan view maps show how the river meander, water current, and gravel bars shifted during the study; (2) cross sections at particular locations depict changes in the stream bottom after varying lengths of time; and (3) thalweg profiles record how the longitudinal profile changed over time. The following discussion requires reference to plan view maps to establish the location of cross sections and the meander of the river in the study area. Distances along stream reaches are recorded in meters, and stations (cross sections) are identified by their position (in meters) along the reach.

General Changes in Stream Meander, Water Current and Gravel Bars

Stream length can be expressed by two measurements: (1) The centerline length of the stream, and (2) the thalweg length that follows the deepest part of the channel. A straight channel would produce a ratio of thalweg to centerline length of one while a meandering channel would produce a ratio of more than one.

Only one major change can be noted between November, 1972 and 1975 at Logan bulldozed site (Figure 12). A pool with depths of greater than 1 m developed between stations 46 and 137, and a large gravel bar was deposited on the convex side of the river bend in the same area. Development of the pool was accompanied by erosion of the bank on the concave side, a process which prompted the landowner to use a bulldozer to remove the gravel bar to fill in the pool and shift the western bank some 5.2 m further east. Between May and November, 1975, most of the 1975 alteration had been restored to pre-alteration condition. This does not imply particularly good conditions, since only 8 percent of the site length contained pools of 1 m depth or greater.

Examination of the plan view maps (Figure 13) discloses several changes which took place at the Blacksmith dredged reach during this study. As mentioned in the discussion of cross sections, dredging usually removed streambed materials along convex banks, and the river subsequently relocated the streambed to the same general locations. Dredging usually widened the river, but deposition later usually returned the stream to near its original width. The numbers and sizes of pools are of interest because of the importance to fish (Table 1). Note that both the number of pools and total linear meters of pools more than one m deep decreased after each dredging. Spring runoff in 1975 not only

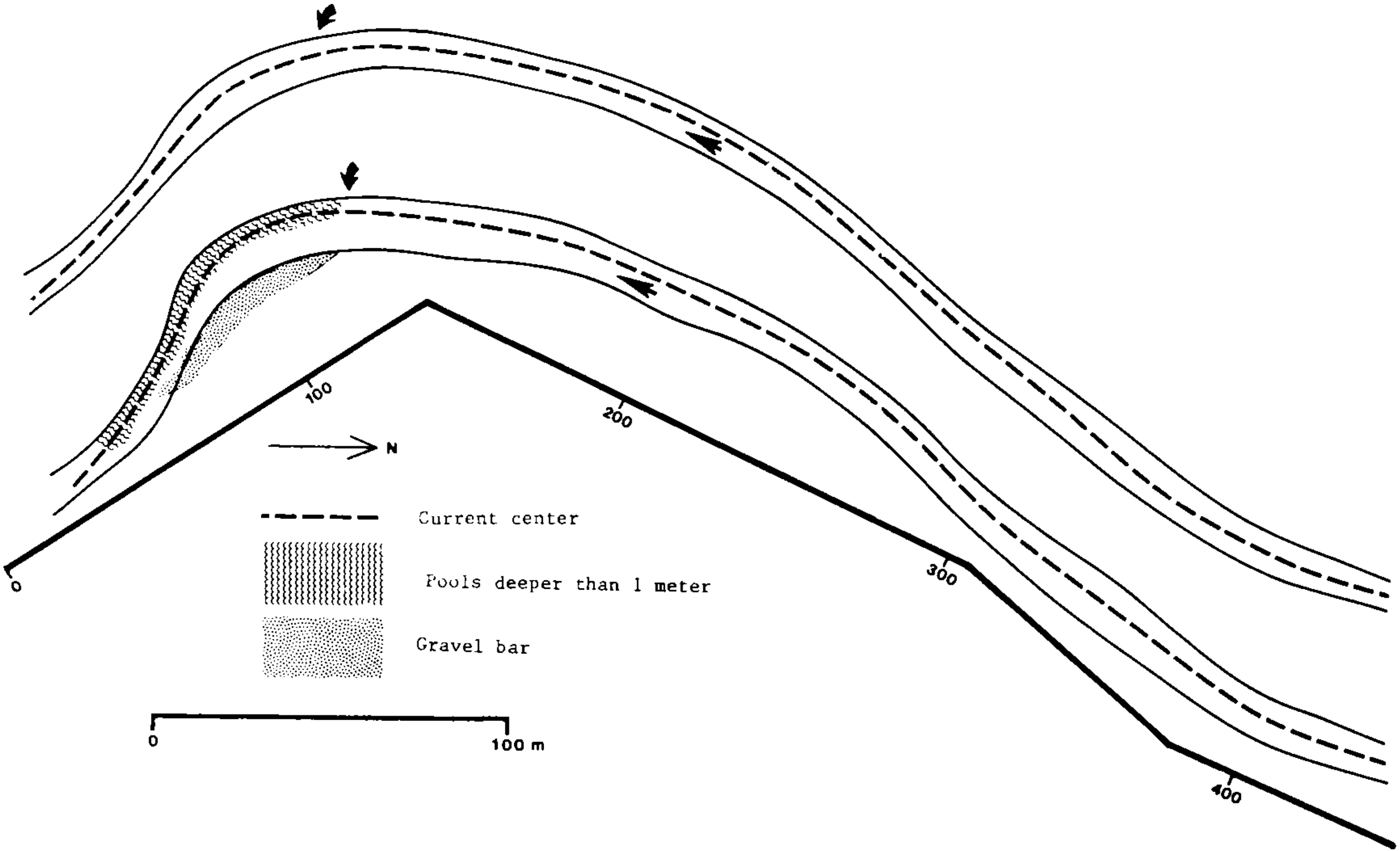


Figure 12. Maps of a bulldozed reach of the Logan River, Cache County, Utah, illustrating conditions in spring 1972 after entire reach was altered (upper), and in November 1975 (lower). Area downstream from arrow was altered again in August 1975.

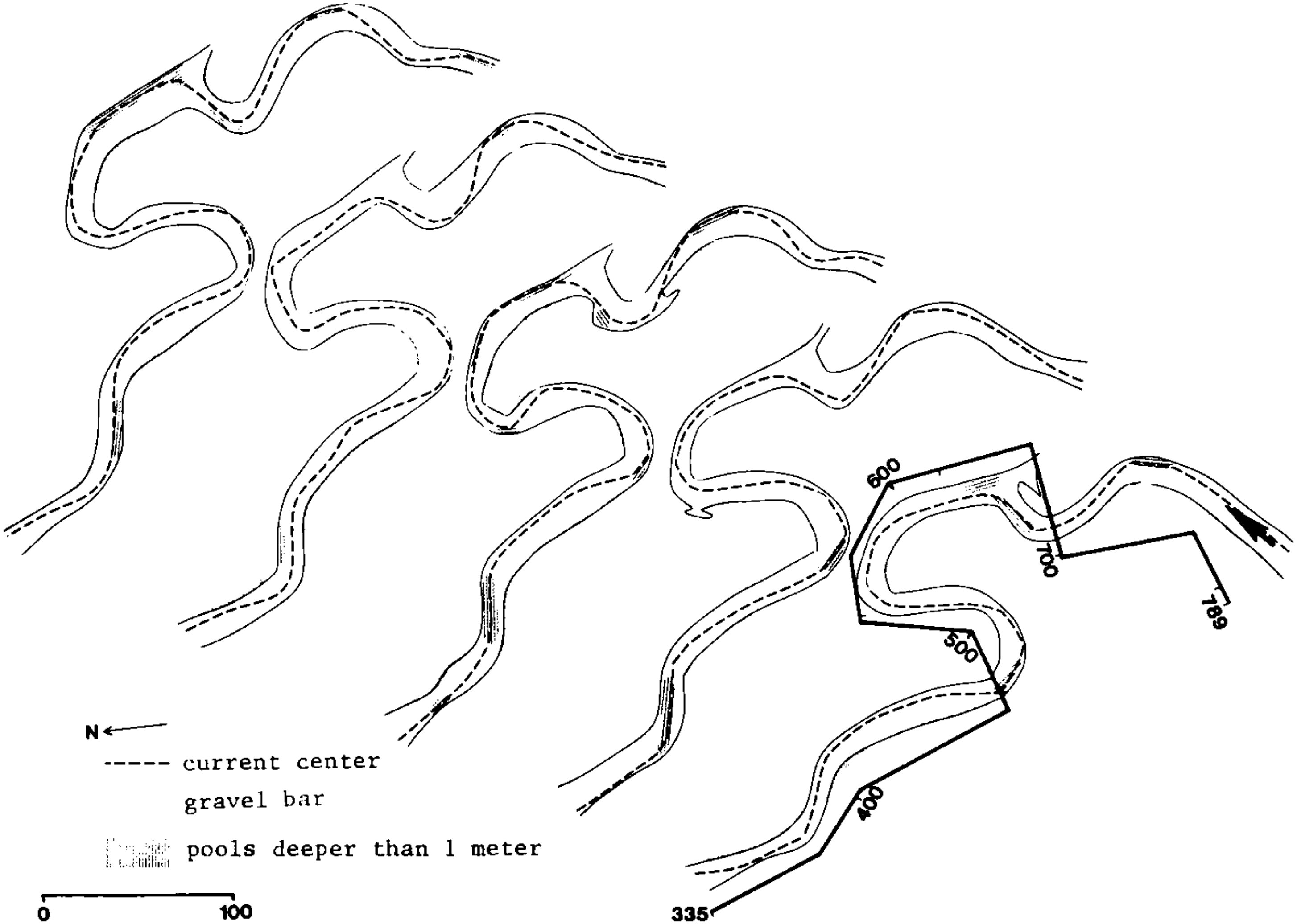


Figure 13. Maps of the newly dredged reach of the Blacksmith Fork River, Cache County, Utah showing conditions in (left to right) January, April, June and September 1975, and June 1976.

restored the number and amount of deep pools, it actually increased both (See values for June). The number and size of the pools did not change much during 1976, probably because of the low runoff.

Table 1. Changes in the number and total linear meters of pools more than one meter deep in a dredged reach of the Blacksmith Fork River, Cache County, Utah, 1975-76.[1]

Parameter	1975 Jan	1975 Apr	1975 Jun	1975 Sep	1976 Jan	1976 Apr	1976 Jun
Number of Pools	5	2	8	2	3	5	4
Total linear meters	128	34	158	64	73	70	73

[1]Dredging of this reach was done by backhoe in late March and late August, 1975.

Certain pools were restored by the spring runoff after one or both dredgings (Table 2), while one (390) was not eliminated by either dredging, but gradually decreased in size until it disappeared.

There was little change in the stream course at Blacksmith control so meander and centerline length were unchanged (Figure 14). Changes in stream bottom elevation were minor, leaving current flow and gravel bars relatively unchanged. The number of pools more than one meter deep decreased because of the decreased flow rather than any changes in the stream bottom.

Alterations in September at the Blacksmith bulldozed site resulted in reduction of some meandering, changing the thalweg to center length ratio from 1.05 to 1.01. This ratio had changed to 1.02 by June, 1976 (Figure 15).

In August, 1975, prior to alterations, there were four pools more than 1 m deep in the area of alterations. All of these pools were filled in by the bulldozer. Three of the four pools had been scoured out and restored by spring runoff as of June, 1976.

Overall there was little change in alignment at Logan control, with the thalweg/centerline length ratio changing slightly from 1.006 to 1.01. There were changes in elevation of the stream bottom ranging from -0.7 m to +0.5 m, indicating possible changes in current velocity. Gravel bars, which were a prominant feature in some locations in late 1972 and in 1973, had apparently been rearranged by November, 1975, and were less numerous and prominant. Pools greater than one meter deep increased from one in 1972 to four in 1975 (Figure 16).

Changes in Cross Section with Time

With 0.42 m of fall per 100 m, the stream bed gradient at Logan River old bulldozed is the lowest of the study sites. This reach was channelized in

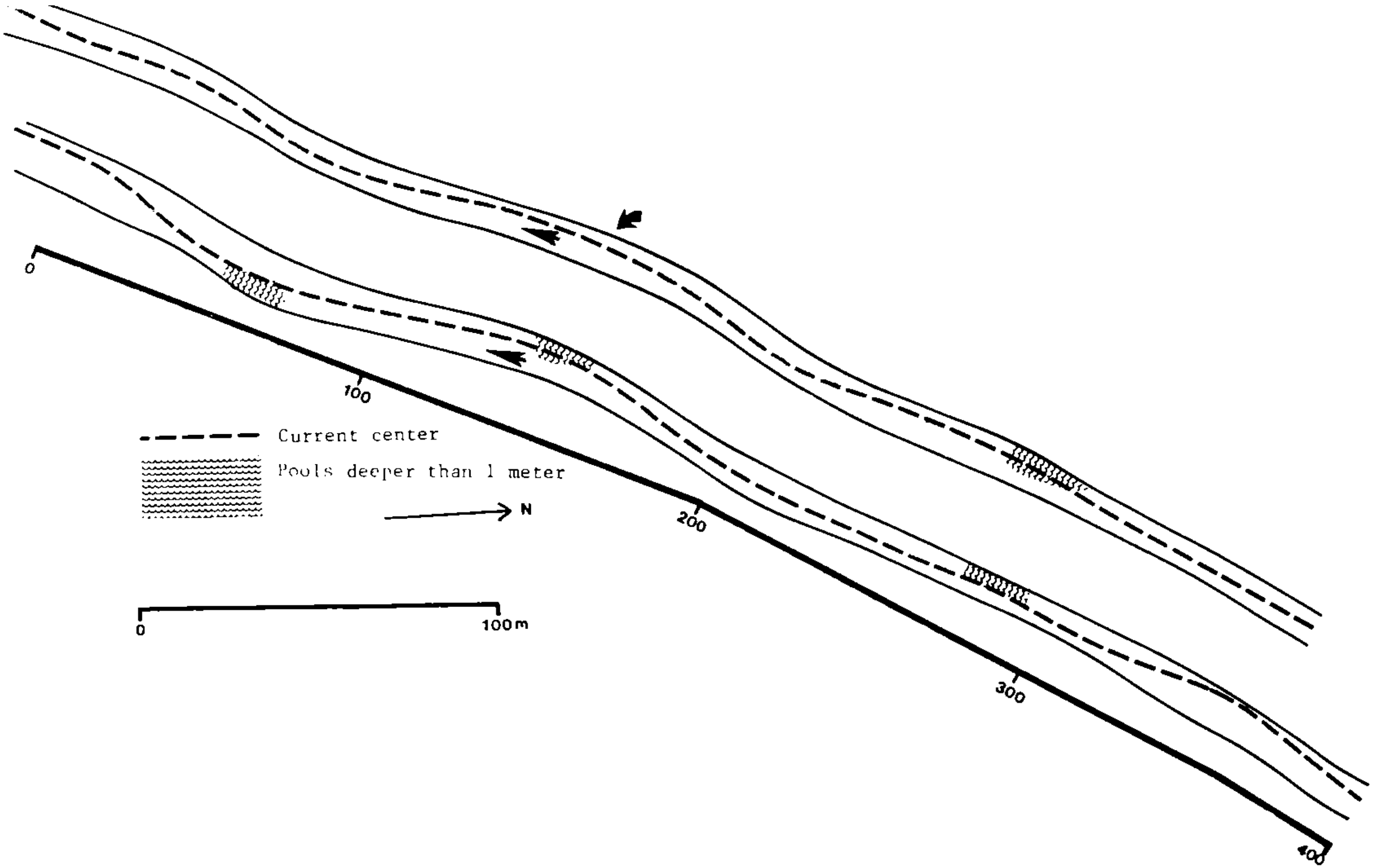


Figure 14. Maps of the control reach of the Logan River, Cache County, Utah in spring 1972 after alterations as far upstream as 152 meters (arrow), and in fall 1975 (lower).

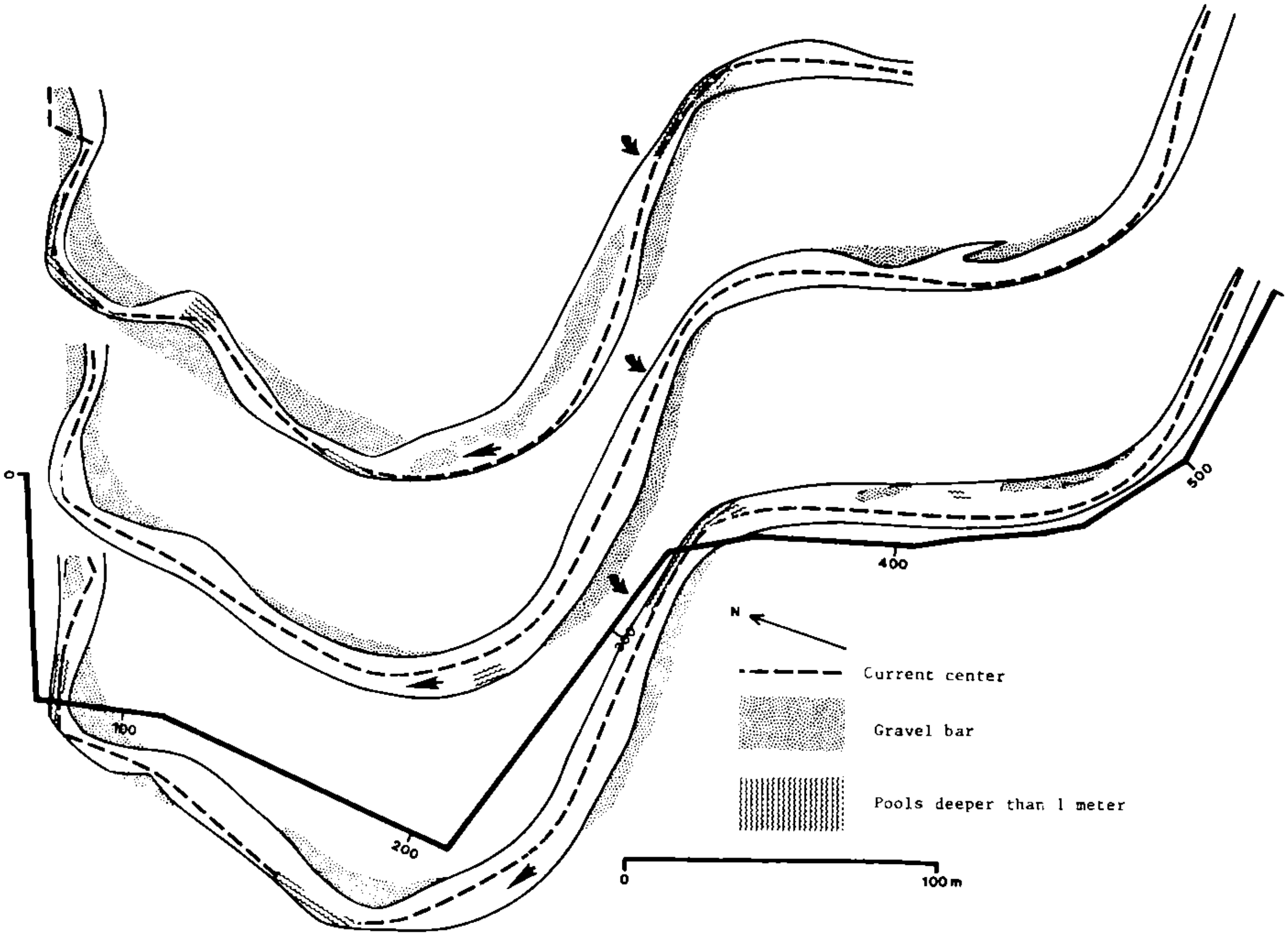


Figure 15. Maps of a bulldozed reach of the Blacksmith Fork River, Cache County, Utah, illustrating conditions in (top to bottom) August 1975 before alterations, September 1975 after alterations (downstream from arrow) and in June 1976.

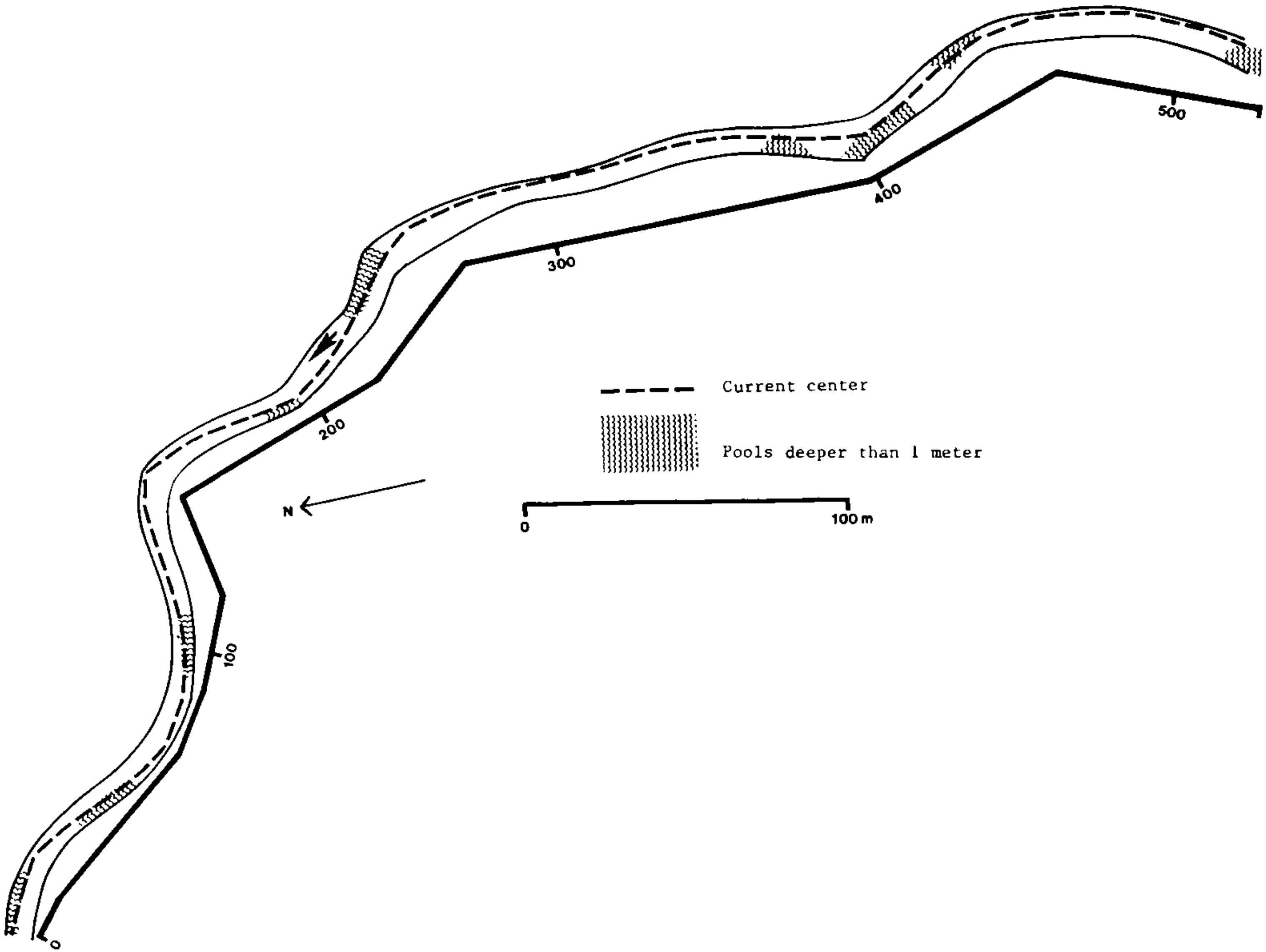


Figure 16. Map of the control reach of the Blacksmith Fork River, Cache County, Utah in November, 1975.

Table 2. Changes in location of pools deeper than one m as indicated by station numbers[1] for a dredged reach[2] of the Blacksmith Fork River, Cache County, Utah, 1975-76.

1975				1976		
January	April	June	September	January	April	June
		351				
390	390	390	390	390	390	
		468	468	468	468	468
		533				
		588				
		603				
622		622			640	640
689		689			689	689
	741	741		741	741	
758	758	758				758
774						

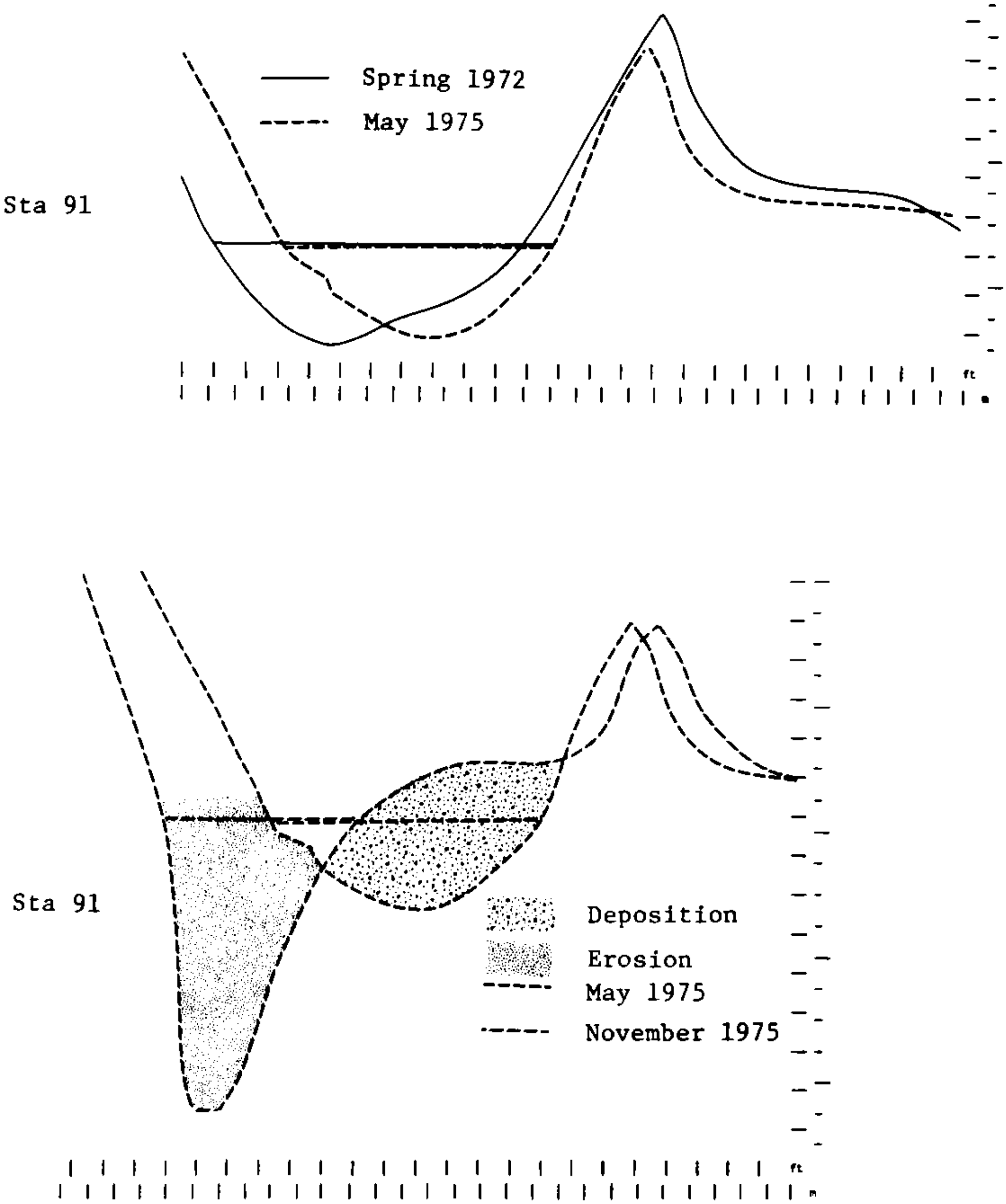
[1]See Figure 13 for location of stations.

[2]This reach was dredged in late March and late August, 1975.

November, 1971, and except for the portion between stations 30 and 122, has not been altered since.

Cross sections were surveyed along more than 1.6 km of stream in spring 1972, not long after this reach was altered by bulldozer. A portion of the area was chosen for study and surveyed in May 1975, shortly after some of it had again been altered with a bulldozer. A final survey was conducted in July, 1976. Thus, the area between cross sections 30 and 122 was altered in 1971 and again in 1975, while the area upstream from 122 was altered in 1971, but not subsequently (Figure 12).

At the downstream end of this site, between stations 30 and 61, erosion of the eastern bank widened the stream an average of 4.6 m between 1972 and the spring of 1975. No significant changes in width occurred between May, 1975 and July, 1976. From station 76 to 122, deposition along the eastern bank formed a gravel bar and erosion along the western bank excavated a deep pool between May and November, 1975 (Figure 17). The stream shifted 5 to 6 m to the west as a result. Just upstream, between stations 137 and 351, and again further up between 411 and 671 (Figure 17) the stream banks were eroded and the bottom elevation raised by deposition. The eastern bank eroded an average of 1.7 m (maximum 3.4 m at 396) while the western bank averaged 0.8 m (maximum 2.4 m at 168). By July, 1976, deposition had raised the stream bed to a level higher than the 1972 level at all but six stations in this reach. Changes of 0.3 m or greater occurred at 12 stations, 10 deposition and 2 erosion. The average change in the area bulldozed twice was a lowering of the bottom by 0.2 m while the change in the remainder was an increase in elevation of the bottom of 0.3 m. The land east of the river from stations 182 to 244 was lower than the water



Scale Vertical = 1 foot and 1/4 meter intervals
Horizontal = 4 foot and 1 meter intervals

Figure 17. Cross section in a bulldozed reach of the Logan River, Cache County, Utah.

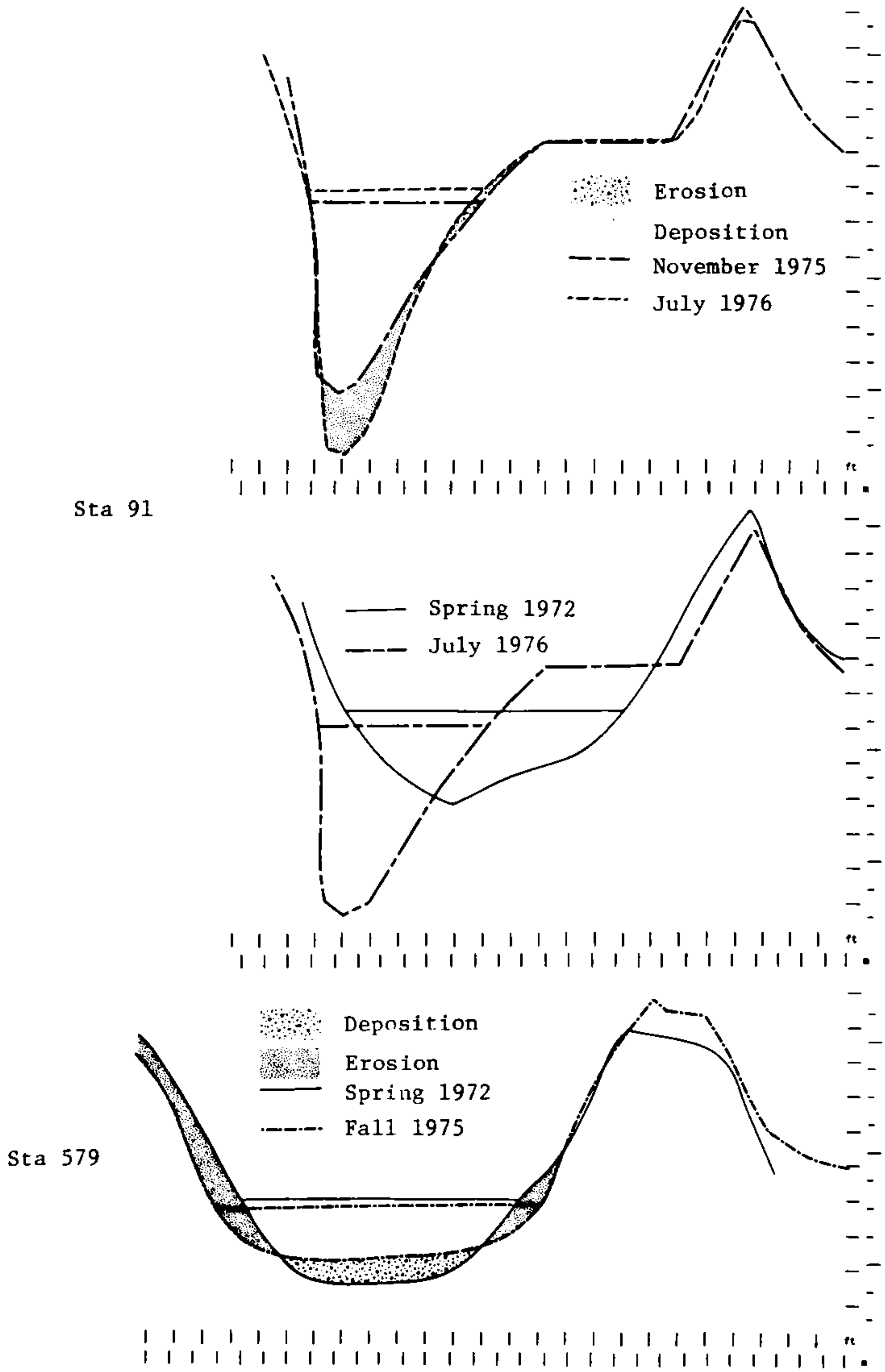


Figure 17. (Continued)

level during normal flow, and at stations 198 and 213 it was lower than the stream bed.

Because of the low gradient and low water velocities at the Blacksmith Fork dredged site gravel deposition has raised the river bed and water table to a point where the adjoining agricultural lands may often be too wet to cultivate in late spring and early summer. To alleviate this problem the landowners periodically deepen this section of river.

Cross sections were surveyed along the entire baseline, from 0 to 1123 m in January, 1975 (Figure 17). In late March, the river was altered with a backhoe between stations 335 and 860. Cross sections of the altered area were surveyed in April. The lower half of the altered area (stations 335 to 481) was surveyed again in May immediately prior to spring runoff. In June, following runoff, cross sections were surveyed from stations 0 to 1123. Landowners again made stream alterations beginning on August 28, 1975 using a bulldozer and backhoe between stations 335 and 789. Cross sections were surveyed in this area in September, 1975, and January, April and June, 1976.

Changes at the downstream end of this study site, between stations 335 and 375, were limited to removal of a long gravel bar on the eastern, convex deposition bank during both alteration operations. After removal of the bar in March, 1975, gravel was deposited in the same general area during the spring runoff, but the bar was not restored to its previous height. Removal of the bar again in August increased the stream width 1.2 m more than the March alteration. By January, gravel had already been deposited along the inside of the bend, and by June, 1976, the bottom contour was virtually the same as measured in June, 1975. Furthermore, the cross sectional area at station 375 varied only five percent from 1975 to 1976.

Nearly 60 m upstream, at station 434, a similar experience was observed. At this location, downstream from a horseshoe bend, the thalweg hugged the east bank and a long gravel bar extended for more than 30 m along the west bank. The gravel bar was removed during the March, 1975 alteration, restored by the spring runoff, removed again in August, and again restored by the spring, 1976 runoff. At this site, the stream bottom was slightly eroded instead of being raised by the deposition that usually occurs at low water flows in late winter and early spring. During the same period, a large deep pool just downstream at 390 was slowly filled in, until by June, 1976 it disappeared. Although the deepest portion of the pool was filled during the alterations in March, 1975, the subsequent high water scoured the streambed and recreated the pool. Apparently some subtle change in the conformation of the stream allowed the streambed material to deposit during the low flow periods of fall and winter, and the high flows in the spring, 1976 were either insufficient to scour out the pool or the change in the streambed redirected the energy of the spring runoff.

Immediately after each alteration the maximum depth of this profile was less than the January, 1975 level, but subsequent rearrangement of streambed materials by the current restored the previous depth. The maximum depth in June, 1975 was a few cm greater than in January, and by June, 1976, the maximum depth was about 23 cm greater than in January, 1976. The cross sectional area was 24 percent greater in June, 1976 than in January, 1975.

Near the upstream end of the horseshoe bend, slightly more than 60 m upstream from station 434, station 502 exhibited a slightly different set of conditions (Figure 18). A large gravel bar on the convex, inner side of the bend was removed in March, 1975, restored by high flows in May, and again removed in August. Width of the water surface was increased from 6 m in January, 1975 to 10 m in August. There was little change in profile until after the spring runoff in 1976. The cross sectional profile in June, 1976 was very similar to that of the previous June, with a water surface width of only 5.5 m, 0.6 m less than before the stream was altered. The cross sectional area had increased by 33 percent from January, 1975 to April, 1976, but by June, 1976 it was 28 percent less than in January, 1975. Maximum cross sectional depth was about 0.4 m greater in June, 1976 than in January, 1975.

Station 545 was in the middle of a sharp bend about 30 m upstream from station 502. As was typical for other locations, the gravel bar on the convex, deposition side of the river was removed each time the stream was altered. Stream width at the water line varied from 7.6 m in January, 1975 to 13.4 m in April after alteration, 7.9 m in June after spring high flow, 10.7 m in September after a second modification and 9.8 m in June, 1976 after high flow. In each case the stream banks above waterlevel remained about the same. Differences in width were caused by a gravel bar that was deposited along the inside of the river bend.

The maximum depth of this cross section was increased about 30 cm by the dredging in March, by an additional 5 cm during spring runoff, by 5 cm more by dredging in August and by another 38 cm during the 1976 spring runoff. Part of this 0.8 m increase in depth was due to normal deepening of the channel by the spring runoff. During low flows, pools commonly decrease in depth because of deposition of streambed materials. High spring flows remove this material again, and deposit it along the convex sides of bends further downstream. The total difference in depth between January, 1975 and June, 1976 is due to the combination of spring high flow and dredging.

Channel cross sectional areas changed from 3.25 m^2 in January, 1975 to 7.5 in April, 4.9 in June, 4.9 in September, 4.2 in January, 1976, 6.4 in April and 8.8 in June, 1976. Water surface elevations changed very little during this time, despite the 79 percent increase in cross sectional area.

Station 662 was midway in a straight reach of the stream about 77 m upstream from station 545. The main water current flowed close to the eastern or left bank. Dredging reduced the stream width from 12 to 9 m in spring, 1975, and other alterations upstream changed the thalweg course sufficiently to cause erosion along the east bank and a large deposition of sand and gravel on the west or right bank during spring runoff. Dredging in late summer did not change the width, but shifted the stream channel to the right. Low flows between September and April eroded 1.8 m of the left bank and deposited 60 cm of gravel along the right bank. The spring runoff had little effect on the left bank but eroded 1.2 m of the right bank and removed about 30 cm of the streambed from the right bank. These changes resulted in a more uniform depth across the stream at this station. The lack of deposition on the right side was probably the result of restoring the channel cross section that would occur normally and which redirected the current at station 622. The maximum depth was

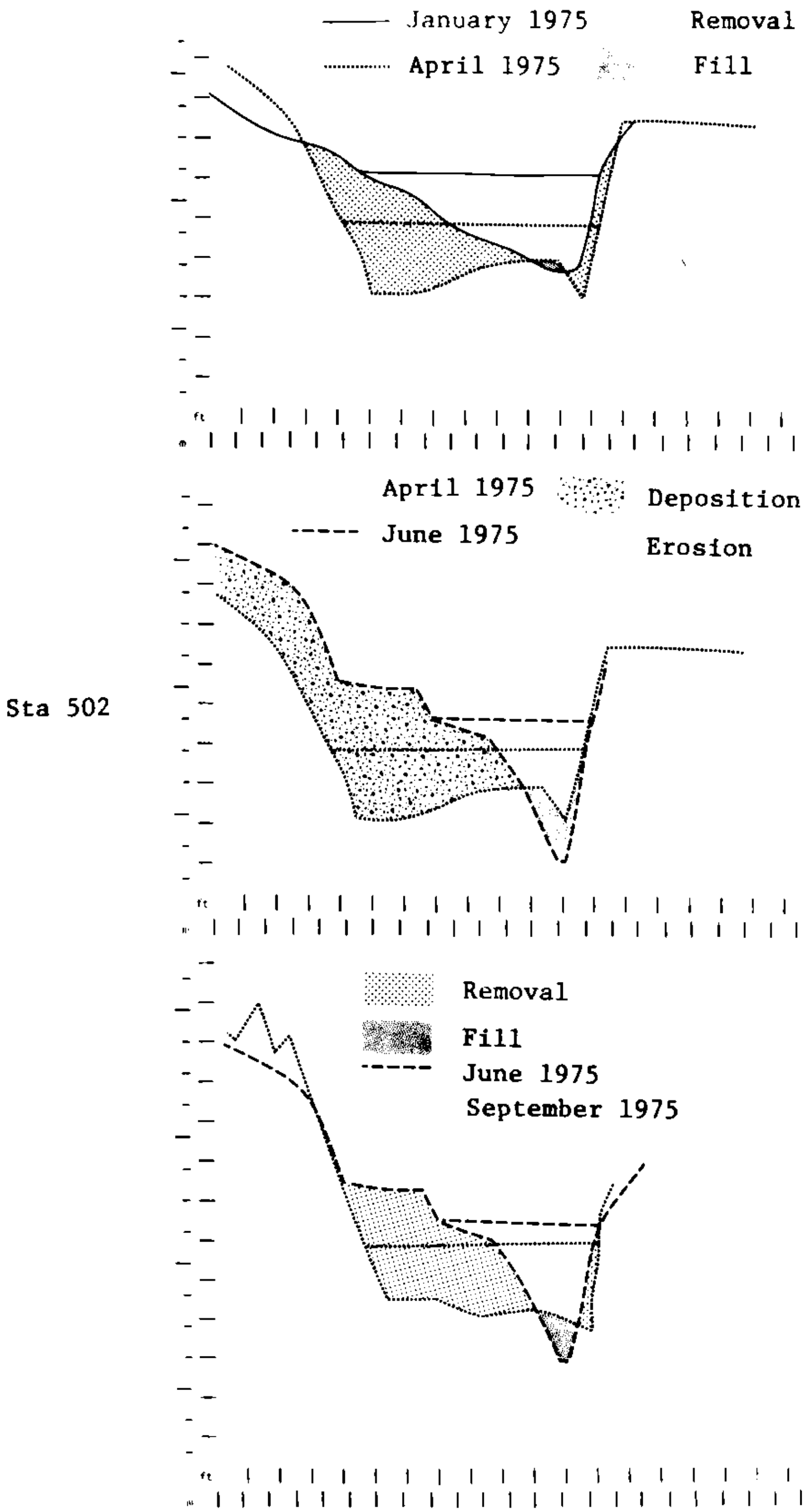
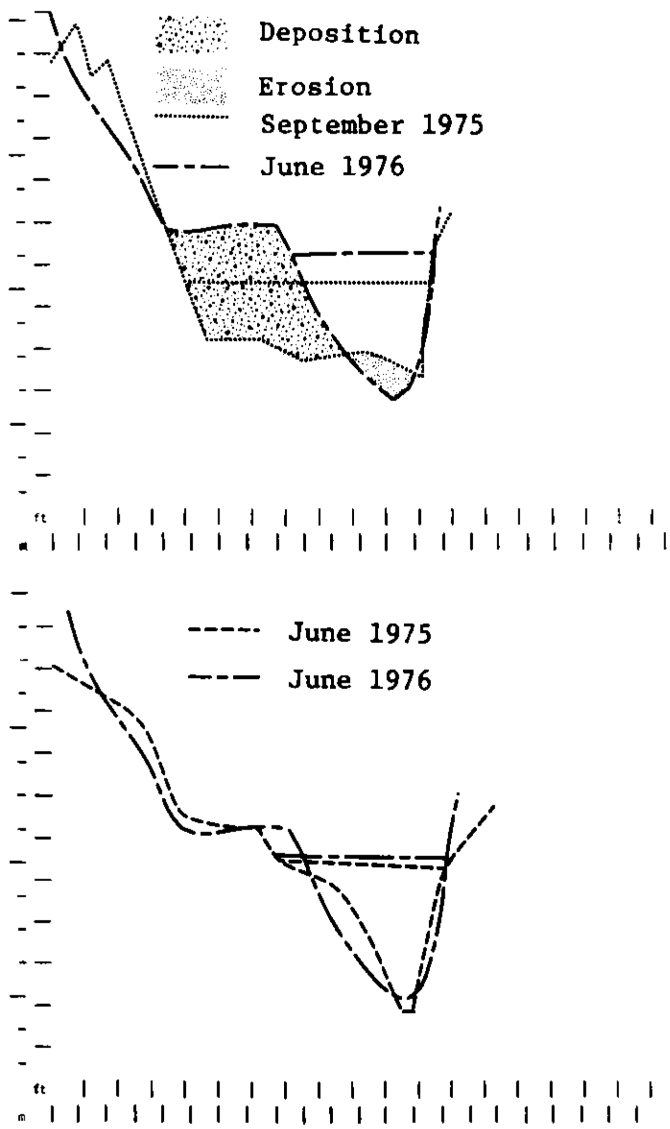


Figure 18. Cross sections in a recently dredged reach of the Blacksmith Fork River, Cache County, Utah.



Sta 502

Figure 18. (Continued)

about 30 cm greater in June, 1976 than January, 1975, but was about the same in June, 1975 and June, 1976.

Station 689 was changed more drastically than any other station (Figure 19). The origin of the profile on the baseline was located on a gravel bar on the convex or deposition side of a sharp bend. Each time the stream was altered, this gravel bar was removed and the deep pool on the outside of the bend was filled. Every year, the spring runoff replaced the bar where it would be expected to occur naturally and re-excavated the deep pool. These changes resulted in the deposition of much bedload from upstream and moved the bedload from the pool area downstream. In addition, the streambank on the north end of this transect needed to be continually stabilized by the landowner. Dredging in August had changed the channel sufficiently to redirect the thalweg, which resulted in rapid erosion of one portion of the bank and created the threat of cutting off an entire meander. This area of bank cutting was filled in with gravel retained by logs on May 1, 1976. After spring runoff in 1976, the outline of the stream in this vicinity was similar to that of January, 1975, but the thalweg location was shifted. Changes in this reach appeared to have a large effect downstream in deposition of streambed material and the location of deep pools.

Shifts in the location of the bank on the north end of this transect resulted in a deposition of 1.8 m of fill during dredging in spring, 1975, erosion of 8.5 m during spring runoff, deposition of 8.8 m during dredging in August, and an erosion of 8.2 m between August, 1975 and April, 1976. The bank was finally relocated about 6.4 m north of where it was located in January, 1975. The maximum depth remained the same in January and June, 1975, and June, 1976, in spite of all the changes that occurred during this time.

Station 724, about 30 m upstream from station 689, and located between two bends in the river, exhibited some great changes during the study. The stream width decreased by more than 50 percent as a result of dredging and sediment deposition during spring runoff in 1975, and subsequently increased again to 82 percent of the original width. This increase was not due to the direct effects of the August dredging, but rather to subsequent shifting of the streambed.

The stream depth changed little; however, it increased about 46 cm with the first dredging, became 15 cm deeper with the 1975 runoff, and was mostly refilled during the 1976 runoff. The final depth was less than 30 cm deeper than it was in January, 1975. With one exception, the deepest part of the cross section was always on the left or eastern side of the stream. Formation of large gravel bars during the 1975 runoff, their removal in August, and the subsequent reappearance of small but apparently stable bars by June of 1976 appear to be linked with changes immediately downstream. When the channel at station 724 was narrow, severe erosion occurred on the concave bank at station 689. A wide channel at 724 appeared to influence the location of the thalweg, and reduce erosion at 689.

Cross sections were surveyed at the Blacksmith control site in November, 1975 and again in July 1976, following the spring runoff (Figure 20). No alteration work was done during the period of study, and according to the land owner it has been over 20 years since any was done.

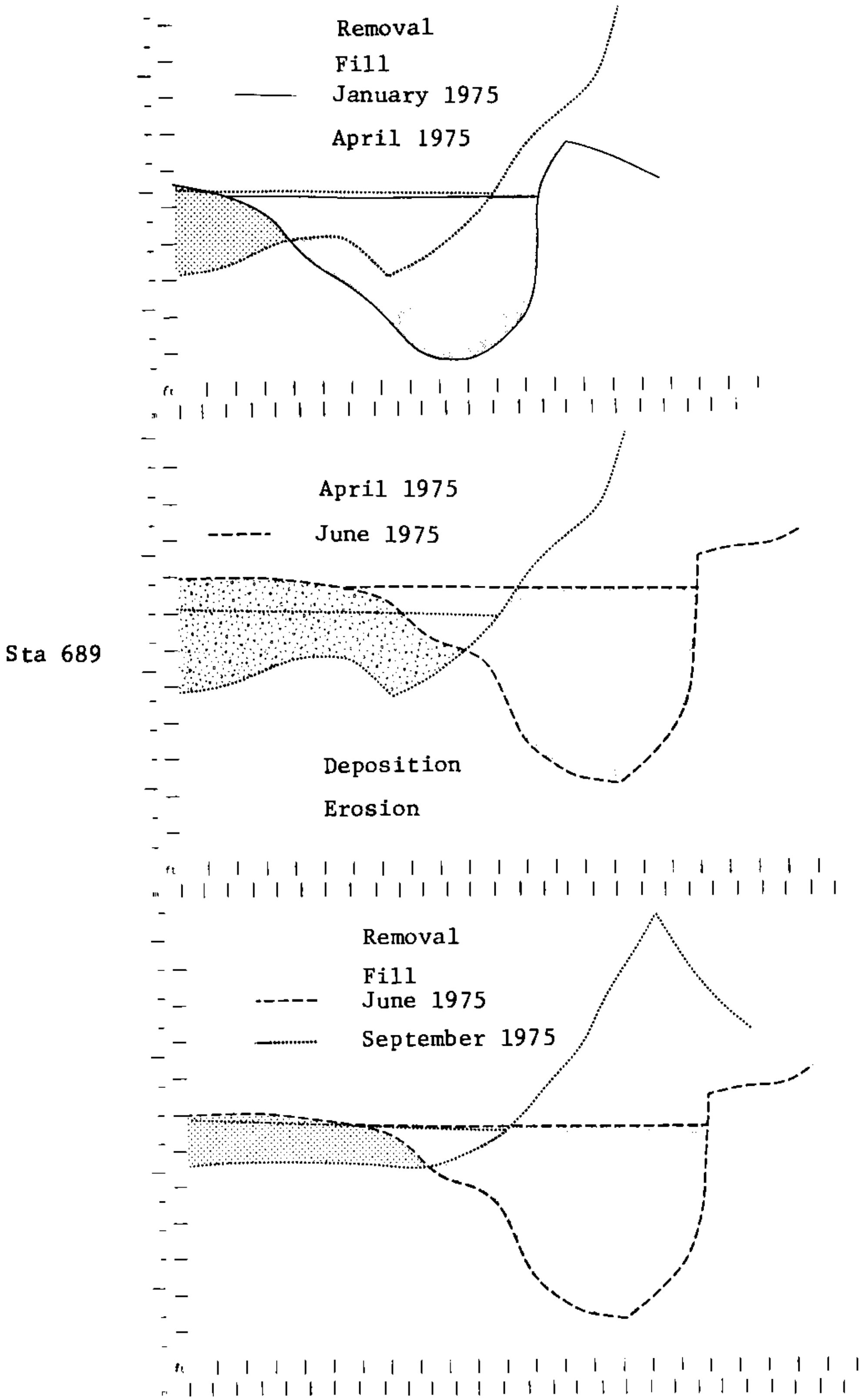


Figure 19. Cross sections in a recently dredged reach of the Blacksmith Fork River, Cache County, Utah.

