Impact of suction dredging on water quality, benthic habitat, and biota in the Fortymile River and Resurrection Creek, Alaska

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Unit Conversions

Throughout this report all results are presented in SI units. Conversions between SI units and English units are presented below for common measures.

To Convert	To	Multiply By
meters (m)	feet	3.28
centimeters (cm)	inches	0.394
liters (L)	gallons	0.265
grams (g)	ounces	0.035

For SI Units:

1 kilometer (km)	= 1,000 meters (m)
1 meter (m)	= 100 centimeters (cm)
1 liter (L)	= 1,000 milliliters (mL)
1 gram (g)	= 1,000 milligrams (mg)

Summary

This report describes the results of our research during 1997 and 1998 into the effects of commercial suction dredging on the water quality, habitat, and biota of the Fortymile River and recreational dredging on Resurrection Creek. On the Fortymile River, water chemistry, heavy metal concentrations, riverbed morphology, algal (periphyton) standing crop, and aquatic macroinvertebrate abundance and diversity were measured in relation to commercial suction dredging. The focus of our work on the Fortymile in 1997 was on an 8-inch suction dredge (Site 1), located on the mainstem, but the effects of a 10-inch dredge (Site 2), located on the South Fork, also were documented. Both dredges were operated by experienced miners. Sampling was performed at fixed transects above and below the dredge locations. Additional sampling above the confluence of the North and South Forks revealed differences in background conditions in these two main tributaries. Our research in 1998 included (1) resampling the 1997 sites on the mainstem and SF Fortymile, (2) sampling a dredge site on the North Fork Fortymile, and (3) again sampling unmined sites on the NF and SF to better document suspected background differences between the two forks in terms of macroinvertebrate communities.

At Site 1, dredge operation had no discernable effect on alkalinity, hardness, or specific conductance of water in the Fortymile. Of the factors we measured, the primary effects of suction dredging on water chemistry of the Fortymile River were increased turbidity, total filterable solids, and copper and zinc concentrations downstream of the dredge. These variables returned to upstream levels within 80-160 m downstream of the dredge. The results from this sampling revealed a relatively intense, but localized, decline in water clarity during the time the dredge was operating. The impact of suction dredging on water clarity and heavy metal concentrations may be greater or lesser than we measured, depending on the type of material the dredge is excavating.

The cross-sectional profiles indicate that the impact of the dredge piles relative to the width of the river was small. The results indicate that the dredge piles at Site 1 were largely obscured after one year following the scouring flows that accompany snow-melt in the Fortymile drainage. However, at Site 2 the piles were clearly discernable after one year. The abundance

and diversity of macroinvertebrates was greatly reduced in the first 10 m below the dredge at Site 1, relative to the upstream reference site. For example, macroinvertebrate abundance was reduced by 97% and the number of taxa by 88% immediately below the dredge. The abundance and diversity of macroinvertebrates returned to values seen at the reference site by 80 to 160 m downstream of the dredge. A similar decline in macroinvertebrate abundance and diversity was observed at Site 2. One year after dredging at both Site 1 and Site 2, recovery of macroinvertebrate diversity appeared to be substantial. The cumulative effect of suction dredging on the biota of the Fortymile cannot yet be assessed fully, but is a function of the number of dredges operating concurrently, the size of the dredges, the strategy and effectiveness of their operators, and the rate and extent of re-colonization on the excavated dredge piles.

We compared conditions in the North Fork versus the South Fork of the Fortymile under the hypothesis that the greater background mining activity (of all types) on the SF would result in reduced macroinvertebrate abundance and diversity. We also expected that suction dredging would be relatively less harmful at already impacted sites than at sites that were less disturbed. A 5-fold greater density of macroinvertebrates was found in the NF, relative to the SF, and this we attributed to the greater food resource (periphyton standing crop and benthic organic matter) that occurred in the NF. We could discern no natural reason for this difference and therefore attribute this result to the greater disturbance in the SF from all forms of mining, historic and current. A future report will examine results directed towards the hypothesis that the relative impact from suction dredging will be greater in the NF than in the already impaired SF.

The second component of this project was to examine the effects of recreational suction dredging on smaller streams in Alaska. In 1997, sampling was conducted on a single site on Resurrection Creek, a designated recreational mining stream on the Kenai Peninsula. In 1998, sampling was conducted on Resurrection Creek, as well as on two additional streams known to be popular for recreational dredging. The Chatanika River was sampled at a location north of Fairbanks, and Cooper Creek was sampled near its confluence with the Kenai River. The results from Resurrection Creek indicated that there was no difference in the macroinvertebrate community between the mining area and the locations downstream of the mining area, in terms of macroinvertebrate density, taxa richness, and EPT richness. In general, our results are in agreement with other studies that have found only localized reductions in macroinvertebrate abundance in relation to recreational suction mining.

Introduction

This report describes the results of research performed during 1997and 1998 to describe the possible impacts of suction dredging on the water quality, benthic habitat, and biota of the Fortymile River, Alaska (hereafter, Fortymile).