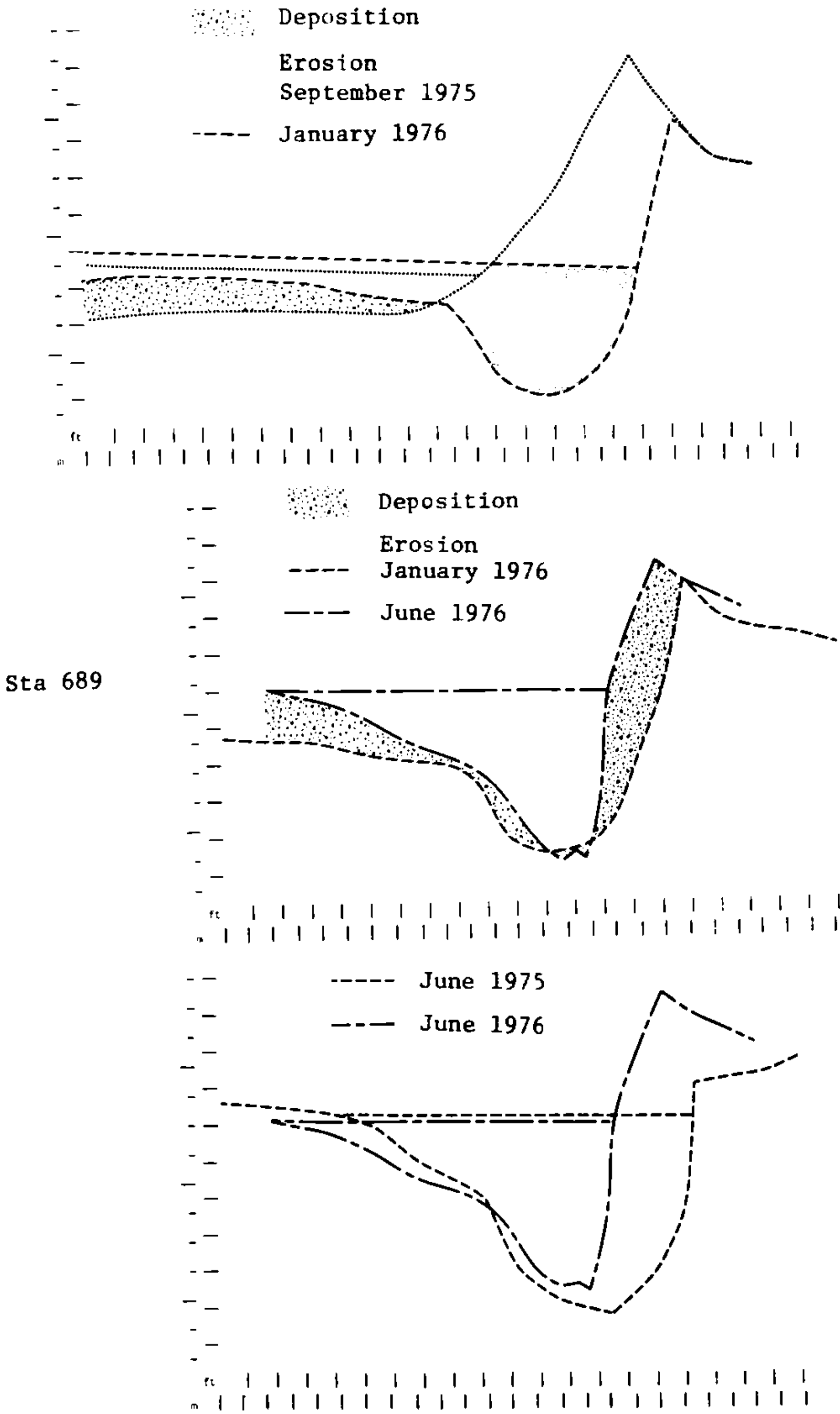


Figure 19. (Continued)

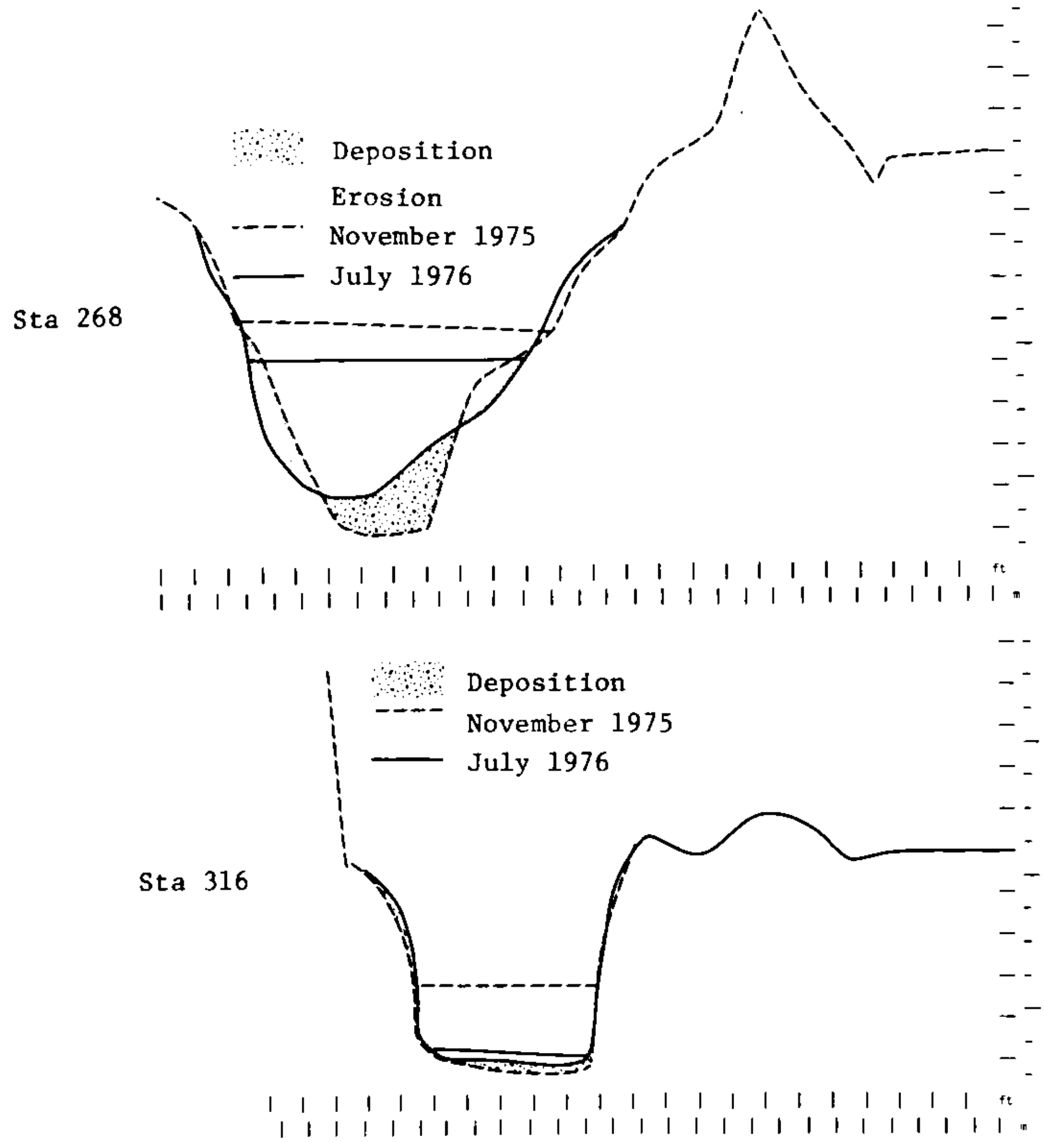
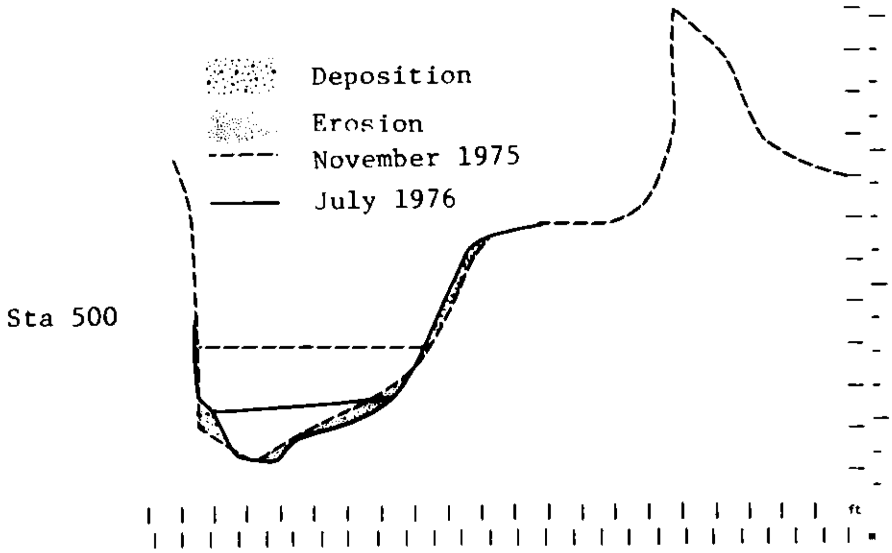


Figure 20. Cross sections in the control reach of the Blacksmith Fork River, Cache County, Utah.



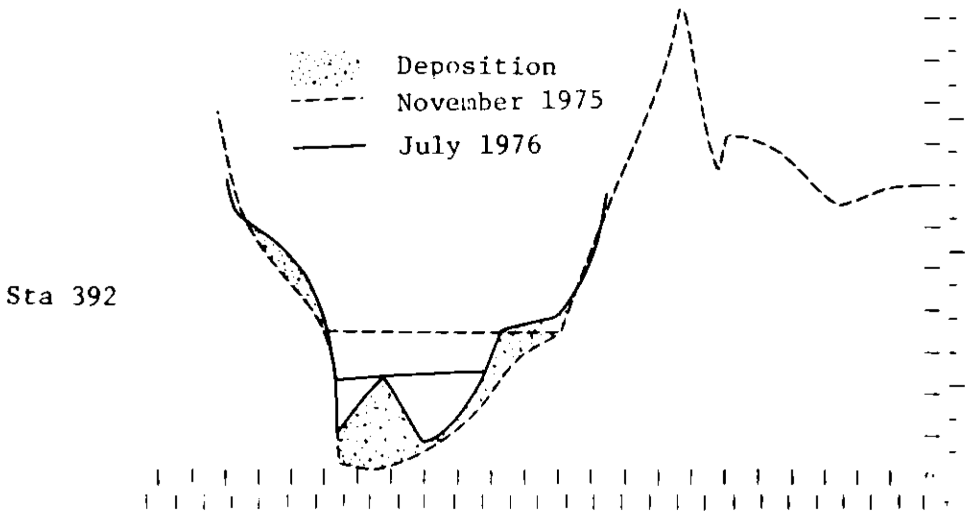


Figure 20. (Continued)

No significant changes in alignment occurred in this reach, although there were some changes in elevation of the stream bottom. Proceeding upstream from station 0 for about 100 meters there was little change except for a modest amount of deposition. A tree fell into the stream between 131 and 147, restricting channel width. The increased velocity caused down cutting from 115 to 131 and the channel constriction impounded water, causing deposition at 147. Erosion of the east bank caused a shift at 196, where the maximum depth increased. There was little change from 211 to 224, but erosion on both sides of the stream caused down cutting at 238. Deposition decreased the depth of a pool between 253 and 268, but from 285 to 361 there was no change (Figure 20). Between 377 and 404 deposition occurred in mid-channel, while little change took place from 417 to 433 and from 460 to 531 (Figure 20). Deposition decreased the depth from 433 to 460 and at 550. There was a decrease of 2.6 m in average width in this reach between November, 1975 and July, 1976. This difference is probably a consequence of irrigation diversion of water rather than a change in stream channel, since the water level at the staff gauge downstream declined sharply about mid-June. Extensive irrigation use of stream water usually begins in mid-May to early June. Since 1976 was a poor water year, diversion decreased the flow more than it would normally, and caused the decrease in average width.

The Blacksmith recently bulldozed site was altered by bulldozing in November, 1971, when the stream was deepened and dikes built along each side of the stream. Cross sections were surveyed between stations 0 and 381 in August, 1975. On September 6, 1975 the landowner altered the stream bed with a bulldozer between stations 81 and 351. Alteration was done to decrease bank erosion by shifting the location of water current impingement on the bank from station 244 downstream to 229a, an area which had been fortified with railroad ties. The channel was straightened between stations 91 and 184 to eliminate bank erosion at 139. After completion of the alterations, the stream was surveyed from station 81 to 591 in September, 1975, and the entire study area was again surveyed in June, 1976 (Figure 21).

Between 81 and 226 the river was straightened and the width increased an average of 4.4 m by the alterations. The pool on the west (right) bank was filled in and the river moved 4.6 m to the east (Figure 21). From 97 to 123 gravel was pushed to the west bank, moving the channel to the east an average of 3.7 m (Figure 21). Gravel was pushed into the pool and against both banks between 139 and 154, and into the pool between 169 and 229a. For about 60 m, from 229b to 321, extensive gravel deposits were removed from mid-stream and pushed against the west bank, reducing stream width by 3.4 m (Figure 21). This shifted the thalweg to the center of the stream until it reached station 215.

During spring runoff in May, 1976, a tree fell into the river at 81, causing development of a large pool extending from 97 downstream to 46. Erosion along the west bank removed the gravel deposited during the alteration and returned the channel to near the August, 1975 position (Figure). Some mid-channel erosion between 112 and 123 lowered the river bed in that area (Figure 21) while deposition raised the bed from 139 to 169. Along the west bank, erosion returned the river to near its August, 1975 position from 184 to 229a. However, from 229b to 321, where the river was narrowed by alteration, little change took place (Figure 21). There was no change from 321 to 381 between

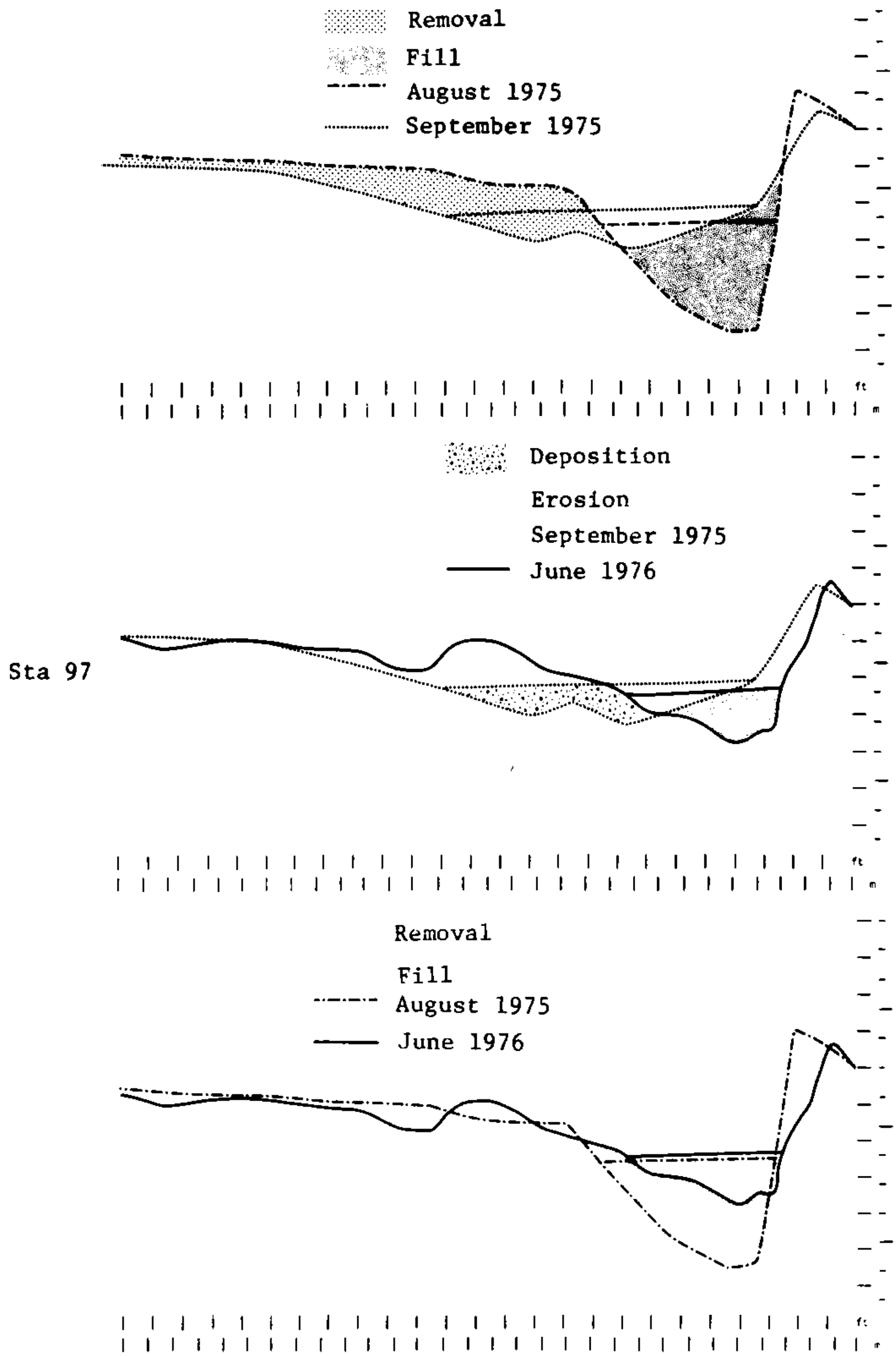


Figure 21. Cross sections in a bulldozed reach of the Blacksmith Fork River, Cache County, Utah.

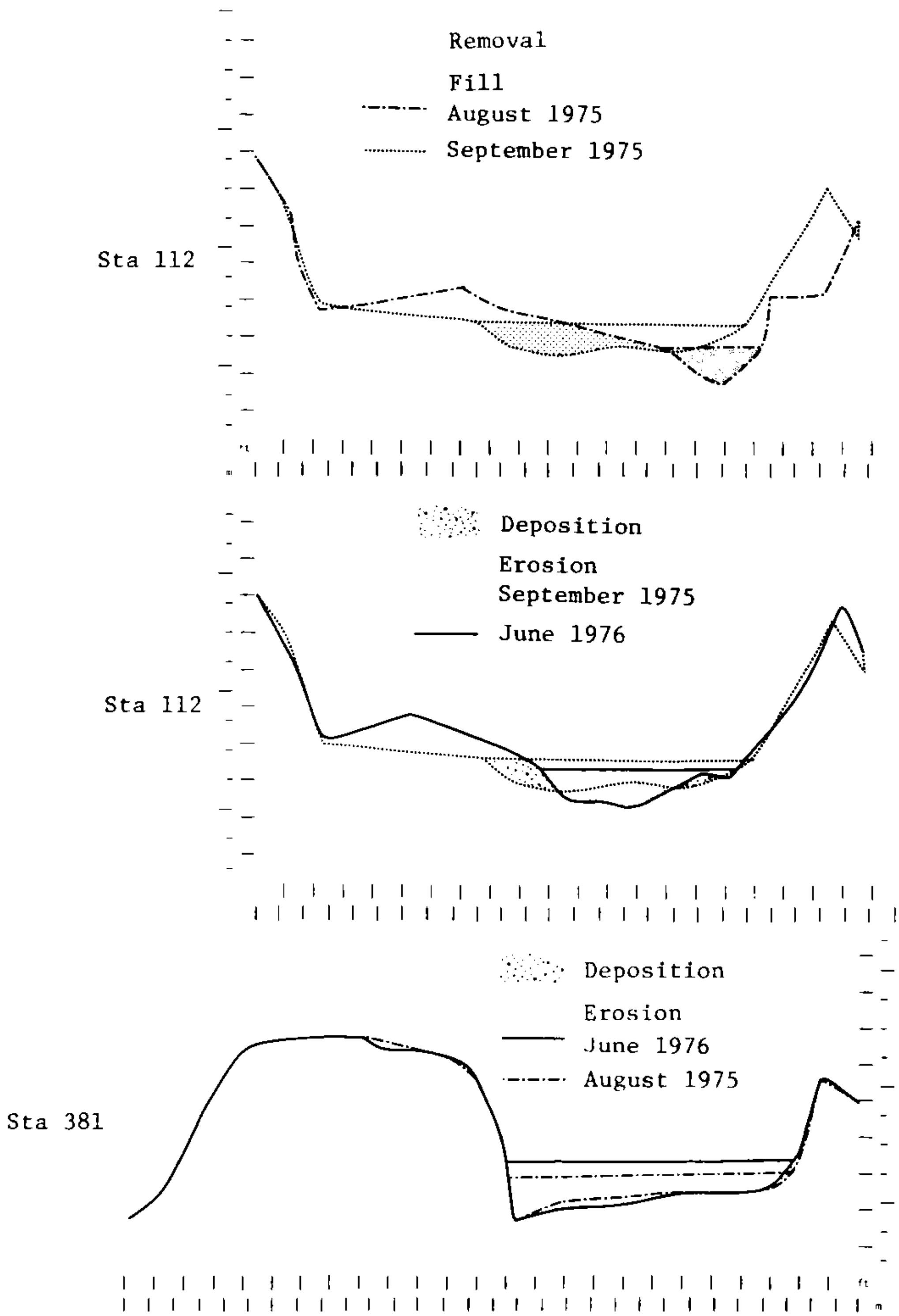


Figure 21. (Continued)

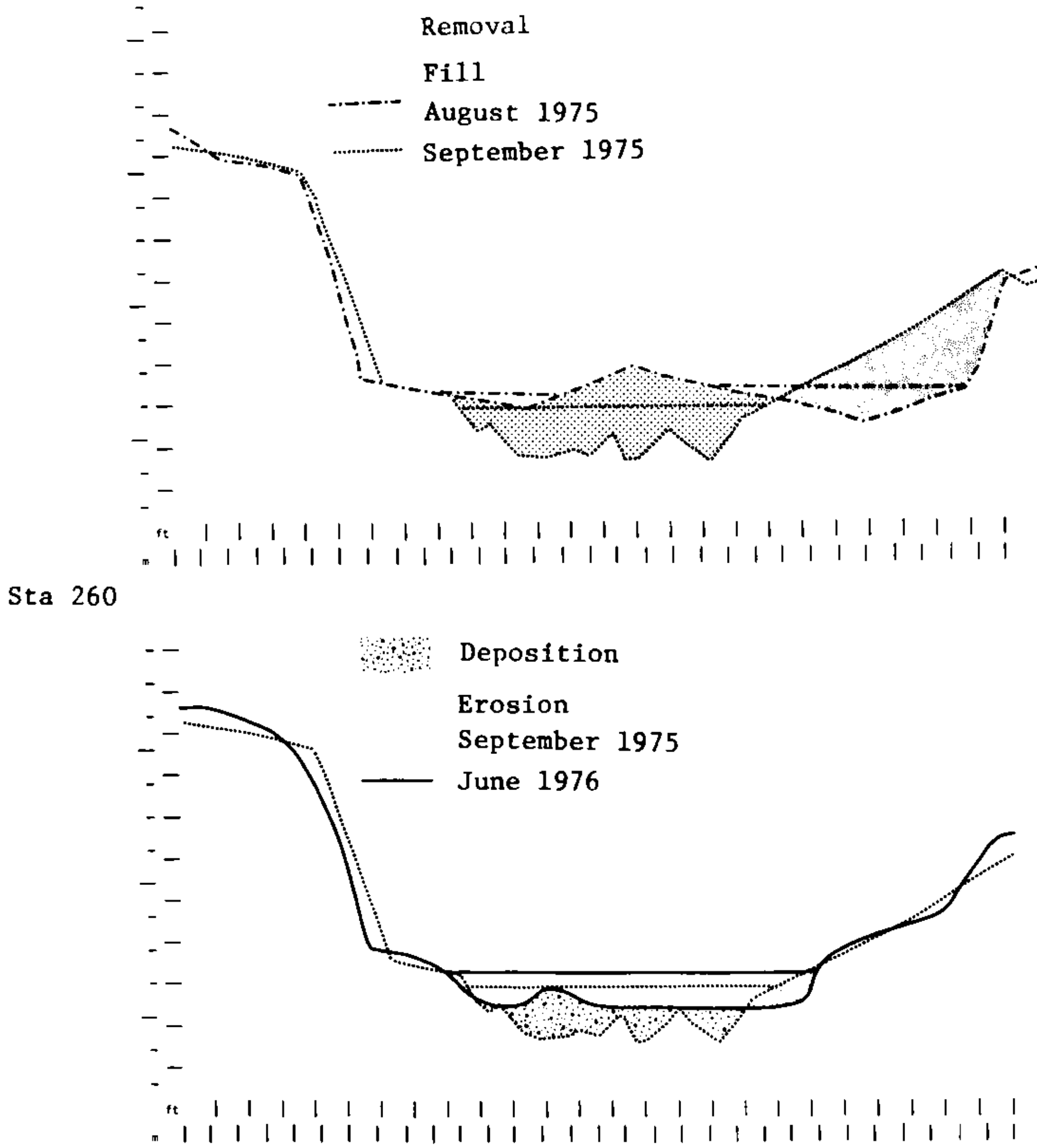


Figure 21. (Continued)

August, 1975 and June, 1976 (Figure 21), but just upstream erosion lowered the stream-bed slightly (.1 m) between 396 and 446. No change was noted in the remainder of the reach, from 462 to 591.

It appears that previous alterations to the river have so changed conditions as to cause sufficient aggradation of the stream bed that normal water level is now above ground level along much of this reach. Ground level east of the river from 107 to 411 is below normal water level (Figure 21, Sta 381), while from 446 to 591 the fields west of the river are below normal water level.

Part of the Logan River control site from 0 upstream to 152, was altered with a bulldozer in November, 1971. The only subsequent alteration was a small area in the vicinity of 76, where a cable crossing was installed, a vehicle crossing (ford) constructed and large rock placed to protect one bank from erosion. Extensive bank erosion had occurred here. From 168 upstream it has been about 30 years since any significant alteration has been done.

Cross sections were surveyed in the spring of 1972, shortly after the alterations, but lack of time and funds required that only part of the transects be surveyed. Thus intervals between cross sections at some locations in this reach were greater than for other reaches. Cross sections were surveyed again in November, 1975 (Figure 22).

There were no significant changes in alignment in this reach, although bank erosion and in-stream deposition and erosion did change the character of the stream in certain locations. From 0 to 137 bank erosion widened the stream an average of 2.1 m and deposition raised the elevation of the stream bed 0.3 m (Figure 22). A hole was scoured near the center of the channel at 152. There was considerable erosion along the west bank from 198 to 213 and downcutting lowered the stream bed an average of 0.4 m between 183 and 320 (Figure 22). There was little change in the pool between 274 and 320, but erosion on both banks widened the river as much as 5.5 m from 290 to 366 (Figure 22).

Sand and Gravel Transport and Deposition

Erosion exceeded deposition during each time period (Table 3) in Logan bulldozed. As might be expected, filling a thalweg pool on a concave bank with loose, unconsolidated sand and gravel merely provided a supply of easily erodable material for rearrangement by the river. Nearly 700 cubic meters of material was eroded from only 112 meters of stream between May and November, 1975. When combined with over 500 cubic meters of deposition in the same time period, this represents a tremendous amount of substrate and bank rearrangement (Figure 23).

Stream alteration between stations 30 and 122 in April, 1975 precluded any comparison between conditions in spring 1972 and later, since no surveys were completed prior to the 1975 alteration. From station 137 upstream however, such comparisons can be made. Total erosion and net erosion exceeded similar values in the downstream area, but when computed in proportion to length of stream involved were less per 100 meters. The disparity would be even greater if values were computed in relation to the amount of time over which such changes occurred.

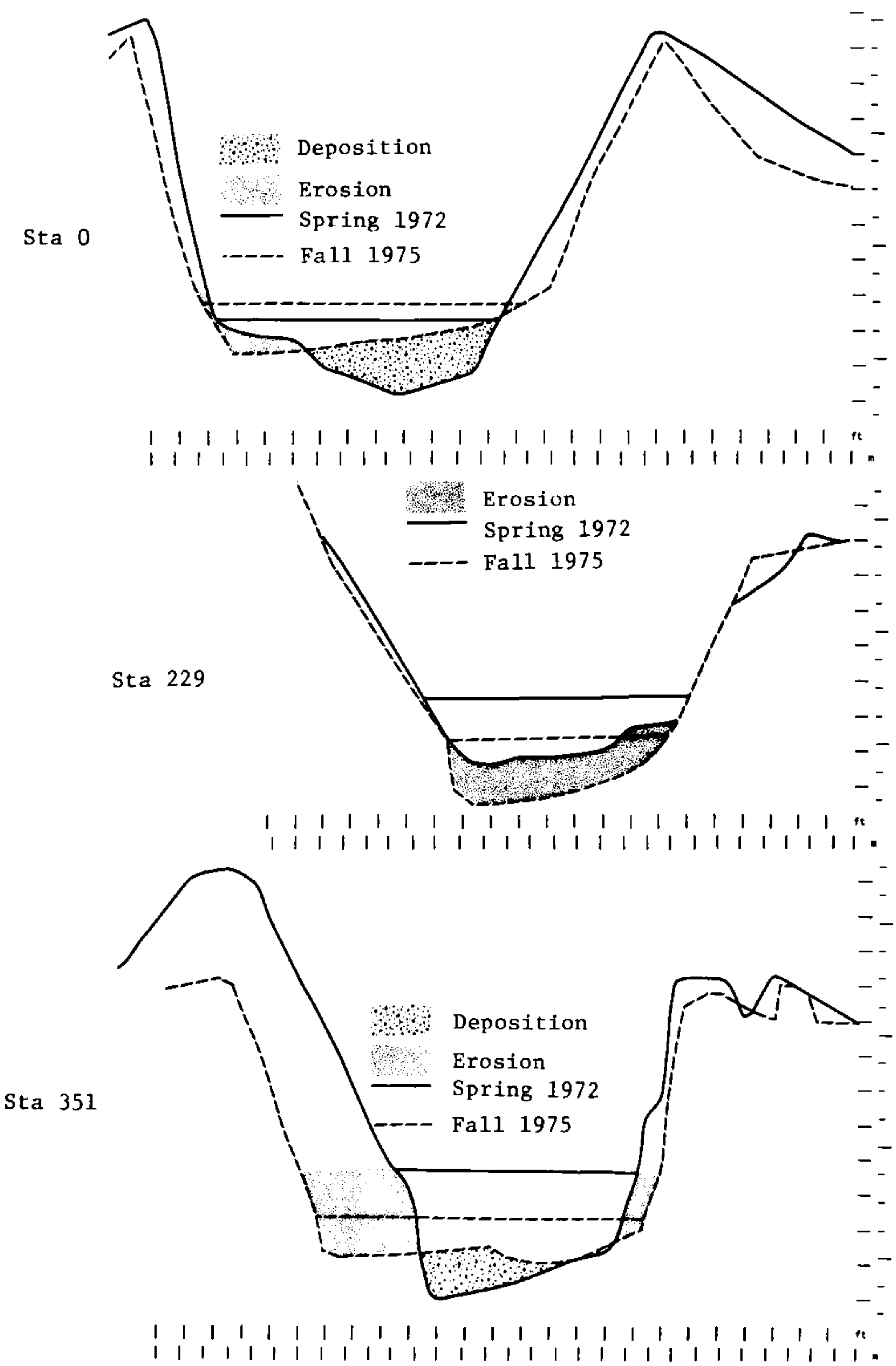


Figure 22. Cross sections in the control reach of the Logan River, Cache County, Utah.

Table 3 . Volume of sand and gravel moved in the Blacksmith Fork and Logan Rivers during various time intervals.

Movement of Substrate	Site and Time Interval							
	Blacksmith Fork Control	Logan River Control	Blacksmith Fork Dredged		Blacksmith Fork Recently Bull-dozed	Logan River Old Bulldozed		
	Nov 75 Jul 76	Spring 72 Nov 75	Apr 75 Jun 75	Sep 75 Jun 76	Sep 75 Jun 76	May 75 Nov 75	Feb 72 Nov 75	Nov 75 Jul 76
Erosion								
m^3 Total	213	881	1390	908	517	671	1024	572
m^3/100 m	38	229	249	221	119	599	293	114
Deposition								
m^3 Total	704	655	2519	1376	729	526	346	461
m^3/100 m	127	171	451	335	168	470	99	92

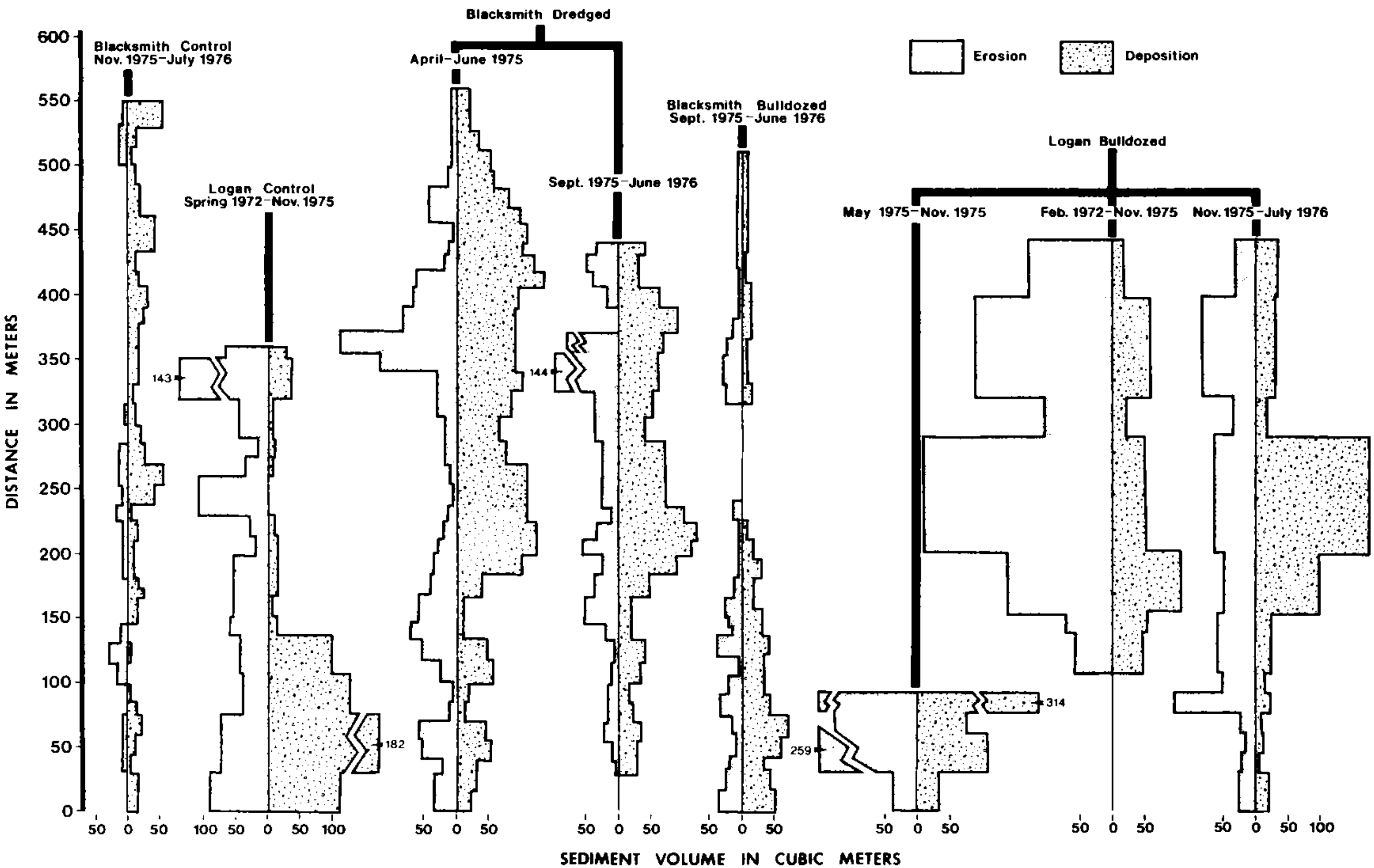


Figure 23. Volume of sediment moved between survey dates on the Blacksmith Fork and Logan Rivers, Cache County, Utah, 1975-76.

During an eight month period encompassing a poor spring runoff period, November, 1975 to July, 1976, erosion and deposition values for the entire reach were computed. A comparison between these values and either of the other periods is possible if these values are divided into two groups encompassing comparable areas. Thus, stations 30 to 122 can be compared to the same stations between May and November, 1975. Far less erosion and deposition occurred during winter and spring, 1976 than during spring and summer, 1975, even though the span of time was similar. The most easily erodable material had been removed and much of the area available for deposition along the convex bank had been filled in by the 1975 spring flows.

A more interesting comparison can be made between the 45 month period of 1972 to 1975 and the more recent 8 month period. Here the amount of recent erosion (317.5 m^3) is nearly double the prorated value (182 m^3) from the 1972-1975 period, and the recent deposition (372.5 m^3) exceeds the entire amount deposited (345.7 m^3) over nearly 4 years between 1972-1975. Erosion of unstable gravel banks probably occurred the first year or two after alteration and the material was transported downstream out of the immediate area. Some down-cutting probably occurred, but was largely obscured by subsequent deposition during low summer and fall flows. As a result the long term changes appear to be slower than the more recent. It is possible, however, that erosion has increased slightly and deposition greatly during the recent period when stream flow was reduced.

Erosion and deposition of streambed materials at Blacksmith dredged were similar in 1975 and 1976, although the actual amounts differed between the two years (Table 3). In 1975, spring runoff was considerably greater than in 1976, which probably explains the differential shifting of streambed materials. In each year, the net deposition exceeded erosion in the study area, indicating that import of bottom materials from upstream exceeded export to downstream areas. Dredging removed the accumulated material on the inside or convex side of river bends, and from the stream bottom in numerous areas, but particularly in the region between cross sections 545 and 660 (see streambed profiles in Figure 25). Spring runoff redeposited the sediments in about the same areas from which they had been removed, and restored the longitudinal profile of the streambed to approximately its profile before the alterations were made.

From the upstream end of Blacksmith dredged (cross section 893), the following changes were observed (Figure 23). After dredging in spring, 1975, deposition exceeded erosion as far downstream as station 706. Dredging in March did not fill the deep pool near station 741, but the pool was filled by dredging in August. Erosion exceeded deposition in spring 1976 when the streambed material was scoured from the pool. Between stations 706 and 660, erosion far exceeded deposition in both years. Dredging filled in a pool each time, and the spring runoff restored the pools.

Between cross sections 660 and 518, deposition ranged from moderate to severe in both years. Most of this deposition occurred on the convex or deposition side of this large bend, but as noted in the stream bottom profiles, (Figure 19) deposition also occurred on the streambed. Downstream from this area, short, alternating zones of erosion and deposition created conditions that were more representative of natural streams. During 1976, the erosion zones were narrower and shifted slightly upstream when compared to 1975. Between stations 518 and 363, there were 7 sections where erosion exceeded deposition in 1975, while in 1976 there were only 3. Note that a long pool between stations 404 and 375 was restored in 1975 but not in 1976.

Erosion per 100 m of stream was far less at Blacksmith Control (Table 3) than in any of the other reaches. Deposition was considerably less than in the dredged reach downstream on the Blacksmith Fork River, but slightly more than in the upstream, recently undisturbed portion of the Logan bulldozed site.

Deposition was low along this reach except for three locations where it was moderate. Downcutting of any consequence was noted at one location. Deposition exceeded erosion in 84 percent of the intervals in this reach.

Erosion and deposition were both quite high at Blacksmith bulldozed (Table 3). As was found in other areas where the stream channel was altered, both erosion and deposition were higher in the altered portion of the reach than elsewhere. Between 1 and 321, where alteration occurred, erosion equalled 186 m^3/100 m and deposition equalled 308 m^3/100 m, while upstream where no alteration occurred during the study, erosion equalled 75 m^3/100 m and deposition equalled 58 m^3/100 m. Most of the erosion (65 percent) in the unaltered area occurred in the lower 35 percent of the area, perhaps a result of changed flows because of the alterations downstream. Deposition in the same area amounted to only 30 percent of the total, a result to be expected if head cutting was caused by the alterations.

The largest values for erosion and deposition were usually found in the vicinity of bends in the stream, where erosive forces on the outside and decreased current on the inside of the bend reconstructed the natural contours which had been altered by the bulldozing. It is quite significant that this much sand and gravel was moved in a year of relatively low spring runoff.

Deposition exceeded erosion in 89 percent of the intervals in the altered area, and in 54 percent upstream. This difference is undoubtedly a result of the deposition of large amounts of material on the convex side of bends in this reach, where bulldozing had removed material and created ideal conditions for deposition.

Erosion exceeded deposition over the entire reach at Logan control, but there were interesting differences between the area altered in 1972 and the unaltered portion. Erosion was somewhat lower (196 m^3/100 m) in the altered area than it was upstream (242 m^3/100 m), but deposition was more than six times higher in the altered area (336 m^3) than in the recently unaltered area upstream (55 m^3). In the recently altered area deposition exceeded erosion, while upstream erosion far exceeded deposition. Over half (62%) of the erosion in the upstream area occurred in only 76 meters (36 percent of the stream length of that area). It appears there was limited import of material into the upstream area, or that such material was merely passed on downstream to the altered area. Erosion in the upstream area probably contributed considerably to the quality of material deposited in the altered area. All these values, as with those from 1972 to 1975 from the bulldozed reach downstream on the Logan River, are minimum values since over several years considerable resorting took place. Thus, material deposited was eroded, redeposited, again eroded and deposited with each change in volume of flow. These values then represent net change over several years, in comparison to the short term changes, which if summed would more nearly represent the total changes.

Stream Length

Stream length changed very little at Logan bulldozed, since only a small portion of the stream was altered, and subsequent changes in other parts of the river were minor. The thalweg/centerline length ratio varied from 1.0099 in 1972 to 1.0049 in 1975 and 1.007 in 1976. All values indicate a nearly straight stream with few meanders.

Dredging in March, 1975, at Blacksmith dredged decreased the centerline length by 3.9 percent and the thalweg length by 4.2 percent (Table 4). The spring runoff in 1975 restored the centerline to its length before alterations and increased thalweg length by 1.2 percent. Dredging in August decreased the centerline length by 4.8 percent and the thalweg length by 7.7 percent. A low spring runoff in 1976 resulted in less energy for bedload movement, and thus the centerline length was 2.9 percent shorter and the thalweg length was 6.8 percent shorter than in June, 1975.

Thalweg/centerline ratios ranged from a high of 1.073 in June, 1975 to a low of 1.030 in June, 1976. Low flows during fall and winter may reduce this ratio under normal conditions and caused the low value in January, 1975. Dredging in March and in August, 1975 reduced the ratio. The lack of normal high stream flows during spring may produce essentially the same result as dredging such as: lowered thalweg/centerline ratio, decreased stream length and fewer deep pools.

There were no changes in stream length at Blacksmith control, since there were no alterations in this reach, nor anywhere close enough to affect it.

Centerline length at Blacksmith bulldozed was decreased from 478 m to 465 m by alteration, and it remained unchanged in June. Thalweg length was changed from 502 m to 468 m by alteration, but in this case natural forces increased it to 475 m by June.

Centerline length at Logan control remained unchanged during the study. Records from 1972 are not adequate to determine whether any change occurred between then and 1975.

Table 4. Centerline and thalweg lengths, and thalweg/centerline ratios for a dredged reach[1] of the Blacksmith Fork River, Cache County, Utah.

Date	Centerline length (m)	Thalweg length (m)	Thalweg/Centerline Ratio
January 1975	462	488	1.057
April	444	468	1.054
June	462	494	1.073
September	440	457	1.040
June 1976	448	462	1.030

[1]The site was dredged by backhoe in late March and late August, 1975.

Stream Bed Gradient

Gradient changes at Logan bulldozed were minor when computed over the length of the study reach. Although there was no change from 1972 to 1975 (.43 m/100 m) and only a slight change in 1976 (.42 m/100 m), the elevation of the bottom changed during this period (Figure 24). Deposition raised the stream bottom 0.3 m at the downstream end of the reach and 0.27 m at the upstream end. Comparison of the thalweg profiles indicates that between 1972 and 1975, maximum depth increased at four of the seven stations between 30 and 122, between 1975 and 1976 it increased at four of seven, and overall between 1972 and 1976 depth increased at five of seven stations. These changes were a result of the development of the deep pool along the concave bank of the large bend. Over the remainder of the reach maximum depth usually decreased. Between 1972 and 1976 depth increased at only 1 of 23 stations.

Between 1972 and 1976 the portion of the reach between 30 and 122 was deepened an average of 0.19 m, and the remainder of the reach aggraded an average 0.27 m. The average change for the entire reach was an increase in bottom elevation of 0.16 m. This indicates that although the net movement of substrate material has been erosion, there has been deposition along the thalweg everywhere except in the large bend, where accelerated current has deepened the stream. Thus, the upstream portion of the reach has been an exporter of substrate material even though the elevation of the bottom has become higher. Much of the erosion took place along the banks, resulting in an increase in stream width along most of this reach. The thalweg has begun to meander from side to side of the stream, and much of the widening appears related to this.

Between May, 1975 and July, 1976, there was little change in bottom elevation between stations 137 and 472. There was no change at 35 percent of the stations, aggradation at 26 percent and erosion at 39 percent. The average change was a decrease of 1 cm in elevation. Since the July, 1976 survey took place just after spring runoff, this change may be a result of a small amount of scouring during the lower-than-normal runoff, and not an

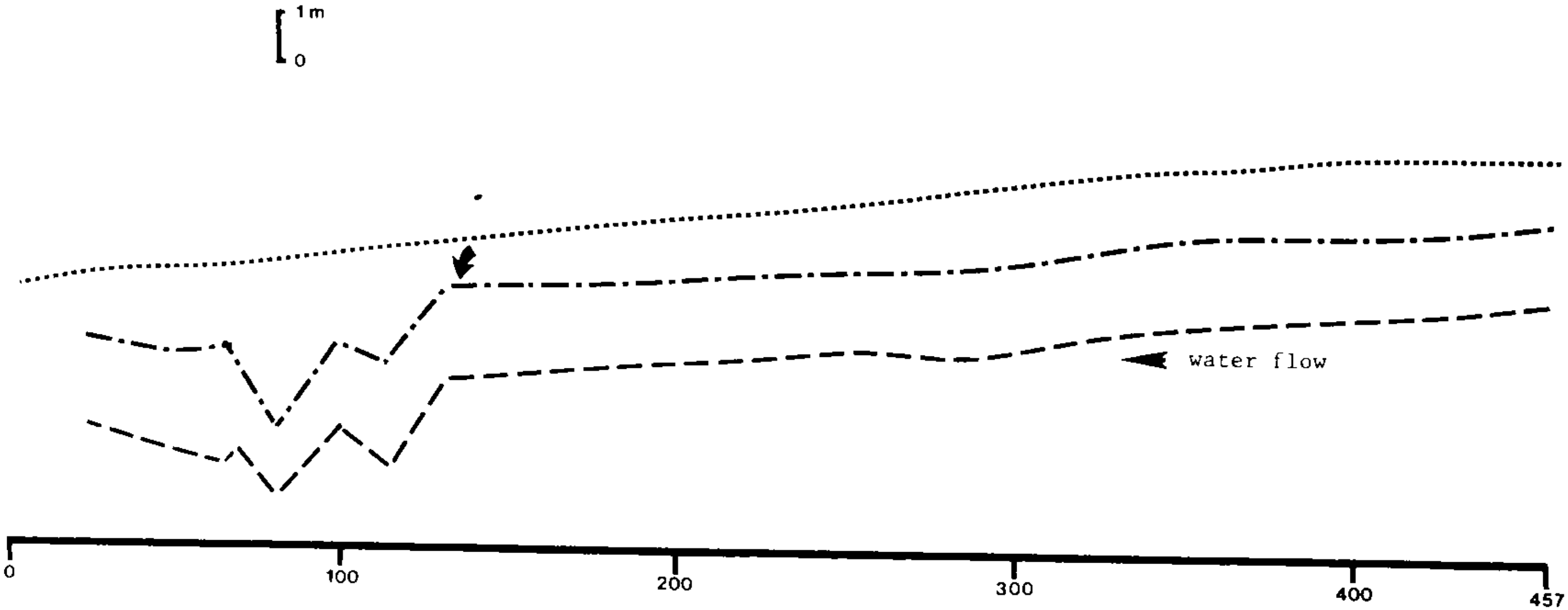


Figure 24. Thalweg profiles for a bulldozed reach of the Logan River, Cache County, Utah showing (upper to lower) conditions in spring 1972 after alteration, in November 1975 and in July 1976. Area downstream from arrow was altered again in August 1975.

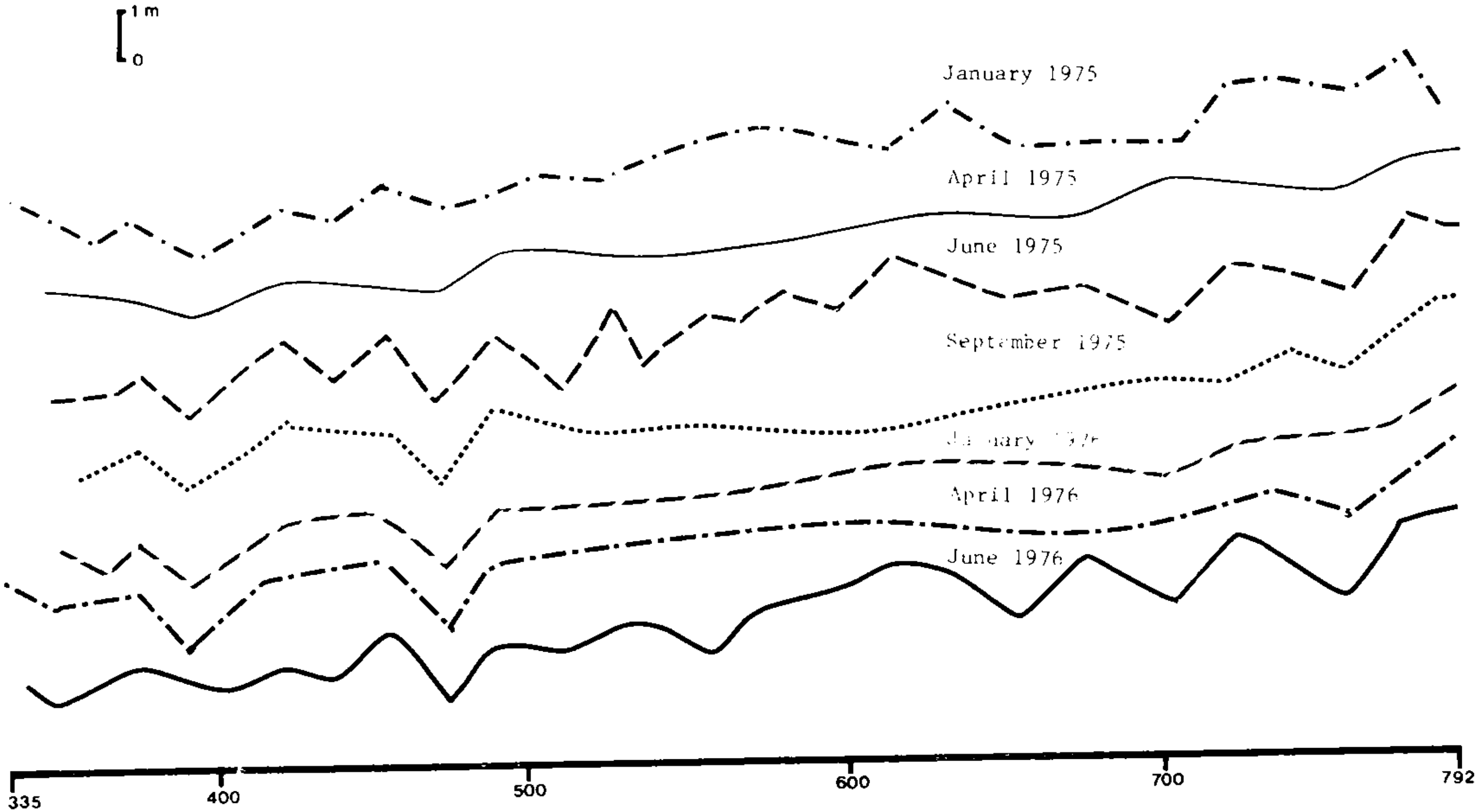


Figure 25. Thalweg profiles for a dredged reach of the Blacksmith Fork River, Cache County, Utah. Dredging occurred in March and August, 1975.

Table 5. Stream bed gradient in a dredged section[1] of the Blacksmith Fork River, Cache County, Utah between January, 1975 and June, 1976.

Date	Gradient (feet per 100 feet)
January 1975	.54
April 1975	.50
June 1975	.58
September 1975	.56
January 1976	.38
April 1976	.38
June 1976	.45

[1]This reach was dredged by backhoe in late March and late August, 1975.

indication of a reversal of the aggradation trend evident since 1972.

Stream alteration and spring runoff change the bottom configuration of the stream and alter the gradient (Table 5). Part of the change is due to changing the elevation of the bottom by cutting or filling, and part is due to changing the length of stream. There was a 17 percent decrease in stream bed slope between January, 1975 and June, 1976. This was caused by downcutting (0.7 m) at the upper end of this reach between September, 1975 and January, 1976. Deposition since then (0.3+ m) is again increasing the gradient.

Gradient at Blacksmith control was about the same as at the dredged reach downstream on the Blacksmith. It changed from 0.45 m/100 m in November, 1975 to 0.48 in July, 1976. This small change occurred because of slight downcutting (.09 m) at the downstream end of the reach and slight deposition (.06 m) at the upstream end (Figure 26).

In the lower, altered portion of Blacksmith bulldozed gradient decreased from .8 to .75 m/100 m as a result of alteration, and then strangely decreased to .71 by June, 1976 (Figure 27). Erosion of the bed at the upstream end and aggradation at the downstream end caused the change. Conversely, in the unaltered area upstream, the gradient changed from .6 in August, 1975 to .64 in June, 1976. Here the upstream end remained unchanged and the erosion of the downstream end, which was the same location as the upstream end of the altered area, caused an increase in slope.

Gradient over the reach at Logan control changed very little, from .44 to .43 m/100 m, but there were moderate changes in certain portions of the reach. At the upstream end there was 0.3 m aggradation of the stream bottom, while for the next 190 m erosion lowered the elevation of the bottom from .15 to .7 m. Downstream from this, aggradation of from .1 to .5 m was noted over a 150 m length. Thus both the upstream and downstream ends of this reach aggraded,

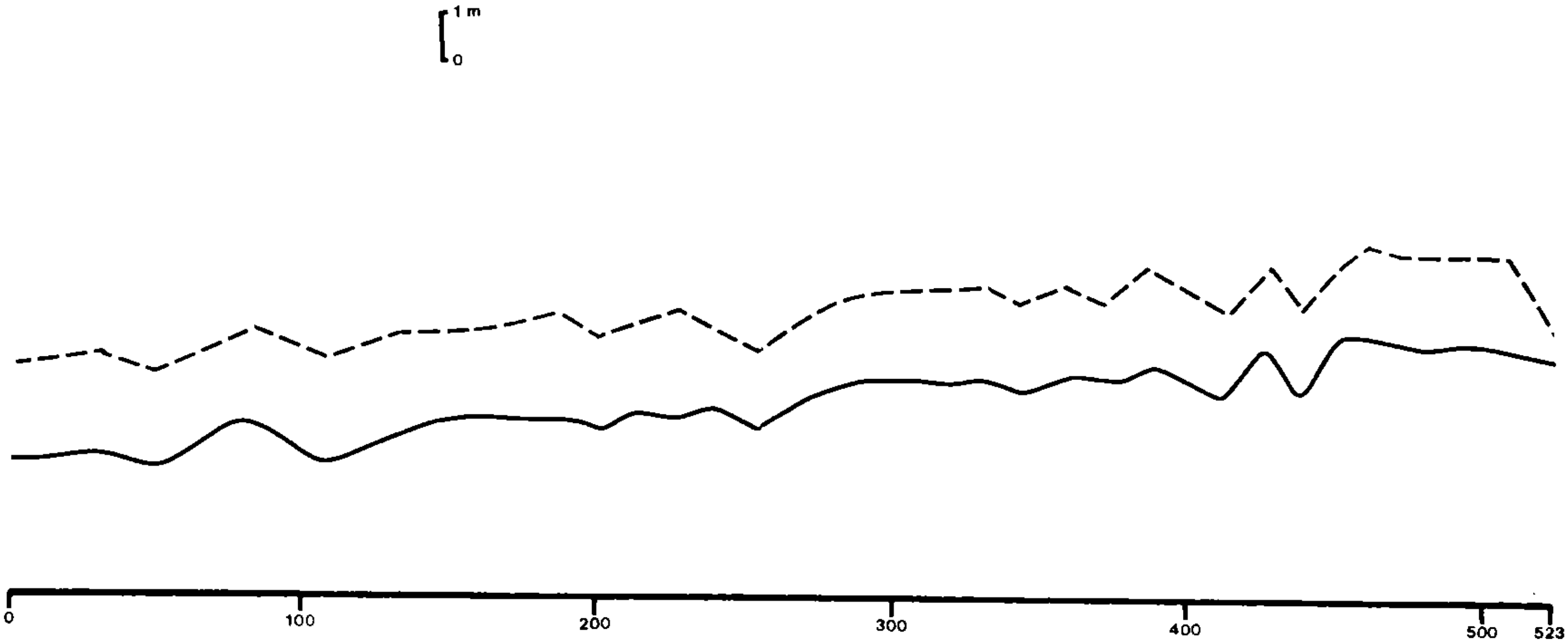


Figure 26. Thalweg profiles for the control reach of the Blacksmith Fork River, Cache County, Utah showing conditions in November 1975 (upper), and July 1976.

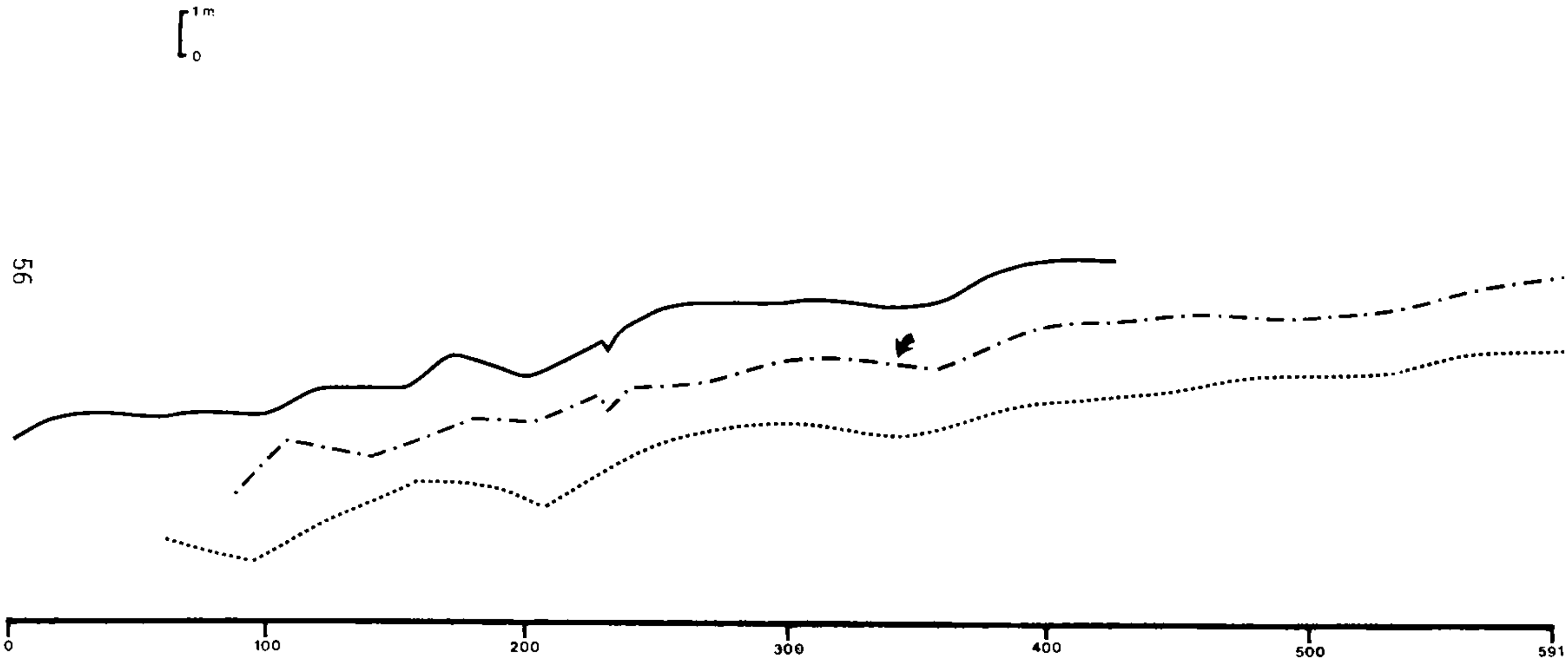


Figure 27. Thalweg profiles for a bulldozed reach of the Blacksmith Fork River, Cache County, Utah showing conditions in August 1975 (upper), September 1975 after alteration and in June 1976. Area downstream from arrow was altered prior to September survey.

while interior portions aggraded or degraded (Figure 28). The upper third of the unaltered area increased in gradient while the remainder decreased. There was a slight decrease in gradient in the recently altered portion.

Time of Sand and Gravel Movement

Four measurements of cross sections were made at Blacksmith dredged between the August, 1975 dredging and the completion of the project. Therefore, a comparison could be made of streambed movement between the first post-dredging mapping in September and January, 1976; between January, 1976 and April; and between April and the first post-spring runoff mapping in June, 1976. For the nine cross section intervals chosen, fall was a period of net erosion (6 to 9 intervals, Table 6) while during winter and spring net deposition of streambed material occurred. Note that these values are for net movement, therefore a large amount of erosion from pools could be obscured by a larger amount of deposition along the convex side of bends for the entire reach.

A comparison of erosion and deposition during the three time intervals revealed the time and magnitude of streambed movement (Table 7). Large amounts of the streambed were eroded in almost all areas, and in contrast to the results in Table 6 , streambed erosion was greatest between April and June in over half of the areas, although total erosion during fall was slightly greater than during spring. In most cases, this large amount of erosion was exceeded, often greatly so, by the amount of deposition. Note that, although more than 31 m^3 of material was eroded during the fall in the vicinity of station 390, deposition during winter and spring exceeded this amount and resulted in the loss of a pool which had existed since the beginning of the study.

Effects of Channel Changes

Comparisons of erosion and deposition among the various reaches must be done with caution because of the differing lengths of time between surveys and the time of year when surveys were made. Such a comparison (Figure 29) indicates that the greatest amount of erosion per 100 m of stream length occurred between May and November 1975 in the bulldozed reach of the Logan River in the area altered in 1975. The second greatest amount was noted on the Blacksmith Fork River between April and June 1975 in an area dredged in March 1975. Nearly equal amounts of erosion were measured in the Logan control in 1975 and Blacksmith dredged in 1976. In this case changes in Logan control occurred over a 3.6 year period while those at Blacksmith dredged resulted from a 9-month interval. When considered as units the remaining reaches showed lesser changes, but in some cases large amounts of erosion occurred in portions of the reaches. Thus, in that portion of Logan bulldozed which had been altered in 1975 erosion was about twice as great as in the remainder of the reach. Similarly at Blacksmith bulldozed, far more erosion occurred in the newly altered area than in the remainder of the reach.

Deposition of sand and gravel was greatest in those areas where erosion was greatest, except at Logan bulldozed in 1976. Here deposition, even in the recently altered area, was very low. Most deposition appeared to occur soon after alteration, although significant amounts occurred in an area that had not been disturbed by man for years. Note that low runoff in 1976 minimized

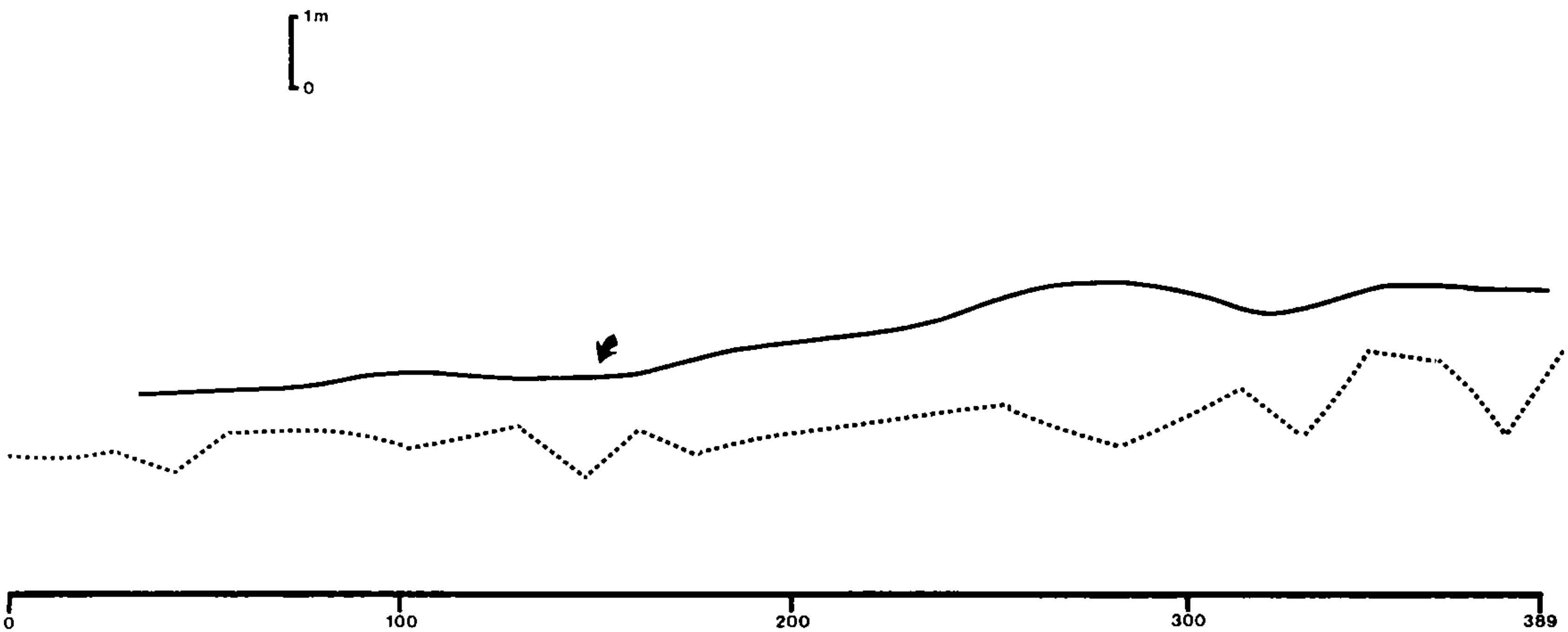


Figure 28. Thalweg profile for the control reach of the Logan River, Cache County, Utah for spring 1972 (upper) and fall 1975. Area downstream from arrow was altered in November 1971.

Table 6. The timing of sand and gravel movement in selected reaches of a dredged section[1] of the Blacksmith Fork River, Cache County, Utah between September, 1975 and June, 1976. All values are in percent of total net movement. E = erosion, D = deposition.

	Cross-section Stations								
Date	758a 741	741 724	545 533	533 518	502 481	481 468	404 390	390 375	375 363
Sep-Dec	E 113	D 32	D 23	E 16	D 57	E 294	E2138	E 148	E 50
Jan-Mar	D 15	D 43	D 9	E 4	E 64	D 81	D 223	D 62	D 78
Apr-Jun	E 2	D 25	D 68	D 112	D 107	D 114	D1815	D 187	D 72

[1]This reach was dredged by backhoe in late March and late August, 1975.

Table 7. Erosion and deposition of sand and gravel for selected reaches in a dredged section[1] of the Blacksmith Fork River, Cache County, Utah between September, 1975 and June, 1976. All values are in cubic meters.

	Cross-section Stations								
Time Interval	758a 741	741 724	545 533	533 518	502 481	481 468	404 390	390 375	375 363
	Erosion								
Sep-Dec	42	11	9	12	12	17	39	31	22
Jan-Mar	9	2.3	18	12	16	11	3.1	2.0	0.6
Apr-Jun	20	18	41	21	18	31	22	11	1.6
	Deposition								
Sep-Dec	13	23	23	3.0	18	2.4	0	4.8	6
Jan-Mar	13	18	24	15	10	15	7	13	26
Apr-Jun	20	24	83	82	29	22	55	44	25

[1]This reach was dredged by backhoe in late March and late August, 1975.

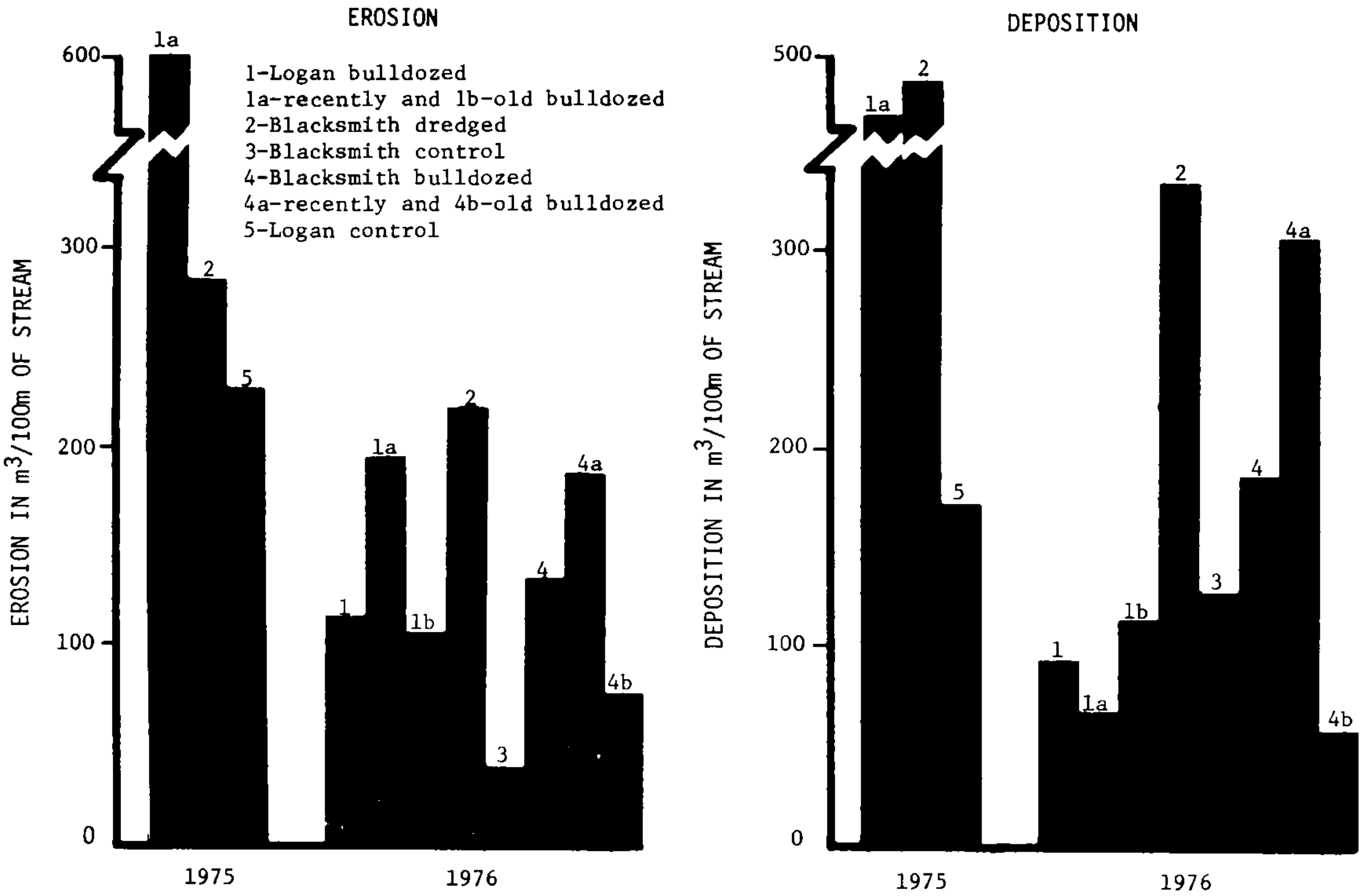


Figure 29. Volume of erosion and deposition over time on the Logan and Blacksmith Fork Rivers, Cache County, Utah.

erosion, but increased deposition in some areas.

Combining values of erosion and deposition to obtain an index of movement or substrate stability reveals that according to 1975 measurements, the most unstable area was the recently altered portion of the Logan River, while in second place was the recently dredged area of the Blacksmith Fork River. The Logan River control, where part of the reach had been altered in 1971, was the most stable.

The Blacksmith Fork River dredged area had by far the lowest stability between 1975 and 1976. Alterations were done late in the year here (August 1975) after spring runoff, so the 1976 survey measured the changes resulting from the first post-alteration runoff. The same situation prevailed at the bulldozed site on the Blacksmith Fork River, which was the second most unstable reach. In third place was the only other reach to be altered in 1975, the bulldozed site on the Logan River. The Blacksmith Fork control was the most stable of those measured in 1975 and 1976, with only 30 percent as much total substrate shifting as in the Blacksmith dredged site. Since parts of the Logan bulldozed and the Blacksmith bulldozed had not been altered since 1971, these reaches could be considered intermediate between completely altered Blacksmith dredged and unaltered Blacksmith control. This is actually where they rate numerically. Some 41 percent of the Blacksmith bulldozed site was altered in 1975 compared to 18 percent of the Logan bulldozed site. The Blacksmith site was rated as less stable than the Logan site. All evidence points to a relationship between the time of most recent alteration, and even the proportion of a reach recently altered, and the amount of sand and gravel eroded and deposited by the river.

Stream length was changed very little by the type of alteration attempted here. The Blacksmith dredged and bulldozed sites were nearly 3 percent shorter one year after alteration than they had been before. Changes in conformation of the stream bottom such as thalweg depth changed the gradient, but not greatly. Changes ranged from .01 to .09 m/100 m for gradients between .43 and .8 m/100 m.

Overall some 43 percent of the erosion measured over a 9-month period in the Blacksmith dredged site occurred in the fall between September and December. Between January and March erosion was only 16 percent of the total, while spring runoff, during a year of low water level, caused only 40 percent. Fall was the period of lowest deposition (15 percent), with winter-early spring contributing 23 percent and the spring runoff period of April to June producing the greatest amount (62 percent). Not all cross sections showed the same relationships. In 5 of the 9 selected (Table 7), erosion was greatest in the spring, but never was the winter period highest for erosion, although on one occasion most deposition occurred during winter. With that one exception deposition was always greatest during spring.

Since fall spawning fish were the dominant species present in the study area, there may be some question about survival and hatching of eggs. Four stations had low erosion values and five had low deposition values during fall, but only one had both low erosion and low deposition. If this is typical of the entire reach only about 11 percent of the area would be suitable for spawning. Of course some or most of the erosion could have occurred in areas of higher velocity flow, where fish would not choose to spawn. Similarly much deposition could have taken place in areas where velocity was too low for spawning. Without specific spawning studies there is no way to evaluate the direct effects of sand and gravel movement on spawning success.

Number and total length of pools more than one meter deep varied from one site to another, and over time (Table 8). In the two control sites, the number of pools remained constant over the survey period, but the amount of pool in the Blacksmith control decreased by 21 percent from fall, 1975 to July, 1976. The low volume of runoff was the probable cause of this decline.

The Blacksmith dredged site offers the most information on the affects of channel alterations and runoff on pools. Here the number of pools decreased by 60 and 75 percent, and the total length by about the same amount as a result of two stream alterations. During a spring of moderate runoff the number and length of pools increased to values exceeding those surveyed the previous January. Note that pools were restored to varying extents by runoff periods wherever alterations occurred.

Stability (total amount of sand and gravel moved per 100 meters of stream) does not correlate well with biomass of either brown trout or whitefish (Table 9). Rank order of number of pools and percent of reach in pools is identical, and this order has a strong correlation with the biomass of brown trout found in the four reaches. Although the Blacksmith bulldozed site has a low percent of its area in pools at least one meter in depth, there is a considerable area in slightly shallower pools. This probably accounts for the inversion of biomass and production of brown trout in Logan and Blacksmith bulldozed sites. Whitefish biomass does not correlate well with number or percentage of pools, nor with stability ranking.

BROWN TROUT

Movement

Marked brown trout recaptures were analyzed for movement (Table 10). The smallest and largest fish exhibited definitive movement (two or more 100 m sections) approximately 50 percent of the time. Fish of intermediate size were essentially stationary, exhibiting definitive movement only about 13 percent of the time.

Small trout (≤ 179 mm) exhibited very little movement into adjacent sections. They either remained in a section or moved great distances, usually downstream. The largest trout (> 350 mm) had the lowest percentage (16%) of stationary fish. The large amount of movement (39%) into adjacent sections may simply reflect a larger territory size which is often bisected by section boundaries. However, almost half (45%) of the movement by this size group was definitive (two or more sections). Many of these largest fish were found only during the spawning season and were not seen during the rest of the year. There is some evidence that these large fish spent the rest of the year below the confluence of the Logan and Blacksmith Fork Rivers, well below the area studied.

Table 8. Changes over time in the number and total length of pools more than one meter deep in the various reaches of the Blacksmith Fork and Logan Rivers, Cache County, Utah.[1]

	Nov 1972	Jan 1975		Apr 1975	Jun 1975	Aug 1975		Sep 1975	Nov 1975	Jan 1976	Apr 1976	Jul 1976
Number of Pools												
Blacksmith Control	--	--		--	--	--		--	4	--	--	4
Logan Control	1	--		--	--	--		--	4	--	--	--
Blacksmith Dredged	--	5	*	2	8	--	*	2	--	3	5	4
Blacksmith Bulldozed	--	--		--	--	4	*	1	--	--	--	3
Logan Bulldozed	0	--	*	0	--	--		--	3	--	--	3
Meters of Pool												
Blacksmith Control	--	--		--	--	--		--	52	--	--	41
Logan Control	28	--		--	--	--		--	54	--	--	--
Blacksmith Dredged	--	128	*	34	158	--	*	64	--	73	70	73
Blacksmith Bulldozed	--	--		--	--	20	*	6	--	--	--	23
Logan Bulldozed	0	--	*	0	--	--		--	24	--	--	24

[1]Alterations are noted by *, -- indicates no survey.

Table 9. Relationship between physical habitat, biomass and production of fish. Rank order of one is most stable, six is least stable.

	Sites[1]						
	Physical parameters			Biomass of fish		Production of fish	
Rank Order	Stability	No. of Pools[2]	% of reach in pools	Brown trout	Whitefish	Brown trout	Whitefish
1975							
1	BD	BD(8)	BD(30)	BD	LTB	BD	LTB
2	LSB	LTB(3)	LTB(2)	LTB	LSB	LTB	LSB
3	LTB	LSB(0)	LSB(0)	LSB	BD	LSB	LD
1976							
1	BOB	BD(4)	BD(24)	BD	LTB	BD	LTB
2	BC	BC(4)	BC(15)	BC	BD	BC	BD
3	LSB	LTB(3)	BRB(4)	BOB	LSB	BOB	LSB
4	LTB	BRB(2)	LTB(2)	LTB	BC	LTB	BC
5	BRB	BOB(1)	BOB(2)	BRB	BRB	BRB	BRB
6	BD	LSB(0)	LSB(0)	LSB	BOB	LSB	BOB

[1] BC = Blacksmith Control; BD = Blacksmith Dredged; BOB = Blacksmith Old Bulldozed; BRB = Blacksmith Recently Bulldozed; LSB = Logan Stable Bulldozed; LTB = Logan Total Bulldozed.

[2] Actual values in parentheses.

Table 10. Total number and percentage of brown trout moving or remaining stationary by size (mm) in the Logan and Blacksmith Fork Rivers, Cache County, Utah.

Fork length in mm	Downstream		Upstream		Total number moving				No. of trout stationary	%
	Adjacent sections	2 or more sections	Adjacent Sections	2 or more sections	Adjacent sections	%	2 or more sections	%		
0-179	3	47	3	21	6	4	68	51	60	45
180-249	47	34	46	32	93	14	66	10	526	77
250-349	110	66	121	95	231	21	161	15	708	64
350+	15	18	18	22	33	39	38	45	14	16

Most of the movement occurred (originated and ended) within the study sites. Obviously, movement within and between study sites was examined most intensely since our study was concerned with standing crops and production within these sites. Movement into study sites by season indicated that little immigration occurred during spring floods (Tables 11-14). During the summer, brown trout showed greater immigration into the control and the recently dredged sites on the Blacksmith Fork River than into other sites. These sites have the most pools which provide shelter for brown trout during low streamflows.

Of the five trout that immigrated into the Logan bulldozed site, four were found in the lowest 100 m. This section has the only large pools for shelter in the entire study site (Figure 12). Although the numbers involved are admittedly small, this section received 80 percent of the immigration while containing only 14 percent of the area.

During the spawning season, the greatest amount of movement into sites occurred in the two control sites, although some immigration occurred in other sites. The control site on the Blacksmith was the only site that had brown trout moving into it from all four of the other study sites. Brown trout immigration was more evenly distributed among study sites during the period of normal stream flows. This may indicate that habitat is less limiting under these conditions, or may simply be the result of trout returning to home territories after spawning.

Many researchers have found that brown trout tend to be essentially nonmobile and to occupy the same area of stream over time (Allen 1951, Gosse 1978, Schuck 1943, and Stefanich 1951). However, brown trout do exhibit migratory behavior, generally with regard to seeking specific types of habitat, such as spawning areas (Gosse 1978, Stuart 1957). Small fish or fish that have been stressed are known to move downstream (Chapman 1966, Gresswell 1973, Miller 1957). Possibly the tags used for marking were too large for the smallest fish and the stress of tagging increased their downstream movement. Considering the small percentage of these fish that moved into adjacent sections (4%) and the percentage that remained in a section (45%), movement among small fish was probably emigration from an area resulting from space becoming limited as their territory size increased (Chapman 1966).

Growth

Sources of Error. Growth rates occasionally differed greatly from expected values. For example, the oldest age group might have a high growth rate during spawning season while the younger groups exhibited a weight loss during the same period. These aberrations occurred most often in the oldest age group and were usually associated with small sample size and increased movement as a result of spawning migration or channel alterations. Growth rates from the next younger age group or from another study site were substituted for rates that were considered erroneous. Such substitutions are noted in the tables, with the original rates and source of new rates listed, and used in calculating production. Generally these changes had little effect on the total production of a site, but they often changed the amount of production for a specific period or age group. The substituted values are in all cases believed to be more realistic than those originally calculated.

Table 11. Movement of brown trout less than 170 mm FL to and from study sites in the Logan and Blacksmith Fork Rivers, Cache County Utah by stage of streamflow, 1975-76. Number of fish moving <u>into</u> a site is found in horizontal row; <u>from</u> a site in vertical column. Numbers with diagonal lines represent no movement; i.e., fish captured at site where marked.

Stage of flow (Dates)	Site	Moved from LTB	BD	BC	BB	LC	Off site
Normal flow (1 December-12 April)							
	LTB	1	0	0	0	0	0
	BD	0	0	0	0	0	0
	BL	0	0	1	0	0	0
	BB	0	0	0	1	0	0
	LC	0	0	0	0	0	0
Spring flood (13 April-27 June)							
	LTB	0	0	0	0	0	0
	BD	0	0	0	0	0	0
	BC	0	0	0	0	0	0
	BB	0	0	0	0	0	0
	LC	-	-	-	-	-	-
Summer irrigation diversions (28 June-25 September)							
	LTB	1	0	0	0	0	0
	BD	0	7	0	0	0	0
	BC	0	0	14	0	0	0
	BB	0	0	0	4	0	0
	LC	-	-	-	-	-	-
Low and normal flows during spawning (26 September-30 November)							
	LTB	2	0	0	0	0	0
	BD	0	0	0	0	0	0
	BC	0	0	1	0	0	0
	BB	0	0	0	1	0	0
	LC	0	0	0	0	1	0

Table 12. Movement of brown trout between 170 and 250 mm FL to and from study sites in the Logan and Blacksmith Fork Rivers, Cache County Utah by stage of streamflow, 1975-76. Number of fish moving <u>into</u> a site is found in horizontal row; <u>from</u> a site in vertical column. Numbers with diagonal lines represent no movement; i.e., fish captured at site where marked.

Stage of flow (Dates)	Site	Moved from LTB	BD	BC	BB	LC	Off site
Normal flow (1 December-12 April)							
	LTB	17	0	0	0	0	0
	BD	0	53	1	0	0	1
	BC	0	2	56	0	0	0
	BB	0	0	1	14	0	0
	LC	0	0	0	1	37	3
Spring flood (13 April-27 June)							
	LTB	6	0	0	0	0	0
	BD	0	21	0	0	0	1
	BC	0	0	6	0	0	0
	BB	0	0	0	3	0	0
	LC	-	-	-	-	-	-
Summer irrigation diversions (28 June-25 September)							
	LTB	37	0	0	0	0	0
	BD	0	116	0	0	0	2
	BC	0	0	91	0	0	1
	BB	0	0	0	19	0	0
	LC	-	-	-	-	-	-
Low and normal flow during spawning (26 September-30 November)							
	LTB	3	0	0	0	1	2
	BD	0	58	1	0	0	0
	BC	0	2	42	0	0	1
	BB	0	0	1	7	0	1
	LC	0	0	0	0	28	2

Table 13. Movement of brown trout greater than 250 mm FL to and from study sites in the Logan and Blacksmith Fork Rivers, Cache County Utah by stage of streamflow, 1975-76. Number of fish moving into a site is found in horizontal row; from a site in vertical column. Numbers with diagonal lines represent no movement; i.e., fish captured at site where marked.

Stage of flow (Date)	Site	Moved from LTB	BD	BC	BB	LC	Off site
Normal flow (1 December-12 April)							
	LTB	40	0	0	0	1	5
	BD	0	37	1	0	0	2
	BC	1	2	113	0	0	4
	BB	0	2	0	35	1	1
	LC	2	0	0	0	74	3
Spring flood (13 April-27 June)							
	LTB	8	0	0	0	0	0
	BD	0	23	0	0	0	1
	BC	0	0	3	0	0	0
	BB	0	0	0	10	0	0
	LC	-	-	-	-	-	-
Summer irrigation diversion (28 June-25 September)							
	LTB	82	0	0	0	2	3
	BD	0	124	1	0	0	5
	BC	0	3	128	2	1	3
	BB	0	0	0	34	0	1
	LC	-	-	-	-	-	-
Low and normal flow during spawning (26 September-30 November)							
	LTB	16	0	0	0	0	4
	BD	0	36	1	0	0	5
	BC	2	3	62	1	2	4
	BB	0	0	3	15	1	3
	LC	2	0	0	0	77	7

Table 14. Number of brown trout immigrating into the study sites of the Logan and Blacksmith Fork Rivers, Cache County, Utah by streamflow and spawning season.

	Study site					
	Blacksmith bulldozed site	Blacksmith control site	Blacksmith dredged site	Logan control site	Logan stable bulldozed	Logan unstable bulldozed
Normal 1 December to 12 April	5	9	5	9	5	1
Spring flood 13 April to 27 June	0	0	2	-	0	0
Summer irrigation season 28 June to 25 September	1	10	8	-	1	4
Spawning season (low and normal flows) 26 September to 30 November	9	15	7	11	5	2

In the Blacksmith control site, the growth rate from the 1975 year-class was used for the 1974 year-class for the period from June to August 1976. Weight loss for the 1974 year-class during this period seems erroneous since other year-classes have high growth rates during this time. Length-frequency histograms for June and August suggest that differential loss (either through emigration or mortality) occurred among the larger fish for this year-class. This probably resulted from low streamflows found during this time. It can be observed that the mean weight for the 1974 year-class decreased during this time while all other mean weights were increased (Figure 30).

Mean weights were not obtained for the 1975 year-class in the Logan bulldozed site from November 1975 to April 1976 because this year-class was not found in the site during the time (Figure 30). The 1971+ year-class effectively disappeared from the site after July 1975 (it was found once again in January). Growth rates for this year-class were taken from the 1972 year-class for the two periods that it appeared because of the small sample size associated with the former.

In the Blacksmith bulldozed site growth rates for the 1971+ year-class from August to December 1975 and for the 1975 year-class for August to November 1976 were erroneous, and rates for the same year-class from the Blacksmith dredged site were used instead. This appeared more valid than using rates from younger year-classes since weight patterns were more similar among sites than among year-classes in this case (Figure 30).

General Trends. All of the study sites exhibited certain general trends in growth rates, however, there were some specific differences among the sites. Growth rates were generally highest for the youngest age group and decreased with increasing age in all study sites. The greatest seasonal growth usually occurred during the spring, but rapid growth also occurred in winter and early summer. Weight loss often occurred during spawning season and early winter, particularly in the older age groups. Similar patterns for growth rates of brown trout have been documented by other researchers (Allen 1951, Beyerle and Cooper 1960, Gosse 1978, Hopkins 1971 and Egglishaw 1970), although only a few researchers have actually reported negative growth (weight loss) in salmonid populations (Bernard 1974, Coche 1960, Gosse 1978, and Hunt 1966).

When growth rates (or mean weights, from which the former are calculated) are compared between the Blacksmith control site and the altered sites, large fluctuations occurred by site, age group, and time of year, but overall patterns were quite similar. Annual patterns of mean weights by age group from the Blacksmith dredged site and the Blacksmith bulldozed site are similar to those obtained for the Blacksmith control site with mean weights from the two altered sites usually slightly heavier.

Age 0 trout from the Logan bulldozed site achieved only about half the weight of age 0 trout from the Blacksmith Fork River during the first fourteen months (Figure 30). Cooler temperatures in the Logan River probably resulted in later emergence and slower growth rates during the first year of life. However, fish from both rivers are comparable in weight by the second summer of life either because of faster growth or immigration of larger fish from other sites. After the first 1 1/2 years of life, trout from Logan

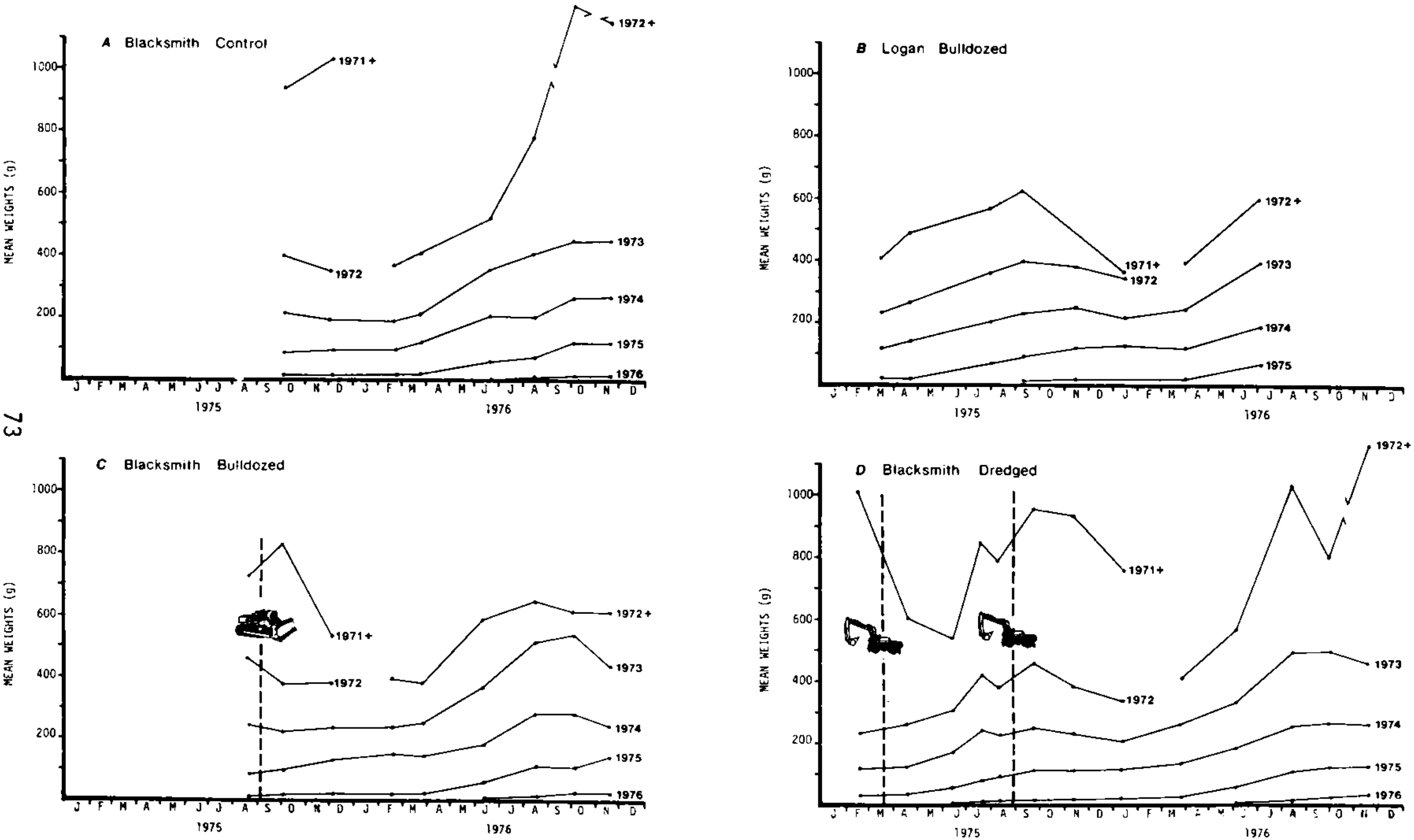


Figure 30. Mean weights of brown trout by year-class in the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

bulldozed grew about the same as trout in the sites on the Blacksmith, except for the oldest age group. Really large fish are simply not found in this site and any trout in this age group are smaller than average.

The recently bulldozed site on the Blacksmith was combined with the old bulldozed site to provide sufficient sample size for calculating growth rates. There were no apparent changes in growth during the period when bulldozing occurred (between August and October 1975) although it may have accounted for some weight loss for the 1972 and 1973 year classes (Figure 30). Growth rates in this site were similar to other sites in the Blacksmith, except that the maximum mean weight of the oldest age-groups was considerably less than that obtained in the control and dredged sites and more similar to that found in the Logan bulldozed site (Figure 30).

The Blacksmith dredged site was altered in 1975 between the February and April samplings and again between the August and September samplings. When growth rates for February 1975 are compared with those from January 1976, it appears that growth was not effected by the dredging. (Note: age I in 1976 should be compared with age I in 1975, etc.). The growth rates for August 1975 are consistently higher than the rates for August 1976, while the rates for the next growth period (25 September to 13 November 1975) are consistently lower than the rates a year later (5 October to 24 November 1976).

Growth was faster for some year classes in early summer than in spring, particularly in 1975, perhaps as a response to dredging. The negative growth which occurred in the older age groups in July 1975 may be correlated to low streamflows and mortality of older fish, apparently caused by an unidentified toxic substance. Mean weights in this site are similar to those found in the Blacksmith control site except that growth appears to begin and end slightly sooner in this site (Figure 30).

Comparison of growth rates and mean weights between the Blacksmith control site and altered sites, or comparison before and after alterations within a site does not produce any readily discernible pattern. Although the first dredging appeared to have little immediate effect on growth, growth rates were probably inhibited during the subsequent measurement period (April-June). High growth rates occurred during the second dredging between August and September followed by low growth rates during the subsequent period (September-November). The effect of bulldozing on growth rates in the Blacksmith Fork River varied among the different age groups.

Alterations appear either to produce no change in growth rates or cause slight increases in growth during the period in which alterations occur. If the latter is the case, it is usual for the increased growth to be offset by decreased growth in subsequent months. The conclusion to be drawn from growth data is that physical alterations to streams have very little effect on brown trout growth, especially over long periods of time. Thus food is probably not a limiting factor in areas of stream that have been altered, and differences in production between altered and unaltered sites cannot be accounted for by growth.

Mean weights at the end of each year of life were consistently higher in all study sites than weights found in Blacksmith Canyon (Table 15). The Logan bulldozed site was similar to the Blacksmith Canyon for age 0, but then closely followed the patterns of the other sites. At the end of the year, the Blacksmith bulldozed had heavier mean weights than the other sites, but this was not true for the rest of the year. Trout in Logan Canyon closely approximated Blacksmith Canyon for the first two years, and then began to approach the mean weights found in the valley.

Population Estimates

Introduction. Population estimates have been converted to the number of fish per hectare to facilitate comparisons among sites. Actual population estimates for the sites with 95 percent confidence intervals are provided in the Appendix B (Tables 6 to 12).

Blacksmith Control. Increases in numbers for the 1975 year class occurred during spring and for the 1975, 1974, and 1973 year classes during fall spawning season (Table 16). Increases in all cases are probably real and represent immigration. Movement data documents immigration in the fall, but not in the spring, probably because of the small sample size in spring. This is further complicated by the fact that the youngest age groups have the lowest ratio of tagged to untagged fish.

The increase in population estimates for all year classes during the fall (except age 0 in 1975 and 1976) indicates that this site was a major spawning area. This theory is supported by movement which showed fish moving through other sites to reach this one (Table 13).

Logan Control. Population estimates were made only twice for this site, in October 1975 and February 1976 (Table 17). Because of the constraints of time and manpower, population change rates and production were not calculated for this site.

The population estimate of brown trout in October was five times larger than the estimate made in February. The larger population estimate in October probably resulted from spawning activity in the site at this time. This assumption is supported by the fact that the 1973 and 1972 year classes are estimated to be greater in number than the younger year classes and by movement data (Table 13). Several trout that were tagged at this site were recaptured later in the control and bulldozed sites on the Blacksmith.

Logan Total Bulldozed. The trend for most year classes at this site was a steady decline in numbers (Table 18). Older age groups did not increase during the November sampling, indicating that few if any trout moved into this site to spawn (which is supported by the movement data). An increase in numbers of the 1972+ year class in January and April 1976 may be due to spawners returning from the areas in which they spawned. The 1976 year class was never recruited in this site during the course of the study.

The 1975 year class in July 1975 was underestimated because the fish were too small to be collected. This year class was effectively recruited by the September sampling but was proportionately not very numerous in comparison to

Table 15. Comparison of estimated mean weights (g) for brown trout at the end of each year of life from selected U.S. waters.

Location	Growing seasons 1	2	3	4	Reference
Logan River, bulldozed site	13[a]	123	213	341	This study
Blacksmith Fork River, recently dredged	19	110	203	337	
Blacksmith Fork River, control	17	119	210	365	
Blacksmith Fork River, bulldozed	18	143	230	378	
Blacksmith Fork River, in Canyon	12	63	116	209	Gosse 1978
Logan River, in Canyon	11	60	172	304	Sigler 1952
Pennsylvania	11	93			Beyerle and Cooper 1960
See Carlander 1969 for other selected waters					

[a]No fish found on 1/17/76; weight on 11/15/75 was 12, and on 4/4/76 was 13 g

Table 16. Population estimates (no/ha) of brown trout by year class for the control site in the Blacksmith Fork River, Cache County, Utah.

	Year Class						
Date	1976	1975	1974	1973	1972	1971+	Total
10/5/75	0	740	99	124	147	91	1202
12/6/75	0	178	134	229	81	35	657
2/24/76	0	143	116	99	50	0	409
3/28/76	0	83	101	64	23	0	271
6/25/76	2103	355	112	78	14	0	2663
8/19/76	1343	147	68	43	10	0	1610
10/9/76	1008	81	194	128	17	0	1428
11/23/76	1085	178	233	48	43	0	1587

Dashed lines indicate the dates used for annual production.

Table 17. Population estimates (no/ha) of brown trout by year class for the control site in the Logan River, Cache County, Utah.

Date	Year Class						Total
	1976	1975	1974	1973	1972	1971+	
10/9/75	0	25	123	233	167	53	600
2/5/76	0	0	47	50	16	0	113

Table 18. Population estimates (number per hectare) of brown trout by year class for the total bulldozed site (0 - 500 m) in the Logan River, Cache County, Utah.

	Year Class						
Date	1976	1975	1974	1973	1972	1971+	Total
3/15/75	0.	0.	72.	134.	94.	28.	328
4/20/75	0.	0.	75.	124.	85.	18.	303.
7/31/75	0.	12.	85.	100.	65.	5.	268.
9/10/75	0.	64.	72.	64.	40.	2.	241.
11/15/75	0.	7.	59.	52.	8.	0.	126.
1/17/76	0.	0.	13.	59.	17.	2.	90.
4/4/76	0.	23.	18.	22.	32.	0.	95.
7/9/76	0.	67.	69.	92.	12.	0.	239.

Dashed lines indicate the data used for annual production.

other sites. By January 1976, none of the 1975 year class were found. Their reappearance in subsequent collections indicates an inability for fish to survive in this site during the first year of life. Either the young trout left this site during the first year of life and returned when they were age I, or (more likely) age I fish immigrated into the site from other reaches of the river. The latter theory is supported by the fact that age I fish had mean weights similar to those found in the Blacksmith.