In stream ecosystems, aquatic macroinvertebrates have become the primary assessment tool for resource managers (see Barbour et al. 1996, Cairns and Pratt 1993). Several characteristics of aquatic macroinvertebrates, as a group, have led to their general acceptance as reliable indicators of ecological condition: (1) they are generally immobile (relative to fish), (2) they consist of a relatively large number of species that, collectively, display a range of sensitivities and responses to various types of habitat degradation, (3) they tend to be ubiquitous throughout streams and rivers, and (4) they are relatively easy to sample and identify. For these reasons, our assessment of the effect of suction dredging on the Fortymile focused on macroinvertebrates. In addition to aquatic macroinvertebrates, water chemistry, streambed geomorphology, algal (periphyton) standing crop, and benthic organic matter (BOM) standing crop also were measured in relation to suction dredging. The latter two components form the food base for stream herbivores and detritivores.

Historically, gold mining occurred throughout the Fortymile basin and several types of operations are still active, including placer mining, hydraulic mining, and suction dredging. Our research was limited to investigations on the effects of suction dredging. We addressed two general topics: (1) the effect of relatively large (6-10 inch) commercial suction dredges on ecological conditions in the Fortymile and (2) the general effect of smaller (2-4 inch) recreational suction dredges on benthic habitat and biota. Part I of this report presents the results from the Fortymile; the examination of recreational dredging was conducted in Resurrection Creek and Cooper Creek on the Kenai Peninsula, and the Chatanika River north of Fairbanks, and is presented in Part II.

Suction dredging typically involves excavating the deeper, largely uninhabited sediments and depositing them on top of the ecologically important surface substrates. Sorting and re-deposition of substrata moved through a dredge were expected to alter the streambed geomorphology and create “dredge piles” downstream of the dredges. Our effort here was directed toward determining the size (height, width) of the dredge piles, relative to the cross-sectional width of the river. This type of physical disturbance of benthic substrata generally reduces periphyton standing crop, BOM, and macroinvertebrate density. Thus, substrata moved through the dredge were expected to support less periphyton than substrata in undisturbed areas of the river (see Peterson 1996). Abundance and diversity of macroinvertebrates also were expected to be sharply reduced in dredged areas, as physical tumbling of substrata is known to kill and/or dislodge associated organisms (see Resh et al. 1988 for review), in addition to reducing the food base.

The impact of commercial suction dredging on benthic organisms was evaluated in 1997 on the South Fork and the mainstem Fortymile River. In addition to resampling the 1997 mainstem and South Fork dredge sites again in 1998, we expanded our sampling to include one dredge site on the North Fork and two additional sites on the South Fork. We also sampled three reference sites unaffected by mining activity on the North and South Forks. Overall, our goals for 1998 were (1) to determine the potential for recolonization of the previous year's dredge spoils, (2) to expand the spatial scale of our sampling by including sites that were dredged early (June), and late (September) in the season, and in different geomorphic settings (inside and outside of a meander bend), (3) to sample dredged sites in a less-disturbed portion of the basin (North Fork) than our other sites, and (4) to compare impact and recovery potentials of dredge mining between more disturbed (South Fork), and less disturbed (North Fork) streams in the same basin.

The research on recreational dredging was designed to assess the potential impacts on the aquatic macroinvertebrate community in streams from geographically diverse locations. Several potential sites were examined but most proved to be unsuitable for study because of the absence of discrete areas of concentrated suction dredging confounded by other disturbances. To date, Resurrection Creek and Cooper Creek have been studied on the Kenai Peninsula, as well as the

Chatanika River in the interior of Alaska, north of Fairbanks. Results from the 1997 Resurrection Creek study are presented here. A full report of this portion of the study is given by Prussian (1999).

Methods

Sampling Design - The majority of our work on the Fortymile in 1997 was conducted at a single site, with an 8-inch suction dredge operated by an experienced miner (hereafter, Site 1). Site 1 was located approximately 13 kilometers (8 miles) upstream of the Taylor Highway-Fortymile River Bridge (approximately 141° 30' W, 65° 17' N; Township 7 south, Range 32 east). Sampling was performed at fixed transects above and below the dredge location (Fig. 1). Work at this site occurred from 14 August through 17 August 1997, under baseflow conditions. Less intensive sampling also was conducted below a larger (10 inch) dredge located on the South Fork Fortymile also by a veteran miner (Site 2), and near the mouth of the North Fork Fortymile (NF). Sampling at Site 2 and in the NF was performed from 17-18 August 1997 and was restricted to recently dredged piles and un-dredged reference areas because the dredge was not active at the time, due to elevated water levels and turbidity following an intense rainstorm over an extensive part of the basin.

During 1998, we returned to both Site 1 and Site 2 to determine the degree to which the areas dredged in 1997 had recovered relative to the reference areas. At Site 1, the previous year's dredge piles were re-sampled using the same design as in 1997. At Site 2, the areas that had been dredged in 1997 were re-sampled and two other areas of different location and history were studied for the first time. During 1998, we also sampled a dredge site located on the NF Fortymile to increase the spatial extent of the study and to determine if the NF and SF respond differentially to effects of suction dredging. Also in 1998 the reference site near the mouth of the NF was resampled and a comparable unmined site on the SF just upstream of the confluence was added for better evaluation of potential SF/NF background differences.