Logan Stable Bulldozed. The channel of the lower 100 m has changed since it was first channelized in 1971 while the remainder of this site has remained relatively stable (see physical parameters). Therefore, population estimates were also made excluding the lower 100 m (Table 19). The estimated number of trout per hectare was 33-50 percent less in this stable portion than in the site as a whole. The large population increase noted in the entire reach in July 1976 did not occur when the lower 100 m was omitted. Trout immigrating into the pools of the lower 100 m during low streamflows probably caused the large population increase. No pools are found upstream from this lower section (Figure 12).

Blacksmith Recently Bulldozed. This site was bulldozed in 1971 and again between the 21 August and 4 October 1975 population estimates (Table 20). The 1975, 1974, and 1973 year classes declined during this and the subsequent time period. This decline occurred when brown trout should have moved into the site for spawning (Table 13). The increase in the two oldest age groups between August and October may have been due to spawning movement. The population increased during this same time a year later except for the 1975 year class.

The 1976 year class had a very large decline between June and August 1976. This decline could have resulted from movement or mortality or a combination of both. The limited information obtained on the age 0 fish indicated that their movement was minimal. Therefore, this sharp decline probably resulted from mortality. In any case, even if spawning and incubation had been successful, the age 0 fish did not survive well here.

Blacksmith Old Bulldozed. The population in this site did not have the large decrease from October to December as was found in the recently bulldozed site (Table 21). The 1974, 1973, and 1971+ year classes had an increase during the period, possibly emigrants from the bulldozed sections downstream. While age groups 0 and I were nearly the same in Ocrober of both years, the older age groups were much fewer in 1976. This may also be indicative that the October 1975 population was larger than normal as a result of emigration from the bulldozed sections.

The fact that the 1972 year class declined from October to December and the lack of a large population increase the following fall indicates that the site was not heavily utilized for spawning. The relatively low number of age 0 fish found in this site indicates that the spawning which does occur may not be very successful.

Blacksmith Dredged. Population estimates are not provided for 19 April 1975 and 30 March 1976 because actual estimates were not made for these dates

Table 19. Population estimates (no/ha) of brown trout by year class for the stable bulldozed site (123-500 m) in the Logan River, Cache County, Utah, 1975-76.

Date	YEAR CLASS 1976	1975	1974	1973	1972	1971+	TOTAL
3/15/75	0	0	67	79	61	27	234
4/20/75	0	0	65	84	52	17	218
7/31/75	0	15	61	94	33	4	207
8/10/75	0	67	21	10	2	0	100
11/15/75	0	6	29	19	6	0	61
1/17/76	0	0	6	36	17	2	61
4/4/76	0	6	6	6	15	0	33
7/9/76	0	42	10	4	0	0	56

Dashed lines indicate the data used for annual production.

Table 20. Population estimates (no/ha) of brown trout by year class for the recently bulldozed site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

	Year Class						
Date	1976	1975	1974	1973	1972	1971+	Total
8/11/75	0	172	111	220	32	11	545
10/4/75	0	93	50	50	40	19	252
12/4/75	0	61	21	45	34	3	164
2/19/76	0	42	21	42	5	0	111
3/31/76	0	50	24	29	5	0	109
6/14/76	2769	69	32	13	8	0	2891
8/20/76	116	40	32	3	3	0	193
10/7/76	101	37	69	3	5	0	214
11/24/76	156	53	82	21	5	0	318

Dashed lines indicate the data used for annual production.

Table 21. Population estimates (no/ha) of brown trout by year class for the old bulldozed site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Date	YEAR CLASS 1976	1975	1974	1973	1972	1971+	TOTAL
10/24/75	0	165	44	109	153	6	477
12/4/75	0	100	72	165	44	16	396
2/19/76	0	37	16	87	84	0	224
3/31/76	0	84	34	53	25	0	196
6/13/76	657	131	53	40	12	0	894
8/20/76	287	72	47	16	0	0	421
10/7/76	171	47	22	3	3	0	246
11/24/76	75	16	40	16	3	0	150

Dashed lines indicate the data used for annual production.

(see Methods). Population levels were calculated from estimates made before and after these dates and were used in standing crop and production estimates.

This site was dredged in 1975 between the February and June samplings and between the August and September samplings. Between February and June the population of all year classes declined (Table 22), and the number of fish per hectare declined by 58 percent (Figure 31). This decrease was greatest for the youngest and oldest age groups.

The second dredging was accompanied by a 53 percent decline in the total population (August to September 1975). Only the three youngest age groups declined, while one of the older remained the same and the other increased after the site was dredged. This increase of older fish may be correlated to spawning movement. The population estimate after the spawning period (January 1976) was 78 percent less than that before dredging in August. The second dredging appeared to have a greater effect on the population than the first.

A comparison of the population estimates for February 1975 (before any dredging) with the estimate from January 1976 demonstrated a 72 percent decline in the brown trout population. Population estimates for October and November 1976 (Table 22) did not show an increase in spawning fish as occurred during the previous fall.

General Trends. Both bulldozed sites on the Blacksmith contained low numbers of age 0 trout in 1975 but the trout population in the control site declined to almost the same low level. The 1975 year class increased during the following spring and again during the spawning season in both the control and recently dredged sites due to immigration from other areas.

The total brown trout population declined in the recently dredged site and recently bulldozed site after each channel alteration (Figure 31). Populations increased at all sites on the Blacksmith Fork River in June 1976, primarily because of new recruits from the 1976 year class. This 1976 year class was considerably lower in the old bulldozed reach than in the other three sites, and declined rapidly and remained at a low level in the recently bulldozed site. Thus, only the control and recently dredged sites on the Blacksmith Fork were able to sustain the 1976 year class in large numbers. This indicates the bulldozed sites do not contain the habitat necessary for survival and growth of significant numbers of age 0 trout.

No spawning immigration by any year class occurred in the Logan bulldozed sites (Tables 18 and 19). Trout from the 1973 and 1974 year classes increased slightly during the spawning season but only in the stable bulldozed site. Thus, very little spawning by brown trout occurred in these sites and fish apparently emigrated to other sites to spawn. The few trout of the 1975 year class found in this altered site indicated there was little suitable habitat for young trout (Tables 18 and 19).

Our movement data and that of several authors (Gosse 1978, Schuck 1943, Stuart 1957) indicate that brown trout return to specific spawning sites. If, as would be logical, these sites are the ones where the spawners had themselves been successfully reared, then alterations which reduced the

Table 22. Population estimates (no/ha) of brown trout by year class for the recently dredged site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Date	YEAR CLASS						TOTAL
	1976	1975	1974	1973	1972	1971+	
2/16/75	0	0	1244	511	209	56	2020
6/16/75	0	0	435	313	89	3	840
7/21/75	0	0	474	254	53	11	792
8/12/75	0	1722	502	223	39	31	2517
9/25/75	0	639	296	170	56	31	1191
11/13/75	0	416	357	368	153	47	1342
1/15/76	0	324	100	84	17	33	558
6/8/76	2545	410	73	61	6	0	3094
8/18/76	1406	259	114	25	14	0	1819
10/5/76	792	151	167	25	14	0	1150
11/24/76	924	153	95	31	8	0	1211

Dashed lines indicate the data used for annual production.

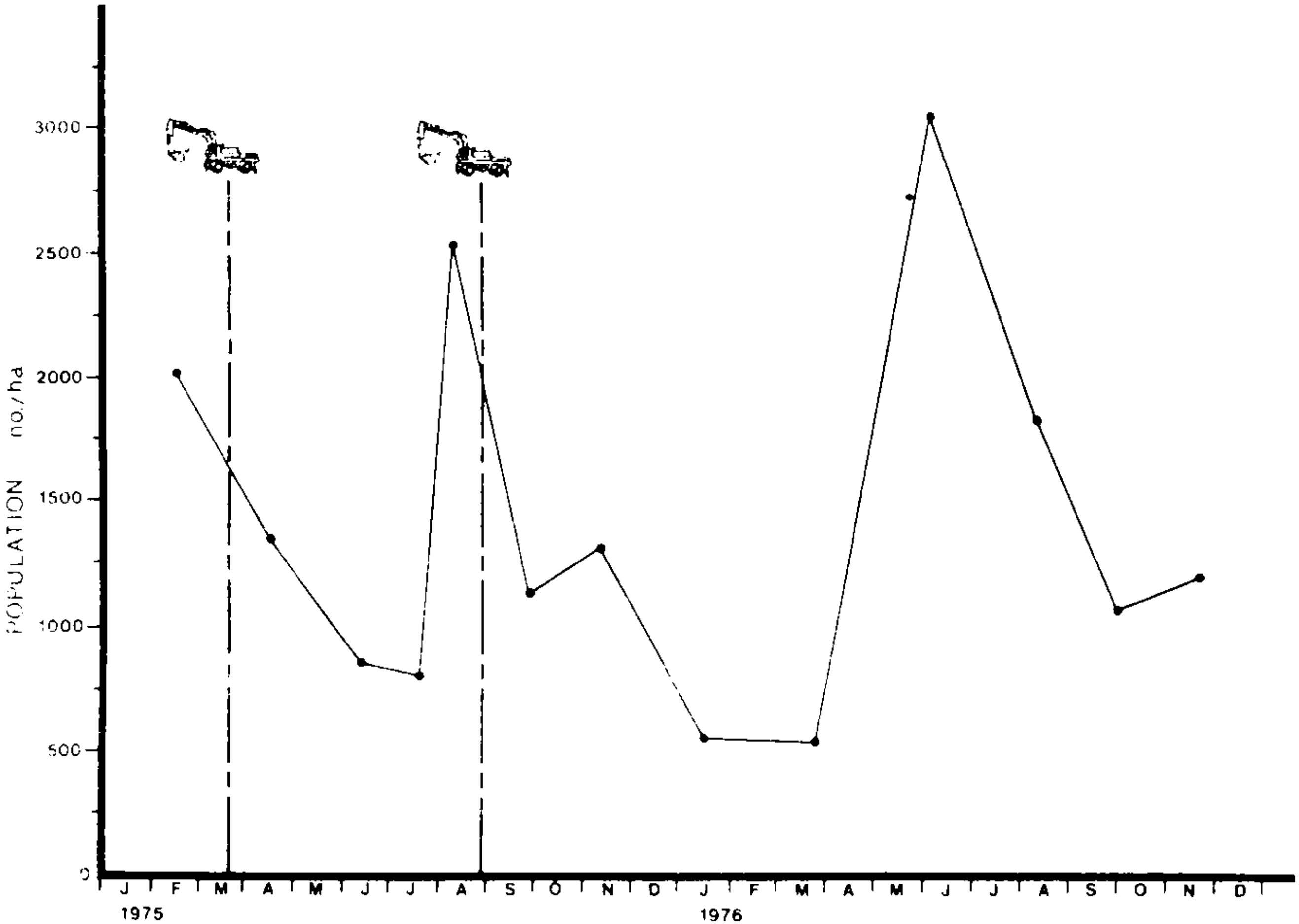


Figure 31. Changes in the total population of brown trout with time in the dredged reach of the Blacksmith Fork River, Cache County, Utah, 1975-76.

success of reproduction or rearing would eventually show a reduction in spawning activity over a period of years.

Logan bulldozed site had a large spawning population for three falls after it was channelized in 1971, but presently has almost no spawning activity. During the falls of 1972 and 1973, the Fishery Techniques Class (WLS 570, Utah State University) under the supervision of W. T. Helm, found a large population of brown trout in the reach that was the Logan bulldozed site in this study. These spawning fish probably either inhabited the area before channel alteration or had been reared in this site. As these spawning fish disappeared from the population over time, the amount of spawning that occurred in this site decreased to its present low level, since little recruitment presently occurs in the site. The Blacksmith dredged site had a large spawning population the fall immediately following dredging but had a reduced spawning population by the succeeding fall while the control site exhibited no such trend.

The affects of alteration do not appear to be uniform upon all segments of the population. Large numbers of the 1974 year class were found in the Blacksmith dredged site before it was altered (Figure 32). After each dredging their numbers declined. A similar pattern was noted in the 1973 year class of trout in the recently bulldozed site (Figure 33). This year class declined dramatically after the channel was bulldozed and did not increase during the spawning season in 1975, although the 1973 year class increased at the three other sites.

Unlike growth rates, the size and age composition of brown trout populations are greatly affected by channel alterations. Post-alteration trout populations are consistently (often drastically) lower than pre-alteration trout populations. The degree of reduction depends on age composition of the population as well as the type and stability of alteration.

Age 0 and I trout are usually reduced dramatically in sites that have been altered by bulldozing. Even when reproduction was successful in such sites, survival of the young fish was extremely low. However, the numbers of young fish did not decrease more than other age groups in the newly dredged site. Bulldozed sites had very little spawning immigration and probably are not self-sustaining.

The greater the degree of physical alteration, the greater the reduction in the trout population. If an altered stream channel has remained stable and retained the artificial configuration produced by alteration, the trout population has remained low. Those areas that have regained some measure of their natural configuration (the first 100 m of the Logan bulldozed site) or where original alteration were less drastic (recently dredged site) have higher populations and more natural age structures than those with stable alterations. These effects are most noticeable during times of low stream flow and spawning.

Comparison of population densities among different studies is difficult for two reasons. Age composition varies greatly among streams (and within streams) and species, and comparison must be made by age groups to have any meaning. Population densities also have a great deal of variation from season to season even within a site (Figure 31) as has been demonstrated in this study.

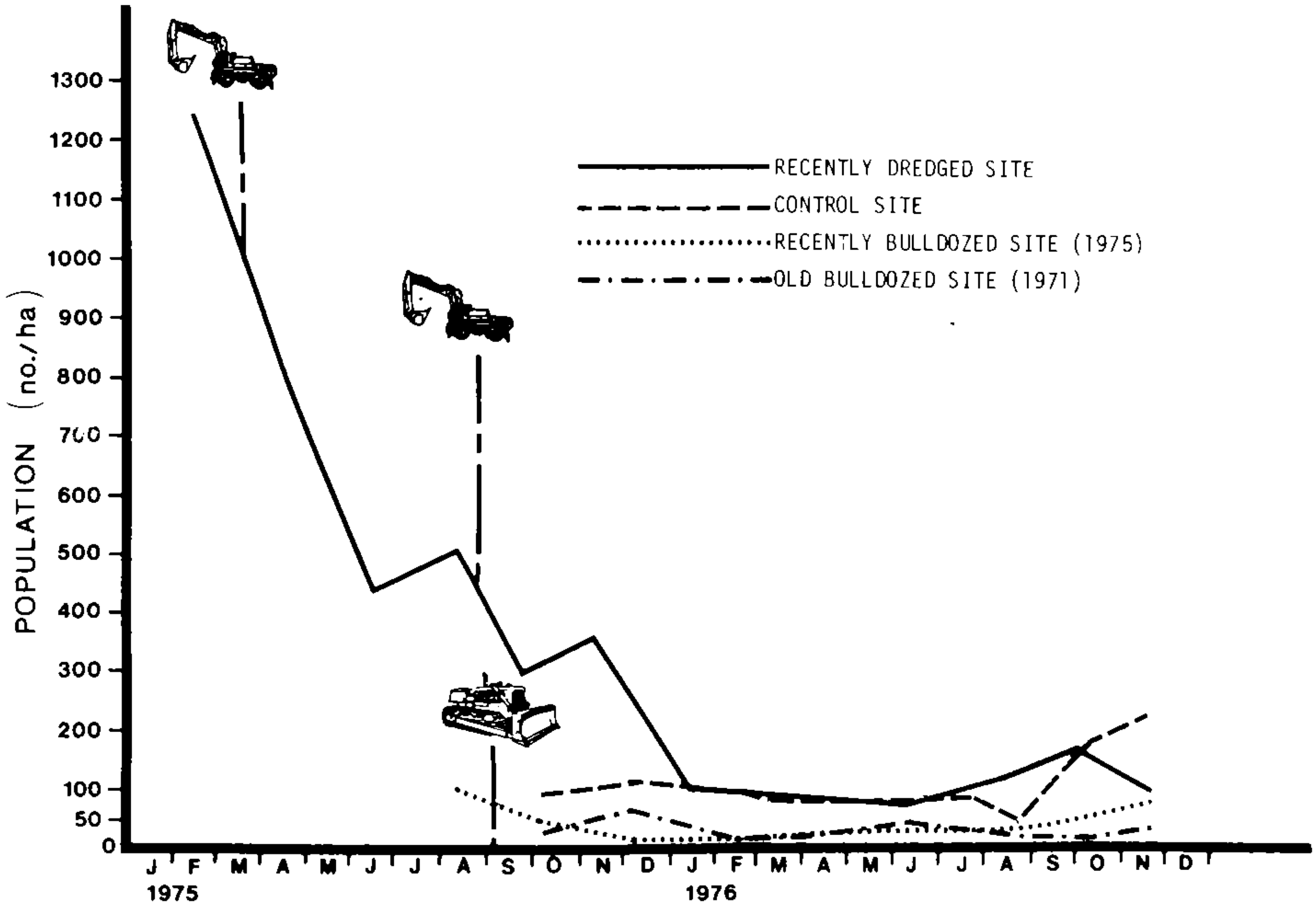


Figure 32. Population estimates (no/ha) of brown trout for the 1974 year class in all study sites of the Blacksmith Fork River, Cache County, Utah 1975-76.

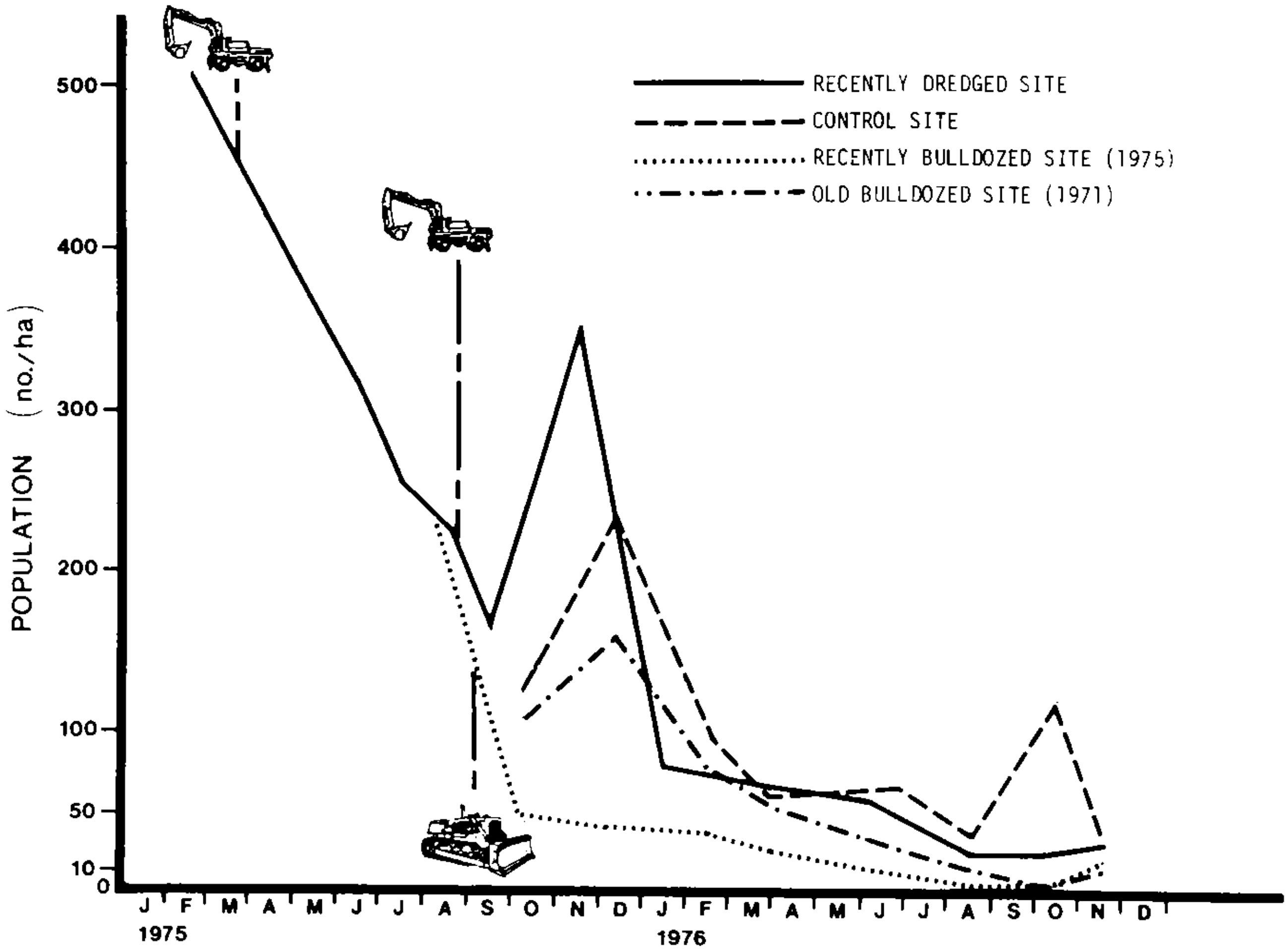


Figure 33. Population estimates (no/ha) of brown trout for the 1973 year class in all study sites of the Blacksmith Fork River, Cache County, Utah, 1975-76.

Comparison for the same season among rivers may be invalid since some sites may have maximum density at that time when others are at minimum density. Making comparisons at different seasons throughout the year however, is helpful in clarifying these variations.

The mean annual density by age groups would be the most meaningful comparison of populations. Although it is possible to make this comparison among the sites for the study (Table 23), few of the other channelization studies have mean annual densities by age group.

Differences in the composition of the population is one of the changes that occurs as a result of channel alteration as has been mentioned earlier. The sites exhibit a decrease in absolute numbers of age 0 trout with increasing physical alteration and a decrease in percent composition. Although the age IV+ fish decrease in absolute numbers they tend to increase in percent composition with increasing degrees of alteration. The middle age groups have a higher percent composition in the more altered sites.

The recently bulldozed site is an anomaly with respect to population composition. Its population composition is now similar to that of the Blacksmith's control and dredged sites although absolute values are lower. The stream morphology of the site also differs from the other two bulldozed sites in that much of the shoreline is braided and shallow, providing habitat for age 0 fish.

Direct comparison of densities with most other channelization studies is not possible as mentioned above, but the trends and changes in population composition can be compared. Cederholm and Koski (1977) found densities 78 to 96 percent lower in channelized areas than in the control. They did not separate age groups, but did find age 1+ steelhead more affected than age 0. Duvel et al. (1976) also found the largest trout (> 6 in) (sic) missing from channelized areas but it is not possible to tell which species nor age groups they dealt with. Brown trout had 77 and 14 percent lower densities in altered mountain and meadow zones, respectively, in Montana (Elser 1968). The mountain zones showed relatively equal changes in density among size groups while the altered meadow zone showed the greatest decreases in the smallest and largest size groups.

Biomass and Production

Introduction. Standing crop and production of trout are presented as kilograms per hectare (kg/ha) for easy comparison among sites. The surface area of each site can be multiplied by these values to determine the actual biomass and production measured (Appendix Table). Biomass and production are provided for all dates for which they were calculated. Dashed lines indicate the beginning and end of the production year when a site was studied for more than one year.

Blacksmith control. The mean biomass (standing crop) of the population for the production year was 101.5 kg/ha, while the total annual production was 72.67 kg/ha (Tables 24 and 25). Maximum biomass for the entire population occurred in the fall while the minimum occurred in spring. Individual year

Table 23. Mean annual population (no/ha) and percent composition ( ) by age group of brown trout in six study sites on the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

	Study site[1]					
Age group	Blacksmith control	Blacksmith dredged	Blacksmith old bulldozed	Logan total bulldozed	Blacksmith recently bulldozed	Logan stable bulldozed
0	767 (65.2)	834 (61.0)	198 (48.5)	14 (7.8)	449 (79.8)	15 (16.9)
I	149 (12.6)	281 (20.5)	70 (17.0)	51 (28.9)	44 (7.8)	27 (30.6)
II	135 (11.5)	152 (11.1)	64 (15.6)	53 (29.8)	39 (6.9)	24 (27.9)
III	91 (7.7)	75 (5.5)	57 (13.8)	48 (26.9)	23 (4.1)	15 (16.7)
IV	34 (2.9)	27 (1.9)	21 (5.1)	12 (6.6)	7 (1.2)	6 (6.7)
Total	1176	1369	410	178	562	87

[1]Sites are arranged by extent of stream channel alteration from least on left to most on right.

Table 24. Biomass (kg/ha) of brown trout by year class for the control site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Date	Year Class 1976	1975	1974	1973	1972	1971+	Total
10/5/75	--	11.0	8.5	26.5	58.2	85.0	189.26
12/6/75	--	2.6	12.6	44.0	28.3	35.9	123.50
2/24/76	--	2.4	11.2	18.8	18.4	--	50.82
3/28/76	--	1.6	12.0	13.4	9.4	--	36.40
6/25/76	4.4	21.5	22.9	28.0	7.0	--	83.83
8/19/76	12.9	11.1	13.7	17.3	7.6	--	62.45
10/0/76	14.7	9.9	51.7	57.0	28.4	--	161.79
11/23/76	19.8	21.8	62.8	21.7	62.5	--	188.67

Dashed lines indicate the data used for annual production.

Table 25. Production (kg/ha) of brown trout by year class for the control site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Time Period	Year Class						Total
	1976	1975	1974	1973	1973	1971+	
10/5/76 12/6/75	--	-0.0	0.9	-3.6	-5.3	-6.6	-14.54
12/6/75- 2/24/76	--	0.4	0.2	-0.3	1.1	--	1.34
2/24/76- 3/28/76	--	0.2	2.5	1.6	1.3	--	5.62
3/28/76- 6/25/76	4.4	8.9	9.0	10.3	2.0	--	34.60
6/25/76- 8/19/76	12.0	3.4	4.2	3.0	0.9	--	23.53
8/19/76- 10/9/76	5.8	5.0	8.0	3.2	1.1	--	23.12
10/9/76- 11/23/76	3.9	0.1	0.7	0.1	0.1	--	4.89

Dashed lines indicate the data used for annual production.

classes deviated from this trend because of differences in growth, mortality, and movement. In general, mean standing crop for a year class increased with age.

Production for the entire population was highest in early fall and spring. Minimum production occurred in late fall-early winter. Production increased slightly between the 1976 and 1974 year classes and then declined rapidly for successive year classes.

Production for the 1976 year class is not truly comparable to the other year classes since this year class was recruited for only the last one-third of the production year.

Logan control. The most obvious change in the biomass estimates for this site was a large decline in biomass between October 1975 and February 1976 (Table 26). It is probable a spawning migration into the area increased the biomass by October, a supposition supported by the domination of older age groups in the total biomass for the site. While the October biomass was probably the annual peak, the biomass in February was probably near minimal for the site, since the influx of spawning fish had left. February was also a time of low biomass in most other sites. The estimate in February probably represents a more normal distribution of biomass among the age groups.

Logan total bulldozed. Maximum biomass of the total population occurred in July for both years (Table 27). The largest mean biomass for the production year occurred in the 1973 year class while biomass of both older and younger age groups declined progressively. Mean biomass for the production year was 35.58 kg/ha.

Production was highest in the spring, remained high through summer and became negative in late fall and early winter (Table 28). Similar to biomass, production was largest for the 1973 year class and declined in both older and younger year classes. Total annual production for this site was 25.54 kg/ha.

Logan stable bulldozed. Biomass was consistently less for this site which did not include the portion of the previous site bulldozed in 1975 (Table 29). Biomass was low in July 1976 instead of the high value that was found for the total site. Streamflow was very low during this time and there were essentially no pools in these upper sections to provide shelter for trout. Changes in biomass by year class were similar, with a dominant part of the biomass comprised of the 1973 year class. The mean total biomass for the production year was 13.74 kg/ha.

Production, similar to biomass, was lower here than in the total site (Table 30). The annual production followed a similar pattern to that found in the total site, but the 1972 year class now accounted for the highest production. Annual production for the site was 10.02 kg/ha.

Blacksmith recently bulldozed. This site was bulldozed between the August and September 1975 collections. The biomass of brown trout decreased 45 percent during the period when the site was bulldozed (Table 31). By 19 February 1976, after the spawning season, the biomass was only 18 percent of

Table 26. Biomass (kg/ha) of brown trout by year class for the control site in the Logan River, Cache County, Utah, 1975-76.

Date	Year Class						Total
	1976	1975	1974	1973	1972	1971+	
10/9/75	0.00	0.26	14.53	57.23	64.74	35.41	172.17
2/5/76	0.00	0.00	5.90	10.49	5.44	0.00	21.83

Table 27. Biomass (kg/ha) of brown trout by year class for the bulldozed site (0-500 m) in the Logan River, Cache County, Utah, 1975-76.

Date	Year Class						Total
	1976	1975	1974	1973	1972	1971+	
3/15/75	0.00	0.00	1.13	14.78	20.98	11.22	48.11
4/20/75	0.00	0.00	1.28	17.07	21.94	8.84	49.13
7/31/75	0.00	0.00	5.75	20.09	23.30	2.81	51.96
9/10/75	0.00	0.49	6.44	14.59	15.72	1.04	38.28
11/15/76	0.00	0.08	6.81	12.74	3.18	0.00	22.81
1/17/76	0.00	0.00	1.65	12.45	5.71	0.60	20.40
4/4/76	0.00	0.30	2.15	5.23	12.37	0.00	20.05
7/8/76	0.00	4.47	12.75	35.75	7.03	0.00	59.99

Dashed lines indicate the data used for annual production.

Table 28. Production (kg/ha) of brown trout by year class for the bulldozed site (0-500 m) in the Logan River, Cache County, Utah, 1975-76.

Date	Year Class 1976	1975	1974	1973	1972	1971+	Total
3/15/75-4/20/75	0.0	0.0	0.1	3.5	3.0	1.3	7.94
4/20/75-7/31/75	0.0	0.0	4.1	6.9	7.4	1.9	20.29
7/31/75-9/10/75	0.0	0.0	1.7	2.3	1.8	0.2	6.01
9/10/75-11/15/75	0.0	0.1	1.7	0.9	-0.2	0.0	2.53
11/15/75-1/17/76	0.0	0.0	0.2	-1.8	-0.5	0.0	-2.08
1/17/76-4/04/76	0.0	0.0	-0.1	1.0	1.1	0.0	2.08
4/04/76-7/08/76	0.0	2.5	2.8	7.6	4.1	0.0	17.02

Dashed lines indicate the data used for annual production.

Table 29. Biomass (kg/ha) of brown trout by year class for the stable bulldozed site (123-500 m) in the Logan River, Cache County, Utah, 1975-76.

Date	Year Class 1976	1975	1974	1973	1972	1971+	Total
3/15/75	0.00	0.00	1.05	8.78	13.58	10.73	34.13
4/20/75	0.00	0.00	1.10	11.53	13.45	8.03	34.11
7/31/75	0.00	0.00	4.09	18.83	11.95	2.34	37.22
9/10/75	0.00	0.52	1.87	2.40	0.82	0.00	5.61
11/15/75	0.00	0.07	3.40	4.63	2.38	0.00	10.49
1/17/76	0.00	0.00	0.77	7.56	5.71	0.75	14.79
4/4/76	0.00	0.08	0.73	1.51	5.70	0.00	8.02
7/9/76	0.00	2.79	1.94	1.63	0.00	0.00	6.36

Dashed lines indicate the data used for annual production.

Table 30. Production (kg/ha) of brown trout by year class for the stable bulldozed site (123-500 m) in the Logan River, Cache County, Utah, 1975-76.

Time period	Year Class						Total
	1976	1975	1974	1973	1972	1971+	
3/15/75-4/20/75	0.0	0.0	0.1	2.2	1.9	1.3	5.43
4/20/75-7/31/75	0.0	0.0	3.1	5.5	4.2	1.6	14.48
7/31/75-9/10/75	0.0	0.0	0.6	1.1	0.4	0.4	2.50
9/10/75-11/15/75	0.0	0.1	0.7	0.8	0.0	0.0	0.95
11/15/75-1/17/76	0.0	0.0	0.1	-0.9	-0.4	0.0	-1.18
1/17/76-4/4/76	0.0	0.0	0.0	0.5	0.7	0.0	1.17
4/4/76-7/9/76	0.0	1.8	0.7	0.9	3.5	0.0	6.58

Dashed lines indicate the data used for annual production.

Table 31. Biomass (kg/ha) of brown trout by year class for the recently bulldozed site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Date	Year Class 1976	1975	1974	1973	1972	1971+	Total
8/11/75	0.0	1.7	8.7	53.0	14.5	7.6	85.49
10/4/75	0.0	1.5	4.7	11.0	14.8	15.3	47.20
12/4/75	0.0	1.1	2.6	10.5	13.0	1.4	28.60
2/19/76	0.0	0.8	3.0	9.7	2.1	0.0	15.59
3/31/76	0.0	1.0	3.2	7.2	2.0	0.0	13.35
6/14/76	4.5	3.6	5.5	4.8	4.6	0.0	23.04
8/20/76	1.1	4.3	8.8	1.3	1.7	0.0	17.25
10/7/76	1.9	3.8	18.8	1.4	3.2	0.0	29.13
11/24/76	3.1	7.4	19.4	9.1	3.2	0.0	42.14

Dashed lines indicate data used for annual production.

the biomass before the site was bulldozed. Biomass of trout never reached the level that was found before this site was bulldozed, but was comparable in the falls of 1975 and 1976.

The largest decrease in biomass occurred in the three older age groups with very little recovery except during spawning season in November 1976. The standing crop of the 1975 and 1974 year classes declined somewhat following bulldozing of the site but recovered fully by November 1976. Mean biomass in this site was 33.53 kg/ha.

Production was negative during the period when bulldozing occurred and remained low through March 1976 (Table 32). Most production occurred in this site from April to August 1976. Production was generally higher in the younger age groups, but was relatively low for all age groups. Total annual production for this site was estimated to be 18.15 kg/ha.

Blacksmith old bulldozed. The total biomass for this site declined steadily (Table 33). There was a slight increase in biomass during the summer of 1976, which may have resulted from trout movement into pools during low streamflow. Mean biomass of each year class increased with increasing age (except for the 1971+ year class). Total mean biomass of the site was 45.02 kg/ha.

Production was highest in spring and summer with the highest production occurring in the middle and younger age groups (Table 34). During the production year, total production for any period never became negative. Total annual production was estimated to be 41.52 kg/ha.

Blacksmith recently dredged. Standing crops and production for 19 April 1975 and 30 March 1976 are provided in Tables 35 and 36, although population estimates were not actually made for these dates. This site was dredged between February and June and again between August and September 1975. The total biomass of brown trout declined 45 percent between February and June 1975, but only 5 percent during a similar time period a year later (January to June 1976) (Figure 34). The biomass of brown trout dropped slightly during the second dredging of the site and then increased sharply as trout moved into the area to spawn. After spawning, numbers dropped to a value below any previous levels, and even during the spawning season in 1976, the biomass of brown trout did not attain the pre-dredging level.

The total biomass for this site generally declined, but exhibited sharp increases during spawning. Mean biomass by year class was highest for the 1973 year class and lower for younger and older year classes. Mean biomass for the site for the entire study period was 117.44 kg/ha while biomass during the production year (25 September 1975 to 5 October 1976) was 106.32 kg/ha.

Total production of brown trout in contrast to biomass, did not decline during either of the periods in which dredging occurred. In both periods when dredging occurred production was high, although subsequent periods were lower when compared with the same periods a year later. Thus, production during the period following the second dredging (25 September 1975) was 11.26 kg/ha while production for a similar period the following year (5 October

Table 32. Production (kg/ha) of brown trout by year class for the recently bulldozed site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Time period	Year Class 1976	1975	1974	1973	1972	1971+	Total
8/11/75-10/4/75	0.0	0.7	1.1	-2.6	-3.0	1.9	-1.79
10/4/75-12/4/75	0.0	0.2	1.0	0.7	0.2	-1.2	0.88
12/4/75-2/19/76	0.0	-0.0	0.4	-0.1	0.2	0.0	0.46
2/19/76-3/31/76	0.0	0.1	-0.2	0.6	-0.1	0.0	0.38
3/31/76-6/14/76	0.0	2.0	1.1	2.2	1.4	0.0	6.68
6/14/76-8/20/76	4.2	2.9	3.3	0.9	1.1	0.0	12.42
8/20/76-10/7/76	1.1	0.4	-0.2	0.1	0.1	0.0	1.45
10/7/76-11/24/76	0.0	0.1	-2.7	-0.9	-0.6	0.0	-4.13

Dashed lines indicate the data used for annual production.

Table 33. Biomass (kg/ha) of brown trout by year class for the old bulldozed site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Date	Year Class 1976	1975	1974	1973	1972	1971+	Total
10/4/75	0.00	2.61	4.06	23.87	56.83	5.13	92.50
12/4/75	0.00	1.83	8.80	38.43	16.49	8.17	73.72
2/19/76	0.00	0.67	2.23	20.07	32.74	0.00	55.70
3/31/76	0.00	1.61	4.64	13.05	9.33	0.00	28.63
6/14/76	1.08	6.85	9.19	14.61	7.21	0.00	38.95
8/20/76	2.70	7.75	12.97	7.90	0.00	0.00	31.32
10/7/76	3.30	4.78	5.95	1.66	1.88	0.00	17.57
11/24/76	1.46	2.17	9.58	6.71	1.87	0.00	21.79

Dashed lines indicate the data used for annual production.

Table 34. Production (kg/ha) of brown trout by year class for the old bulldozed site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Time period	Year Class 1976	1975	1974	1973	1972	1971+	Total
10/4/75-12/4/75	0.0	0.3	1.7	1.9	0.5	-1.4	3.01
12/4/75-2/19/76	0.0	-0.0	0.7	-0.3	0.7	0.0	1.06
2/19/76-3/31/76	0.0	0.1	-0.2	1.1	-0.7	0.0	0.29
3/31/76-6/14/76	0.0	3.6	1.7	5.3	3.6	0.0	14.16
6/14/76-8/20/76	3.1	5.3	5.2	3.7	2.9	0.0	20.18
8/20/76-10/7/76	2.1	0.6	-0.2	0.2	0.0	0.0	2.82
10/7/76-11/24/76	0.0	0.0	-1.1	-0.8	-0.4	0.0	-2.15

Dashed lines indicate data used for annual production.

Table 35. Biomass (kg/ha) of brown trout by year class for the recently dredged site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Date	Year Class 1976	1975	1974	1973	1972	1971+	Total
2/16/75	0.0	0.0	25.6	58.7	46.5	55.8	186.51
4/19/75	0.0	0.0	22.7	53.3	36.5	10.1	122.61
6/16/75	0.0	0.0	21.6	52.6	26.7	1.5	102.30
7/21/75	0.0	0.0	35.8	58.9	21.5	9.4	125.64
8/12/75	0.0	16.5	42.7	49.3	14.6	23.8	146.94
9/25/75	0.0	11.0	32.9	41.0	24.8	29.0	138.80
11/13/75	0.0	7.6	37.6	84.1	58.8	43.9	232.03
1/15/76	0.0	6.1	11.1	17.0	5.7	25.2	65.06
3/30/76	0.0	8.9	11.4	18.4	4.5	0.0	43.24
6/8/76	1.3	23.9	13.1	20.4	3.1	0.0	61.76
8/18/76	16.4	28.4	28.7	12.2	14.3	0.0	100.02
10/5/76	16.9	18.2	44.9	12.4	11.1	0.0	103.35
11/24/76	24.8	18.7	24.7	13.9	16.3	0.0	98.48

Dashed lines indicate data used for annual production.

Table 36. Production (kg/ha) of brown trout by year class for the recently dredged site in the Blacksmith Fork River, Cache County, Utah, 1975-76.

Time period	Year Class 1976	1975	1974	1973	1972	1971+	Total
2/16/75-4/19/75	0.0	0.0	8.0	6.5	5.1	-13.4	6.21
4/19/75-6/16/75	0.0	0.0	12.1	14.1	5.4	-0.6	30.97
6/16/75-7/21/75	0.0	0.0	11.8	17.9	7.3	2.0	39.05
7/21/75-8/12/75	0.0	0.0	4.7	-2.7	-1.5	-1.3	-0.80
8/12/75-9/25/75	0.0	8.0	10.1	4.0	3.3	5.2	30.58
9/25/75-11/13/75	0.0	0.6	-2.0	-3.3	-5.8	-0.8	-11.26
11/13/75-1/15/76	0.0	0.2	1.0	-5.0	-2.8	-7.0	-13.50
1/15/76-3/30/76	0.0	1.9	2.1	4.0	0.8	0.0	8.79
3/30/76-6/8/76	0.0	13.1	3.8	5.2	1.2	0.0	24.67
6/8/76-8/18/76	18.6	16.5	6.5	6.1	4.5	0.0	50.12
8/18/76-10/5/76	10.0	2.2	2.4	0.2	-3.2	0.0	15.00
10/5/76-11/24/76	4.8	0.2	-1.0	-1.1	12.2	0.0	2.23

Dashed lines indicate data used for annual production.

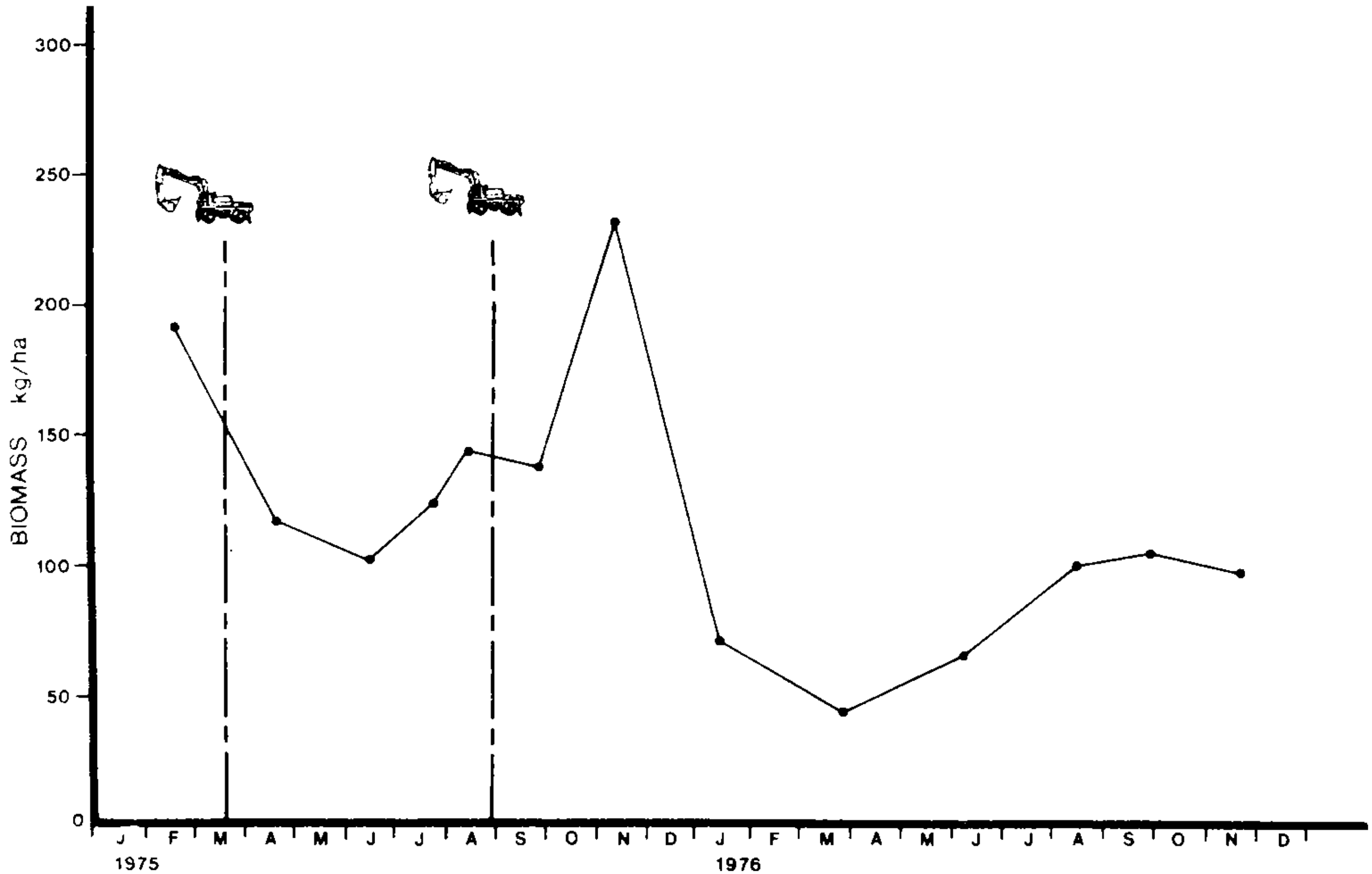


Figure 34. Changes in the biomass of brown trout in the dredged reach of the Blacksmith Fork River, Cache County, Utah, 1975-76.

1976) was 2.23 kg/ha.

Production of brown trout during the year did not exhibit any pattern, possibly because of changes produced by dredging. Production tended to be highest in summer and spring. Annual production (25 September 1975 to 5 October 1976) by year class indicated that the youngest two year classes had the highest production. This is particularly remarkable since the 1976 year class was newly recruited and only used in production calculations for one-third of the production year. The total annual production for this site was 73.82 kg/ha.

General Trends. The biomass estimates of brown trout in the Blacksmith Fork River were low in all sites during the spring (Figure 35). Three of the sites contained their lowest biomass during that time while the Blacksmith old bulldozed site had minimum biomass during the fall. Biomass was minimal in the spring for the Logan total bulldozed site but was minimal in fall for th Logan stable bulldozed site (Figure 36).

The biomass of brown trout was often greatest during the fall spawning season but channel alterations and low streamflows greatly affected this pattern. The recently dredged site had a high biomass of trout immediately after the channel was dredged in the fall 1975 but the trout biomass was greatly reduced in the fall of 1976. Neither the Blacksmith old bulldozed site nor the Logan stable bulldozed site had an increase of biomass during the fall spawning season, indicating that spawning was not extensive in these sites

In the canyon of the Blacksmith Fork River, maximum biomass was observed in late spring (Gosse 1978). Coho salmon consistently reached a maximum in early spring (Chapman 1965) while brook trout obtained a maximum biomass in late fall and early winter (Hunt 1966), both measured over a four year period. Brown trout in New Zealand (Hopkins 1971) and Scotland (Egglishaw 1970) obtained maximum biomass during late summer and fall.

The variability in maximum and minimum biomass found in this study and in the ones listed above demonstrate the danger in attempting biomass comparisons among studies. Single biomass estimates or estimates from a single season may be at any point within the large range of fluctuation found in most studies conducted throughout the year. Thus mean annual biomass (per surface area) is the only valid comparison, since it must of necessity encompass both maximum and minimum annual fluctuations in biomass. Unfortunately, the number of studies that measure trout biomass throughout the year is still relatively few.

The maximum biomass of trout in the Logan total bulldozed site occurred in July when biomass in the stable site was close to minimum. Low streamflows in the severely channelized area restricted the amount of shelter available for trout and the fish emigrated to other areas where deep pools provide cover. This phenomenon was not observed on study sites of the Blacksmith Fork River, possibly because all sites there contained some pools but also because they were not sampled during the period of lowest streamflows as the fish were already severely stressed at this time.

The biomass of trout decreased sharply in the Blacksmith dredged site

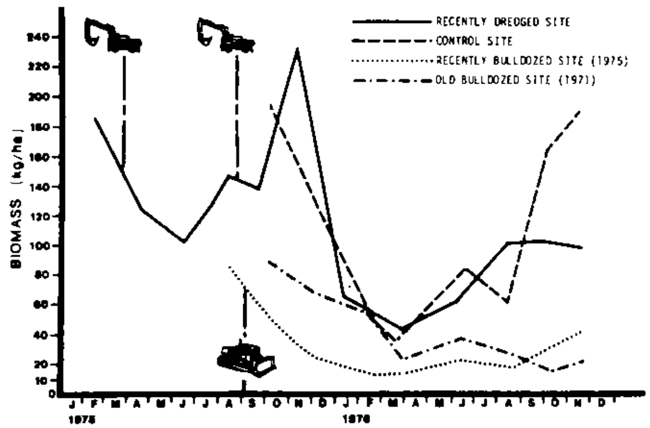


Figure 35. Estimates of total biomass of brown trout for study sites in the Blacksmith Fork River.

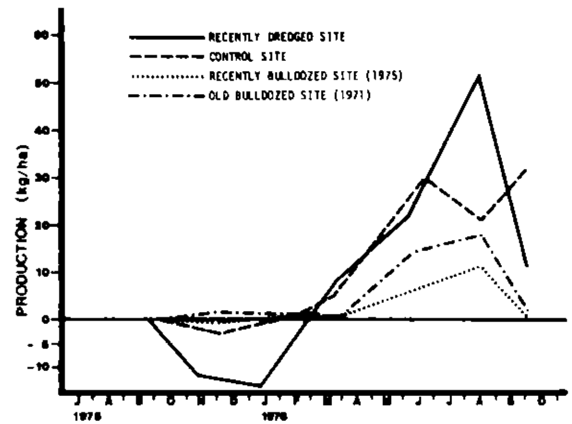


Figure 37. Estimates of total production of brown trout for study sites in the Blacksmith Fork River.

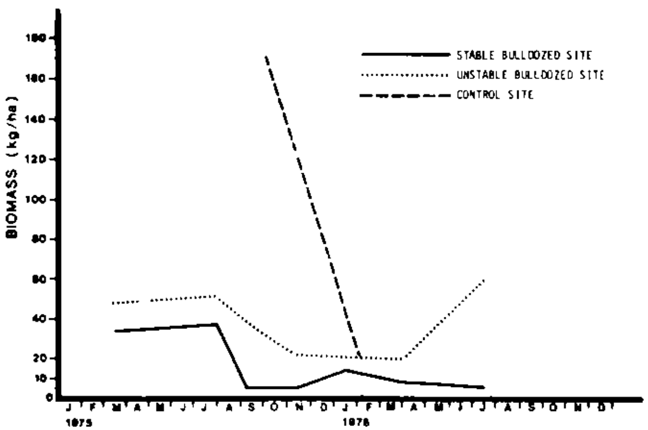


Figure 36. Estimates of total biomass of brown trout for study sites in the Logan River.