The Before-After-Control-Impact (BACI) approach is a powerful and generally accepted sampling design for detecting environmental impacts (e.g., Smith et al. 1993, Stewart-Oaten et al. 1986, Green 1979). For the present study, a BACI design was used for water chemistry and turbidity sampling at Site 1. Water samples were collected prior to and during dredge operation (Before and After) as well as upstream and downstream of the dredge (Control and Impact).

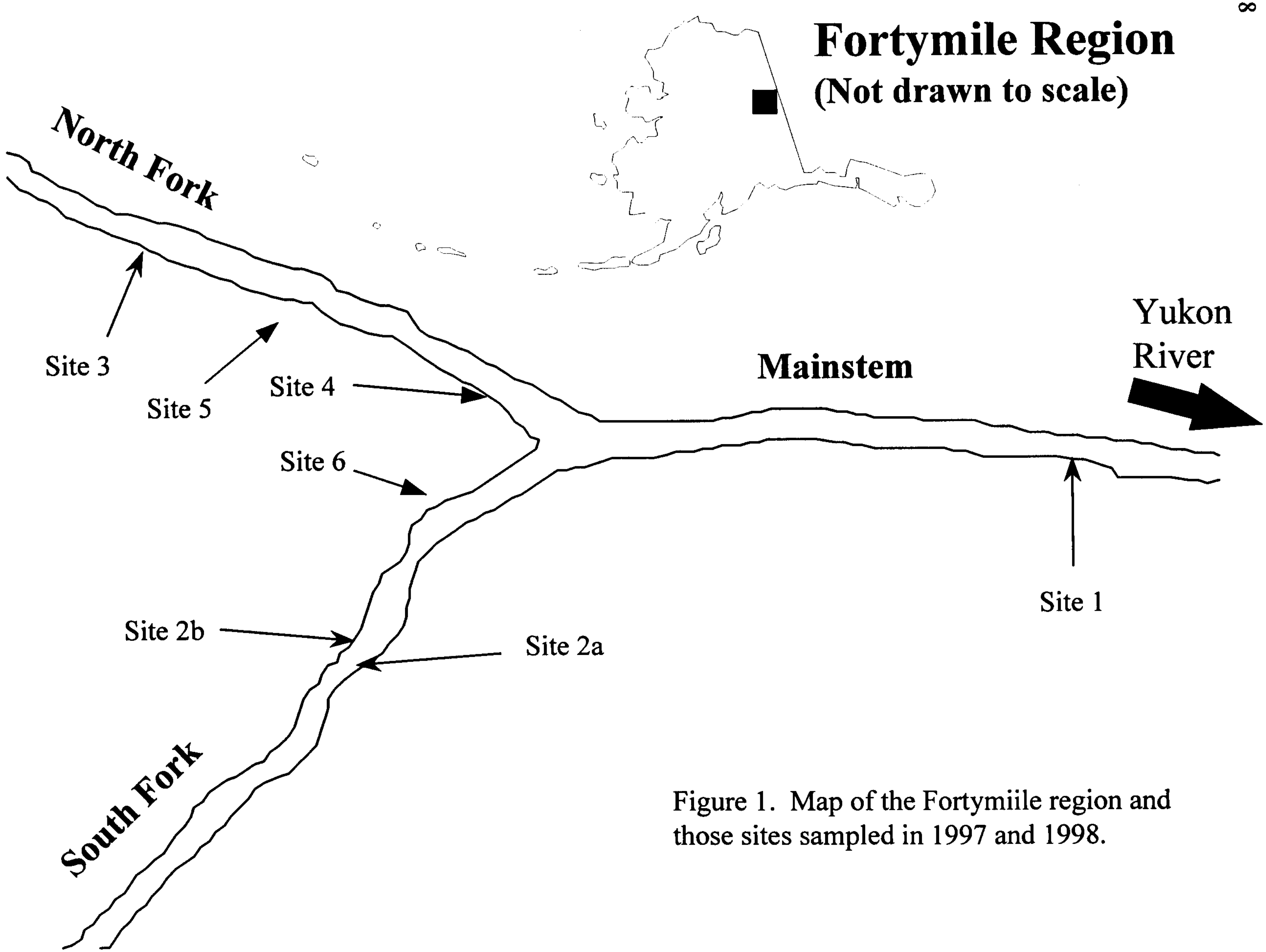


Figure 1. Map of the Fortymiile region and those sites sampled in 1997 and 1998.