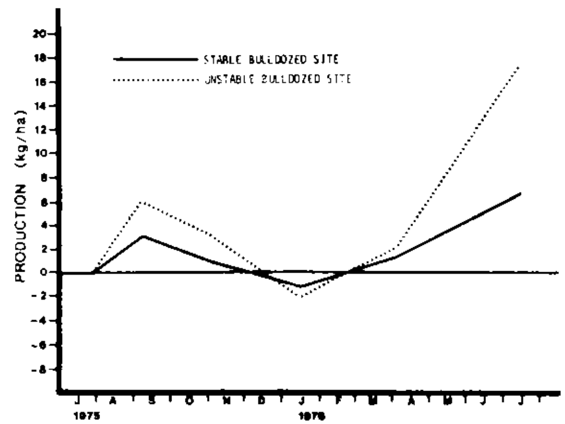


Figure 38. Estimates of total production of brown trout for study sites in the Logan River.

immediately after the reach was altered for the first time. Except for spawning season in 1975, the biomass of trout never returned to the level preceding dredging. A sharp decline in trout biomass occurred after alteration of the Blacksmith recently bulldozed site, and the biomass had not returned to pre-alteration level after one year. The 1973 class exhibited the sharpest decrease in biomass during the period in which bulldozing occurred (Figure 33). Those age groups which are the most abundant, beyond normal age composition, appear to be most greatly affected by alterations, as was found with population estimates.

Total trout production was generally highest in spring and early summer at all sites (Figures 37 and 38). Negative production occurred in late fall and early winter in all sites except the Blacksmith old bulldozed reach. Channel alterations do not result in an immediate decrease in production as was found with biomass. However, reduced production occurred during subsequent sampling periods. Such delayed responses are a reflection of trout growth rates which have the same pattern.

Trout production and mean biomass show a tendency to decrease as the degree of stream alteration increases (Tables 37 & 38). The differences between the control site and the recently dredged site are too small to be meaningful. That is not to imply that dredging had no effect on the recently dredged site. There is every indication that biomass was reduced with each dredging and did not recover to predredging levels. Similarly, it can be assumed that production must also have been reduced. However, before dredging occurred, this site was in all probability much higher in both biomass and production than the control site. Several reasons for this original difference between sites might be the greater meander and proportion of pools found in the dredged site (Table 9) and the influence of Ballard Springs on temperature extremes. There is also reason to believe that spawning and recruitment may continue to decrease in the dredged site over the years.

The recently bulldozed site on the Blacksmith and Logan total bulldozed site are quite similar in the degree of alteration they have undergone, which is probably why the production and biomass values for these sites are so similar. Brown trout biomass and production increased from the most severely altered sites to the most natural sites by a factor of 8 and 7, respectively.

The advantages of production estimates over biomass estimates in assessing a fish population have been discussed by many authors (Ricker and Foerster 1948, Macfayden 1948, Hunt 1966, Hopkins 1971, Chapman 1965). Hunt (1966, 1971, 1974) was the first to use production to determine the effects of physical stream alterations on fish population. In his study, the alterations were man-made attempts to improve stream habitat for brook trout. He found (Hunt 1966) that while the total production of the most improved section increased an average of only 17 percent, age III trout increased production by as much as 700 percent. This was particularly important since this was the age group that was being harvested by anglers.

The best correlation of "trout carrying capacity" and physical factors was with pools and permanent bank cover. Hunt (1974) also found that while annual stream production was stable, it was negatively related among stream

Table 37. Total annual production and percent contributed ( ) by age group of brown trout in six study sites on the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

Age group	Study site[1] Blacksmith control	Blacksmith dredged	Blacksmith old bulldozed	Logan total bulldozed	Blacksmith recently bulldozed	Logan stable bulldozed
0	22.2 (30.1)	30.7 (42)	5.5 (13.3)	0.1 (0.4)	5.6 (24.6)	0.1 (1)
I	18.8 (25.5)	32.7 (45)	12.0 (28.9)	6.1 (24.0)	6.8 (30.3)	3.2 (31)
II	20.3 (27.6)	6.5 (9)	8.1 (19.4)	4.1 (16.1)	4.6 (20.5)	1.1 (11)
III	12.5 (17.0)	6.9 (9)	11.5 (27.8)	9.7 (32.2)	4.2 (18.8)	1.4 (14)
IV+	-0.2 (-0.2)	-3.2 (-4)	4.4 (10.6)	5.4 (21.3)	1.3 (5.3)	4.4 (43)
Total	73.67	73.82	41.52	25.54	22.27	10.02

[1] Study sites are arranged by extent of stream channel alteration with natural reach on left and most altered reach to the right.

Table 38. Mean annual biomass (kg/ha) and percent contributed ( ) by age group of brown trout in six study sites on the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

	Study site[1]					
Age group	Blacksmith control	Blacksmith dredged	Blacksmith old bulldozed	Logan total bulldozed	Blacksmith recently bulldozed	Logan stable bulldozed
0	6.5 (6.4)	6.1 (5.7)	1.6 (3.4)	0.1 (0.3)	1.4 (5.7)	0.1 (1.2)
I	9.7 (9.5)	23.0 (21.5)	4.9 (10.2)	4.0 (11.1)	3.1 (12.5)	2.0 (14.8)
II	26.0 (25.7)	31.6 (29.6)	13.9 (28.7)	10.7 (30.0)	8.7 (34.9)	4.9 (35.5)
III	31.5 (31.2)	25.3 (23.6)	18.7 (38.5)	15.9 (44.8)	7.5 (29.9)	4.3 (31.2)
IV+	27.4 (27.0)	21.0 (19.6)	9.2 (19.0)	4.9 (13.8)	4.3 (17.3)	2.3 (16.6)
Total	101.15	106.32	48.34	35.58	24.88	13.74

[1] Study sites are arranged by extent of stream channel alteration with the natural reach on the left and most altered reach to the right.

sections as well as among age groups. Thus, while production increased in the improved section, it decreased in the control sections. Hunt warns that in this case simply measuring total production values didn't give a true picture of the benefit of habitat improvements, since most of the production increase went into fish that were available for harvest.

The findings of Hunt seem to agree well with several findings in this study. Habitat alterations affect the production of different age groups to varying degrees. In order to truly assess the impact of habitat alterations, one has to understand how each age-group contributes to the total stream ecology. Similarly, one must be able to assess physical alterations in one stream section in view of the total stream. In this study as in Hunt's, pools and bank cover appear to be very important to trout production.

MOUNTAIN WHITEFISH

Movement

About two thirds (67% of 2900 recapture records) of the mountain whitefish were recaptured in the same 100 m section where they were last captured or the section immediately adjacent to it (Table 39).

Table 39. Numbers of recaptured mountain whitefish as related to distance travelled and direction of movement since their last capture in Logan and Blacksmith Fork Rivers, Utah, 1975-76.

Size group	Stationary or moved between adjacent 100 m sections	Moved downstream more than 100 m	Moved upstream more than 100 m
$\leq$ 235 mm	134	68	32
> 235 mm	1869	464	423

There was no difference in upstream or downstream movement (464 and 423 fish respectively) of large whitefish (> 235 mm) that had moved at least 100 m since their last capture. However, fish less than 235 mm in length were recaptured more often downstream (68 observations) than upstream (32 observations) (X^2 = 12.96, d.f. = 1, $p < 0.025$). The greatest distance between recaptures of a whitefish was 7.2 km for a 258 mm fish that was marked in the Blacksmith recently bulldozed site on 9 October 1975 and recaptured in the Logan control site on 5 February 1976. A 313 mm whitefish that was marked on 22 November 1975 in the Logan stable bulldozed site had moved downstream to the confluence of the Logan and Blacksmith Fork Rivers, then upstream in the Blacksmith Fork River and was recaptured 18 days later in the Blacksmith recently bulldozed site (5.8 km from the point of first capture). This was the longest distance that was travelled by a whitefish in the shortest time in this study. Seventy-two of the marked whitefish moved between the two rivers during this study. Most of these (60) moved downstream from one of the Logan River sites then upstream into the Blacksmith Fork River.

Earlier studies indicated little movement of stream-dwelling mountain whitefish. In Utah, Sigler (1951) reported relatively little upstream movement of pre-spawning whitefish in the upper Logan River. Brown (1952) observed no marked movement or migration during the spawning season of whitefish in several Montana rivers, although he reported that a small number of whitefish moved into tributaries to spawn. Later, McAffee (1966) stated that stream populations of whitefish do not seem to travel long distances to spawn. In contrast to these studies, most recent authors (Bergersen 1973, Bridges 1963, Davies and Thompson 1976, Erickson 1966, Matthews 1966, Peters 1974, Pettit and Wallace 1975) have reported pronounced movement by stream-dwelling mountain whitefish.

Movement of Adult Fish

Spawning Season. The peak of the spawning season for whitefish occurred during late October and early November in the Logan and Blacksmith Fork Rivers. Sampling for whitefish eggs in the study sites and the presence of ripe and partially-spent fish in all sites during October and November indicated that whitefish spawned in all study sites. Mountain whitefish are broadcast spawners that use gravel and rubble areas in pools and riffles (Brown 1952, Stalnaker and Gresswell 1974, Thompson and Davies 1976).

Although all study sites contained areas suitable for spawning, many whitefish travelled between sites and between rivers before spawning. During the spawning season, up to one-third of the marked mature whitefish (19-33%) had moved between sites or emigrated from other reaches into the study sites since their last recapture (Table 40). Whitefish moved both upstream and downstream during this period. About a fourth (24%; 144 or 602) of the whitefish that were recaptured during the spawning season and during at least one other season were captured in different areas of the river system during the two seasons (Table 41). Many of the fish marked during the spawning season were never recaptured and presumably had moved prior to and following spawning. Other researchers have reported extensive movements of whitefish during the spawning season (Erickson 1966, Pettit and Wallace 1975).

Although mountain whitefish moved extensively in the Logan and Blacksmith Fork system during the spawning season, no overall pattern or direction of travel was apparent. Movement during this period, however, should not be considered random. The dramatic increase in numbers of whitefish at all sites suggests that spawning fish were emigrating from reaches with conditions unsuitable for spawning (perhaps the lower Logan River) or may have been homing to areas where they were hatched. Movement was by no means passive as evidenced by the pronounced upstream movements of some whitefish and movement between the two rivers (downstream in one river followed by upstream movement in the other). One whitefish (286 mm long) was captured in the Blacksmith control site, recaptured in the Logan stable bulldozed site during the spawning season and finally recaptured again during late winter in the Blacksmith control.

The highest densities of spawning whitefish occurred in the Logan stable bulldozed site. The majority (36 of 59) of mature whitefish which moved

Table 40. Movement of mountain whitefish greater than 250 mm FL to and from study sites in the Logan and Blacksmith Fork Rivers, Cache County, Utah, by stage of streamflow, 1975-76. Number of fish moving into a site is found on horizontal row; from a site in vertical column. Numbers within diagonal lines represent no movement, i.e., fish captured at site where marked.

Stage of Flow (Dates)	Site	Moved from LTB	BD	BC	BB	LC	Off-site
Normal flow (1 December - 12 April)							
	LTB	460	0	1	0	17	9
	BD	2	28	0	1	0	7
	BC	11	7	206	11	1	3
	BB	7	4	12	143	1	3
	LC	32	0	0	0	116	5
Spring flood (13 April - 27 June)							
	LTB	72	0	0	0	0	0
	BD	3	28	4	0	0	3
	BC	0	1	50	1	0	0
	BB	0	0	3	23	0	0
	LC	0	0	0	0	0	0
Summer irrigation diversion (28 June - 25 September)							
	LTB	82	0	1	0	5	0
	BD	0	6	3	1	0	11
	BC	2	0	61	0	1	2
	BB	0	0	0	2	0	0
	LC	6	0	0	0	0	0
Low and normal flows during spawning (26 September - 30 November)							
	LTB	456	3	2	0	49	56
	BD	0	29	2	1	1	9
	BC	3	4	77	9	0	6
	BB	0	0	3	6	0	0
	LC	4	0	0	0	97	19

Table 41. Number and location[1] of adult mountain whitefish (> 250 mm TL) captured in the Logan and Blacksmith Fork Rivers, Utah, during spawning season that were also captured during the winter or summer period, 1975-76.

		Site of Capture During Spawning Season				
		BB	BC	BD	LC	LB
Site of Capture During Summer	BB	2	0	0	0	0
	BC	0	24	0	0	0
	BD	0	5	8	0	2
	LC	0	0	0	38	15
	LB	0	0	0	2	57
	N	0	0	6	1	31
Site of Capture During Winter	BB	9	10	3	1	8
	BC	2	40	5	0	14
	BD	0	2	16	0	2
	LC	0	0	0	60	23
	LB	0	1	0	9	203
	N	0	0	0	0	0

[1]BB = Blacksmith recently and old bulldozed; BC = Blacksmith control; BD = Blacksmith dredged; LC = Logan control; LB = Logan bulldozed; N = Area outside study site boundaries.

between rivers were captured in the Logan River during October and November and probably spawned there. Conditions (water velocity, water depth, and substrate size) in the Logan stable bulldozed site were probably optimum for whitefish reproduction. The high numbers of ripe fish would have tended to insure complete fertilization of eggs. The gravel and rubble bottom in the site would allow adequate aeration and the stability of the substrate in most of the site would minimize egg mortality from mechanical damage. Stalnaker and Greswell (1974) listed incomplete fertilization, predation by insects and fish, and mechanical damage from agitation as environmental factors influencing survival of whitefish eggs.

Since young-of-the-year were not recruited to electro-fishing gear at any site until three to four months after emergence it was impossible to determine any difference in survival through the incubation period among sites. The unstable bottom and spring dredging probably had a detrimental effect on the survival of eggs and newly-hatched fry in the Blacksmith dredged site. Paradoxically, this site usually had the highest numbers of young-of-the-year after they were recruited to gear in the summer. It is likely that many of these young fish had drifted into the site from upstream after emerging or used Ballard Springs as a refuge and nursery area.

Some whitefish in the Blacksmith Fork and Logan Rivers apparently returned to the same area for spawning in successive years. Over half of the mature whitefish (23 to 40 fish) that were captured during both spawning seasons of this study were found in the same stream reach both times. None of these repeat spawners were captured in their spawning area during summer or early fall. It is unlikely that most of these repeat spawners remained in the same site for the entire year without being recaptured during sampling in the summer and early fall when electrofishing efficiency was highest. Other researchers (Liebelt 1970, Pettit and Wallace 1975, Erickson 1966) have reported evidence for homing of adult mountain whitefish.

Winter. After spawning, many whitefish remained in the spawning areas throughout the winter. Most ($>$ 80%) whitefish that were captured during the spawning season and again during late winter had not moved (Table 41). Whitefish that did not remain in their spawning areas generally (66 to 80 fish) moved upstream.

Whitefish movement following spawning was probably to reaches with pools that are used as overwintering areas. Most sites provided sufficient water depth for cover during the winter months. Pettit and Wallace (1975) and Davies and Thompson (1976) reported that post-spawning whitefish moved downstream in the North Fork Clearwater River and the Sheep River, respectively. Both studies indicated that the movement to downstream reaches provided more favorable overwintering areas for the fish. Matthews (1966) and Bergersen (1973) reported that whitefish in the lower Logan River, moved predominantly downstream during the winter.

Spring and Summer. Little information was obtained during the spring because high stream flows made sampling impractical. Almost all (173 of 188) of the marked whitefish that were recaptured at the study sites during spring had not moved since their last capture. The few fish that had moved and were recaptured appeared to move randomly up or downstream. Other authors (Davies and Thompson 1976, Erickson 1966) have reported upstream movement and movement into tributaries during spring which they suggested were related to feeding activities of whitefish.

Recaptures of marked fish indicated little movement during spring and summer in the present study. However, there was obviously a pronounced emigration of mountain whitefish from all sites as evidenced by the dramatic fluctuations in the population estimates of fish for the early spring and summer.

The lowest estimated populations in all sites occurred during summer. There was virtually total emigration of the population of mature fish from the Logan stable bulldozed site and Blacksmith recently bulldozed site during the summer. At this time, the whitefish probably moved to areas of the river with pools, where depth provides cover for this species. During summer sampling, the majority of fish in study sites were captured in the deeper pools.

Movements of Juvenile Fish. The movement of juvenile mountain whitefish (170 to 250 mm) in the study area was less defined (Table 42). Populations of subadults in the study sites did not demonstrate the pronounced increase during spawning season that was evident for mature fish. Numbers of one and two year old fish were more closely associated with streamflows and were often highest during the spring. Most of the juvenile whitefish (9 of 13) that moved between the two rivers were captured in the Logan River during the low streamflows of summer. While the Logan bulldozed sites appeared to be marginal habitat for larger fish they apparently provided sufficient cover for some smaller fish. Juvenile whitefish probably moved in response to changes in streamflows and associated changes in cover (water depth).

Movement of Young-of-the-Year. Only eight of 101 young-of-the-year mountain whitefish that were freeze-branded were recaptured. All of these fish were recaptured in the same reach where they were marked (Blacksmith dredged and control sites). Age 0 whitefish were first sampled in a shallow area at the mouth of Ballard Springs in the Blacksmith dredged site. At this time (8 June), young-of-the-year whitefish were 41 to 61 mm TL. Later in the summer, young-of-the-year fish were found in all sites sampled, often in mid-stream areas deeper than 25 cm and with relatively fast water velocities.

After hatching, whitefish fry drift downstream to suitable holding areas of shallow backwaters (Davies and Thompson 1976). Fry inhabit these protected side pools and shallow areas near shore until summer when they move into deeper areas of streams (Brown 1952, Brown 1972, Davies and Thompson 1976, Pettit and Wallace 1975). Erickson (1966) reported that young-of-the-year whitefish in the Snake River, Wyoming apparently used a small tributary spring (15 cfs) as a nursery area during spring, summer and fall. In this study, Ballard Springs may have provided age 0 whitefish with a nursery and refuge area during high stream flows of spring and the low flows associated with the

Table 42. Movement of mountain whitefish less than 250 mm FL to and from study sites in the Logan and Blacksmith Fork Rivers, Cache County, Utah by stage of streamflow, 1975-76. Number of fish moving <u>into</u> a site is found on horizontal row; <u>from</u> a site in vertical column. Numbers within diagonal lines represent no movement, i.e., fish captured at site where marked.

Stage of flow (Dates)	Site	Moved from LTB	BD	BC	BB	LC	Off-site
Normal flow (1 December - 12 April)	LTB	28	0	0	0	0	0
	BD	0	11	2	0	0	2
	BC	1	7	38	5	0	1
	BB	0	0	0	0	0	0
	LC	3	0	0	0	16	1
Spring flood (13 April - 27 June)	LTB	9	0	0	0	0	0
	BD	0	8	7	0	0	1
	BC	0	0	19	0	0	0
	BB	1	0	0	0	0	0
	LC	0	0	0	0	0	0
Summer irrigation diversion (28 June - 25 September)	LTB	16	3	1	0	1	7
	BD	0	62	0	0	0	4
	BC	0	0	11	2	0	1
	BB	0	0	0	5	0	0
	LC	1	0	0	0	0	0
Low and normal flows during spawning (26 September to 30 November)	LTB	17	0	0	0	6	1
	BD	2	16	0	0	0	0
	BC	0	2	10	0	0	0
	BB	0	0	0	1	0	0
	LC	0	0	0	0	13	3

irrigation season in summer.

Whitefish that hatched in the Logan stable bulldozed site probably drifted downstream, since few suitable holding areas were available for them at that site. Young-of-the-year whitefish that were 68 to 89 mm long were sampled in the Logan total bulldozed site on 9 July 1976 (n = 9) and 16 July 1976 (n = 17). These fish may have emigrated into or been passing through the site. Large numbers of young-of-the-year whitefish were observed in deep pools downstream from the bulldozed reach on the Logan River during late summer of 1974 (Mongillo[1]).

Movement in Response to Stream Alterations. The stream bed alterations undoubtedly caused some displacement of whitefish during the actual dredging or bulldozing operations. However, the ultimate effect of the alterations on whitefish distribution, as well as the immediate response of whitefish in the altered reaches, was obscured by other variables and the "normal" movement behavior of the fish. Many whitefish appeared to return to altered areas within a short period of time following the alteration. In the Blacksmith dredged site, about one-third (24 and 31%) of the marked fish captured at the site during the sampling immediately before the two dredgings were later recaptured at the same site. Most of these (29 of 38) were recaptured in that site within one month after dredging. Recapture records for whitefish in the Blacksmith dredged site indicated that at least two fish remained during both dredgings or returned quickly after being displaced. Only four fish were marked in the Blacksmith recently bulldozed site prior to the 1975 alteration. One of these fish was later recaptured there.

Stationary Fish. While many whitefish moved extensively in the Logan and Blacksmith Fork Rivers, other fish apparently remained in the same site during the entire year. A total of 46 whitefish was recaptured five or more times after they were first marked. Only six (13%) of these fish were ever recaptured more than 1 km away from the point where they were marked. Further evidence of a limited home range for some whitefish was given above for the two whitefish repeatedly captured in the same location (Blacksmith dredged site) in spite of the two alterations that occurred there.

Summary of Movement. Although extensive movement was apparently not a universal phenomenon among whitefish, many fish did demonstrate complex patterns of movement. Interpretations of data obtained over a relatively short period of study and from a limited portion of the available habitat, however, can only be indicative of movement. While many factors (cover, feeding, reproduction) undoubtedly operate as proximate and ultimate reinforcers for whitefish behavior associated with movement, more study is needed to determine the mechanism(s) that influence the movement of whitefish. In general, the whitefish appeared to use deep riffles, glides and pools with substrates of small gravel to rubble; during low streamflows in summer, they move to areas with deeper pools.

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[1]Personal communication, Paul E. Mongillo, Fall, 1975, Department of Wildlife Science, Utah State University.

Growth

Ages were assigned to 549 mountain whitefish from analysis of scales. The oldest whitefish was seven years old. The largest whitefish that was sampled during this study was 471 mm FL and weighed 1270 g. Only nine of approximately 10,000 whitefish weighed over one kilogram.

General Trends. Mountain whitefish in the Blacksmith Fork and Logan Rivers grew at a rate similar to that reported by other authors for whitefish in the Logan River and faster than whitefish in rivers in Idaho and Alberta (Table 43). During this study, age groups I and II were slightly larger at the time of annulus formation than whitefish of similar ages from other reaches of the Logan River (Bergersen 1973, Matthews 1966, Sigler 1951). After three growing seasons, whitefish in the study area were approximately the same size as that reported by Bergersen (1973) and Sigler (1951) but larger than that reported by Matthews (1966).

Mean weights for whitefish of comparable age groups at all study sites were similar within seasons (Figure 39). Whitefish in the two rivers generally grew fastest in the spring and summer and grew slower or lost weight during spawning season and winter. The mean weights for age IV+ fish fluctuated because that age/size group was open to recruitment between samplings. Such fluctuations were most evident during the spawning season when mature fish moved extensively. The youngest age classes showed the highest growth rates at all sites. Young-of-the-year whitefish consistently exhibited the fastest rate of growth of any group in the study area.

Seasonal growth patterns of whitefish in this study were similar to those found by Bergersen (1973) for whitefish in the lower Logan River. Bergersen, however, reported that age II and older whitefish in his study lost weight from July through November 1971. While there were instances of weight loss during the summer in the present study, whitefish generally gained weight throughout the summer and did not lose weight until fall or early winter. Bergersen (1973) reported that age groups 0 to I did not demonstrate negative growth rates. He attributed the negative growth in the older age classes to low food production and high water temperatures during the summer and fall. Goodnight and Bjornn (1971) documented growth for mountain whitefish in the Lemhi River, Idaho from June 8 through September 7. In their study, whitefish grew fastest during the first half of that period. Goodnight and Bjornn believed that little tissue was produced between November 1 and April 1 and that some negative growth (weight loss) was probable during winter. Young-of-the-year whitefish grew faster than any other age/size group of whitefish in the Lemhi River. Hagen (1970) stated that mountain whitefish in Phelps Lake, Wyoming increased considerably in size before they reached age one. He observed that mature fish in the lake showed practically no growth after the middle of October until late in June when water temperatures had started to increase. Other authors (Bernard 1976, Cooper 1953, Egglishaw 1970, Gosse 1978, Headrick 1976, Hopkins 1971, Lowry 1966, McFadden 1961) have reported similar growth patterns for other salmonids with most growth occurring in spring and summer and low growth rates during late fall and winter. In general, young fish produce the largest increments of growth that become less with the age of the fish (Carlander 1969).

Table 43. Comparison of mean fork length (mm) of mountain whitefish at the end of each year of life for selected waters.

Location	Age 1	2	3	4	5	Reference
Logan River	124	210	274	310	336	Bergersen (1973)
Logan River	106	140	182	215	245	Matthews (1966)
Logan River	117	206	259	294	325	Sigler (1951)
North Fork Clearwater River, Idaho	104	197	245	271	293	Pettit and Wallace (1975)
Morrison Lake, B.C.	188	226	241	---	---	Godfrey (1955)
Logan and Black-smith Fork Rivers, Utah	125	215	260	285	---	This study

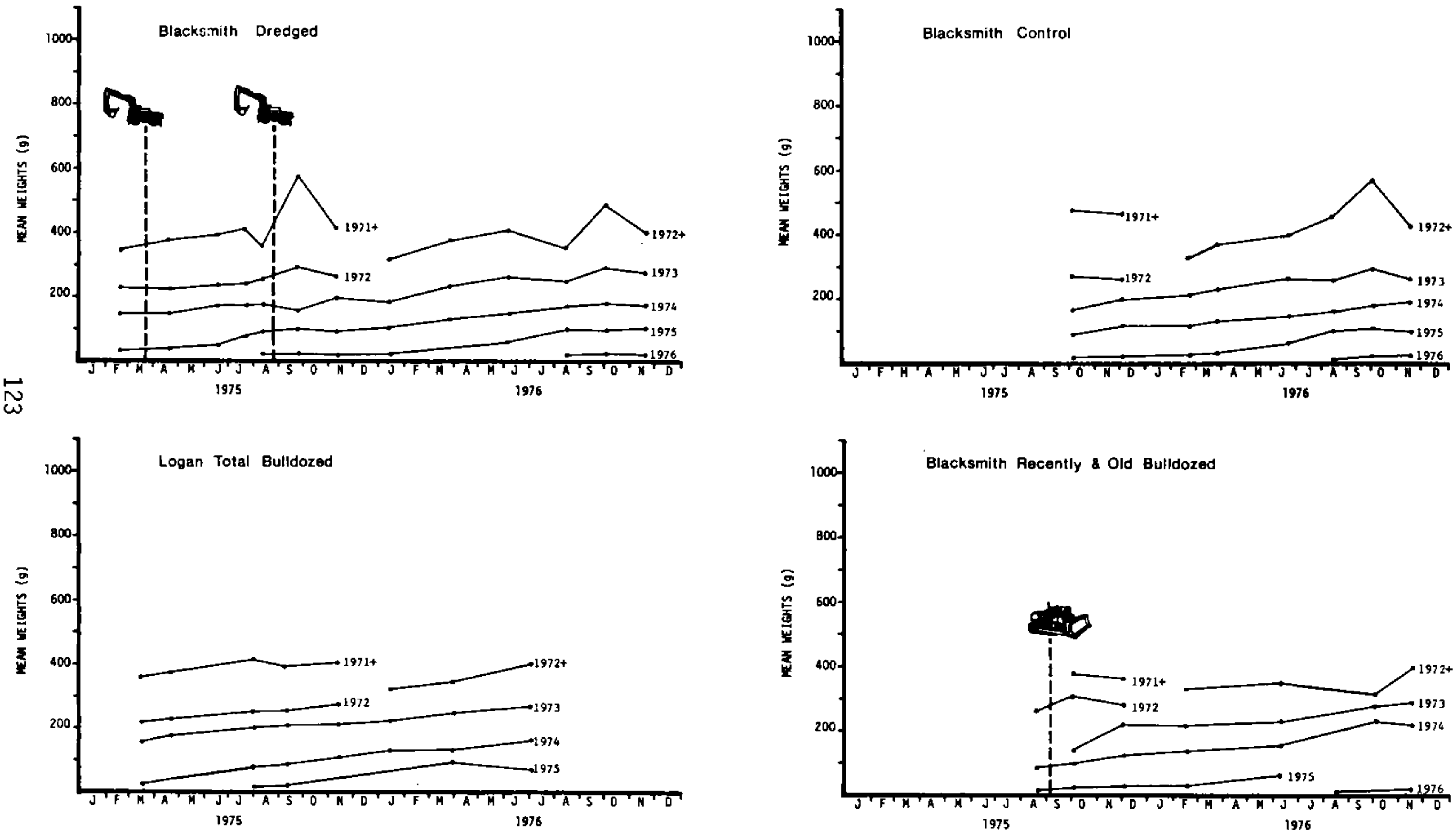


Figure 39. Mean weights of mountain whitefish by year class in the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

Variations from the General Growth Pattern. The majority of mountain whitefish in this study exhibited growth on a seasonal basis and throughout life in the general pattern described above. There were instances, however, when fish of a particular age group deviated from the usual growth. Such deviations may have resulted from actual differences in growth or from poor estimates of the mean weight for an age group because of small sample size.

Although numbers and biomass of whitefish in the Logan total bulldozed site fluctuated greatly, the fish that remained at this site consistently gained weight. Age groups of whitefish in the Logan total bulldozed site had the fewest (two) periods of weight loss of any of the study sites (Figure 39). Weight loss occurred for whitefish in the older age groups during the low streamflows of summer 1975 and the spawning season in 1975.

Whitefish lost weight more often in the Blacksmith dredged site than at any other site. All but one of the intervals of weight loss (negative growth) occurred during the low streamflows of summer or the spawning season. There were no evident differences in mean weights or growth rates of comparable groups of whitefish between the year of dredging (1975) and the following year.

Factors Influencing Growth in Whitefish. McHugh (1941) lists food and temperature as two important factors influencing whitefish growth rates. Other factors affecting the growth of fish are well outlined by Weatherly (1976). Thompson and Davies (1976) and Brown (1972) reported differences in length and weight of young-of-the-year whitefish in different reaches of the Sheep River, Alberta and the Logan River, respectively. Both authors attributed the larger size of fry in downstream reaches to warmer water temperatures that resulted in earlier emergence. Thompson and Davies (1976) stated that the increase in temperatures downstream also reflected a more abundant food supply. Significant differences in back-calculated lengths of age I and age II whitefish from different areas of the North Fork Clearwater River may have been due to warmer temperatures in lower reaches (Pettit and Wallace 1975). In the present study, water temperatures in the Blacksmith Fork River were generally higher than those in the Logan River throughout the year (Figures 6 and 7). While warmer temperatures may have resulted in earlier emergence and faster growth of whitefish fry in the Blacksmith Fork River, young-of-the-year whitefish were seldom sampled in the Logan River so no comparisons could be made. There were no significant differences between the mean weights of older (age I+) fish between rivers.

The standing crops of macroinvertebrates during this study were highest during the winter at all sites. The lowest standing crops of macroinvertebrates occurred during summer in the Logan total bulldozed site and Blacksmith control site, and during the fall following alterations in the Blacksmith dredged site and Blacksmith recently bulldozed site. Although alterations drastically reduced standing crops of macroinvertebrates temporarily, altered reaches "recovered" in four or five months. The effect of the alterations and resulting decrease in bottom organisms on growth of the whitefish in the recently altered reaches was not clear. Although the general morphology of the mountain whitefish and its food habits suggest that they generally feed off the bottom, this species also feeds on drifting organisms (Brown 1972, Thompson and Davies 1976). Research by Pontius and Parker (1973) indicated that mountain whitefish in the Snake River, Wyoming did not feed randomly from the drift alone or solely from the bottom. The rapid recolonization of the recently altered areas by macroinvertebrates during this study suggests a substantial drift of macroinvertebrates into those areas. Thus, drift may have ameliorated the effect of a decrease in bottom forage organisms on growth of whitefish in the Blacksmith dredged and bulldozed sites.

One reason for the similarity of growth rates among study sites was the mobility of whitefish throughout the study area. Whitefish moved readily from reaches with little cover (low streamflows and absence of pools) to areas with more suitable habitat. Movement probably also moderated the effect of other factors (i.e., food availability, temperature) influencing the growth of whitefish in different sites. Other authors (Davies and Thompson 1976, Erickson 1966) have hypothesized that some movements of whitefish were ostensibly to areas of high food production.

Sources of Error in Estimating Growth. As mentioned above, some estimates of mean weights when fish populations were low were questionable. The influence of such biased mean weights was considered negligible in production estimates. Since production is a function of the mean biomass of whitefish and their growth rate, the error in estimating production (positive or negative) for low populations of fish would be small.

Growth rates for the oldest age group (IV+) of whitefish were sometimes adjusted because fish moved between sampling periods. Since the IV+ age group of whitefish was bounded only by a lower size limit, it was open to recruitment between sampling. Selective immigration and/or emigration of the larger or smaller fish in this age group resulted in biased mean weight and growth rate estimates. Lowry (1966) discussed a similar problem for cutthroat trout in three Oregon streams when he recorded negative growth for fish in the 1959+ year class (age III+). He believed that the estimate of negative growth resulted from selected emigration of the large members of that age group to spawning areas in the small tributaries outside of his study sections.

In this study, the growth rate for age III fish was used in estimating production of older fish when it was believed that movement of differentially smaller or larger fish in the IV+ age group had occurred between sampling for growth rates. The seasonal growth for age II whitefish provided by Bergersen (1973) was similar to that for older fish. Increments of annual growth (growth between successive annuli) are similar for age III and older whitefish (to age VII) (Matthews 1966, Pettit and Wallace 1975, Rawson and Elsey 1949, Sigler 1951, Thompson and Davies 1976). The use of growth rates from age III whitefish for older age groups probably resulted in a slight overestimate of production for those groups.

Population Estimates

General Trends. Estimated densities of mountain whitefish in the study area varied greatly (0-3466 fish/ha) by site and season (Figure 40). The greatest density occurred at all sites during the spawning season in late fall or in winter. The numbers generally declined through the spring, then decreased dramatically during the low streamflow period of summer. Bergersen

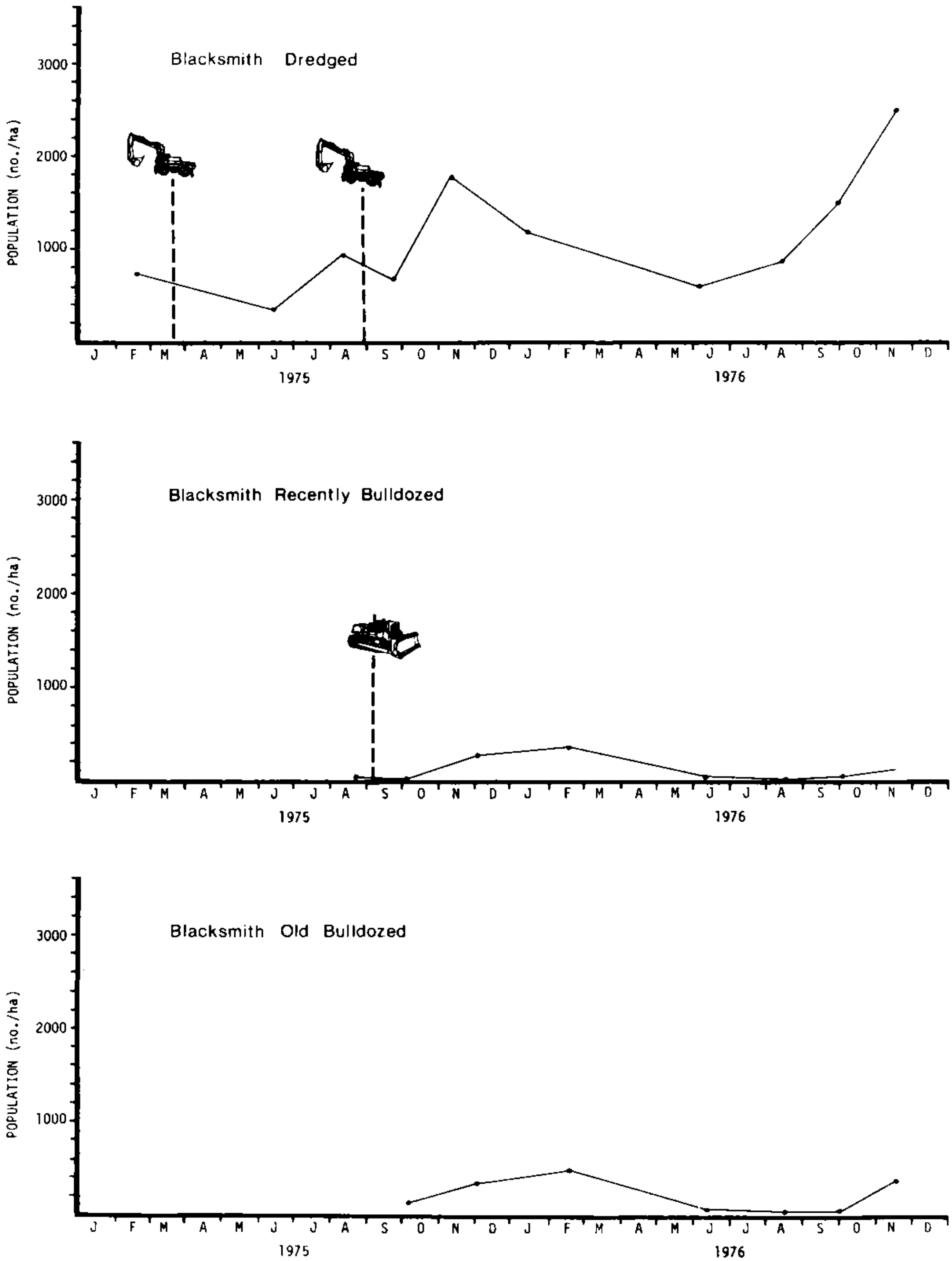


Figure 40. Population estimates of mountain whitefish in the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

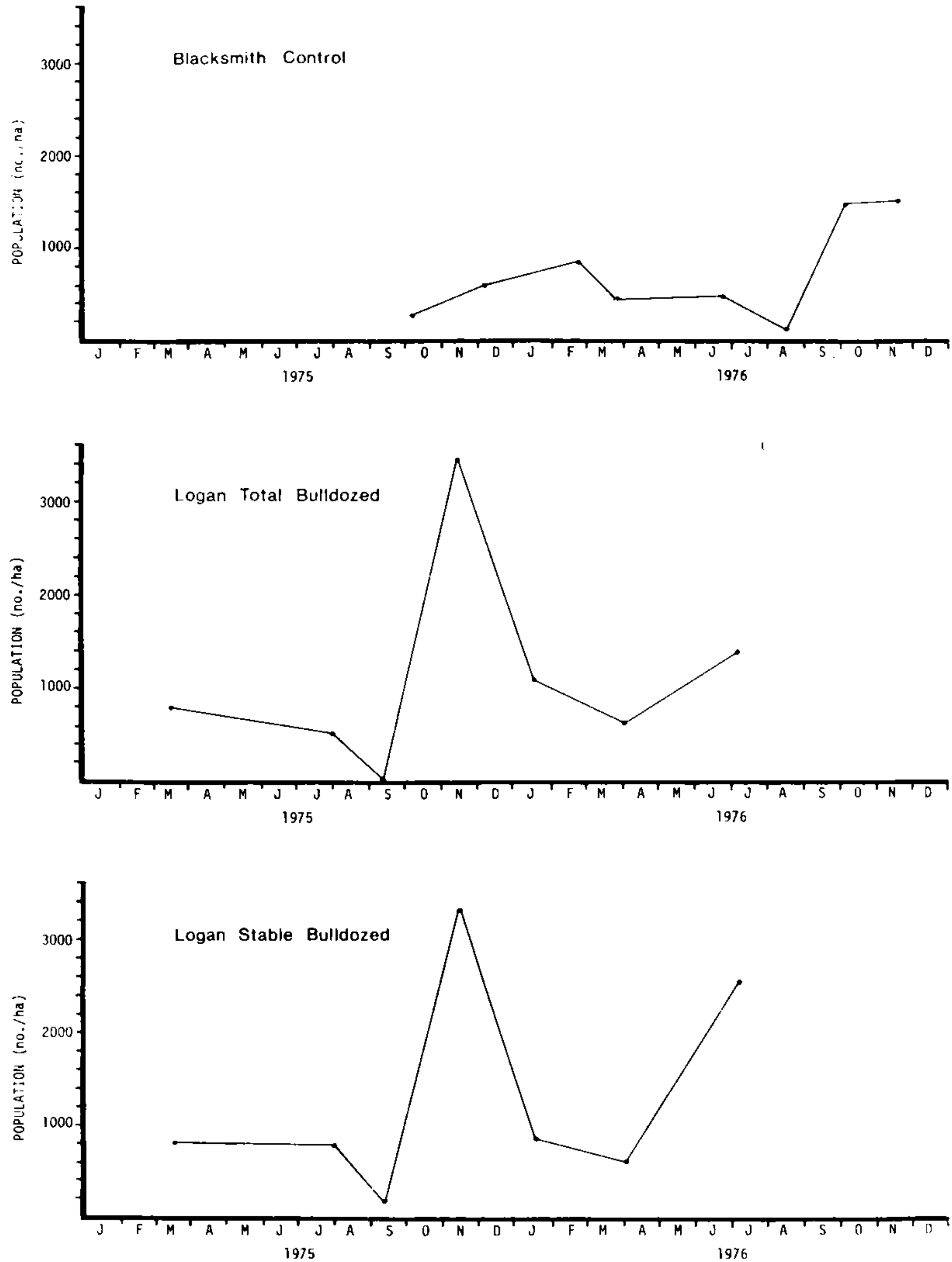


Figure 40. (Continued)

(1973) found the highest density of whitefish in the lower Logan River above 7-mile Creek during November 1971 in his study (June 1970-November 1971). He reported an annual average population size of 689 whitefish/1000 m above 7-mile Creek. Other researchers have reported densities of mountain whitefish up to 65,983 whitefish/1000 m (Binns 1972). The marked variation in numbers of whitefish by season, however, and different age structure between populations makes any comparisons with reported densities of total whitefish populations nebulous. Pettit and Wallace (1975), Davies and Thompson (1976), Peters and Alvord (1964), Stefanich (1951), and Erickson (1966) described changes in density and distribution of whitefish with season and/or area sampled although they did not estimate densities quantitatively.

The whitefish populations at all sites often had an inverted population structure with the older age groups numerically dominant. Poor availability of young-of-the-year to electrofishing gear was one reason for the inverted structure of the estimated population. Age 0 whitefish were not easily captured by electrofishing until mid-summer. Other investigators (Bergersen 1973, Brown 1952, Goodnight and Bjornn 1971) have reported similar sampling problems for young whitefish elsewhere. Another reason for the inverted structure was the mobility of whitefish within the Blacksmith Fork-Logan System. The population at any particular site was not closed. Although the whitefish population at a particular reach often did not exhibit the age structure expected for a closed, self-sustaining population, the actual population for the entire system may have had such an age composition. Brown (1952), Erickson (1966), Pettit and Wallace (1975), and Davies and Thompson (1976) have noted different spatial distribution and/or movement of stream dwelling whitefish by age or size group.

Population Differences Among Sites. The Logan stable bulldozed site exhibited the greatest variation in numbers of whitefish over the year. No whitefish were found there during the sampling on 10 September 1975. The succeeding population estimate (during spawning season) for that site was 3467 fish/ha. The number of whitefish/ha for the Logan stable bulldozed site was approximately the same as that in the Logan total bulldozed site during the fall and winter. During the summer months (low streamflows), however, the number of whitefish/ha was at least 1.5 times greater for the total bulldozed site. There was virtually total emigration of whitefish from the two bulldozed reaches on the Blacksmith Fork River also. No whitefish were captured during sampling in the Blacksmith recently bulldozed site on 21 August 1976 and the population estimate for 8 October 1976 was only three fish/ha. The density of whitefish in the Blacksmith bulldozed site on the above dates was 25 fish/ha. The old bulldozed site consistently had higher densities of whitefish than the recently bulldozed site. Densities of whitefish in the Blacksmith control and dredged sites were always higher than estimates for the two bulldozed reaches on the Blacksmith Fork River.

The low numbers of whitefish during the summer, especially for the bulldozed reaches may be attributed to the lack of cover (pools or deep runs). The differences in densities of whitefish between the Logan stable and bulldozed sites and between the Blacksmith recently and old bulldozed sites is a result of the same phenomenon. Sigler (1951) stated that upstream movement of whitefish apparently ceased where pools have less than a maximum width of 16 feet and a maximum depth of four feet at low streamflow. Goodnight and Bjornn (1971) stated that whitefish were usually abundant in deep, fast runs. During the irrigation season water depths in the bulldozed sites were usually less than about 0.6 m. The Blacksmith recently bulldozed site was severely dewatered during 4 July through 10 July 1976 when virtually the total streamflow was diverted for irrigation at a point about 50 m upstream from that site.

The summer distribution of whitefish which returned to the study sites in fall was ill-defined. Deep pools (refuge areas) occurred in the Logan River below its confluence with the Blacksmith Fork River. One large pool was located above an irrigation diversion in the Blacksmith Fork River between the dredged site and the confluence with the Logan River. Other possible refuge areas were located intermittently upstream and downstream from sites in both rivers.

The differences in population structure between the bulldozed reaches and other sites was also a probable consequence of the lack of suitable habitat, especially for very young fish and larger, older fish. Young-of-the-year whitefish were seldom found in substantial numbers in the bulldozed reaches. Although large numbers of eggs were spawned and incubated in these altered reaches, newly hatched fry probably drifted downstream to more suitable areas. As mentioned earlier, concentrations of young-of-the-year whitefish were observed in pools in the lower Logan River below the study sites in late summer of 1974. The largest populations of age 0 whitefish in the study sites occurred in the Blacksmith dredged and control sites. These reaches contained pools and backwater areas which were suitable habitat for fingerling whitefish (Brown 1952, Davies and Thompson 1976, Erickson 1966, Pettit and Wallace 1975). Ballard Springs in the Blacksmith dredged site may have also served as a nursery area for young-of-the-year whitefish. Erickson (1966) stated that young whitefish evidently used a small spring-fed creek as a nursery area in the Snake River drainage, Wyoming.

Larger, older whitefish also appeared to be absent in populations in the bulldozed reaches. Of the 10 fish sampled during this study which weighed over 1 kg, none were captured in the bulldozed reaches of either river. Deep pools may be even more critical to larger fish.

The immediate, short-term effects (if any) of channel alterations on numbers of mountain whitefish in the altered areas were not clear. The density of whitefish decreased in the Blacksmith dredged site following both periods of dredging. This reach was first dredged between the sampling periods of mid-winter and late spring, a season when the whitefish densities in most sites also decreased the following year (1976). Densities of whitefish in the Blacksmith control site increased slightly from mid-winter to late spring in 1976. During the period of the second dredging the numbers of age 0, age I and age IV+ whitefish in the dredged site decreased. Numbers of these age groups increased in both the Blacksmith control and dredged sites during the same season (mid-August to October) of the following year. Few whitefish were in the Blacksmith recently bulldozed site before and after the alteration there in late summer of 1975.

Peters and Alvord (1964) captured nearly 10 times as many whitefish in natural channels as in equal areas of altered channels in 13 Montana streams. Barton and Winger (1973), however, reported equal populations of whitefish in altered areas with stream improvement structures and recently unaltered areas of the Weber River, Utah but did not give details concerning sampling techniques or the estimator used. Lund (1976) reported the highest number of whitefish in reaches of the St. Regis River, Montana that had been altered. The highest density of whitefish in his study occurred in a channel that had been relocated in the January previous to the estimate in summer.

While whitefish may be displaced for a short time during and following the actual alteration, they appeared to quickly repopulate the altered area if suitable habitat remained or was created by the alteration.

Sources of Error in Estimating Populations. Point estimates of numbers of comparable age groups of whitefish were often quite different between sites and seasons. The wide confidence intervals for the estimates, however, from low sample numbers and high degree of confidence used (95%) resulted in few statistically significant differences. Unfortunately tables or graphs for calculating confidence intervals of less than 95 percent for the binomial distribution are not available.

It was obvious from the whitefish movement that the assumption of negligible recruitment to the catchable population between marking and recapture dates (Ricker 1975) was not always met. The modified estimator used in such instances was based upon movement rates of tagged fish and the estimated ratio of tagged fish to the total population throughout the study area. Although the study area was sampled extensively throughout 1975 and 1976, only rough approximations of the above parameters were available for any particular site or season. Consequently, the reliability of the population estimates, especially during periods of peak movement may be open to criticism. Other investigators have largely ignored the problem of possible bias from movement when estimating whitefish populations (Bergersen 1973, Goodnight 1971, Lund 1976, Matthews 1966). Ricker (1975) listed several methods to correct for recruitment during the time when recoveries are being made; most are concerned with recruitment due to growth. Although some bias may exist in estimated densities in this study, the adjusted estimates probably more closely approximated the actual densities than estimates made disregarding assumptions implicit in the estimator.

Movements of whitefish between 100 m sections made estimates of whitefish in the short unstable portion of the Logan total bulldozed site alone impractical. The population estimates for the Logan total and stable bulldozed sites were not statistically independent since many of the same marks and recaptures were used in both estimates. Comparisons between the estimates for the two sites must be viewed with caution. Estimates of whitefish densities (no fish/ha) were usually higher in the total bulldozed site than the stable bulldozed site. Such a difference in densities implies that the unstable portion of the total site had a substantially higher density of whitefish than the rest of the site. A higher estimate for the total site would also occur if the actual density of whitefish in the unstable part was the same as that in the stable part but there was proportionally more immigration by unmarked fish into the unstable part. Such a situation may have occurred during the summer since the unstable area provided the only refuge area (pool) in the Logan total bulldozed site during low streamflows. The difference in densities of whitefish during the summer may have been exaggerated by the above phenomenon. The relatively short interval, however, between mark and capture samples would have suppressed any bias due to differential immigration into the unstable part of the site.

The estimators used in this study also assumed no differential mortality or movement of marked and unmarked fish. Differential mortality and growth of fin-clipped fish have been observed for other salmonids (Nichola and Cordone 1973). The general downstream movement of small marked whitefish (Table 39) may have been an indication of stress from handling and marking. Bergersen (1973) suggested that his capture and tagging procedure had a limited traumatic effect on whitefish and resulted in a downstream movement. Although some bias in estimates during this study may have resulted from a similar effect, any bias should be similar among sites and should not appreciably affect comparisons.

Based upon observations in the study area after sampling, there were few instances of short term (within 10 days) delayed mortality from handling. Mortality during sampling averaged 3.4 percent. The long term effect of sampling and marking procedures on the growth and mortality of whitefish was assumed to be negligible for comparisons of estimates in the study sites.

Biomass and Production

General Trends. All biomass estimates were converted to standing crop (kg/ha) to facilitate comparisons between sites. The estimated standing crop of mountain whitefish in the study sites (Figure 41) followed a seasonal pattern similar to the populations, being highest during the spawning season and winter, then decreasing to a low point during the summer. Differences in standing crop between the period of summer low streamflows and spawning season were often more pronounced than the variation in numbers because the mature fish immigrating into sites were of the older, larger age groups. Differences in standing crop of whitefish among sites followed the pattern of density also.

Since the growth rates of fish were usually similar by site, season, and age group, the differences in the estimated production were the result of different mean biomasses during a production period. Headrick (1976) reported that the differences in annual production of brook trout in natural, recently altered, and old altered reaches were due to the different biomass of fish in the three areas. Although he reported that the annual production in the new altered reach was the lowest, the growth rates of the fish there were the highest for fish in the three study sites.

Production at most sites was high in late winter and early spring (Figure 42) when the estimated biomass of whitefish was high. In sites where some whitefish remained through the summer (Blacksmith dredged and control sites and Logan total bulldozed sites) production continued at a relatively steady rate through the summer. Although biomass estimates were high during the spawning season for all sites, negative production or relatively little

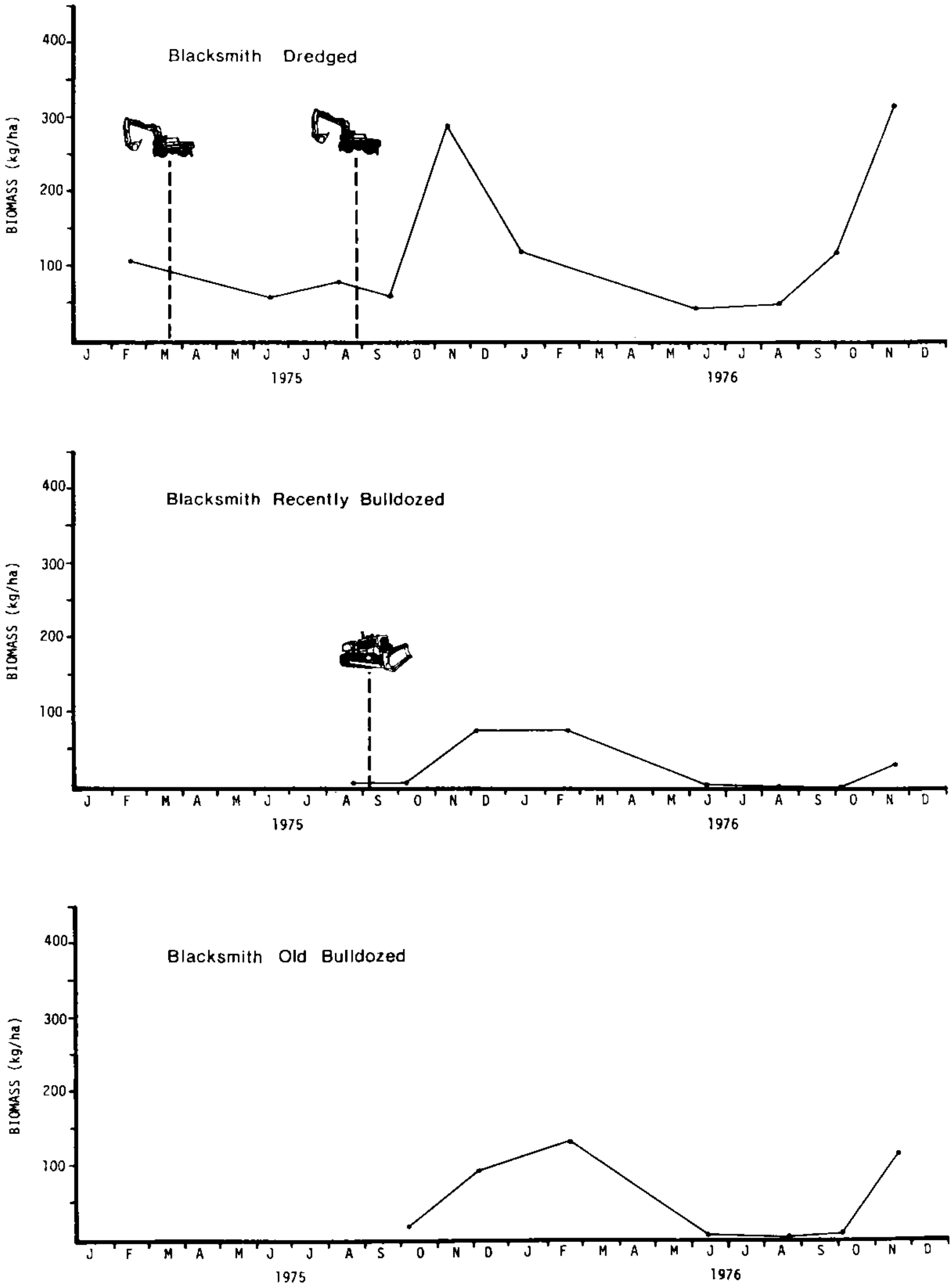


Figure 41. Total biomass (kg/ha) of mountain whitefish in the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

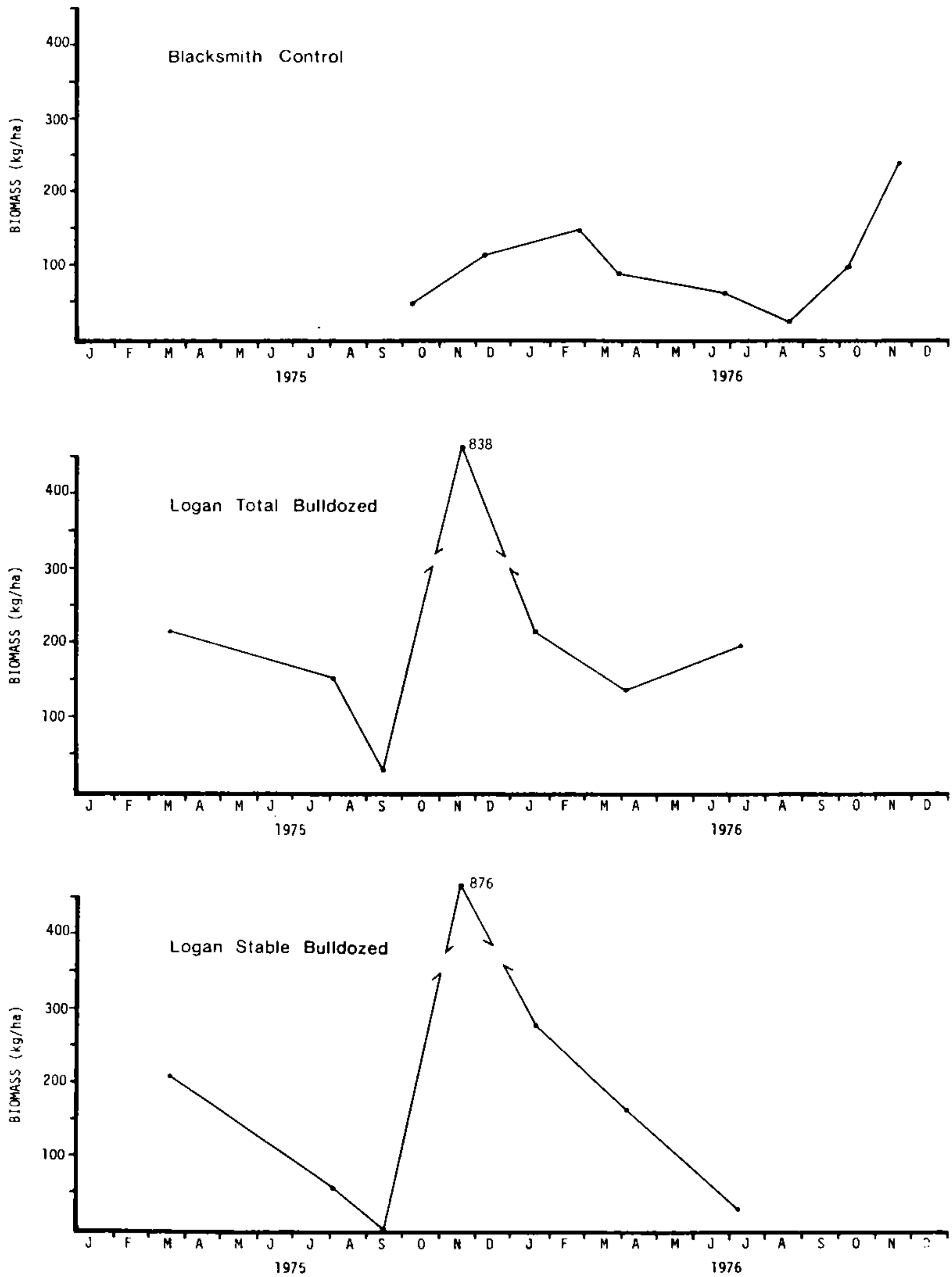


Figure 41. (Continued)

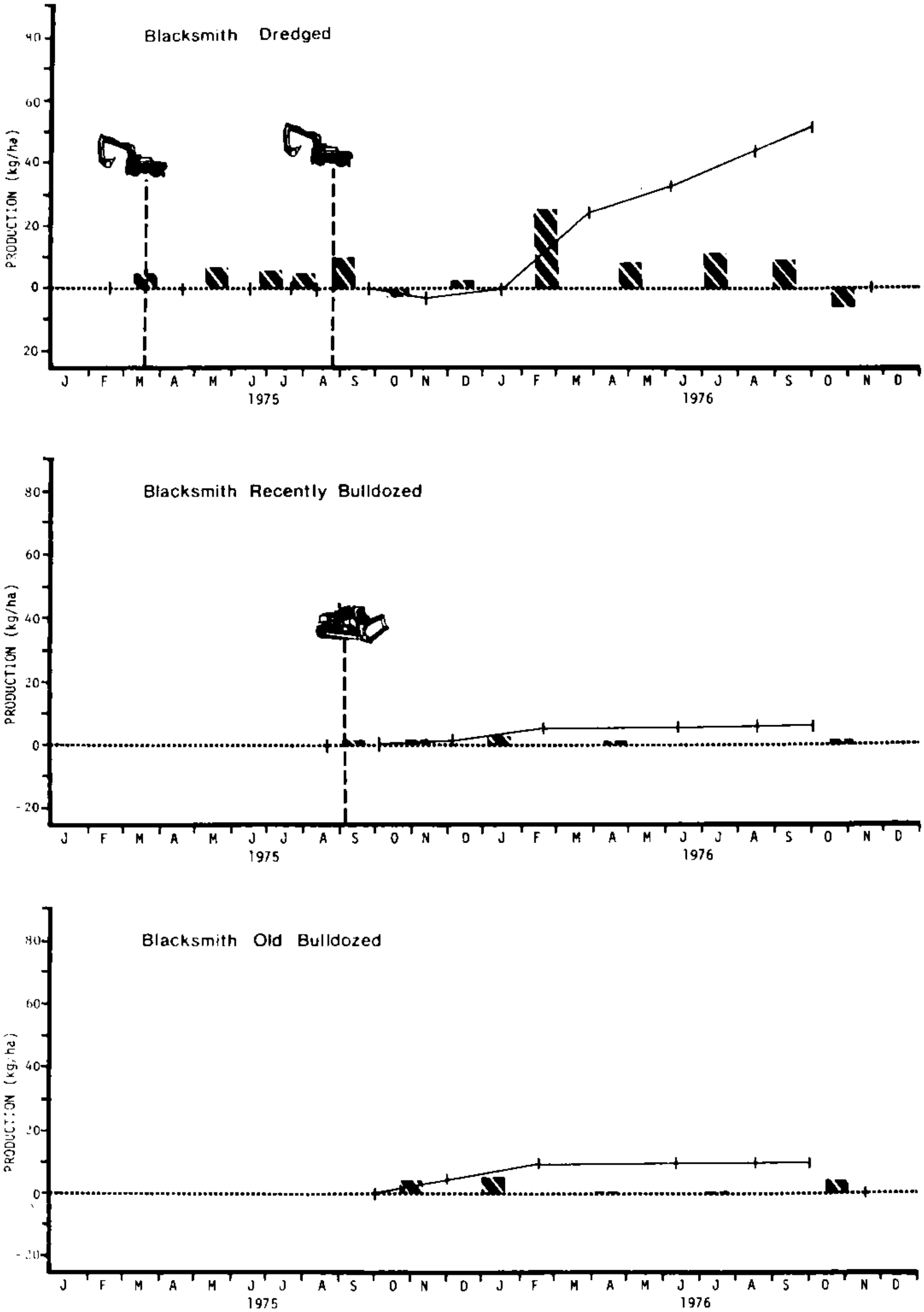


Figure 42. Production (kg/ha) of mountain whitefish in the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1976-75. Production is shown per time interval (bar graph) and as cumulative production for the period used in estimating annual production.

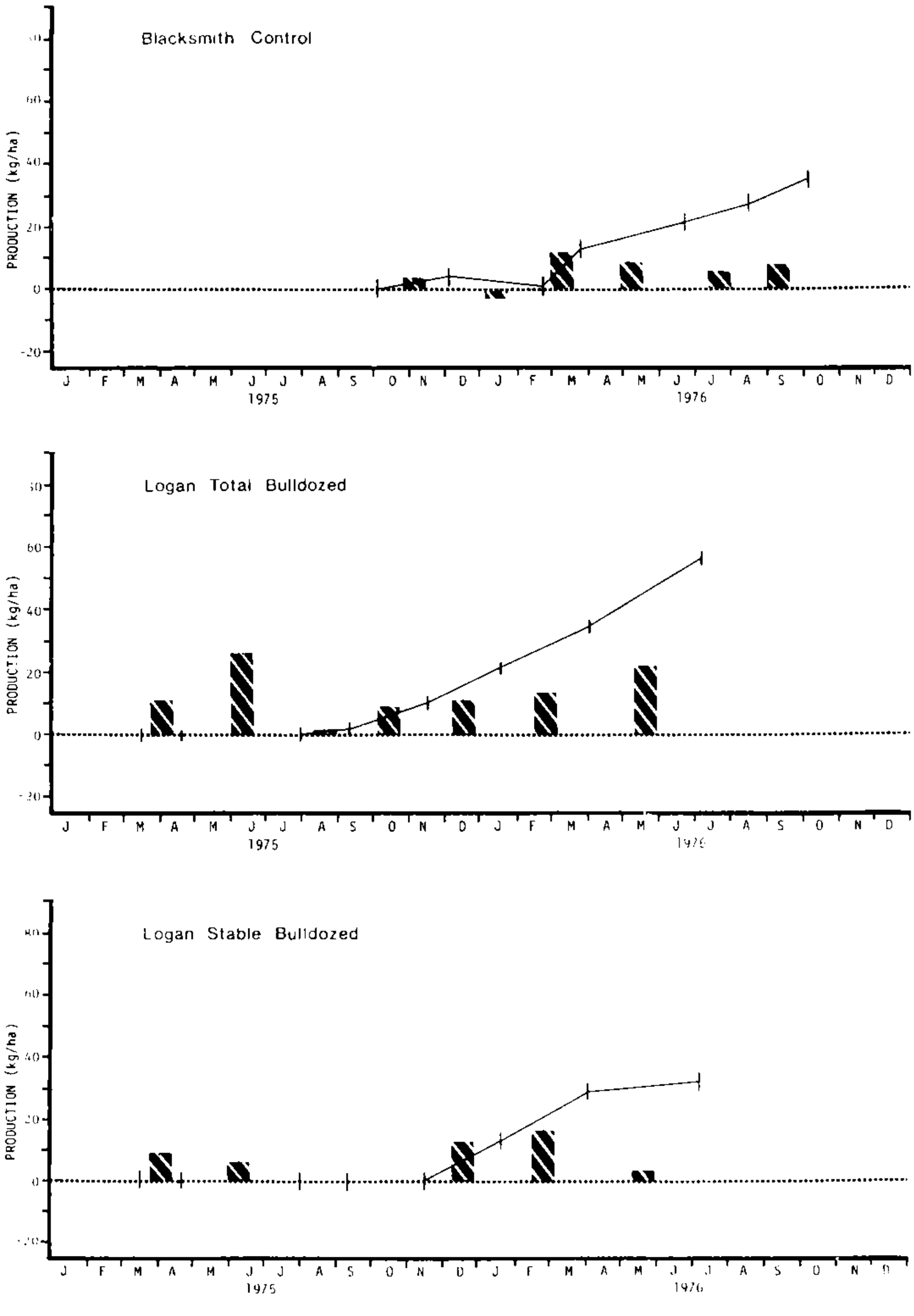


Figure 42. (Continued)

positive production during this period, resulted from an actual loss of somatic tissue and/or weight loss due to the release of sexual products. Bergersen (1973) reported production slightly above maintenance levels during the spawning season and winter for whitefish in the lower Logan River. The maximum production during his study occurred during spring. He observed net negative production during the summer months in 1970 and 1971. Goodnight and Bjornn (1971) estimated production of whitefish in the Lemhi River, Idaho from 1 June to 15 September 1969. They reported that most production occurred during the first half of their sampling period and suggested that fish produced little tissue from 1 November to 1 April. Similar seasonal patterns of production occur in other salmonids with the greatest amount of production during the spring and summer and less production during the winter (Chapman 1965, Egglishaw 1970, Gosse 1978, Hunt 1966).

The estimates of annual production of whitefish somatic tissue for the study sites in the Blacksmith Fork-Logan System ranged from 5.48 kg/ha/yr (0.548 $g/m^2/yr$) at the Blacksmith recently bulldozed site to 58.20 kg/ha/yr (5.820 $g/m^2/yr$) at the Logan total bulldozed site (Table 44). Only two other estimates of annual production of mountain whitefish have been reported. Bergersen (1973) estimated annual production of somatic tissue for whitefish in the lower Logan River at 3.0779 $g/m^2/yr$ and 1.5090 $g/m^2/yr$ for reaches above 7-mile Creek and below 7-mile Creek, respectively. Bergersen considered these values to be unusually low and believed his study area to be marginal whitefish habitat. Goodnight and Bjornn (1971) estimated production of somatic tissue for whitefish in the Lemhi River, Idaho from 1 June to 15 September 1969. They extrapolated from their production data to encompass the period 1 April to 1 November and considered that estimate (7.1 $gm/m^2/yr$) to approximate annual production. This figure may have differed considerably from the actual annual production of somatic tissue of whitefish depending upon the amount of production occurring in winter and early spring in the Lemhi River. Studies of other species of salmonids have reported annual production values from 0.5 $gm/m^2/yr$ for brook trout in the Lemhi River, Idaho (Goodnight and Bjornn 1971) to 54.7 $g/m^2/yr$ for brown trout in the Horokiwi Stream, New Zealand (Allen 1951). Chapman (1968) summarized production estimates for many species in various waters. Annual production of whitefish in the Logan and Blacksmith Fork Rivers was at the lower end of the range he reported for other stream-dwelling salmonids.

Ratios of production to initial or mean biomass have been calculated as an index of efficiency of growth (Chapman 1968, Hopkins 1971, Lowry 1966). The meaning of such an index, however, is nebulous for populations that exhibit pronounced seasonal fluctuations in biomass as a result of immigration and emigration.

Differences in Production Among Sites. Annual production in the two bulldozed reaches on the Blacksmith Fork River was less than one-third of that in the other two sites (dredged and control) on that river. The biomass of whitefish in the two bulldozed reaches on the Blacksmith Fork River was unusually low, especially during the summer months. The total whitefish biomass in the Blacksmith recently bulldozed site was estimated at less than 1 kg/ha from 14 June through 3 October 1976. The lowest biomass (0.17 kg/ha) for the Blacksmith old bulldozed site occurred on 20 August 1976 when young-of-the-year whitefish accounted for all of the biomass. There was virtually no production at these two sites during the summer and very little contributed by fish less than two years old at any time. Poor production in these two sites was the result of poor habitat and low whitefish populations associated with low streamflows and lack of pools. As mentioned earlier, the Blacksmith recently bulldozed site was the most severely dewatered of any site during the 1976 irrigation season.

Differences in production between the Blacksmith dredged and control sites were due to the higher production (more than 2 times) of age 0 and age I fish in the dredged site. Annual production of fish two years old and older was approximately the same in both sites. Ballard Springs was probably an important nursery and refuge area for whitefish in the Blacksmith dredged site and was one reason for the higher production there.

The estimates of annual production of mountain whitefish in the bulldozed reach of the Logan River were relatively high in comparison to those for the Blacksmith Fork River sites. As in the Blacksmith Fork River, the available habitat and age structure of the whitefish population influenced production there. The estimated production for the Logan total bulldozed site was 14.4 kg/ha and 3.1 kg/ha higher than the Logan stable bulldozed site during the summers of 1975 and 1976, respectively. The importance of a summer refuge area (pool) was evident from the influence of the unstable part of the total bulldozed site on production there during the summer. Channel widening with the associated decrease in pool numbers adversely affected whitefish production during periods of low streamflows. The resulting loss in production was a function of the decrease in the biomass of whitefish in such areas.

Sources of Error in Estimating Production. Annual production was probably underestimated in sites where numbers and biomass of a year class were estimated to be 0 at some time during the production year. In such instances, production for the interval beginning or ending with the 0 population and biomass could not be estimated because there were no data to determine the mean biomass $\bar{B}$ or the growth rate G for the period. It was assumed that production (negative or positive) during such intervals was negligible. The validity of this assumption was dependent on the rate of immigration of the formerly absent year class or the rate of emigration/ mortality of year classes that decreased to a 0 biomass during the production interval.

Annual production for young-of-the-year whitefish was also underestimated for sites where they were found. The production of this age group was not estimated before they were recruited to electrofishing gear. Production of young-of-the-year during the first several months after emergence has been shown to contribute substantially to total production for other salmonids (Egglishaw 1970, Hopkins 1970, Allen 1951, Chapman 1965). Bergersen (1973), using a single population estimate and data on catch per effort estimated production for age 0 whitefish in the lower Logan River. In his study, the 1970 year class (age 0 in 1970 and age I in 1971) produced 1.1315 gm/m^2 and 0.9961 gm/^{2} (32 and 66 % of the total somatic tissue production) during the period June 1970-May 1971 in two reaches of the lower Logan River. Age 0 whitefish in the Lemhi River, Idaho accounted for 7.8 percent of the estimated total annual whitefish production there (Goodnight and Bjornn 1971).

In this study, estimates for sites with the greatest number of young-of-the-year present prior to full recruitment (probably the Blacksmith dredged and control sites) would be most affected by bias described above.

Chapman (1968) and Toetz (1967) have discussed the importance of accounting for gonadal products in production studies. Bergersen (1973) estimated whitefish gonadal at 0.8007 and 0.1507 $g/m^2/yr$ in two areas of the Logan River. Goodnight and Bjornn (1971) did not estimate gonadal production in their study. In this study, large numbers of whitefish apparently spawned at all study sites. The decrease in the mean weight of mature age groups of whitefish due to the loss of sexual products resulted in an underestimate of the actual production during the spawning season. Data were collected on fecundity of whitefish. However, no adjustments were made for the negative bias introduced by the above phenomenon because accurate estimates of the sex ratios and the actual numbers of fish spawning at a given site were not available. Consequently, the annual production of whitefish at the study sites was underestimated to some degree. It was assumed that this negative bias did not appreciably effect comparisons between sites.

Table 44. Annual production of mountain whitefish at six study sites in the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

	Study Sites					
	LTB	LSB	BD	BC	BRB	BOB
Production (kg/ha/yr)	58.2	31.9	51.2	35.8	5.5	10.8

MACROINVERTEBRATES

The effects of stream perturbations are often described by the resultant changes in the benthic macroinvertebrate community. The benthic community is a good indicator of the severity of perturbations as its members are 1) very sensitive, 2) necessary for the survival of higher organisms, and 3) exposed to environmental changes throughout long periods and during critical intervals of their life cycle. Such communities have been analyzed from the standpoints of species frequency, species per unit area, spatial distribution of individuals and numerical abundance of species (Hairston 1959).

Community Structure

The benthic macroinvertebrate communities (Appendix E) at all four study sites had six dominant families in common: Chloroperlids, Heptageniids, Ephemerellids, Baetids, Leptophlebiids, and Chironomids. Perlodids were a dominant family at all but the recently bulldozed site. Three families were prominant at two sites: Hydropsychids (control and recently dredged); Elmids (control and recently dredged); and Simuliids (recently dredged and recently bulldozed). Only two families were of major consequence at only one site: Brachycentrids (control) and Lepidostomatids (old bulldozed). Dominant families were most similar at the recently dredged and control sites, and most dissimilar at the recently bulldozed and control sites.

Families of Macroinvertebrates

The total number of different families found (Figure 43) was highest at the recently dredged site (39) and the old bulldozed site (38) and was lower at the control site (35) and the recently dredged site (33). However, the mean number of different families found was highest for the control site (30; 86% of the total), next being the old bulldozed site (29; 76% of the total), then the recently dredged (26; 67% of the total), and lowest, the recently bulldozed (24; 73% of the total). Significant differences in number of taxa were:

mean: recently dredged < control
mean: recently bulldozed < control and old bulldozed
Fall, 1975: recently dredged < control and old bulldozed
recently bulldozed < control and old bulldozed
Winter, 1975: recently bulldozed < old bulldozed

There were no significant seasonal differences within any of the sites.

Diversity Indices

Recently diversity indices based on information theory, such as that of Shannon, have been accepted by many biologists as being among the most sensitive indicators of ecological change (Hooper 1969; Warren 1971). Wilhm (1968a) has categorized $\bar{d}$ values of greater than 3 as indicative of "clean" waters and values less than 1 as indicative of "polluted" waters.

The control site had the highest mean diversity index value, 3.27, and the lowest seasonal variation. The mean diversity at the recently bulldozed site was 2.87, at the recently dredged site, 2.82, and at the old bulldozed site 2.37 (Figure 44). Diversity rose at all but the old bulldozed site following spring run-off. At both recently altered sites diversity increased following the disturbance then decreased until slightly prior to run-off. Significant differences in diversity were:

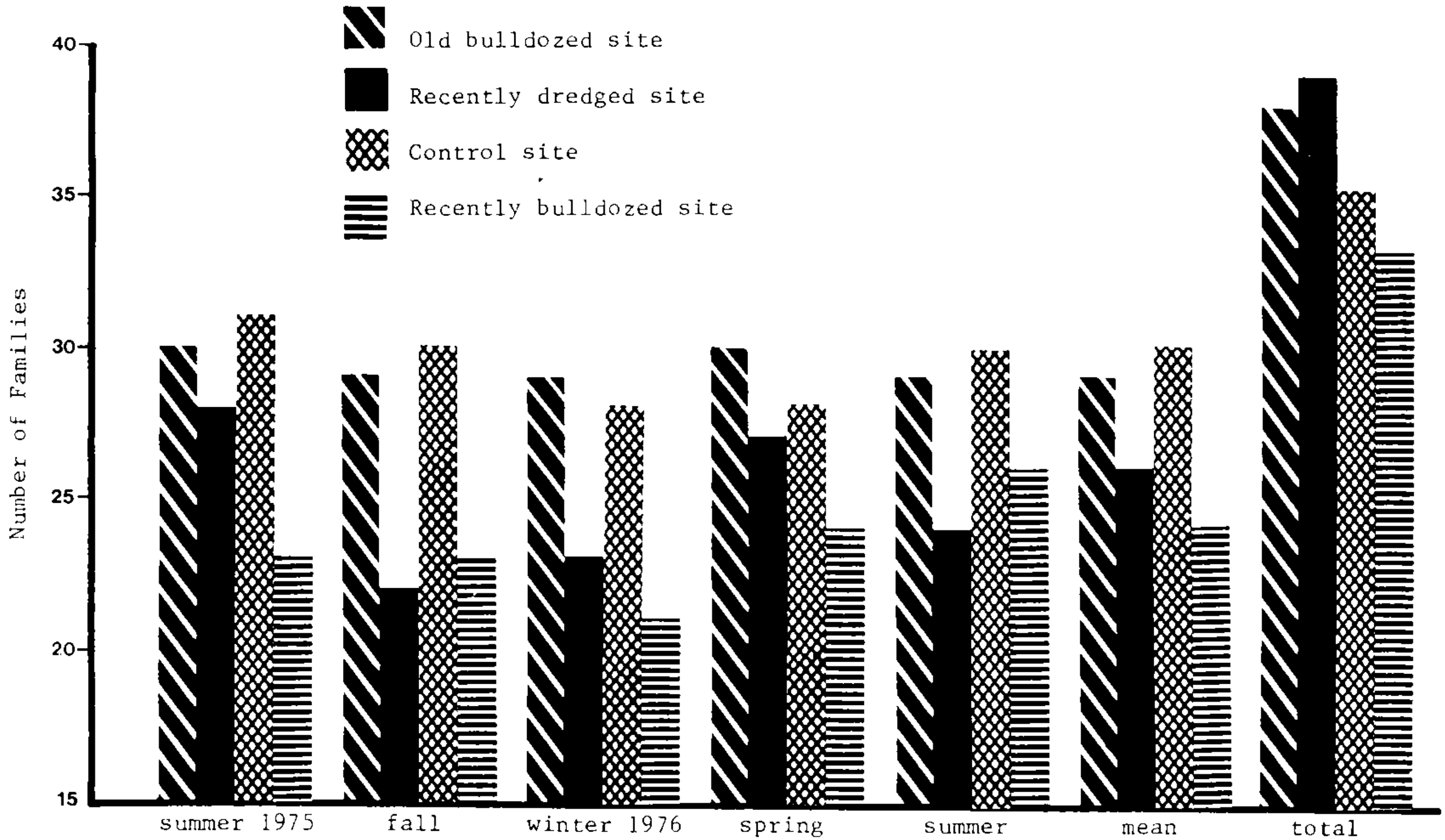
mean: old bulldozed < control
Summer 1975: old bulldozed < all other sites
Summer 1976: old bulldozed < control
Winter 1976: recently bulldozed < old bulldozed and control
Winter 1976: recently dredged < control

Significant seasonal differences within sites were:

old bulldozed - Summer 1975 < Spring 1976
recently bulldozed - Winter 1976 < Summer 1976

The sensitivity of this index is seen in the results for the old bulldozed

Figure 43. Mean number and total of macroinvertebrate families in the study sites of the Blacksmith Fork and Logan Rivers during different seasons, 1975-1976.



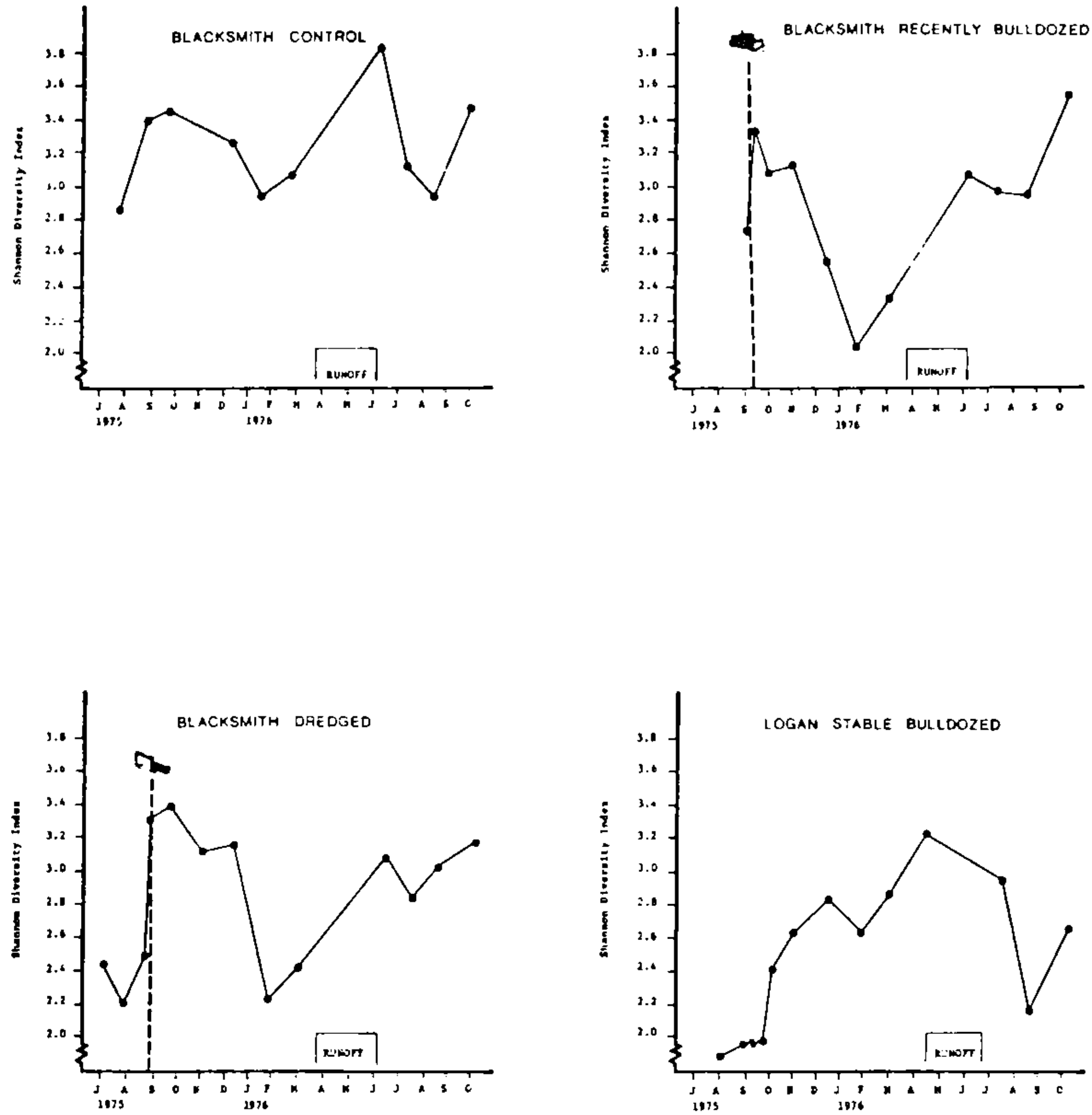


Figure 44. Changes in the Shannon diversity indices for macroinvertebrates over time at the study sites on the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

site, where high number of taxa and high densities produced a low diversity index value. This reflected the distribution being concentrated in a very few taxa. Reductions in diversity at the recently altered sites occurred after a time lag (Figure 44). This is typical for colonization by large numbers of rapidly reproducing and mobile taxa, such as Baetids, Chironomids, and Simuliids (Waters 1964, Uresk 1967), which subsequently reduce the density when the rest of the community becomes established (Allan 1975).

Size Separation

The use of sieves to separate invertebrates into size categories was highly successful. The only technical problem encountered was that when organic detritus was present in large amounts, small invertebrates sometimes became entangled in the detritus and were trapped in the largest sieve. In this study this was relatively infrequent and was rectified by reassigning these invertebrates to the appropriate sieve based on the length determinations made for each family by sieve size (Appendix E). Excluding the samples mentioned previously, sieve size versus ash-free dry weight were highly correlated (Appendix F). Differences in the slopes of these regressions are attributed to the differences in body shape of the various taxa, particularly of maximum diameter sclerotized parts, such as head capsules of dipterans (Jonasson 1955) or thoracic segments of hydropsychids (Barber and Kevern 1974). Similarly some of the taxa with lower correlation coefficients are those that exhibit greater changes in body shape with growth. The very high correlation (.9988) for combined taxa strongly supports the use of the sieve size versus ash-free dry weight regression, rather than total lengths, for standing crop and Hynes production estimates. This method of size classification is also extremely rapid in comparison to the morphometric measurements previously utilized, especially as it allows sub-sampling of each size category prior to enumeration.

Density

The mean density of macroinvertebrates (number of individuals/m^2) was highest at the old bulldozed site, followed by the recently dredged, recently bulldozed and control sites, in that order (Figure 45). Channel alterations drastically reduced macroinvertebrate densities (Figure 46), especially at the recently dredged site, which went from the highest to the lowest densities recorded during the course of the study. Significant differences were:

Fall 1975: recently dredged < old bulldozed
Winter 1976: recently dredged < all other sites

The only significant seasonal difference within a site was at the control site; Spring 1976, Summers 1975 and 1976 < Winter 1976.

Standing Crops

The mean standing crop (grams ash-free dry weight/m^2) was also highest at the old bulldozed site, however, the second highest standing crop was that of the control site, followed by the recently bulldozed, then recently dredged sites (Figure 47). The seasonal pattern and response to alterations nearly

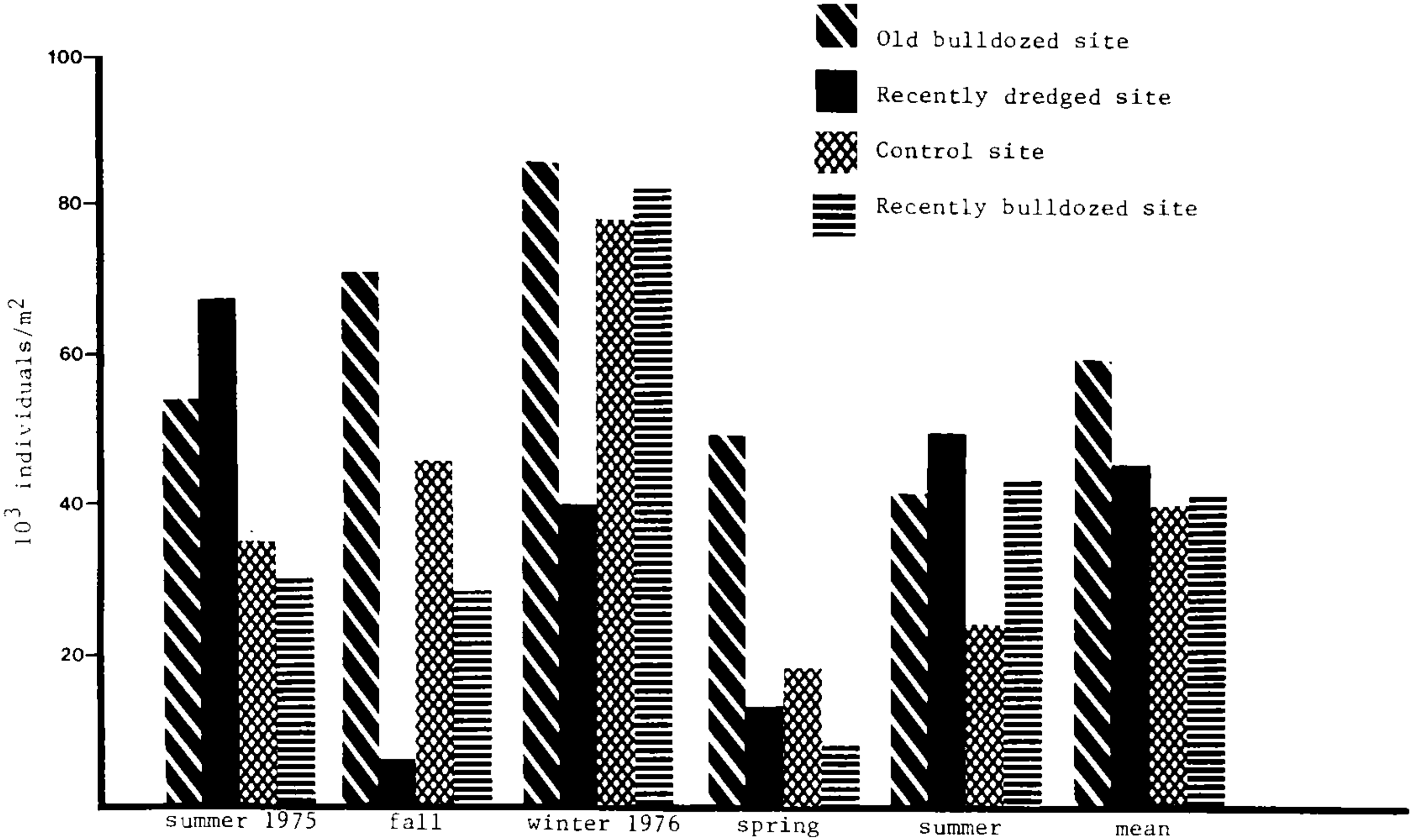


Figure 45. Densities of macroinvertebrates in the study sites of the Blacksmith Fork and Logan Rivers, Cache County, Utah during different seasons, 1975-1976.

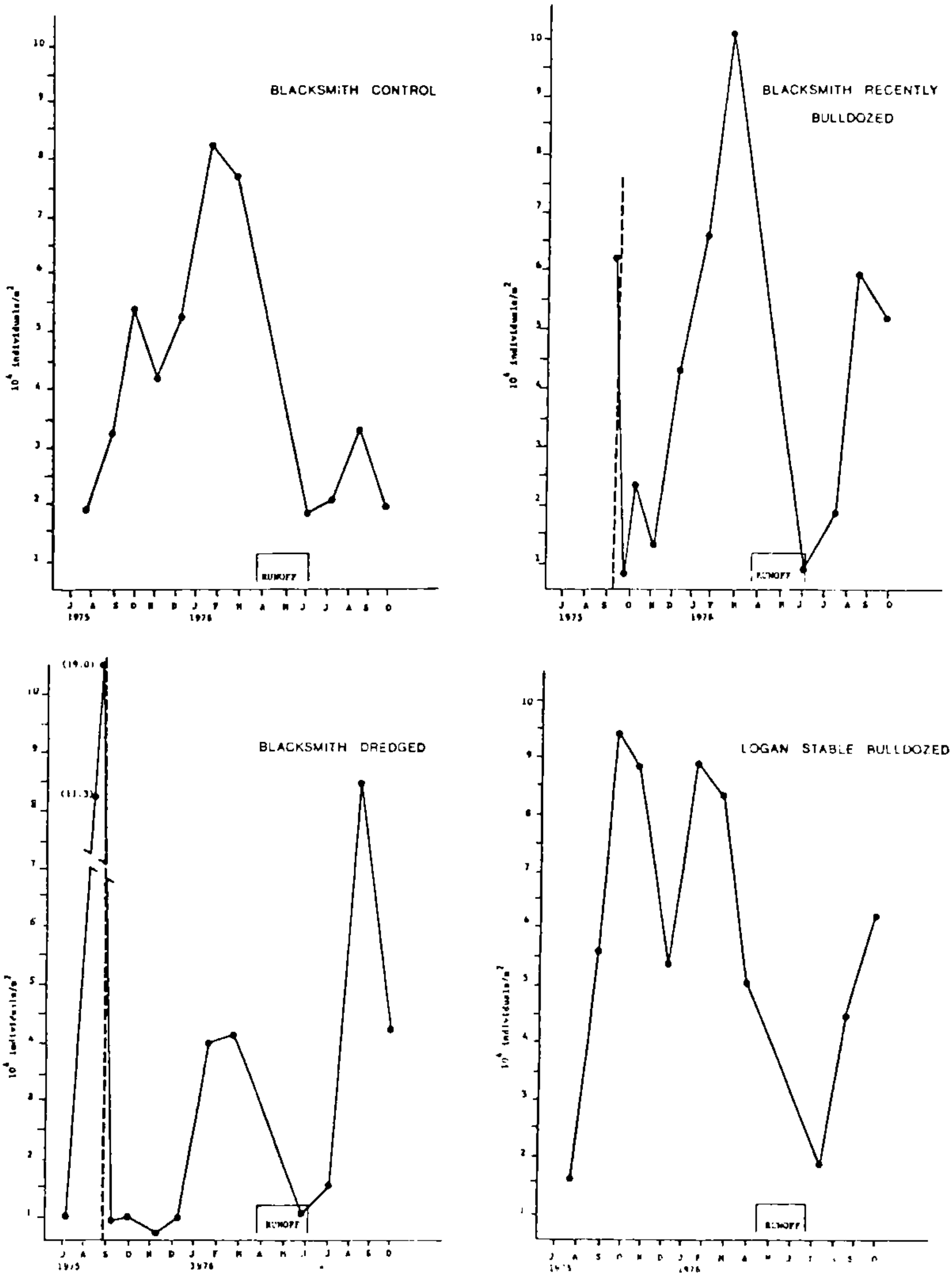


Figure 46. Changes in the density of macroinvertebrates over time at the study sites on the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

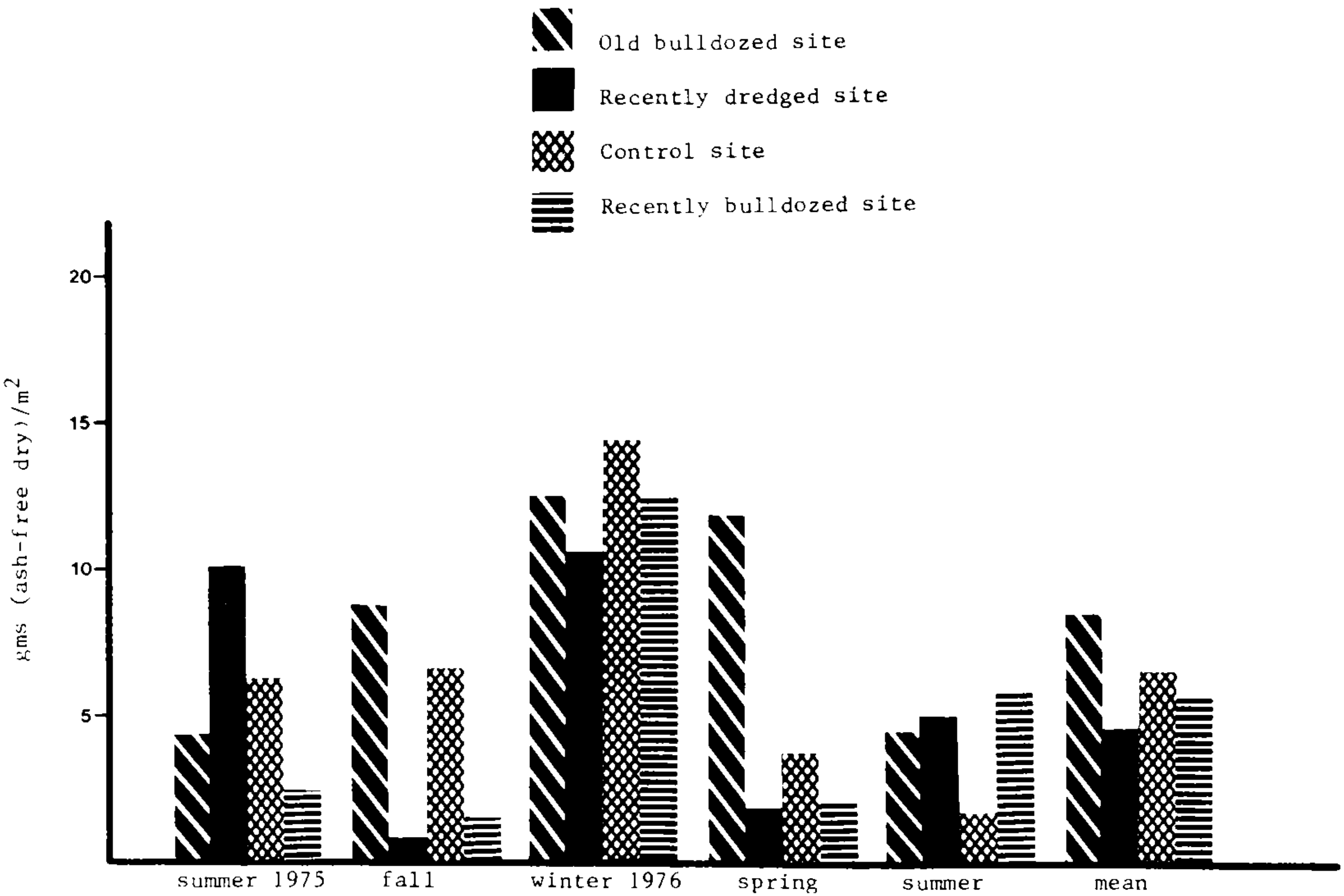


Figure 47. Standing crops of macroinvertebrates in the study sites of the Blacksmith Fork and Logan Rivers, Cache County, Utah during different seasons, 1975-1976.

paralleled, but were more marked than those of density (Figure 48). Both exhibited a similar bimodal seasonal pattern at all of the study sites. Populations peaked in early winter, were lowest following runoff, had a small peak in late summer, then dropped again by late fall. Significant differences were:

Fall 1975: recently dredged < old bulldozed and control
Fall 1975: recently bulldozed < old bulldozed and control

Significant seasonal differences within sites were:

old bulldozed: Summer 1975 < Winter 1976
control: all other seasons < Winter 1976
control: Spring, Summer 1976 < Summer and Fall 1975

Annual Production

The old bulldozed site had the highest annual production, 55.8 grams ash-free dry weight/m^2/yr (turnover ratio 6.75), followed by the control site, 39.6 (6.27), and the two recently altered sites were the lowest - recently bulldozed 32.4 (5.95), recently dredged 28.8 (6.34).

The range of turnover ratios (5.95-6.75) was higher than considered normal (3.5-5.0), but below the potential maximum (7-8) reported by Waters (1969b).

The potential difficulties with the Hynes method of estimating total community production have been largely corrected by Hamilton (1969). Other criticisms by Fager (1969), and Zwick (1975) have been largely dispelled by Benke and Waide (1977). The major problems are:

(1) All taxa are not capable of reaching the same maximum size. This can be resolved by calculating production for each group capable of reaching a given maximum size and summing.

(2) Many small animals were missed in sampling - either by mechanical errors during analysis, or, more likely, by growth through more than one size class between sampling dates. While changes in the sampling schedule can solve this problem for individual taxa, to alleviate it for the entire community would require inordinately frequent sampling (Waters 1969a, Cummins 1975, McClure and Stewart 1976). Waters and Crawford (1973) found this problem to result in an underestimate of production by 10-20 percent.

(3) All taxa were assumed to have one cohort per year, which is known to be untrue in several cases: Pteronarcids (2 year cycle); Perlids (2 years ?); Baetids (2 years); Chironomids (2 or more); Simuliids (2?) per year. The major error to be encountered is in the multivoltine taxas contribution to community production being underestimated by roughly the number of annual life cycles. This is true for all sites, but especially for both the old and recently bulldozed sites, due to their relative preponderance of such taxa. This can largely be resolved, when desired, by calculating the production of these groups separately and summing.