Single measurements were made at each of the ten transects. It was not possible to employ a BACI design for periphyton and macroinvertebrate measurements because of the logistic problems associated with using an actual dredge and the limited amount of time available for sampling under baseflow conditions. Instead, samples at Site 1 were collected upstream and downstream of the dredge while the dredge was in operation. Five samples were collected at each transect, except the 0 m, 5 m, and 10 m transects. Sampling the 0 m, 5 m, and 10 m transects individually was not practical due to the narrow width of the dredge piles; collection of five samples across their limited width was not possible. Therefore, ten macroinvertebrate and periphyton samples were collected from the 0-10 m area to document conditions immediately below the dredge. At Site 2, sampling was limited to recent dredge piles located at transects 25, 35, and 70 m below the moored dredge, and a reference transect located 250 m upstream of the dredge. Although the dredge was not in operation during sampling at Site 2, it had been in operation during the preceding week. Finally, the samples from the reference area at Site 2 were used with similarly collected samples from the mouth of the NF to compare conditions in the two forks of the Fortymile River.

Field and Laboratory Methods - The methods used throughout this study are standard and widely accepted techniques in stream ecology. Published reference sources provide detailed instructions regarding these methods (Hauer and Lamberti 1996, APHA 1995, Cuffney et al. 1993, Porter et al. 1993, Platts et al. 1983,). These references often provide multiple methods for sampling a given variable. We selected the techniques that were most applicable to our work on the Fortymile; specific details and modifications used on the Fortymile are described below.

Turbidity, the inverse of water clarity, and specific conductance, a measure of the amount of total dissolved mineral salts in the water, were measured on location with portable meters (Hach model 2100P and Orion model 135, respectively) immediately after collection of the water samples. The meters were calibrated on a regular basis, as indicated in the manufacturer's instructions. Water samples for alkalinity and hardness were stored in insulated containers after collection to minimize chemical and biological activity in the water. For analysis, the samples were sent to the Stream Ecology Center, Idaho State University. The alkalinity and hardness of each sample was determined in the laboratory using standard titration methods (APHA 1995).

Samples for total filterable solids were filtered on location within 3 hours of collection. The filters containing the samples were stored in insulated containers to minimize bacterial degradation of filtered organics. Upon completion of the field sampling, the samples were sent for analysis to the Stream Ecology Center, Idaho State University. These samples were analyzed by determining the amount of mass lost on combustion at 550°C for 3 hours. The amount of mass lost on combustion is equivalent to the organic mass of the sample and is referred to as ash-free dry mass (AFDM). Standard procedures were used to determine the AFDM of the samples (APHA 1995). Total settleable solids were measured on-site immediately after sample collection using Imhoff cones; settleable solids were measured only while the dredge was in operation.

Water samples from the Fortymile River were collected for determination of heavy metal concentrations using the "clean hands/dirty hands" procedure as prescribed by the US Environmental Protection Agency. All materials (sample containers, filters, coolers, etc.) and protocols used in the collection of heavy metal samples were provided by US EPA. Samples were sent for analysis to the US EPA laboratory in Manchester, WA. In 1998, macroinvertebrates were collected to examine the potential of these organisms to concentrate heavy metals within their tissues. Macroinvertebrates were collected from four locations: Alder Creek, Polly Creek, and two locations on the NF Fortymile. Alder and Polly creeks are tributaries to the mainstem of the Fortymile; Alder served as the reference site and Polly as a site that has been mined historically and currently experiences some mining activity. On the NF Fortymile, the USGS has identified an area of upwelling groundwater that potentially is a source for dissolved heavy metals in that river. One of the NF Fortymile sites from which macroinvertebrates were collected was located above this possible heavy metal source, the other downstream of it. After collection, the invertebrates were immediately frozen and kept frozen until analysis. Analysis of the metal concentrations within the invertebrate tissues was conducted by James Crock at the USGS, Mineral Resources Program, Denver. To obtain a sufficient mass of tissue for analysis, all individuals from a site were combined; thus the results are based on a single measurement per site. The invertebrates were dried, pulverized, and weighed. The material was then transferred to a Teflon™ vessel and digested in 10 mL of concentrated nitric acid. One mL of the solution was diluted to 10 mL and analyzed using the USGS standard ICP-MS method. Mercury was determined using a cold vapor-atomic fluorescence spectrometry on a separate 1 mL aliquot diluted to 10 mL in sodium dichromate/nitric acid (James Crock, personal communication).

Description of streambed geomorphology was accomplished by developing cross-sectional profiles (see Platts et al. 1983) of the river at the transects described above (Fig. 2). Distance out from a fixed location on the bank was measured along a (Kevlar) cable stretched taut across the river. At numerous points across the width of the river, the distance from the cable to the water surface and the total water depth were measured. A visual estimate of substrata size and composition also was made at each point.

All macroinvertebrate sampling was done with a Portable Invertebrate Box (PIB) sampler that was modified to be used in water deeper than the height of the sampler. The PIB sampler encompassed 0.093 m^2 of streambed (the sampler was approximately 30 cm on a side). The sampler was placed into position on the streambed and held in place by one operator while the second operator disturbed the substrata enclosed by the sampler to dislodge the organisms. A removable 250µm mesh net was attached to the downstream end of the sampler to collect the dislodged organisms. Although designed to be used in deep water, the current velocity of the Fortymile precluded use of the sampler at most deep-water locations, particularly those in the center of the river. At some deep-water locations, SCUBA techniques were used to collect the samples; SCUBA was required for collection of approximately 5% of the samples collected within the sediment plume. In general, all macroinvertebrate samples were collected from near-shore habitats, approximately 2-30 meters from the bank. This is the same distance from the bank in which the dredge was operating.

Following collection, each sample was placed into a labeled plastic bag (Whirl-pak brand) to which approximately 10-15 ml of concentrated formalin was added to preserve the organisms. In the laboratory, the contents of each macroinvertebrate sample were spread-out in a white sorting tray and all organisms removed. The sorting was accomplished with the aid of a dissecting microscope of 10X magnification. The organisms were then identified to the lowest

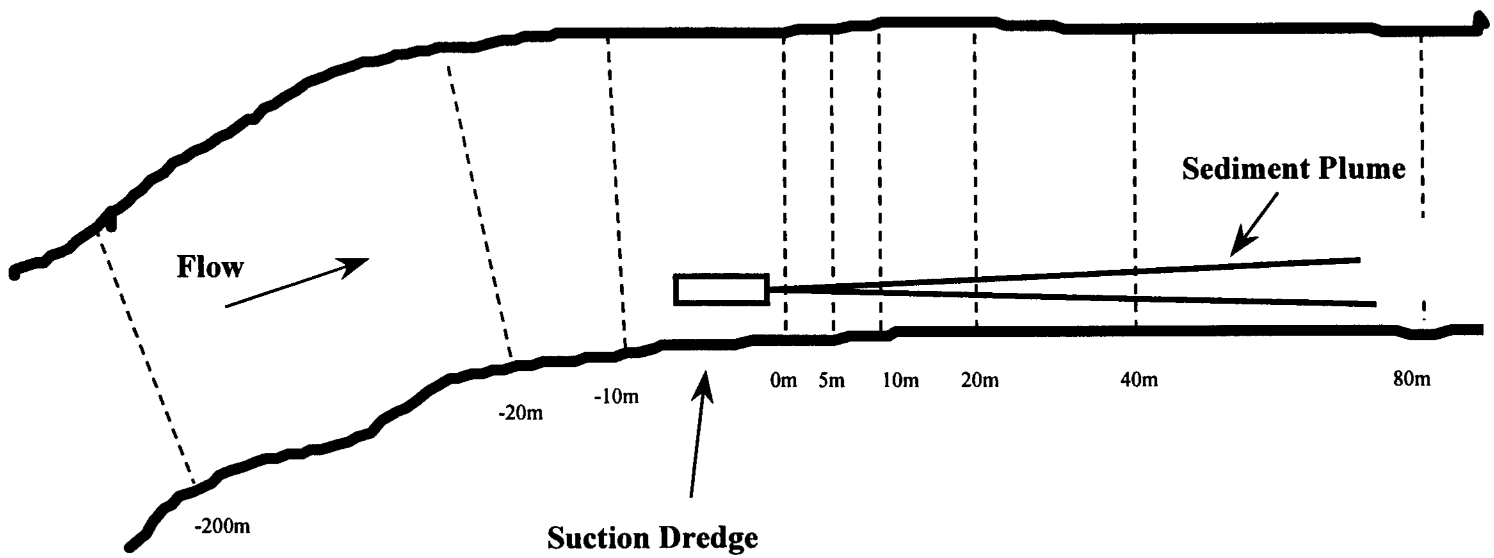


Figure 2. Schematic diagram of the relative position of the sampling transects and the position of the suction dredge. Diagram is <u>not</u> drawn to scale. Different transects were used for various components of the study; not all transects are shown. Most of the sampling occurred within the sediment plume or directly upstream of it.

feasible taxonomic level, usually genus, using published taxonomic references, primarily Merritt and Cummins (1996), Wiggins (1996), and Stewart and Stark (1993). A reference collection was established and voucher specimens will be deposited in the Idaho State Museum of Natural History, Pocatello, Idaho.

Periphyton samples were collected from individual rocks located just upstream of each macroinvertebrate sample. The processing was done immediately after collection of the rock and followed the procedures of Robinson and Minshall (1986). Briefly, the process involved removing all material within an enclosed area (3.14 cm^2) from the rock surface. The removed material was then suctioned onto a pre-fired, glass microfiber filter (Whatman GF/F). Filters were frozen with liquid nitrogen in a modified dewar flask (Taylor-Wharton model 3DS) and sent to the Stream Ecology Center, Idaho State University for processing. Periphyton samples were extracted with reagent grade methanol (Holm-Hansen and Riemann 1978) and the chlorophyll-a content determined with a spectrophotometer (Gilford Instruments model 2600). Following centrifugation, approximately 3 ml of the sample was removed and used in the chlorophyll-a determination, the remaining material was used for measuring the AFDM of the sample, as described above under total filterable solids.