The advantage is that this method can be used on populations in which

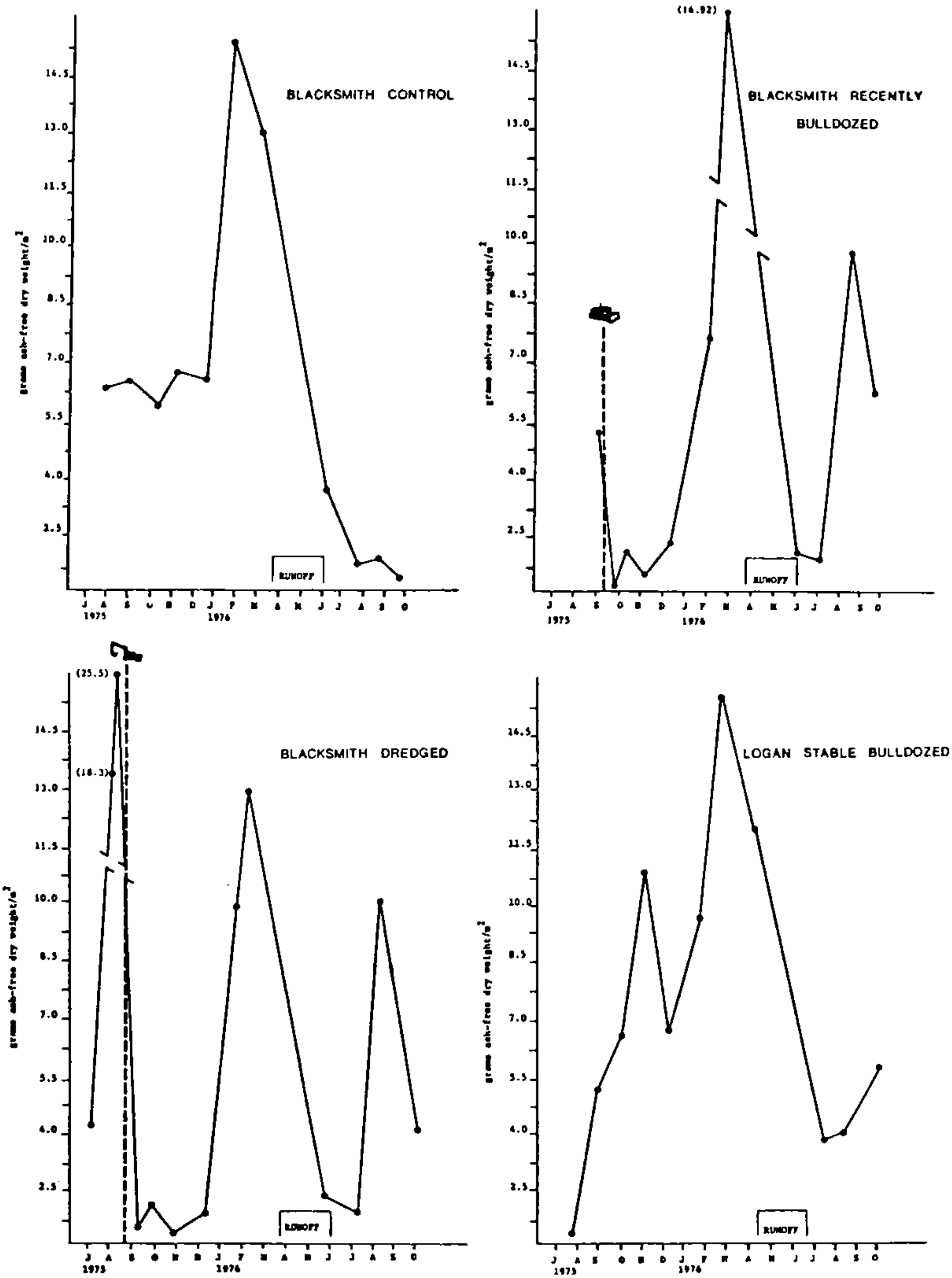


Figure 48. Changes in the standing crop of macroinvertebrates over time at the study sites on the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

cohorts cannot be distinguished, and on the entire community (if the refinements suggested in problems 1 and 3 are not followed). Hamilton (1969), Waters and Crawford (1973), and Benke and Waide (1977) appear to have validated the use of an average cohort for monospecific populations, but no data for entire populations is available other than that of Fisher and Likens (1973). Unfortunately, they did not sample for an entire year or sample smaller size classes. Their production estimate (4.78 gms dry wt/m^2/yr) is thus understandably lower than those found in this study.

Responses of Macroinvertebrates to Perturbation

Total number of organisms is a relatively crude method of presentation that is simply a summation of many overlapping waxing and waning populations representing many different life cycles (Pennack and Van Gerpen 1947). The fact that mean density showed no significant differences between sites is thus not surprising, as it reflects the heterogeneity of the stream habitat and its resultant sampling variability (Needham and Usinger 1956, Hynes 1970) as well as seasonal variation (Pearson and Kramer 1972, Good 1974). Standing crops showed no significant differences between seasons in the recently altered sites, yet did in the other two sites. This and the significant differences between sites only in Fall 1975 and Winter 1976 indicate the relatively short-lived effect of alterations. It also appears that these data (Figures 47 and 48, Table 45) indicate that dredging had a longer lasting effect on the macroinvertebrate community than did bulldozing. This is attributed to the stability of the substrate subsequent to alteration (Table 9).

The duration of the impact by the perturbation of the benthic community is largely dependent on the return of substrate stability. Many other studies of both man-caused and natural perturbations (Larimore et al. 1959, Kennedy 1935, Moffet 1936, Gaufin 1959, Winger 1972, Meehan 1971, Lund 1976, Dodge et al. 1976, Duvel et al. 1976) have shown that 3 to 6 months are needed for substrate to stabilize, and that a "normal" benthic community is re-established within this period. Erman (1968) indicated a shorter time was necessary for recovery further downstream in the Logan River. If the substrate in her study was similar to that in the old bulldozed site, it represents a very stable area. This compares well with the results found in this study - the Logan was less affected by spring runoff, the recently altered sites "recovered" in 4 to 5 months, and the dredged site, with its less stable substrate after alteration, took longer than the recently bulldozed site to recover (Table 45).

Differences in flow pattern between the two years and between the two streams affected the benthic community substantially. The low water of 1976 reduced summer standing crops from 1975 levels. The slightly later runoff in the Logan River is largely responsible for its relatively higher spring diversity and standing crop than the Blacksmith. The more stable substrate in the Logan probably enhances this effect (Dunstan 1951, Hynes 1970). Erman (1968) noted a bimodal pattern in density further downstream on the Logan similar to those found in this study. She attributed this to the physical action of scouring by the higher flows of spring and fall (Figure 4). The densities and low standing crop at these times, and concommitant rise in diversity correspond to times of emergence and oviposition of most of the dominant taxa. Thus

Table 45. Responses of macroinvertebrates to two channel alterations in the Blacksmith Fork River, Cache County, Utah, 1975-76.

	Recently dredged		
	Before	After	1 year after
Number of families	33	24*	24*
10^3 Ind/m^2	152^3	8^1	50^2
gm afd/m^2	21.9^3	0.8^1	4.9^2
$\bar{d}$	2.33	3.26	2.98

	Recently bulldozed		
	Before	After	1 year after
Number of families	24	22	26
10^3 Ind/m^2	62	15*	56
gm afd/m^2	5.2	1.1	7.9
$\bar{d}$	2.75	3.21	3.22

*significantly < prior to alteration

1 significantly < 2

2 significantly < 3

it seems likely that the benthic community has evolved to avoid this physical disruption of habitat that occurs with reasonable predictability (Slobodkin and Sanders 1969, Good 1974, Cloud and Stewart 1974, Pearson and Kramer 1972, Egglishaw 1964).

This interpretation is further strengthened by the observation that the fall peak in standing crop was later at the old bulldozed site on the Logan River than for the Blacksmith Fork sites. As the maturation of many organisms, especially multivoltine species, is regulated by cumulative degree days Israelson et al. 1975, Cummins 1975) the later emergence, because of lower water temperatures in the Logan River (Figure 6), provide additional support to this interpretation.

Other influences are also important, particularly irrigation practices (Little 1973). Irrigation diversions in the recently bulldozed site reduced the downstream flow to essentially zero during the summer of 1976. This reduced the standing crop in both downstream (control and recently dredged) sites to lower levels than occurred during the summer of 1975 (Figure 48). The combined effect of low flows and dredging was more serious than bulldozing alone. Another uncontrolled variable effecting these two sites was the introduction of some toxic substance above the control site in summer 1975, probably via irrigation returns, which caused a fish kill and presumably affected the invertebrates as well.

All these perturbations had the same type of effect: lowered density and standing crop, slightly higher diversity, and reduced production. The main reason for this is the non-selective action of these perturbations, resulting in the remaining community having a few individuals of most of the families present before the perturbation. Following the perturbation, the smaller, more motile taxa quickly recolonize (Uresk 1967, Waters 1964, Allan 1975), thus density increases faster than standing crop. As diversity was calculated using numbers of individuals, it decreased belatedly. It is also possible that low stream flows and high temperatures favored smaller organisms with a larger surface to volume ratio.

Despite the stable substrate in the old bulldozed site on the Logan River, which resulted in high densities, standing crops, and production, there was a low diversity, even with the large number of taxa found at this site. This is directly attributable to the relative uniformity of the substrate and subsequent loss of habitat variability (Zimmer and Backman 1976, Little 1973, Dunstan 1951, Slobodkin and Sanders 1969, Allan 1975, Cole 1973).

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

Stream channels in the semi-arid intermountain west have been modified for many years by agricultural interests, primarily to provide flood protection. Little information has been available on the long-term physical and biological consequences of channel modification in this geographic region. Of special concern is the relationship between stream channel modification and the high value fishery resource. This report describes an investigation of the effects of stream channelization on fish and macroinvertebrates in low gradient reaches of Blacksmith Fork River and the Logan River in the floodplain of Cache Valley in northern Utah. Channelization adversely affected both fish and macroinvertebrate populations and biomass, with the severity of impact directly related to the amount and duration of disturbance of the physical habitat.

17. Document Analysis a. Descriptors

Fisheries, Stream Improvement, Streambeds, Dredging, Freshwater Fish, Fish Populations, Aquatic Environment, Fish Food Organisms, Invertebrates, Channel Morphology

b. Identifiers/Open-Ended Terms

Channelization, Brown trout, Mountain Whitefish, Logan River, Blacksmith Fork River, Cache Valley, Utah, Trout

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EFFECTS OF ALTERATIONS TO LOW GRADIENT REACHES OF UTAH STREAMS:

APPENDIX

by

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APPENDIX
(Microfiche)

APPENDIX A

WATER TEMPERATURE FLUCTUATIONS AND WATER CHEMISTRY OF THE BLACKSMITH FORK AND LOGAN RIVERS, CACHE COUNTY, UTAH

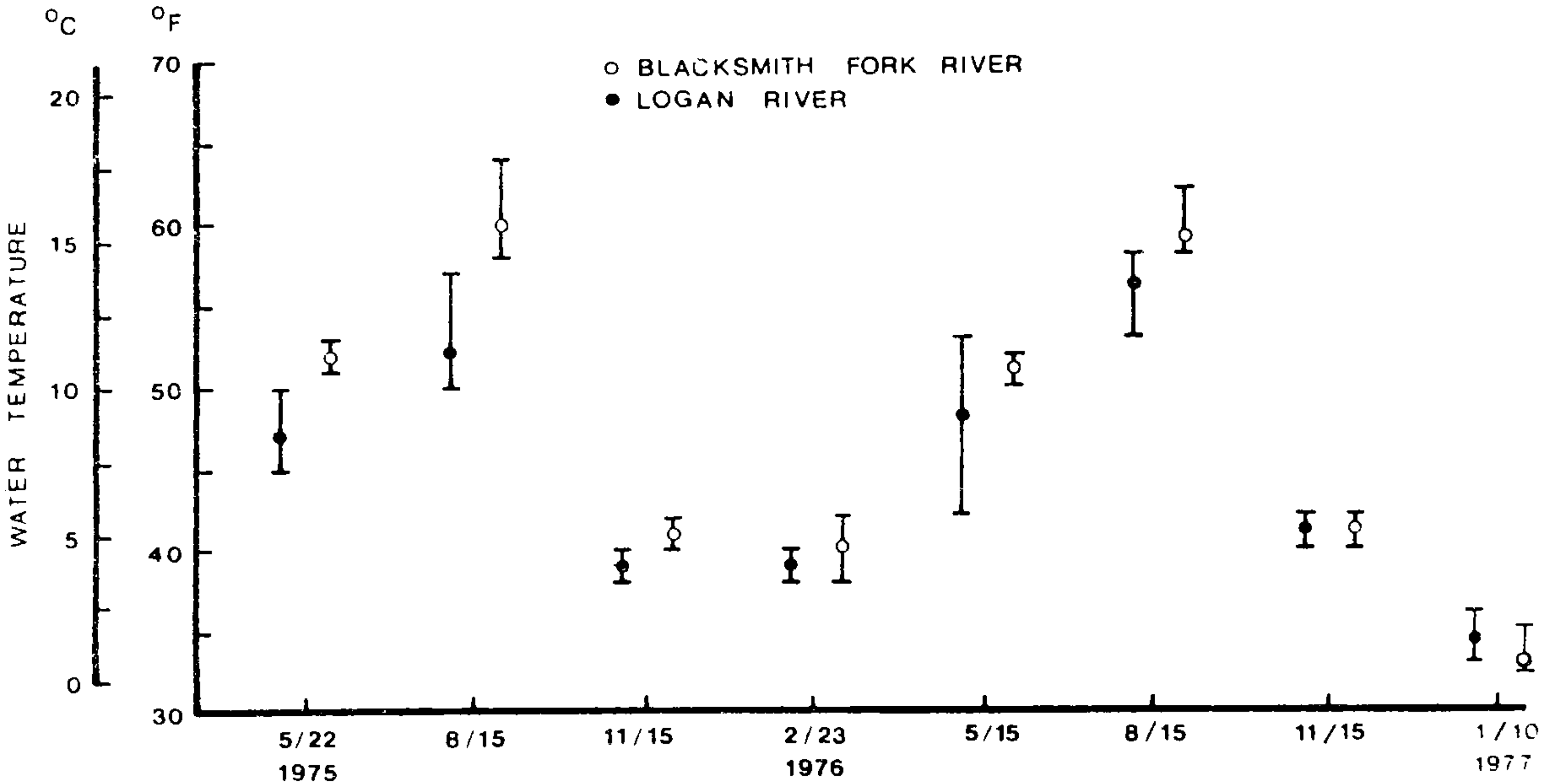

Figure A1. Representative fluctuations in daily water temperature during different seasons in the Blacksmith Fork and Logan Rivers, Cache County, Utah, 1975-76.

Table A1. Mean values for chemical analyses of water from the Blacksmith Fork River, Utah.

Measurement[1]	Year 1966-67[2]	1970[3]	1971[3]
Number of samples	4	18	23[4]
Calcium (Ca)	48	44.1(30.5-52.0)	45.4(29.8-58.0)
Magnesium (Mg)	18	18 (9.8-24.7)	18.3(9.2-29.0)
Sodium (Na)	4.5	3.9(1.8-60)	3.3(0.8-5.0)
Potassium (K)	0.8	3.2(0.3-11.7)	0.8(0.1-2.0)
Bicarbonate (HCO_3)	215	186 (36-238)	--
Carbonate (CO_3)	1	--	--
Sulfate (SO_4)	17	17 (4.8-62.4)	--
Nitrate (NO_3)	--	0.9 (0.1-3.8)	0.23(0.1-1.0)
Chloride (Cl)	5.6	11.1 (3.5-42.5)	7.9(3.5-14.2)
Hardness			
(Ca, Mg)	194	--	--
(Noncarbonate)	16	--	--
Conductivity (μmhos)	--	369 (268-413)	338 (278-389)
pH	--	7.0-8.3	6.5-8.22

[1]All values are given as milligrams per liter (mg/l) except for conductivity which is given in micromhos (μmhos/cm @ 25C).

[2]Data for 1966-67 from Waddell and Price (1972).

[3]Data for 1970 and 1971 from Hart, Southard, and Williams (1973).

[4]Range of 18 to 23 measurements.

Table A2. Chemical analyses of water from the Logan River, Utah.

Measurement[1]	1956-57[2] Range	1965[3] Mean	1965[3] Range
Calcium (Ca)	28-58	55	34-75
Magnesium (Mg)	24-28	20	13-26
Sodium (Na)	5-25	5	3-8
Potassium (K)	0.1-2.0	1.2	0.8-2.3
Bicarbonate (HCO_3)	240-264	240	160-336
Carbonate (CO_3)	-	0.7	0.4-1.1
Sulfate (SO_4)	12-15	21	10-35
Nitrate (NO_3)	0.0-4.9	-	-
Chloride (Cl)	6.0-8.0	6	3-9
Total dissolved solids (TDS)	185-230	235	180-336
Conductivity (μmhos)	-	410	292-540
pH	-	-	7.4-8.5

[1]All measurements are given in milligrams per liter (mg/l) except conductivity which is given in micromhos (μhos/cm @ 25C).

[2]From McConnell (1958).

[3]From U. S. Bureau of Reclamation, Logan, Utah as given by Bergerson (1973).

Table A3. Comparison of ranges in total dissolved solids, hardness, alkalinity, and pH at several sites in the Blacksmith Fork and Logan Rivers, 1966-67[1,2].

Location	Dissolved Solids	Hardness	Alkalinity	pH
Blacksmith Fork below Mill Creek near Hyrum, Utah	127-243	133-229	121-212	7.6-8.6
Blacksmith Fork above Utah Power and Light Dam near Hyrum, Utah	160-236	147-222	144-211	7.4-8.3
Logan River above state dam near Logan, Utah	155-210	148-224	149-207	7.4-8.1
Logan River below confluence with Blacksmith Fork	164-336	151-294	137-274	7.5-8.5

[1]Data from Waddell and Price (1972).

[2]Values for dissolved solids, hardness and alkalinity are given in milligrams per liter.

APPENDIX B

SAMPLING SCHEDULE

REVISED POPULATION ESTIMATOR

AREA OF INDIVIDUAL STUDY SITES

BROWN TROUT POPULATION ESTIMATES

MOUNTAIN WHITEFISH ESTIMATES,

STANDING CROP ESTIMATES,

INSTANTANEOUS GROWTH AND

PRODUCTION ESTIMATES

Table B1. Dates of population estimates for whitefish and brown trout in the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

Logan bulldozed	Blacksmith dredged	Blacksmith control	Blacksmith bulldozed	Logan Control
15 Mar 75	16 Feb 75			
31 Jul 75	16 Jun 75			
10 Sep 75	12 Aug 75		11 Aug 75	
15 Nov 75	25 Sep 75	5 Oct 75	4 Oct 75	9 Oct 75
17 Jan 76	13 Nov 75	6 Dec 75	4 Dec 75	
4 Apr 76	15 Jan 76	24 Feb 76	19 Feb 76	5 Feb 76
9 Jul 76		28 Mar 76	31 Mar 76	
	8 Jun 76	25 Jun 76	14 Jun 76	
	18 Aug 76	19 Aug 76	20 Aug 76	
	5 Oct 76	9 Oct 76	7 Oct 76	
	24 Nov 76	23 Nov 76	24 Nov 76	

Table B2. Dates of special collections for whitefish and brown trout in the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-76.

Date	Length of Reach Sampled (meters)	Data Collected
8, 17 Feb 75	400	P, M, G
15 Feb; 1, 2 Mar 75	700	P, M, G
9, 21 Mar 75	300	P, M, G
22 Mar 75	100	M
5 Apr 75	300	M
16, 18 Jul 75	800	M
21 Jul 75	400	G, M
22, 23 Jul 75	700	M
20 Aug 75	700	M
26 Aug 75	500	M
27 Aug 75	600	M
11 Sep 75	700	M
25 Aug 76	200	M
27 Aug 76	1600	M

P = Population estimate

M = Movement

G = Growth

F = Fecundity

Table B3. Macroinvertebrate sampling schedules at the four study sites on the Logan and Blacksmith Fork Rivers, Cache County, Utah, 1975-1976.

			Logan stable bulldozed	Blacksmith dredged	Blacksmith control	Blacksmith recently bulldozed
1975	March	20		dredged		
	July	9		2H[1]		
		28	1H, 1B[2]		1H	
	August	2		2H, 2B		
		22		2H, 2B		
		28		dredged		
		29	2H, 2B		2H	
	Sept.	3		2H		2H
		6				bulldozed
		9				2H
		29	2H, 2B	2H		
		30			2H, 1B	2H
	Oct.	30	2H, 2B	2H		
		31			2H, 1B	2H
	Dec.	8	2H, 2B	2H		
		9			2H, 1B	2H
1976	Jan.	20		2H	2H, 1B	2H
		23	2H, 2B			
	Feb.	25	2H, 2B			2H
		26			2H, 1B	
		27		2H		
	Apr.	5	2H, 2B			
	June	8		2H	2H, 1B	2H
	July	8	2H	2H	2H, 1B	2H
	Aug.	11	2H	2H	2H	2H
	Sept.	24	2H	2H	2H	

[1] Hess sample.

[2] Basket sample.

Table B4. Derivation of revised population estimates.

Fish movement was incorporated into the estimator when two percent or more of the marked fish captured at a site had immigrated into that site between mark and capture samples. It was assumed that the movement behaviors of marked and unmarked fish were the same, so that:

$$\frac{n}{am} = Q \text{ or } n = am(Q)$$

where

n = total number of fish captured in the second (recapture) sample which had moved into the site between mark and recapture sample dates.

am = number of marked fish which had moved into the site between mark and recapture sample dates.

Q = ratio of the total number of fish in the area where immigrants originated: number of marked fish in the area where immigrants originated.

Chapman's equation was then modified to

$$N^* = \frac{(M+1)\{C-am(Q)+1\}}{R+1} - 1$$

where

N* = revised estimate of the number of fish in the population

am, Q = as defined above

M,C,R = as usually defined

Table B5. Area of individual study sites.

Site	Area (ha)
Blacksmith Fork Control	.52
Blacksmith Dredged	.36
Logan Stable Bulldozed	.48
Logan Total Bulldozed	.60
Logan Control	.32
Blacksmith Recently Bulldozed	.38
Blacksmith Old Bulldozed	.32
Blacksmith Bulldozed (total)	.70

Table B6. Population estimates of brown trout for the total bulldozed site in the Logan River, Cache County, Utah. Confidence limits (95%) are given in parentheses.

Date	Year Class					
	1976	1975	1974	1973	1972	1971+
3/13/75	----	0	43	80	56	17
	----	----	(23-118)	(54-141)	(48-77)	(10-46)
7/29/75	----	7	51	60	39	3
	----	(2-153)	(17-285)	(40-112)	(19-210)	----
9/8/75	----	38	43	38	24	1
	----	(19-105)	(27-98)	(27-70)	(11-131)	(0-39)
9/13/75	----	4	35	31	5	0
	----	(1-99)	(11-691)	(14-174)	----	----
1/18/76	0	0	8	35	10	1
	----	----	(2-153)	(13-705)	----	----
4/6/76	0	14	11	13	19	----
	----	(4-299)	(3-230)	(3-285)	(5-399)	----
7/11/76	135	40	41	55	7	----
	----	(19-110)	(21-98)	(19-303)	(3-159)	----

Table B7. Population estimates of brown trout for the stable bulldozed site in the Logan River, Cache County, Utah. Confidence limits (95%) are given in parentheses.

Date	Year Class 1976	1975	1974	1973	1972	1971+
3/13/75	----	0	32	38	29	13
	----	----	(17-88)	(29-70)	(26-42)	(8-35)
7/29/75	----	7	29	45	16	2
	----	(2-153)	(9-161)	(27-93)	(10-81)	----
9/8/75	----	32	10	5	1	0
	----	(17-88)	(8-25)	(2-119)	----	----
11/13/75	----	3	14	9	3	0
	----	(0.3-76)	(5-293)	(4-199)	----	----
1/18/76	0	0	3	17	8	1
	----	----	(0.2-58)	(8-359)	----	----
4/6/76	0	3	3	3	7	----
	----	(0.3-76)	(0.3-76)	(0.3-76)	(2-153)	----
7/11/76	7	20	5	2	0	----
	(3-159)	(7-411)	----	----	----	----

Table B8. Population estimates of brown trout for the control site in the Logan River, Cache County, Utah. Confidence limits (95%) are given in parentheses.

	Year Class					
Date	1976	1975	1974	1973	1972	1971+
10/9/75	----	8	39	74	53	17
	----	(3-176)	(27-87)	(62-106)	(35-111)	(6-352)
2/5/76	0	4	53	82	50	----
	----	----	(40-84)	(60-132)	(27-108)	----

Table B9. Population estimates of brown trout for the dredged site in the Blacksmith Fork River, Cache County, Utah. Confidence limits (95%) are given in parentheses.

Date	Year Class 1976	 1975	 1974	 1973	 1972	 1971+
2/15/75	---- ----	0 ----	445 (259-814)	183 (132-290)	75 (44-170)	20 (9-110)
6/16/75	---- ----	76 ----	156 (80-400)	112 (65-249)	32 (21-76)	0 ----
8/12/75	---- ----	617 (403-991)	180 (129-274)	80 (46-156)	14 (10-36)	11 (7-58)
9/25/75	---- ----	225 (158-375)	106 (78-175)	61 (43-105)	20 (10-71)	11 (7-58)
11/13/75	---- ----	149 (106-239)	128 (71-281)	132 (65-372)	55 (23-196)	17 (8-91)
1/15/76	0 ----	116 (82-183)	36 (24-72)	30 (20-67)	6 (4-36)	12 (10-26)
6/10/76	912 (693-1224)	147 (84-324)	26 (17-62)	22 (10-117)	2 (1-14)	---- ----
8/20/76	504 (398-668)	93 (78-121)	41 (35-58)	9 (7-19)	5 (3-29)	---- ----
10/7/76	284 (174-508)	54 (37-111)	60 (32-143)	9 (4-199)	3 (5-29)	---- ----
11/25/76	331 (182-729)	55 (25-153)	34 (17-116)	11 (3-64)	3 (1-79)	---- ----

Table B10. Population estimates of brown trout for the control site in the Blacksmith Fork River, Cache County, Utah. Confidence limits (95%) are given in parentheses.

Date	Year Class 1976	1975	1974	1973	1972	1971+
10/5/75	----	382	51	64	76	47
	----	(133-2142)	(30-111)	(47-99)	(44-180)	(22-162)
12/6/75	----	92	69	118	42	19
	----	(60-174)	(41-139)	(78-226)	(26-99)	(13-44)
2/24/76	0	436	60	51	27	----
	----	(95-9499)	(30-146)	(35-84)	(14-72)	----
3/30/76	0	43	52	33	13	----
	----	(24-101)	(25-183)	(23-72)	(8-66)	----
6/27/76	1085	183	58	41	7	----
	(835-1447)	(151-238)	(44-90)	(29-79)	(4-19)	----
8/21/76	694	76	35	22	5	----
	(562-842)	(62-107)	(27-54)	(18-37)	(3-19)	----
10/11/76	520	42	100	66	9	----
	(291-1117)	(21-102)	(47-288)	(23-374)	(4-56)	----
11/25/76	560	92	120	25	22	----
	----	(59-167)	----	(13-132)	(12-77)	----

Table B11. Population estimates of brown trout for the recently bulldozed site in the Blacksmith Fork River, Cache County, Utah. Confidence limits (95%) are given in parentheses.

Date	Year Class					
	1976	1975	1974	1973	1972	1971+
8/21/75	----	65	42	83	12	4
	----	----	----	----	----	----
10/4/75	----	35	19	19	15	7
	----	(25-68)	(5-399)	(12-41)	(4-307)	(2-153)
12/4/75	----	23	7	127	13	1
	----	(15-57)	(7-19)	(31-2666)	(6-279)	----
2/19/76	0	17	8	17	2	----
	----	(11-37)	(3-176)	(11-43)	(0.2-58)	----
6/16/76	1046	26	12	5	3	----
	(676-1643)	(16-65)	(6-44)	(3-19)	(1-79)	----
8/22/76	44	15	12	1	1	----
	(28-85)	(10-35)	(10-39)	----	----	----
10/9/76	38	14	26	1	2	----
	(20-103)	(6-78)	(9-528)	(0-39)	(0.2-58)	----
11/26/76	59	20	31	8	2	----
	(21-332)	(9-110)	(7-666)	(5-23)	(0.2-58)	----

Table B12. Population estimates of brown trout for the old bulldozed site in the Blacksmith Fork River, Cache County, Utah. Confidence limits (95%) are given in parentheses.

	Year Class					
Date	1976	1975	1974	1973	1972	1971+
10/4/75	---- ----	53 (32-111)	14 (6-78)	35 (18-115)	49 (14-999)	3 (2-21)
12/4/75	---- ----	32 (16-88)	23 (10-126)	53 (13-999)	14 (4-299)	5 (1-117)
2/19/76	0 ----	12 (9-28)	5 (1-117)	28 (15-65)	27 (18-59)	---- ----
6/16/76	211 (112-475)	42 (24-89)	17 (10-58)	13 (9-30)	4 (2-15)	---- ----
8/22/76	92 (63-157)	23 (20-41)	15 (8-81)	5 (2-119)	0 ----	---- ----
10/9/76	55 (13-1166)	15 (4-307)	7 (5-43)	1 (0-39)	1 ----	---- ----
11/26/76	24 (7-499)	5 (2-119)	13 (10-81)	5 (2-119)	1 ----	---- ----

Table B13. Population estimates of mountain whitefish (no/ha) for the total bulldozed site in the Logan River, Cache County, Utah. Actual estimates and 95% confidence limits are given in parentheses.

Date	Year Class 1976	1975	1974	1973	1972[a]	1971+	Total
3/15/75	----	0*	0*	44	445	318	807
	----	----	----	(26; 16-55)	(266;219-321)	(190;172-222)	
4/20/75**	----	0	0	54	402	223	677
	----	----	----	----	----	----	
7/31/75	----	2	310	99	298	82	791
	----	(1; 0-39)	(185;79-658)	(59;21-332)	(178;61-999)	(49; 28-117)	
9/10/75	----	0*	45	60	37	8	150
	----	----	(27; 9-151)	(36;13-194)	(22; 11-59)	(5; 1-117)	
11/15/75	----	0*	161	1650	921	587	3319
	----	----	(96;52-226)	(986;850-1174)	(550;475-650)	(351;283-445)	
1/17/76	0*	0*	37	435	370	----	842
	----	----	(27***;---)	(260;197-382)	(221;173-329)	----	
4/4/76	0*	2	186	238	166	----	592
	----	(1; 0-39)	(111;46-399)	(142;75-343)	(99;55-228)	----	
7/9/76	1220	574	604	109	79	----	2586
	(729***;--)	(343;113-1894)	(361;197-790)	(65;17-1221)	(47;12-888)	----	

[a]1972+ after 11/15/75.

*No fish captured during mark or recapture sample.

**Estimates based on previous (3/15/75) and succeeding (7/31/75) population estimates.

***No confidence limits calculated due to insufficient number of recaptures.

Table B14. Population estimates of mountain whitefish (no/ha) for the stable bulldozed site in the Logan River, Cache County, Utah. Actual estimates and 95% confidence limits are given in parentheses.

	Year Class						
Date	1976	1975	1974	1973	1972[a]	1971+	Total
3/15/75	----	0*	0*	52	421	312	785
	----	----	----	(25; 13-77)	(201;166-264)	(149;131-189)	
4/20/75**	----	0	0	50	222	144	416
	----	----	----	----	----	----	
7/31/75	----	0*	397	48	36	17	498
	----	----	(19;68-1038)	(23;10-126)	(17;11-88)	(9; 8-40)	
9/10/75	----	0*	0*	0*	0*	0*	0
	----	----	----	----	----	----	
11/15/75	----	0*	157	1749	946	615	3467
	----	----	(75;39-175)	(836;687-1023)	(452;390-546)	(294;237-378)	
1/17/76	0*	0*	44	464	542	----	1050
	----	----	(21;)	(222;172-336)	(259;182-421)	----	
4/4/76	0*	0*	107	174	322	----	603
	----	----	(51;18-282)	(83;43-196)	(154;60-828)	----	
7/9/76	1128	190	50	4	0*	----	1372
	(539***;---)	(91;34-1764)	(24***;---)	(2***;---)	----	----	

[a]1972+ after 11/15/75.

*No fish captured during mark or recapture sample.

**Estimates based on previous (3/15/75) and succeeding (7/31/75) population estimates.

***No confidence limits calculated due to insufficient number of recaptures.

Table B15. Population estimates of mountain whitefish (no/ha) for the control site in the Logan River, Cache County, Utah. Actual estimates and 95% confidence limits are given in parentheses.

	Year Class						
Date	1976	1975	1974	1973	1972	1971+	Total
10/9/75	----	0*	478	795	616	104	1993
	----	----	(152;73-423)	(253;200-384)	(196;160-251)	(33;20-82)	
2/5/76	0*	16	229	647	371	63	1326
	----	(5**;----)	(73; 47-132)	(209;173-265)	(119;87-193)	(20;15-43)	

*No fish captured during mark or recapture sample.

**No confidence intervals calculated due to insufficient number of recaptures.

Table B16 Population estimates of mountain whitefish (no/ha) for the dredged site on the Blacksmith Fork River, Cache County, Utah. Actual estimates and 95% confidence limits are given in parentheses.

Date	Year Class 1976	1975	1974	1973	1972[a]	1971+	Total
2/16/75	----	0*	388	75	162**	142**	767
	----	----	(139;35-2856)	(27;6-570)	(58;----)	(51;----)	
4/19/75***	----	0	220	75	100	98	493
	----	----	----	----	----	----	
6/16/75	----	0*	131	75	64	67**	337
	----	----	(47;12-888)	(27;10-31)	(23;10-131)	(22;----)	
7/21/75***	----	0	179	45	33	95	352
	----	----	----	----	----	----	
8/12/75	----	544	215	33	22	120**	934
	----	(195;56-1124)	(77;50-138)	(12;10-31)	(8;5-22)	(43;----)	
9/25/75	----	402	92**	61	56	31	642
	----	(144;48-513)	(33;----)	(22;10-71)	(20;14-40)	(11;9-19)	
11/13/75	----	656	8	477	463	165	1769
	----	(235;58-4322)	(3;0-76)	(171;88-444)	(166;70-594)	(59;21-325)	
1/15/76	0*	569	248	259**	109**	----	1186
	----	(204;110-512)	(89;46-211)	(93;----)	(39;----)	----	
3/30/76***	0	299	167	75	50	----	591
	----	----	----	----	----	----	
6/8/76	254	165	103**	25	25	----	572
	(91;35-323)	(59;30-162)	(37;---)	(9;3-176)	(9;4-199)	----	
8/18/76	597	106	47	20	47	----	817
	(214;101-610)	(38;25-69)	(17; 11-43)	(7; 3-20)	(17;3-332)	----	

Table B17 Continued

	Year Class						
Date	1976	1975	1974	1973	1972[a]	1971+	Total
10/5/76	840*	262**	148	42	70	----	1362
	(301;----)	(94;----)	(53;107-904)	(15;43-666)	(25;22-269)	----	
11/24/76	871**	299	703	338	140	----	2351
	(312;----)	(107;45-366)	(252;107-904)	(121;43-666)	(50;22-269)	----	

[a]1972+ after 11/13/75.

*No fish captured during mark or recapture sample.

**Adjusted for fish movement.

***Estimates based on population estimates made on previous and succeeding dates.

Table B18 Population estimates of mountain whitefish (no/ha) for the control site in the Blacksmith Fork River, Cache County, Utah. Actual estimates and 95% confidence limits are given in parentheses.

Date	Year Class 1976	1975	1974	1973	1972[a]	1971+	Total
10/5/75	----	93	21	39	33	58	244
	----	(48;25-132)	(11;4-234)	(20;7-411)	(17;12-30)	(30;18-59)	
12/6/75	----	114	107	188	85	83*	577
	----	(59;40-295)	(55;16-1099)	(97;53-234)	(44;30-90)	(43;----)	
2/4/76	0**	120*	291*	200*	196*	----	807
	----	(62;----)	(150;----)	(103;----)	(101;----)	----	
3/28/76	0**	37*	163*	89*	124*	----	413
	----	(19;----)	(84;----)	(46;----)	(64;----)	----	
6/25/76	25	171*	188	25	47*	----	456
	(13;3-285)	(88;----)	(97;26-1777)	(13;7-46)	(24;----)	----	
8/19/76	17	16	14	10	33	----	89
	(9;4-199)	(8;4-18)	(7;2-21)	(5;4-11)	(17;8-48)	----	
10/9/76	1165	93	91*	12	79*	----	1440
	(601;164-2800)	(48;27-114)	(47;----)	(6;3-22)	(41;----)	----	
11/23/76	609	45	368	246*	213*	----	1481
	(316;166-766)	(23;12-80)	(190;113-399)	(127;----)	(110;----)	----	

[a]1972+ after 12/6/75.

*Adjusted for fish movement.

**No fish captured during mark or recapture sample.

Table B19 Population estimates of mountain whitefish (no/ha) for the recently bulldozed site in the Blacksmith Fork River, Cache County, Utah. Actual estimates and 95% confidence limits are given in parentheses.

Date	Year Class 1976	1975	1974	1973	1972[a]	1971+	Total
8/11/75	---- ----	3 (1 ± 0)	11 (4 ± 0)	0* ----	5 (2****;)	0* ----	19
10/4/75	---- ----	0* ----	3 (1**;----)	8 (3; 0-58)	5 (2; 1-14)	0* ----	16
12/4/75	---- ----	3 (1**;----)	8 (3**;----)	69 (25**;---)	116*** (44;----)	82*** (31;----)	278
2/19/76	0* ----	19 (7; 3-159)	61 (23; 7-461)	159 (60; 39-113)	111 (42; 25-106)	---- ----	350
6/14/76	16 (6; 0-142)	0* ---	24 (9; 3-175)	0* ----	3 (1; 0-39)	---- ----	43
8/20/76	0* ----	0* ----	0* ----	0* ----	0* ----	---- ----	0
10/7/76	0* ----	0* ----	0* ----	3 (1**;----)	0* ----	---- ----	3
11/24/76	5 (2; 0-58)	0* ----	34 (13;6-280)	40 (15; 3-332)	34 (13; 5-75)	---- ----	113

[a]1972+ after 12/4/75.

*No fish captured during mark or recapture sample.

** No confidence limits calculated due to insufficient number of recaptures.

***Adjusted for fish movement.

****Conservative estimate. Conditions for 2-catch method (Zippin 1958) not met.

Table B20 Population estimates of mountain whitefish (no/ha) for the old bulldozed site in the Blacksmith Fork River, Cache County, Utah. Actual estimates and 95% confidence limits are given in parentheses.

Date	Year Class						Total
	1976	1975	1974	1973	1972[a]	1971+	
10/4/76	---- ----	31 (10;4-199)	9 (3**;----)	37 (12;4-234)	12 (4**;----)	16 (5; 2-119)	105
12/4/75	---- ----	0* ----	6 (2**;----)	106*** (33; ----)	140*** (44; ----)	72*** (22; ----)	324
2/19/76	0* ----	0* ----	47 (15; 4-307)	206 (66; 17-1221)	234 (75;57-117)	---- ----	487
6/14/76	3 (1**;----)	16 (5; 4-14)	31 (10; 8-25)	9 (3; 1-79)	3 (1**;----)	---- ----	62
8/20/76	25 (8;3-176)	0* ----	0* ----	0* ----	0* ----	---- ----	25
10/7/76	0* ----	0* ----	16 (5; 3-29)	6 (2; 0-58)	3 (1; 0-39)	---- ----	25
11/24/76	3 (1; 0-39)	0* ----	75 (24; 13-66)	165 (53; 21-202)	121*** (39; ----)	---- ----	364

[a]1972+ after 12/4/75.

*No fish captured during mark or recapture sample.

**No confidence limits calculated due to insufficient number of recaptures.

***Adjusted for fish movement.

Table B21 Standing crop estimates (kg/ha) of mountain whitefish for the total bulldozed site in the Logan River, Cache County, Utah.

Date	Year Class						Total
	1976	1975	1974	1973	1972[a]	1971+	
3/15/75	----	0.00	0.00	6.66	93.93	112.57	213.16
4/20/75	----	0.00	0.00	9.32	89.97	82.36	181.65
7/31/75	----	0.02	24.15	19.75	73.58	33.54	151.04
9/10/75	----	0.00	3.84	12.29	9.17	3.26	28.56
11/15/75	----	0.00	16.87	339.94	246.69	234.39	837.90
1/17/76	0.00	0.00	4.60	94.86	117.62	----	217.08
4/4/76	0.00	0.08	23.60	57.51	56.33	----	137.52
7/9/76	6.10	38.46	94.25	28.61	30.91	----	198.34

[a]1972+ after 11/15/75.

Table B22 Standing crop estimates (kg/ha) of mountain whitefish for the stable bulldozed site in the Logan River, Cache County, Utah.

Date	Year Class						Total
	1976	1975	1974	1973	1972[a]	1971+	
3/15/75	----	0.00	0.00	8.00	88.73	110.35	207.08
4/20/75	----	0.00	0.00	8.74	49.67	53.41	111.82
7/31/75	----	0.00	31.00	9.62	8.78	6.85	56.26
9/10/75	----	0.00	0.00	0.00	0.00	0.00	0.00
11/15/75	----	0.00	16.47	360.28	253.42	245.41	875.59
1/17/76	0.00	0.00	5.49	101.25	175.31	----	279.04
4/4/76	0.00	0.00	13.55	42.02	109.54	----	165.11
7/9/76	5.64	12.76	7.83	1.10	0.00	----	27.33

[a]1972+ after 11/15/75

Table B23 Standing crop estimates (kg/ha) of mountain whitefish for the control site in the Logan River, Cache County, Utah.

	Year Class						
Date	1976	1975	1974	1973	1972	1971+	Total
10/9/75	----	0.00	41.56	143.12	161.38	43.97	390.03
2/5/76	0.00	0.31	26.61	139.19	99.38	28.22	293.72

Table B24 Standing crop estimates (kg/ha) of mountain whitefish for the dredged site in the Blacksmith Fork River, Cache County, Utah.

Date	Year Class						Total
	1976	1975	1974	1973	1972[a]	1971+	
2/16/75	----	0.00	10.08	10.70	35.28	47.95	104.02
4/19/75	----	0.00	7.49	10.62	21.40	35.74	75.25
6/16/75	----	0.00	6.03	12.35	14.50	25.85	58.74
7/21/75	----	0.00	12.86	7.32	7.77	38.23	66.18
8/12/75	----	6.53	17.40	5.76	5.47	42.00	77.15
9/25/75	----	7.63	8.56	9.27	15.96	17.37	58.80
11/13/75	----	10.49	0.75	90.65	118.57	65.85	286.31
1/15/76	0.00	10.25	25.08	46.45	33.52	----	115.29
3/30/76	0.00	9.55	20.93	17.10	18.43	----	66.01
6/8/76	0.58	8.89	15.01	6.43	10.04	----	41.02
8/18/76	8.96	9.75	7.83	4.79	16.36	----	47.69
10/5/76	15.96	24.39	26.17	11.89	33.55	----	111.96
11/24/76	16.54	29.56	119.53	91.83	55.39	----	312.84

[a]1972+ after 11/13/75

Table B25 Standing crop estimates (kg/ha) of mountain whitefish for the control site on the Blacksmith Fork River, Cache County, Utah.

Date	Year Class 1976	1975	1974	1973	1972[a]	1971+	Total
10/5/75	----	1.67	1.79	6.16	8.80	27.27	45.69
12/6/75	----	2.29	11.94	36.66	22.00	38.17	111.05
2/24/76	0.00	2.64	32.27	41.52	63.81	----	140.24
3/28/76	0.00	1.03	20.51	20.24	44.90	----	86.68
6/25/76	0.07	10.06	26.32	6.40	18.00	----	60.85
8/19/76	0.17	1.50	2.10	2.43	14.69	----	20.91
10/9/76	22.13	9.58	15.94	3.35	44.58	----	95.58
11/23/76	10.95	4.23	67.38	63.25	88.04	----	233.87

[a]1972+ after 12/6/75.

Table B26 Standing crop estimates (kg/ha) of mountain whitefish for the recently bulldozed site in the Blacksmith Fork River, Cache County, Utah.

Date	Year Class						Total
	1976	1975	1974	1973	1972[a]	1971+	
8/11/75	----	0.00	0.90	0.00	1.38	0.00	2.31
10/4/75	----	0.00	0.26	1.09	1.61	0.00	2.95
12/4/75	----	0.07	0.96	14.59	32.62	29.55	77.79
2/19/76	0.00	0.54	8.22	33.68	36.47	----	78.91
6/14/76	0.03	0.00	3.57	0.00	0.91	----	4.51
8/20/76	0.00	0.00	0.00	0.00	0.00	----	0.00
10/7/76	0.00	0.00	0.00	0.72	0.00	----	0.72
11/24/76	0.09	0.00	7.43	11.32	13.42	----	32.27

[a]1972+ after 12/4/75.

Table B27 Standing crop estimates (kg/ha) of mountain whitefish for the old bulldozed site in the Blacksmith Fork River, Cache County, Utah.

Date	Year Class						Total
	1976	1975	1974	1973	1972[a]	1971+	
10/4/75	----	0.65	0.91	5.12	3.78	5.83	16.30
12/4/75	----	0.00	0.75	22.45	39.25	25.79	88.26
2/19/76	0.00	0.00	6.31	43.59	76.64	----	126.53
6/14/76	0.01	0.93	4.67	2.04	0.68	----	8.33
8/20/76	0.17	0.00	0.00	0.00	0.00	----	0.17
10/7/76	0.00	0.00	3.47	1.69	0.96	----	6.12
11/24/76	0.05	0.00	16.15	47.06	47.38	----	110.64

[a] 1972+ after 12/4/75

Table B28 Daily instantaneous growth rates for mountain whitefish for the total bulldozed site in the Logan River, Cache County, Utah.

Interval		Length of interval in days	Year Class					
			1976	1975	1974	1973	1972[a]	1971+
3/15/75	4/20/75	36	----	----	----	0.003573	0.001661	0.001228
4/20/75	7/31/75	102	----	----	----	0.001365	0.000958	0.000982
7/31/75	9/10/75	41	----	----	0.002096	0.000483	0.000197	-0.001223
9/10/75	11/15/75	66	----	----	0.003202	0.000148	0.001114	0.000385
11/15/75	1/17/76	63	----	----	0.002768	0.000899	-0.000050	----
1/17/76	4/4/76	78	----	----	0.000204	0.001339	0.000858	----
4/4/76	7/9/76	96	----	0.004146	0.002142	0.000867	0.001509	----

[a]1972+ after 11/15/75.

Table B29. Daily instantaneous growth rates for mountain whitefish for the stable bulldozed site in the Logan River, Cache County, Utah.

Interval		Length of interval in days	Year Class					
			1976	1975	1974	1973	1972[a]	1971+
3/15/76	4/20/75	36	----	----	----	0.003573	0.001661	0.001228
4/20/75	7/31/75	102	----	----	----	0.001365	0.000958	0.000982
7/31/75	9/10/75	41	----	----	----	----	----	----
9/10/75	11/15/75	66	----	----	----	----	----	----
11/15/75	1/17/76	63	----	----	0.002768	0.000899	-0.000100	----
1/17/76	4/4/76	78	----	----	0.000204	0.001339	0.000858	----
4/4/76	7/9/76	96	----	----	0.002142	0.000867	0.001509	----

[a] 1972+ after 11/15/75.

Table B30. Daily instantaneous growth rates for mountain whitefish for the dredged site in the Blacksmith Fork River, Cache County, Utah.

Interval		Length of Interval in days	Year Class					
			1976	1975	1974	1973	1972[a]	1971+
2/16/75	4/19/75	62	----	----	0.004327	-0.000114	-0.000374	0.001331
4/19/75	6/16/75	58	----	----	0.005212	0.002605	0.001021	0.000917
6/16/75	7/21/75	35	----	----	0.012801	0.000000	0.000749	0.001231
7/21/75	8/12/75	22	----	----	0.005354	0.002165	0.002478	0.002478[b]
8/12/75	9/25/75	44	----	0.010444	0.003140	-0.002959	0.003517	0.003517[b]
9/25/75	11/13/75	49	----	-0.003507	-0.000897	0.004689	-0.002262	-0.002262[b]
11/13/75	1/15/76	63	----	0.001870	0.002008	-0.000947	0.000738	----
1/15/76	3/30/76	75	----	0.007672	0.002843	0.003168	0.002337	----
3/30/76	6/8/76	70	----	0.007475	0.002218	0.001718	0.001230	----
6/8/76	8/18/76	71	0.026410	0.007504	0.001723	-0.000619	-0.000619[b]	----
8/18/76	10/5/76	48	0.004925	0.000225	0.001463	0.003077	0.003077[b]	----
10/5/76	11/24/76	50	0.000000	0.001250	-0.000807	-0.000863	-0.003839	----

[a] 1972+ after 11/13/75

[b] Growth rate of Age III fish used for Age IV and older fish.

Table B31 Daily instantaneous growth rates for mountain whitefish for the control site in the Blacksmith Fork River, Cache County, Utah.

Interval		Length of Interval in days	Year Class					
			1976	1975	1974	1973	1972[a]	1971+
10/5/75	12/6/75	62	----	0.001699	0.004640	0.003292	-0.000553	-0.000383
12/6/75	2/24/76	80	-----	0.001191	-0.000112	0.000807	0.002924	----
2/24/76	3/28/76	33	----	0.007308	0.003841	0.002649	0.003174	----
3/28/76	6/25/76	89	----	0.008375	0.001184	0.001263	0.000750	----
6/25/76	8/19/76	55	0.023145	0.009040	0.001851	-0.000216	0.002580	----
8/19/76	10/9/76	51	0.012585	0.001177	0.002380	0.002696	0.002696[b]	----
10/9/76	11/23/76	45	-0.001201	-0.001797	0.000993	-0.002531	-0.002531[b]	----

[a]1972+ after 12/6/75.

[b]Growth rate for Age III fish used for Age IV and older fish.

Table B32. Daily instantaneous growth rates for mountain whitefish for the recently bulldozed site in the Blacksmith Fork River, Cache County, Utah.

Interval		Length of Interval in days	Year Class					
			1976	1975	1974	1973	1972[a]	1971+
8/11/75	10/4/75	44	----	----	0.003001	----	0.003466	----
10/4/75	12/4/75	61	----	----	0.003624	0.007157	-0.001348	----
12/4/75	2/19/76	77	----	0.000928	0.001422	0.000000	0.000361	----
2/19/76	6/14/76	116	----	----	0.000908	----	0.000360	----
6/14/76	8/20/76	67	----	----	----	----	----	----
8/20/76	10/7/76	48	----	----	----	----	----	----
10/7/76	11/24/76	47	----	----	----	0.001072	----	----

[a]1972+ after 12/4/75

Table B33. Daily instantaneous growth rates for mountain whitefish for the old bulldozed site in the Blacksmith Fork River, Cache County, Utah.

Interval		Length of Interval in days	Year Class					
			1976	1975	1974	1973	1972[a]	1971+
10/4/75	12/4/75	61	----	----	0.003624	0.007157	-0.001348	-0.000625
12/4/75	2/19/76	77	----	----	0.001422	0.000000	0.000859	----
2/19/76	6/14/76	116	----	----	0.000908	0.000589	0.000360	----
6/14/76	8/20/76	67	0.010464	----	----	----	----	----
8/20/76	10/7/76	48	----	----	----	----	----	----
10/7/76	11/24/76	47	----	----	-0.000679	0.001072	0.001072[b]	----

[a]1972+ after 12/4/75.

[b]Growth rate of Age III fish used for Age IV and older fish.

Table B34. Production of mountain whitefish (kg/ha) for the total bulldozed site in the Logan River, Cache County, Utah. Period used for annual production estimate is shown by dashed lines.