Results

Water Chemistry and Clarity

At Site 1, dredge operation had no discernable effect on alkalinity, hardness, or specific conductance in the Fortymile (Fig. 3). Alkalinity ranged from <20 to >50 mg $CaCO_3$/L, regardless of whether or not the dredge was operating. Hardness ranged from approximately 80 to 115 mg $CaCO_3$/L. Both alkalinity and hardness displayed a large amount of variability in the immediate vicinity of the dredge, whether or not the dredge was operating. Values of alkalinity and hardness measured at 320 m below the dredge were similar during operation of the dredge to values measured when the dredge was not in use (Fig. 3). Specific conductance showed only slight spatial and temporal variation during our sampling. Values ranged from 131 to 135 μS/cm, with a small decrease immediately downstream of the dredge, when in operation (Fig. 3).

Turbidity and total filterable solids (TFS) both displayed an increase below the dredge (Fig. 4). During operation of the dredge, turbidity increased from values around 1 NTU upstream of the dredge to values of approximately 25 NTU immediately downstream of the dredge. The elevated turbidity declined rapidly downstream and by 160 m (= 525 ft) turbidity had returned to values measured upstream of the dredge. No such increase in turbidity was recorded when the dredge was not in operation. TFS showed a pattern similar to that of turbidity, increasing from 3 mg AFDM/L upstream of the dredge to 46 mg AFDM/L immediately downstream of the dredge (Fig. 4). As with turbidity, TFS did not display an increase downstream of the dredge when the dredge was not operating. Regardless of whether or not the dredge was operating, a longitudinal increase in TFS was measured from 80 m to 320 m downstream of the dredge. At 160 m downstream of the dredge, values of TFS were 28 and 23 mg AFDM/L during operation and non-operation, respectively. Total settleable solids showed a pattern very similar to that observed for TFS (Fig. 5).

During operation of the dredge, specific conductance and turbidity were measured across the width of the Fortymile at 0, 5, 10, 20, and 320 m downstream of the dredge to identify the proportion of the river width affected by the dredge plume. Specific conductance was unaffected