	Year Class						
Interval	1976	1975	1974	1973	1972[a]	1971+	Total
3/15/75 to 4/20/75	----	0.00	0.00	1.02	5.50	4.27	10.78
4/20/75 to 7/31/75	----	0.00	0.00	1.93	8.00	5.45	15.34
7/31/75 to 9/10/75	----	0.00	0.95	0.31	0.25	-0.65	0.87
9/10/75 to 11/15/75	----	0.00	1.86	0.96	5.31	1.37	9.50
11/15/75 to 1/17/76	0.00	0.00	1.65	10.87	-0.81	----	11.71
1/17/76 to 4/4/76	0.00	0.00	0.18	7.80	5.57	----	13.55
4/4/76 to 7/9/76	0.00	2.45	10.49	3.44	6.14	----	22.52

[a] 1972+ after 11/15/75

Table B35. Production of mountain whitefish (kg/ha) for the stable bulldozed site in the Logan River, Cache County, Utah. Period used for annual production estimate is shown by dashed lines.

	Year Class						
Interval	1976	1975	1974	1973	1972[a]	1971+	Total
3/15/75 to 4/20/75	----	0.00	0.00	1.08	4.03	3.47	8.57
4/20/75 to 7/31/75	----	0.00	0.00	1.28	2.31	2.27	5.86
7/31/75 to 9/10/75	----	0.00	0.00	0.00	0.00	0.00	0.00
9/10/75 to 11/15/75	----	0.00	0.00	0.00	0.00	0.00	0.00
11/15/75 to 1/17/76	0.00	0.00	1.74	11.55	-0.96	----	12.33
1/17/76 to 4/4/76	0.00	0.00	0.14	7.03	9.27	----	16.44
4/4/76 t0 7/9/76	0.00	0.00	2.15	0.93	0.00	----	3.08

[a] 1972+ after 11/15/75

Table B36. Production of mountain whitefish (kg/ha) for the dredged site on the Blacksmith Fork River, Cache County, Utah. Period used for annual production estimate is shown by dashed lines.

Interval	Year Class 1976	1975	1974	1973	1972[a]	1971+	Total
2/16/75 to 4/19/75	----	0.00	2.34	-0.08	-0.64	3.43	5.05
4/19/75 to 6/16/75	----	0.00	2.04	1.73	1.05	1.62	6.44
6/16/75 to 7/21/75	----	0.00	4.04	0.00	0.28	1.36	5.69
7/21/75 to 8/12/75	----	0.00	1.77	0.31	0.36	2.19	4.62
8/12/75 to 9/25/75	----	3.25	1.72	-0.96	1.52	4.32	9.84
9/25/75 to 11/13/75	----	-1.54	-0.14	8.20	-5.67	-4.03	-3.19
11/13/75 to 1/15/76	0.00	1.22	0.88	-3.94	4.16	----	2.31
1/15/76 to 3/30/76	0.00	5.69	4.89	6.98	4.42	----	21.98
3/30/76 to 6/8/76	0.00	4.82	2.77	1.31	1.19	----	10.09
6/8/76 to 8/18/76	5.75	4.96	1.35	-0.24	-0.57	----	11.25
8/18/76 to 10/5/76	2.87	0.17	1.07	1.15	3.54	----	8.79
10/5/76 to 11/24/76	0.00	1.68	-2.48	-1.69	-8.36	0.00	-10.85

[a]1972+ after 11/13/75

Table B37. Production of mountain whitefish (kg/ha) for the control site in the Blacksmith Fork River, Cache County, Utah. Period used for annual production is shown by dashed lines.

Interval	Year Class 1976	1975	1974	1973	1972[a]	1971+	Total
10/5/75 to 12/6/75	----	0.21	1.54	3.49	-0.49	-0.77	3.97
12/6/75 to 2/24/76	0.00	0.23	-0.18	2.52	-3.20	----	-2.57
2/24/76 to 3/28/76	0.00	0.41	3.29	2.59	5.64	----	11.92
3/28/76 to 6/25/76	0.00	2.95	2.45	1.35	1.97	----	8.72
6/25/76 to 8/19/76	0.15	2.24	0.98	-0.05	2.31	----	5.62
8/19/76 to 10/9/76	2.91	0.26	0.83	0.39	3.70	----	8.10
10/9/76 to 11/23/76	-0.86	-0.53	1.59	-2.32	-7.27	----	-9.39

[a]1972+ after 12/6/75

Table B38. Production of mountain whitefish (kg/ha) for the recently bulldozed site in the Blacksmith Fork River, Cache County, Utah. Period used for annual production estimate is shown by dashed lines.

Interval	Year Class						Total
	1976	1975	1974	1973	1972[a]	1971+	
8/11/75 to 10/4/75	----	0.00	0.06	0.00	0.23	0.00	0.30
10/4/75 to 12/4/75	----	0.00	0.12	2.27	-0.85	0.00	1.54
12/4/75 to 2/19/76	0.00	0.02	0.37	0.00	2.56	----	2.94
2/19/76 to 6/14/76	0.00	0.00	0.59	0.00	0.40	----	0.99
6/14/76 to 8/20/76	0.00	0.00	0.00	0.00	0.00	----	0.00
8/20/76 to 10/7/76	0.00	0.00	0.00	0.00	0.00	----	0.00
10/7/76 to 11/24/76	0.00	0.00	0.00	0.19	0.00	----	0.19

[a] 1972+ after 12/4/75

Table B39. Production of mountain whitefish (kg/ha) for the old bulldozed site in the Blacksmith Fork River, Cache County, Utah. Period used for annual production estimate is shown by dashed lines.

	Year Class						
Interval	1976	1975	1974	1973	1972[a]	1971+	Total
10/4/75 to 12/4/75	----	0.00	0.18	5.12	-1.25	-0.51	3.54
12/4/75 to 2/19/76	0.00	0.00	0.29	0.00	4.60	----	4.89
2/19/76 to 6/14/76	0.00	0.00	0.57	0.93	0.73	----	2.23
6/14/76 to 8/20/76	0.07	0.00	0.00	0.00	0.00	----	0.07
8/20/76 to 10/7/76	0.07	0.00	0.00	0.00	0.00	----	0.07
10/7/76 to 11/24/76	0.00	0.00	-0.26	0.68	0.60	----	1.02

[a]1972+ after 12/4/75

APPENDIX C

Reliability of the Mechanical Device for Subsampling Invertebrates

Index of dispersion (variance to mean ratio) tests for agreement with Poisson series were calculated for 25 actual samples with 8 subsamples each. Of 286 observations, 274 fell within the 95 percent confidence limits for a Poisson series, 3 indicated regular distribution, and 9 indicated contagious distribution (Tables 1 and 2).

A goodness-of-fit-test for agreement with a Poisson distribution was calculated for an artificial universe (created with 3 taxa) distributed in 32 subsamples. Frequency tables are shown for each taxa (Tables 3-5) and total insects (Table 6). All of these goodness-of-fit-tests showed agreement with a Poisson series at the 95% probability level. These two tests indicated that the subsampler gave random subsamples from the original sample.

Table C1. Summary of index of dispersion (variance to mean ratio) tests for agreement with a Poisson series for 286 observations (taxa-sieve combinations of 25 samples each distributed into 8 subsamples). Columns summarize the number of times each sieve fell within or outside of the 95% probability ($p < 0.05$, d.f. = 7) of agreement with the Poisson series (Elliot 1971).

Sieve Size	Type of Distribution Regular	Random	Contagious
14	0	65	0
18	1	46	1
25	1	48	0
35	1	38	1[e]
45	0	35	4[a,b,d]
60	0	42	3[c,e]
Total	3	274	9

[a]Small sample size caused clumped distribution; in this case all three individuals were found in one subsample.

[b]Problems associated with one taxa were often reflected in the totals. In the example noted, Brachycentrids were abundant and clumped, giving the same distribution to total invertebrates. Without the Brachycentrids the totals were randomly distributed.

[c]Problems in identification by technicians were suspected. In the example noted, there was apparently confusion between the smallest Ephemerelidae (E) and Leptophlebiidae (L). Different subsamples were high in one and low in the other, i.e.:

E	0	3	12	11	19	15	26	14
L	19	12	17	7	5	7	6	3

[d]Some organisms, such as the tubificids noted above, tangle together and/or are broken in the subsampler and counted as more than one individual (this was the same sample discussed in footnote "b").

[e]In two cases the invertebrate totals exhibited clumped distribution although all the taxa included were randomly distributed. In these two exceptions, the distribution was barely outside the 95% confidence limit.

Table C2. Summary of index of dispersion (variance to mean ratio) tests for agreement with a Poisson series for 286 observations (taxa-sieve combinations of 25 samples each distributed into 8 subsamples). Columns summarize the number of times each taxa fell within or outside of the 95% probability ($p<0.05$), d.f. = 7) of agreement with the Poisson series (Elliot 1971).

Taxonomic Group	Type of Distribution		
	Regular	Random	Contagious
Hydracarina	0	14	0
Plecoptera			
Pteronarcidae	0	3	0
Nemouridae	0	1	0
Chloroperlidae	0	21	0
Perlodidae	1	20	1[a]
Acroneuria (Perlidae)	0	2	0
Trichoptera			
Hydropsychidae	0	8	0
Rhyacophilidae			
Rhyacophila	0	3	0
Glossosoma	0	9	0
Hydroptilidae	0	1	0
Brachycentridae	0	6	1[b]
Leptoceridae	1	14	0
Ephemeroptera			
Heptageniidae	0	21	0
Ephemerella (Ephemerellidae)	0	21	1[c]
Baetidae	1	20	0
Paraleptophlebia (Leptophlebiidae)	0	17	1[c]
Diptera			
Tipulidae	0	1	0
Simuliidae	0	13	0
Chironomidae larvae	0	22	0
Chironomidae pupae	0	13	1
Coleoptera			
Elmidae larvae	0	19	0
Elmidae adults	0	5	0
Tubificidae	0	2	1[d]
All invertebrates combined	0	22	3

[a-e]See preceding table footnotes a-e.

Table C3. Chi-square (x^2) test for goodness-of-fit to a Poisson series for a sample containing 292 Elmidae larvae distributed into 32 subsamples (mean = 9.125). The obtained x^2 value of 5.28 is significantly below the value of 18.31 where α = 0.050 and d.f. = 10 (Snedecor and Cochran 1967). Therefore the subsamples follow a Poisson series.

Number of Insects	Observed Frequency	Expected Frequency	Ratio of Obs.-Exp.	x^2
0-4	1	1.62	-0.63	0.24
5	2	1.84	0.16	0.14
6	1	2.80	-1.80	1.15
7	5	3.64	1.35	0.51
8	7	4.15	2.85	1.95
9	4	4.21	-0.21	0.01
10	4	3.84	0.16	0.01
11	3	3.19	-0.19	0.01
12	1	2.42	-1.43	0.84
13	1	1.70	-0.70	0.30
14	1	1.11	-0.11	0.01
15 or more	2	1.44	-0.56	0.22
Total	32	31.98		5.28

Table C4. Chi-square (x^2) test for goodness-of-fit to a Poisson series for a sample containing 300 Simuliidae larvae distributed into 32 subsamples (mean = 9.375). The obtained x^2 value of 6.92 is significantly below the value of 18.31 where α= 0.050 and d.f. = 10 (Snedecor and Cochran 1967). Therefore the subsamples follow a Poisson series.

Number of Insects	Observed Frequency	Expected Frequency	Ratio of Obs.-Exp.	x^2
0-4	0	1.40	-1.40	1.39
5	1	1.64	-0.64	0.25
6	5	2.56	2.44	2.33
7	4	3.48	0.52	0.08
8	3	4.02	-1.01	0.26
9	3	4.18	-1.18	0.34
10	6	3.93	2.07	1.09
11	3	3.35	-0.35	0.04
12	2	2.62	-0.62	0.15
13	3	1.89	1.11	0.66
14	1	1.26	-0.26	0.06
15 or more	1	1.71	0.71	0.29
Total	32	32.01		6.92

Table C5. Chi-square (x^2) test for goodness-of-fit to a Poisson series for a sample containing 197 Heptageniidae nymphs distributed into 32 subsamples (mean = 6.156). The obtained x^2 value of 6.97 is significantly below the value of 15.51 where α = 0.050 and d.f. = 8 (Snedecor and Cochran 1967). Therefore the subsamples follow a Poisson series.

Number of Insects	Observed Frequency	Expected Frequency	Ratio of Obs.-Exp.	x^2
0-2	4	1.77	2.23	2.81
3	2	2.64	-0.64	0.15
4	4	4.06	-0.06	0.00
5	4	5.00	-1.00	0.20
6	6	5.13	0.87	0.15
7	2	4.51	-2.51	1.40
8	2	3.47	-1.47	0.62
9	3	2.37	0.63	0.17
10	2	1.46	0.54	0.30
11 or more	3	1.58	1.42	1.27
Total	32	32.00		6.97

Table C6. Chi-square (x^2) test for goodness-of-fit to a Poisson series for a sample containing 789 insect larvae distributed into 32 subsamples (mean = 24.656). The obtained x^2 value of 8.86 is significantly below the value of 23.68 where α = 0.050 and d.f. = 14 (Snedecor and Cochran 1967). Therefore the subsamples follow a Poisson series.

Number of Insects	Observed Frequency	Expected Frequency	Ratio of Obs.-Exp.	x^2
0-17	2	2.20	-0.20	0.01
18	2	1.11	0.89	0.71
19	3	1.44	1.56	1.69
20	1	1.78	-0.78	0.34
21	2	2.09	-0.09	0.00
22	1	2.34	-1.34	0.77
23	3	2.51	0.50	0.10
24	1	2.57	-1.57	0.96
25	2	2.54	-0.54	0.11
26	2	2.40	-0.41	0.07
27	3	2.19	0.80	0.29
28	2	1.94	0.06	0.00
29	1	1.65	-0.65	0.25
30	1	1.35	-0.35	0.09
31	3	1.08	1.92	3.44
32 or more	3	2.81	0.19	0.01
Total	32	31.99		8.86

APPENDIX D

LIST OF MACROINVERTEBRATES COLLECTED FROM
THE STUDY SITES ON THE BLACKSMITH FORK AND LOGAN RIVERS,
CACHE COUNTY, UTAH 1975-76

Table D1. List of macroinvertebrates collected from the control site of the Blacksmith Fork River, Cache County, Utah 1975-76.

Class/Order	Family	Genus/Species
Acarina		
	Hydrachinidae	
		Hydracarina sp.
Plesiopora		
	Tubificidae	
Nematoda		
Opisthopora		
	Lumbricidae	
Gastropoda		
Pelecypoda		
	Sphaeriidae	
Decapoda		
	Astacidae	
Collembola		
Plecoptera		
	Pteronarcidae	
		Pteronarcella badia
	Nemouridae	
		Capnia confusa
	Chloroperlidae	
		Alloperla severa
	Perlodidae	
		Isoperla fulva
		Arcynopteryx signata
	Perlidae	
		Acroneuria pacifica
Trichoptera		
	Hydropsychidae	
		Hydropsyche sp.
	Rhyacophilidae	
		Rhyacophila arcopedes-wallowa
		Glossosoma sp.
	Hydroptilidae	
	Brachycentridae	
		Brachycentrus americanus
		Micrasema sp.

Table D1. Continued

Class/Order	Family	Genus/Species
	Lepidostomatidae	
		Lepidostoma sp.
Ephemeroptera		
	Heptagniidae	
		Rhithrogena sp.
	Ephemerellidae	
		Ephemerella coloradensis
	Baetidae	
		Baetis sp.
	Leptophelibiidae	
		Paraleptophlebia sp.
Hemiptera		
	Corixidae	
Diptera		
	Tipulidae	
		Tipula sp.
		Antocha sp.
		Hexatoma sp.
		Dicranota sp.
		Limonia sp.
		Genus 1
	Ptychopteridae	
		Ptychoptera sp.
	Psychodidae	
		Pericoma sp.
	Simuliidae	
	Stratiomyidae	
	Rhagionidae	
		Atherix variegata
	Empidae	
	Chironomidae	
	Ceratopogonidae	
Coleoptera		
	Elmidae	
	Dytiscidae	
	Haliplidae	

Table D2. List of macroinvertebrates collected from the recently dredged site of the Blacksmith Fork River, Cache County, Utah, 1975-76.

Class/Order	Family	Genus/Species
Acarina		
	Hydrachnidae	
		Hydracarina sp.
Amphipoda		
	Gammaridae	
Plesiopora		
	Tubificidae	
Nematoda		
Opisthopora		
	Lumbricidae	
Gastropoda		
	Sphaeriidae	
Decapoda		
	Astacidae	
Rhynchobdellida		
	Glossiphonidae	
Lepidoptera		
	Pyrallidae	
		Paragyractus sp.
Collembola		
Odonata		
	Coenagrionidae	
		Argia sp.
Plecoptera		
	Pteronarcidae	
		Pteronarcella badia
	Nemouridae	
	Chloroperlidae	
		Alloperla severa
	Perlodidae	
		Isoperla fulva
		I. patricia
		Arcynopteryx signata
		Isogenus sp.
	Perlidae	
		Acroneuria pacifica

Table D2. Continued

Class/Order	Family	Genus/Species
Trichoptera		
	Philoptomatidae	
	Hydropsychidae	*Hydropsyche* sp.
	Rhyacophilidae	
		Rhyacophila arcopedes-wallowa
		Glossosoma sp.
	Hydroptilidae	
	Brachycentridae	
		Brachycentrus americanus
		Micrasema
	Lepidostomatidae	
		Lepidostoma sp.
Ephemeroptera		
	Heptageniidae	
		Rhithrogena sp.
		Cinygmula sp.
		Ironopsis sp.
	Ephemerellidae	
		Ephemerella coloradensis
		E. sp.
	Baetidae	
		Baetis sp.
		Centroptilum sp.
	Leptophlebiidae	
		Paraleptophlebia sp.
	Siphulanuridae	
		Siphulanurus sp.
Hemiptera		
	Corixidae	
	Gerridae	
Diptera		
	Tipulidae	
		Tipula sp.
		Hexatoma sp.
		Antocha sp.
		Dicranota sp.
		Genus 1
		Genus 2
		Genus 3
	Simuliidae	
	Stratiomyidae	
	Tabanidae	
	Rhagionidae	
		Atherix variegata

Table D2. Continued.

Class/Order	Family	Genus/Species
	Empidae	
	Chironomidae	
Coleoptera		
	Elmidae	
	Dytiscidae	
	Haliplidae	

Table D3. List of macroinvertebrates collected from the recently bulldozed site of the Blacksmith Fork River, Cache County, Utah, 1975-76.

Class/Order	Family	Genus/Species
Acarina		
	Hydrachnidae	
		Hydracarina sp.
Plesiopora		
	Tubificidae	
Nematoda		
Opisthopora		
	Lumbricidae	
Gastropoda		
Pelecypoda		
	Sphaeriidae	
Rhynchobdellida		
	Glossiphonidae	
Collembola		
Plecoptera		
	Pteronarcidae	
		Pteronarcella badia
	Nemouridae	
	Chloroperlidae	
		Alloperla severa
	Perlodidae	
	Perlidae	
		Acroneuria pacifica
Trichoptera		
	Philoptomatidae	
	Hydropsychidae	
		Hydropsyche sp.
	Rhyacophilidae	
		Rhyacophila arcopedes-wallowa
		Glossosoma sp.
	Hydroptilidae	
	Brachycentridae	
		Brachycentrus americanus
		Micrasema sp.
	Lepidostomatidae	
		Lepidostoma sp.
Ephemeroptera		
	Heptageniidae	
		Rhithrogena sp.

Table D3. Continued.

Class/Order	Family	Genus/Species
	Ephemerellidae	
		Ephemerella coloradensis
	Baetidae	
		Baetis sp.
	Leptophlebiidae	
		Paraleptophlebia sp.
Hemiptera		
	Corixidae	
Diptera		
	Tipulidae	
		Tipula sp.
		Hexatoma sp.
		Antocha sp.
		Genus 1
		Dicranota sp.
	Psychodidae	
		Pericoma sp.
	Simuliidae	
	Stratiomyidae	
	Rhagionidae	
		Atherix variegata
	Empidae	
	Chironomidae	
Coleoptera		
	Elmidae	
	Dytiscidae	

Table D4. List of macroinvertebrates collected from the old bulldozed site of the Logan River, Cache County, Utah, 1975-76.

Class/Order	Family	Genus/Species
Acarina		
	Hydrachnidae	
		Hydracarina sp.
Amphipoda		
	Gammaridae	
Plesiopora		
	Tubificidae	
	Naididae	
Nematoda		
Tricladia		
	Planariidae	
Rhynchobdellida		
	Glossiphonidae	
Opisthopora		
	Lumbricidae	
Gastropoda		
Pelecypoda		
	Sphaeriidae	
Plecoptera		
	Pteronarcidae	
		Pteronarcella badia
	Nemouridae	
	Chloroperlidae	
	Perlodidae	
		Isoperla fulva
		Arcynopteryx parallela
	Perlidae	
		Acroneuria pacifica
Trichoptera		
	Philoptomatidae	
	Hydropsychidae	
		Arctopsyche sp.
	Rhyacophilidae	
		Rhyacophila arcopedes-wallowa
		Glossosoma sp.
	Hydroptilidae	
	Brachycentridae	
		Brachycentrus americanus
		Micrasema sp.

Table D4. Continued.

Class/Order	Family	Genus/Species
	Limnephilidae	
	Lepidostomatidae	
		Lepidostoma sp.
Ephemeroptera		
	Heptageniidae	
		Rhithrogena sp.
	Ephemerellidae	
		Ephemerella coloradensis
		Ephemerella sp.
	Baetidae	
		Baetis sp.
	Siphulanuridae	
		Ameletus sp.
	Leptophlebiidae	
		Paraleptophlebia sp.
Hemiptera		
	Corixidae	
Diptera		
	Tipulidae	
		Tipula sp.
		Hexatoma sp.
		Genus 1
		Genus 2
		Antocha sp.
		Dicranota sp.
	Psychodidae	
		Pericoma sp.
	Simuliidae	
	Stratiomyidae	
		Odontomyia sp.
	Rhagionidae	
		Atherix variegata
	Empidae	
	Chironomidae	
Coleoptera		
	Elmidae	
	Dytiscidae	
	Haliplidae	

APPENDIX E

MEAN TOTAL LENGTHS OF SELECTED INVERTEBRATE FAMILIES AS SORTED BY U.S. STANDARD SIEVES

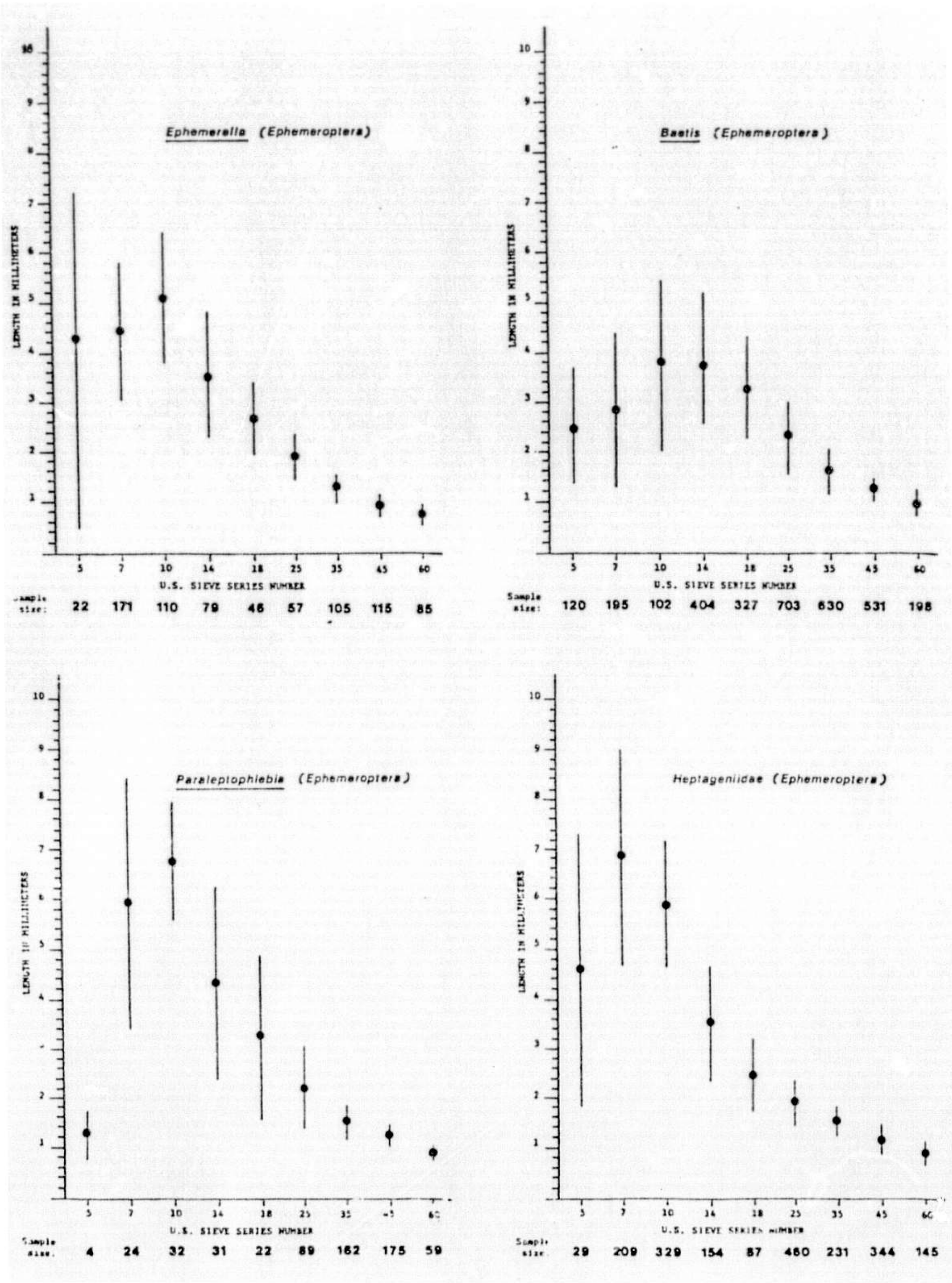

Figure E1. Relation of mean total length (± 1 standard deviation) of invertebrate taxa with U.S. standard sieves.

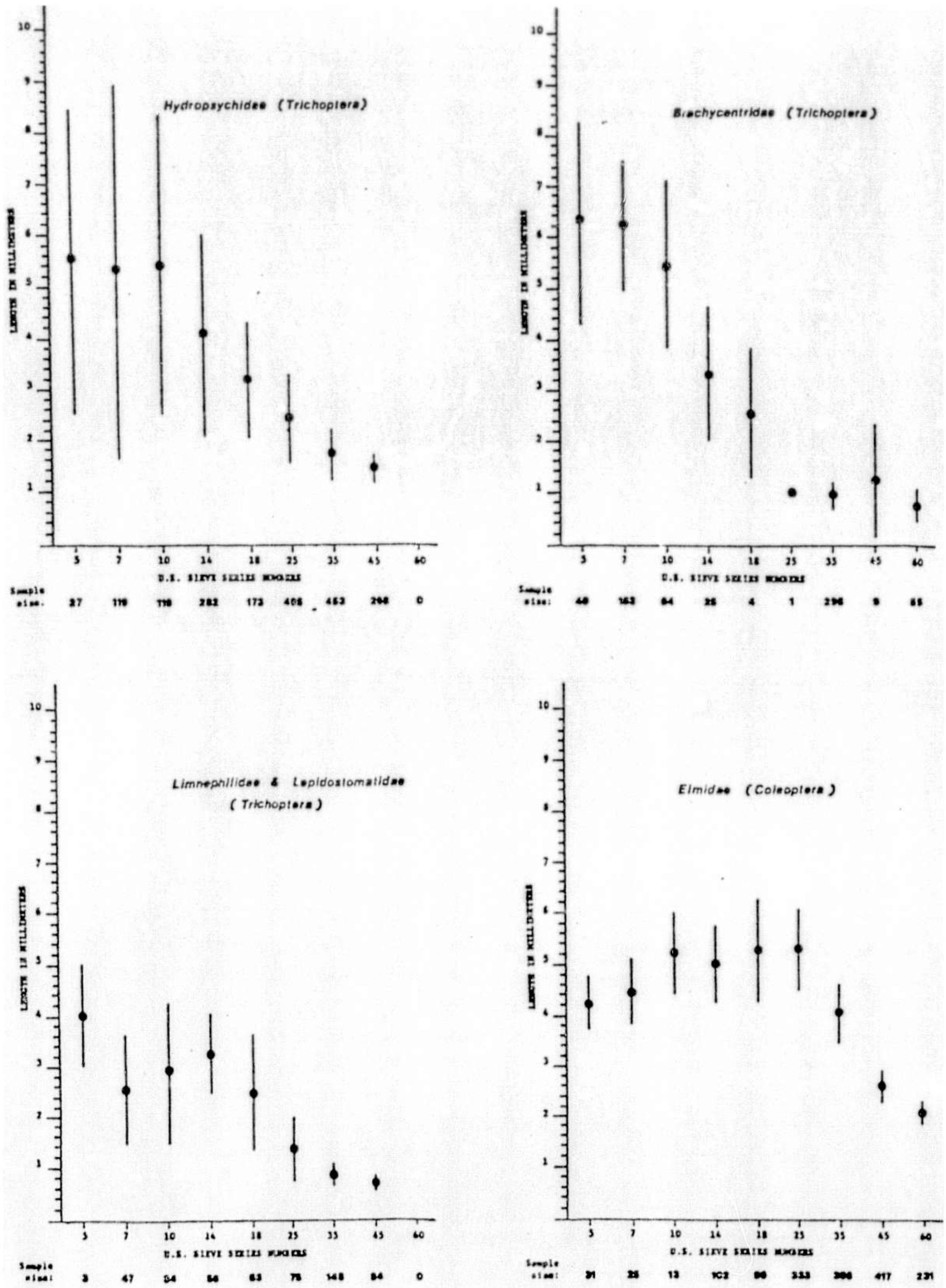

Figure E2. Relation of mean total length (± 1 standard deviation) of invertebrate taxa with U.S. standard sieves.

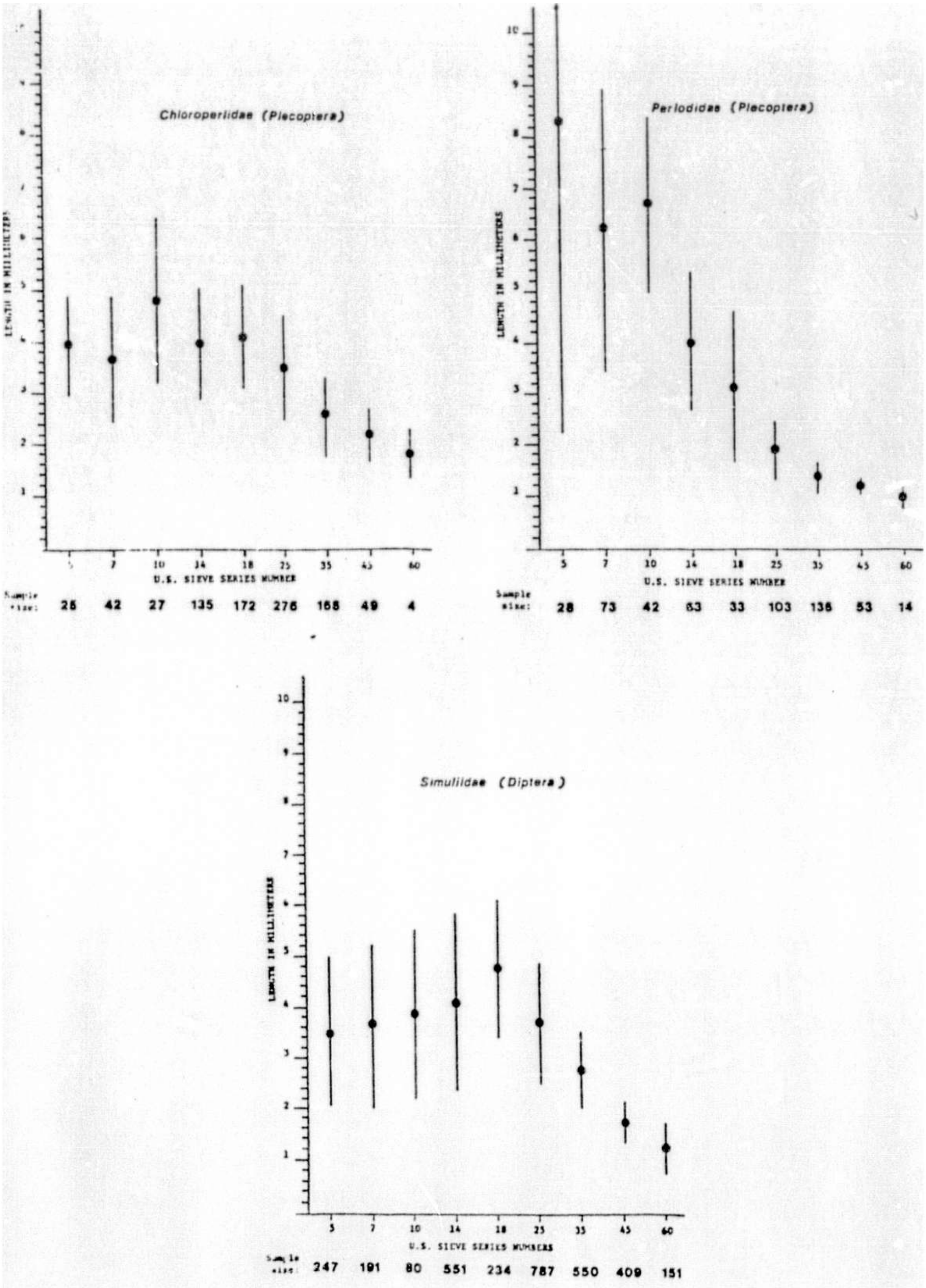

Figure E3. Relation of mean total length ± 1 standard deviation) of invertebrate taxa with U.S. standard sieves.

APPENDIX F

MEAN ASH-FREE DRY WEIGHTS OF SELECTED

INVERTEBRATE FAMILIES BY SIEVE SIZE

Table F1. Slopes, y-intercepts, correlation coefficients, and sieve sizes used to calculate regressions of log ash-free dry weight vs. sieve size for various invertebrates.

Taxon	Sieve sizes	Slope	y-intercept	Correlation coefficient
Hydracarina	25-60	-.4886	-.9272	.9901
Plecoptera				
Pteronarcidae	5-25	-.4227	-1.4649	.9939
Nemouridae	7-25	-.3388	-2.0929	.9843
Chloroperlidae	10-45	-.2223	-2.6444	.9905
Perlodidae	10-35	-.4174	-1.6629	.9963
Perlidae				
Acroneuria	5-25	-.4958	-1.0769	.9636
Trichoptera				
Hydropsychidae	7-45	-.3965	-1.6132	.9976
Rhyacophilinae	5-25	-.4186	-1.6701	.9723
Glossostomatinae	10-25	-.5133	-1.2683	.9622
Brachycentridae	5-25	-.4445	-1.8014	.9833
Lepidostomatidae & Limnephilidae	7-35	-.2982	-2.7122	.9761
Ephemeroptera				
Heptageniidae	7-45	-.4322	-1.6844	.9948
Ephemerellidae				
Ephemerella	5-45	-.3955	-2.0315	.9811
Baetidae				
Baetis	14-60	-.3541	-1.9352	.9938
Leptophlebiidae				
Paraleptophlebia	10-45	-.3511	-2.0444	.9973
Diptera				
Tipulidae				
Genus 1	14-35	-.2882	-2.4050	.9990
Tipula	5-10	-.7292	- .3961	.9321
Hexatoma	5-18	-.1768	-1.3926	.9867
Simuliidae	14-60	-.3091	-2.2434	.9621
Chironomidae	14-45	-.1896	-3.5125	.9821
Coleoptera				
Elmidae	18-45	-.4273	-1.5426	.9867
Combined Taxa	5-60	-.3206	-2.2440	.9988

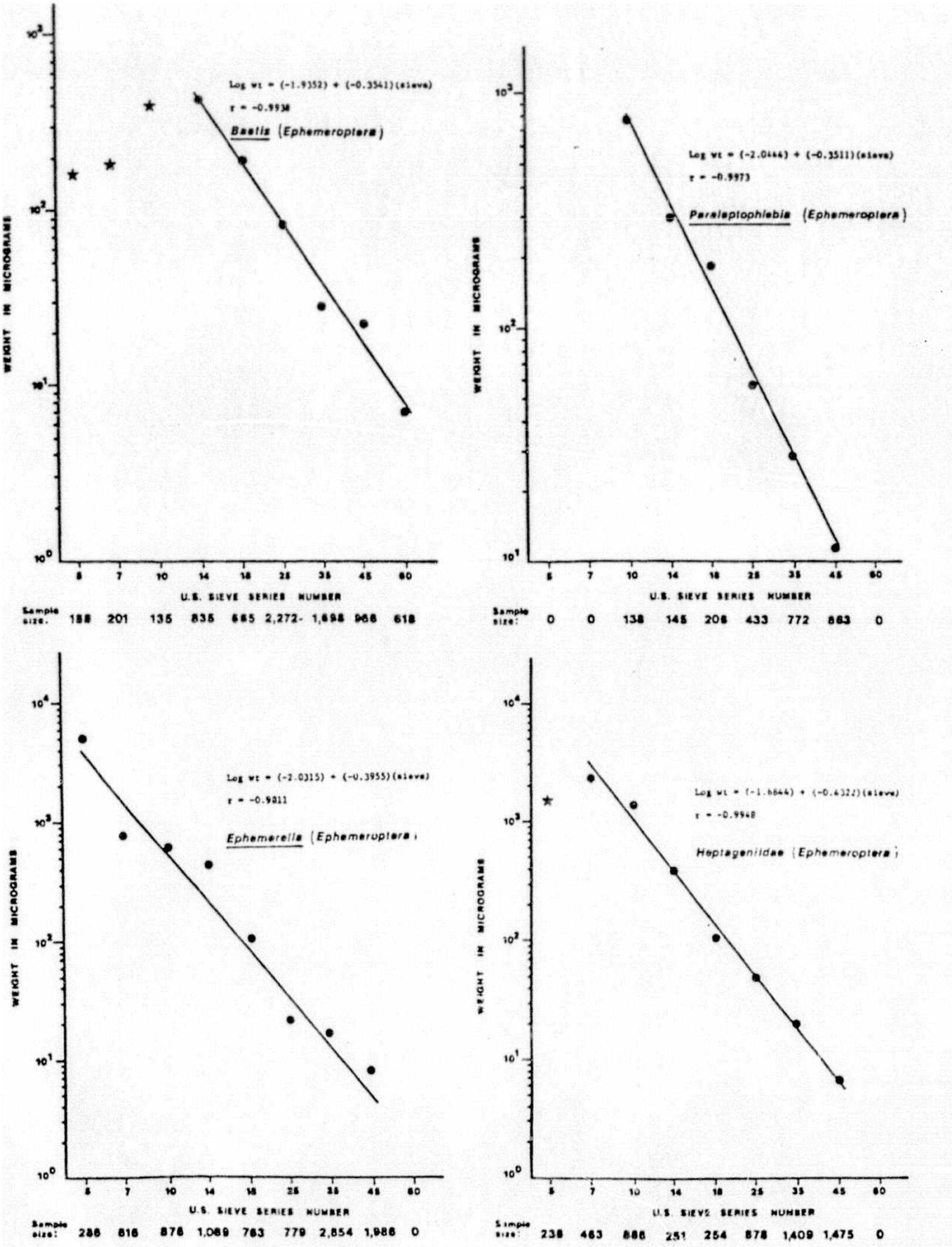

Figure F2. Relation of ash-free dry weight of invertebrate taxa to U.S. standard sieves.

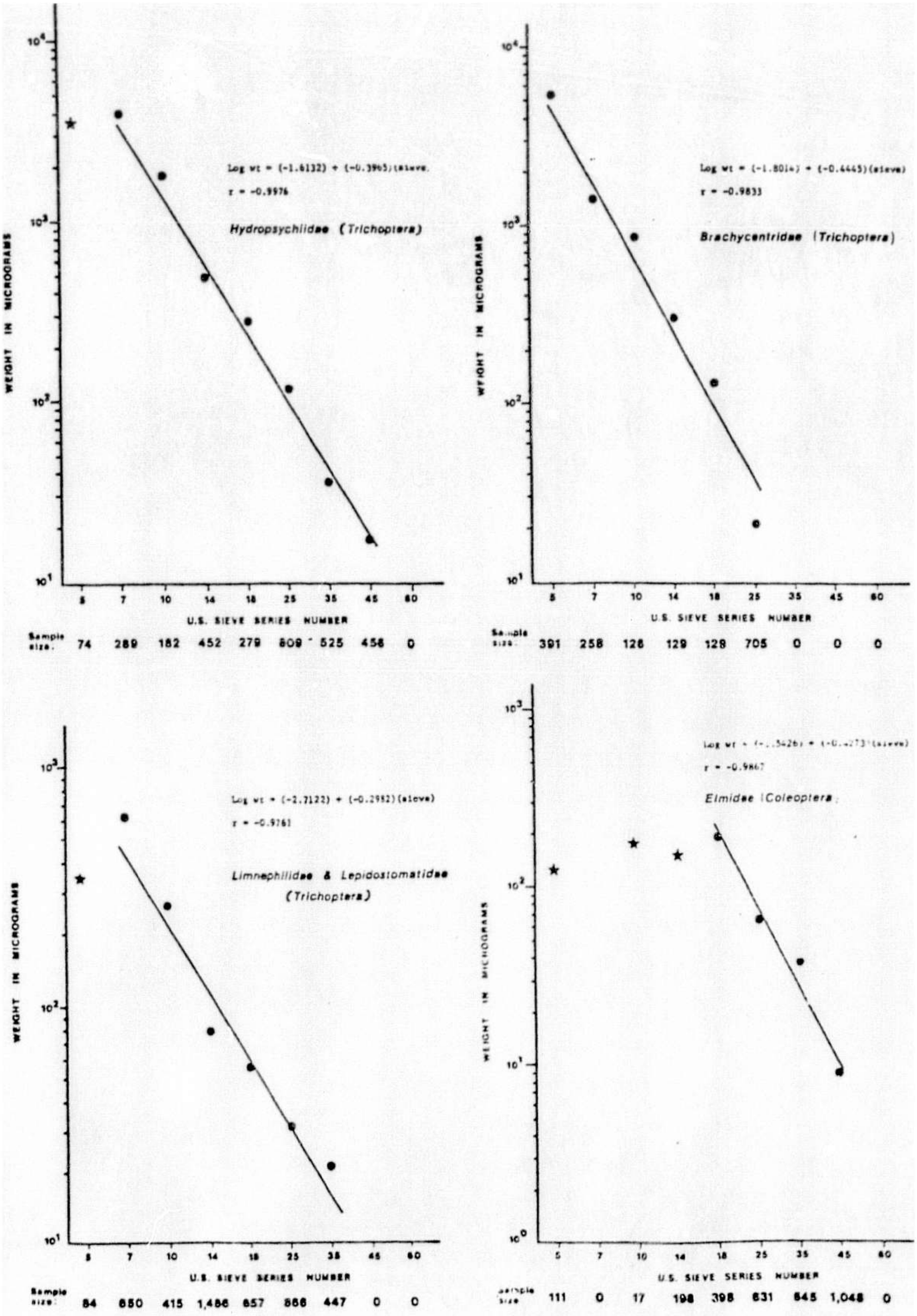

Figure F3. Relation of ash-free dry weight of invertebrate taxa to U.S. standard sieves.

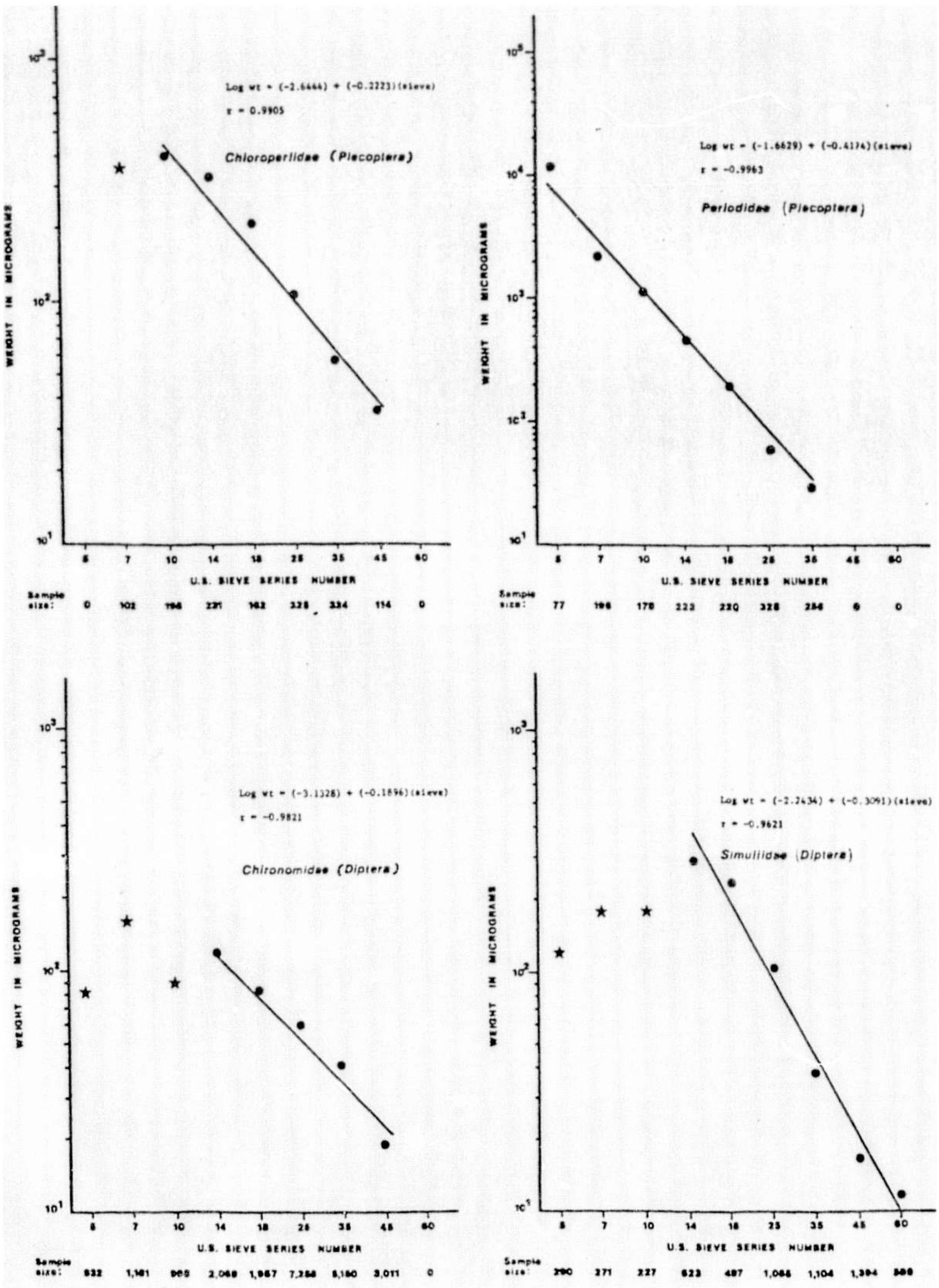

Figure F4. Relation of ash-free dry weight of invertebrate taxa to U.S. standard sieves.

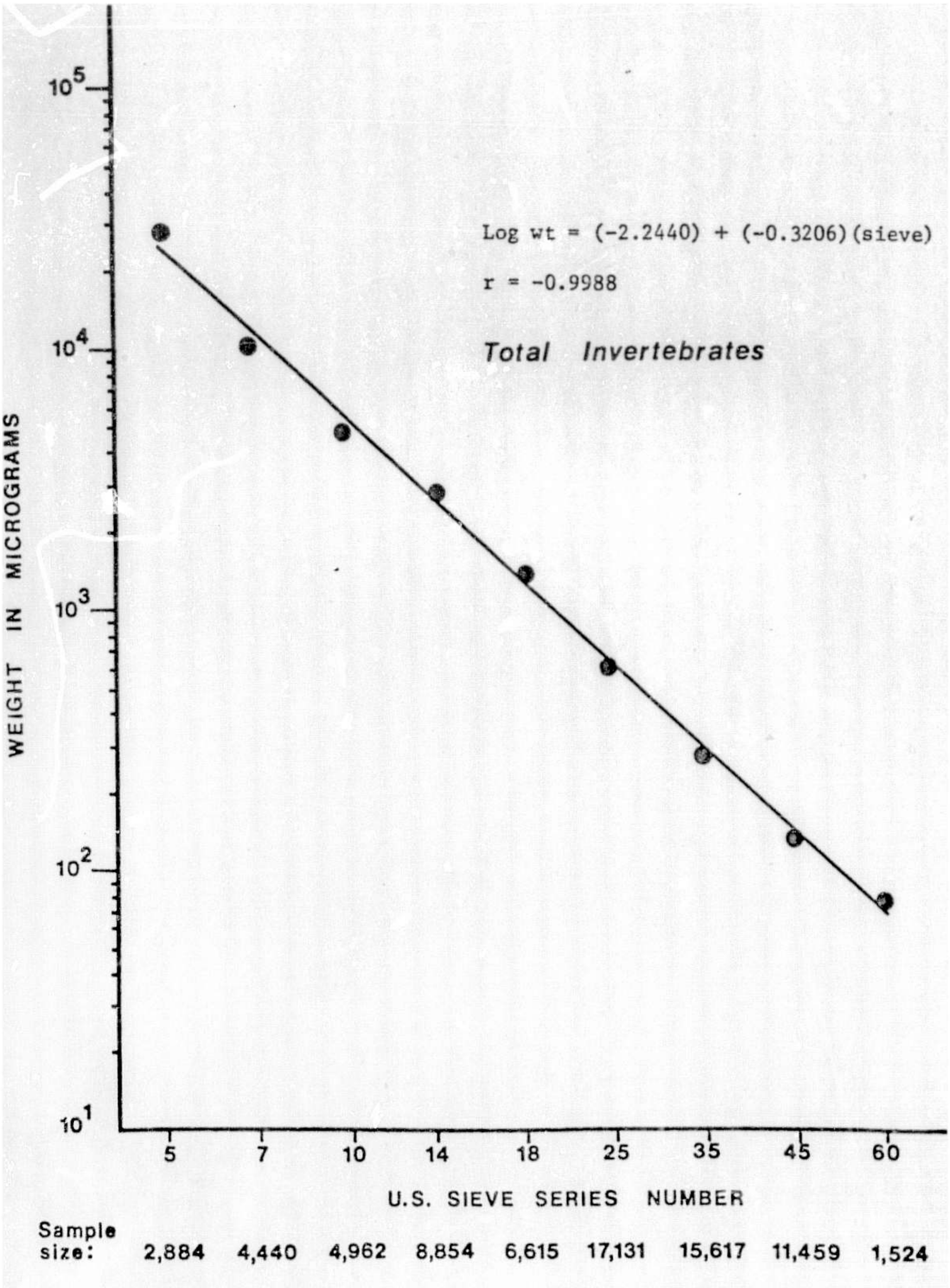

Figure F5. Relation of ash-free dry weight of total invertebrates to U.S. standard sieves.

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