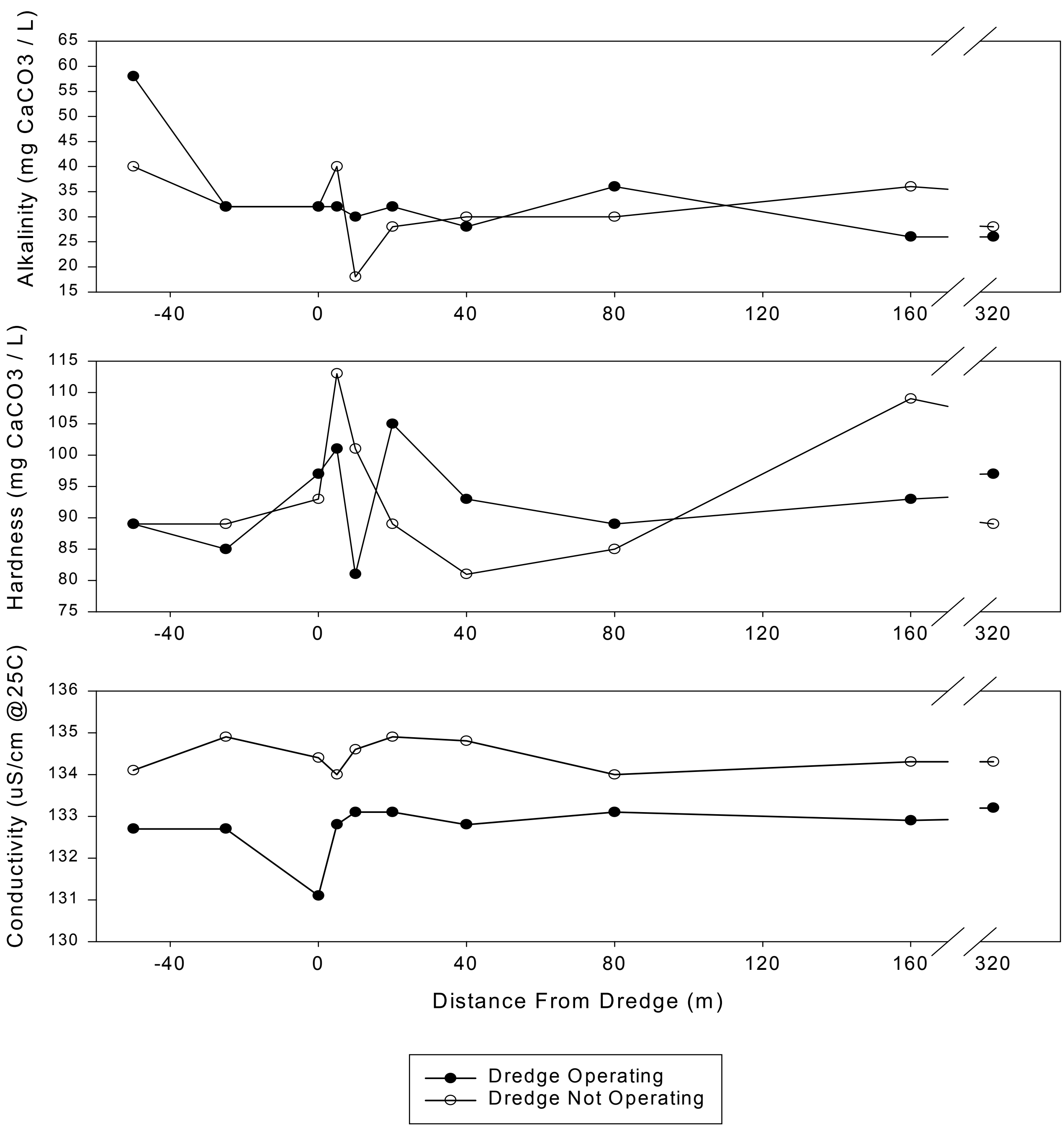


Figure 3. Alkalinity, hardness, and specific conductance measured in the Fortymile River, Alaska in relation to operation of an 8-inch suction dredge. Negative values on the x-axis indicate samples collected at locations upstream of the dredge; the dredge was located at zero on the x-axis.

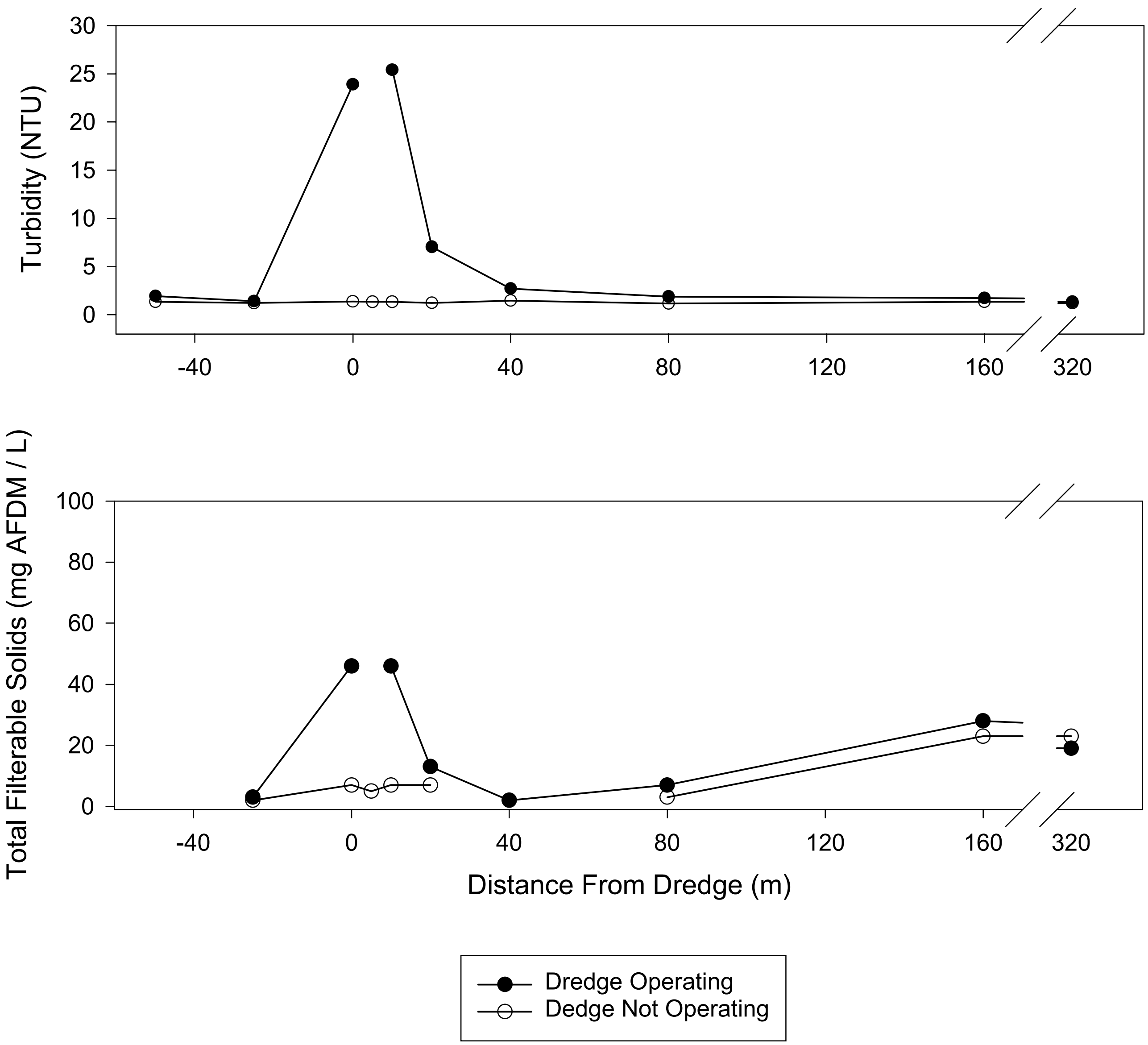


Figure 4. Turbidity and Total Filterable Solids measured in the Fortymile River, Alaska in relation to operation of an 8-inch suction dredge. Negative values on the x-axis indicate samples collected at locations upstream of the dredge; the dredge was located at zero on the x-axis.

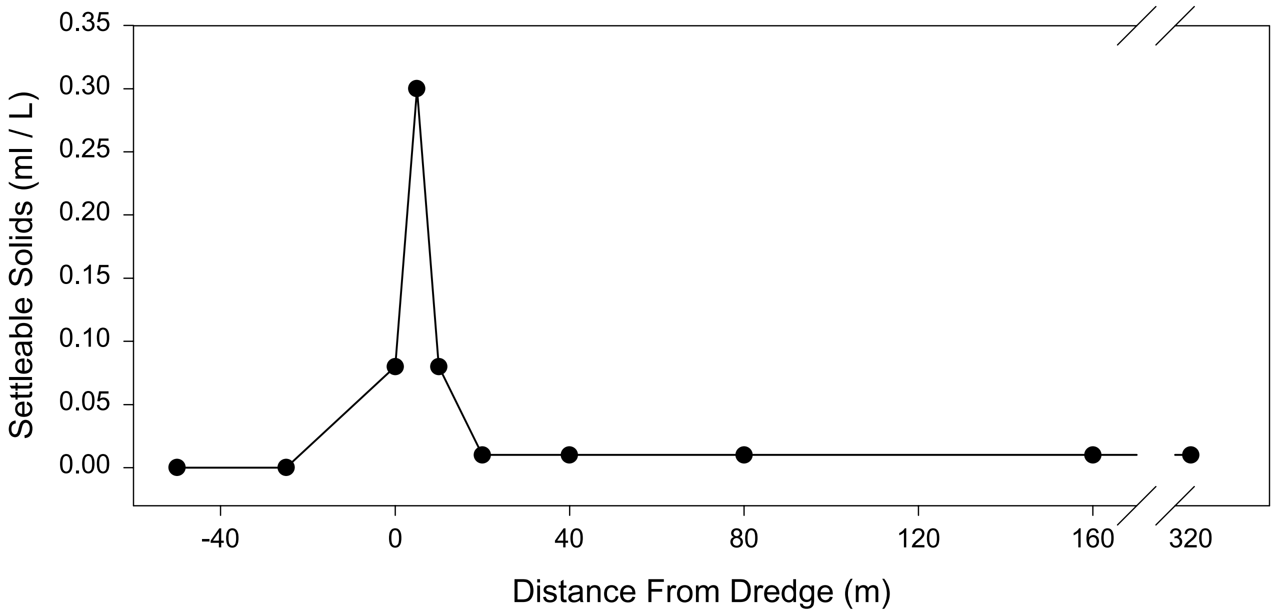


Figure 5. Total settleable solids measured in the Fortymile River, Alaska in relation to operation of an 8-inch suction dredge. Negative values on the x-axis indicate samples collected at locations upstream of the dredge; the dredge was located at zero on the x-axis.

by the dredge plume which was located along the right bank, but did decrease near the left bank (Fig. 6). This decrease was most likely due to groundwater and/or a small tributary that joined the Fortymile on the left bank just upstream of the study area.

Unlike specific conductance, cross-sectional measurements of turbidity from within the dredge plume showed a large increase, relative to areas outside the plume (Fig. 7). However, at 320 m downstream of the dredge, cross-sectional variation in turbidity was quite low, ranging from 1.2 to 2.5 NTU. During this sampling, the dredge was operating in close proximity to the right bank. Under these conditions, the plume tended to remain near the right bank and did not extend to the center of the river. In terms of turbidity, approximately 7% of the river width was affected by the dredge plume for a distance of less than 320 m.

Heavy Metals

For the unfiltered samples, two metals, copper and zinc, showed distinct increases downstream of the dredge (Fig. 8). Total copper increased approximately 5-fold and zinc approximately 9-fold at the transect immediately downstream of the dredge, relative to the concentrations measured upstream of the dredge. For both metals, the concentrations declined to near upstream values by 80 m downstream of the dredge. The pattern observed for total copper and zinc concentration is similar to that for turbidity and TFS (see Fig. 4), suggesting that the metals were in particulate form, or associated with other sediment particles.

The results of sampling for dissolved heavy metals area are shown in Table 1. Zinc, arsenic, and copper displayed an average value downstream of the dredge that was greater than the average value measured upstream of the dredge (note that samples sizes are low, particularly upstream of the dredge). Copper displayed the greatest change, increasing by approximately 3-fold downstream of the dredge. Dissolved lead concentrations did not appear to be affected by operation of the dredge. Values of dissolved mercury actually were greater upstream of the dredge, suggesting that any effect of the dredge was likely within the range of natural variation. (The operator reported observing deposits of liquid mercury within the sediments he was working.) For both dissolved and total concentrations, budgetary limitations precluded multiple

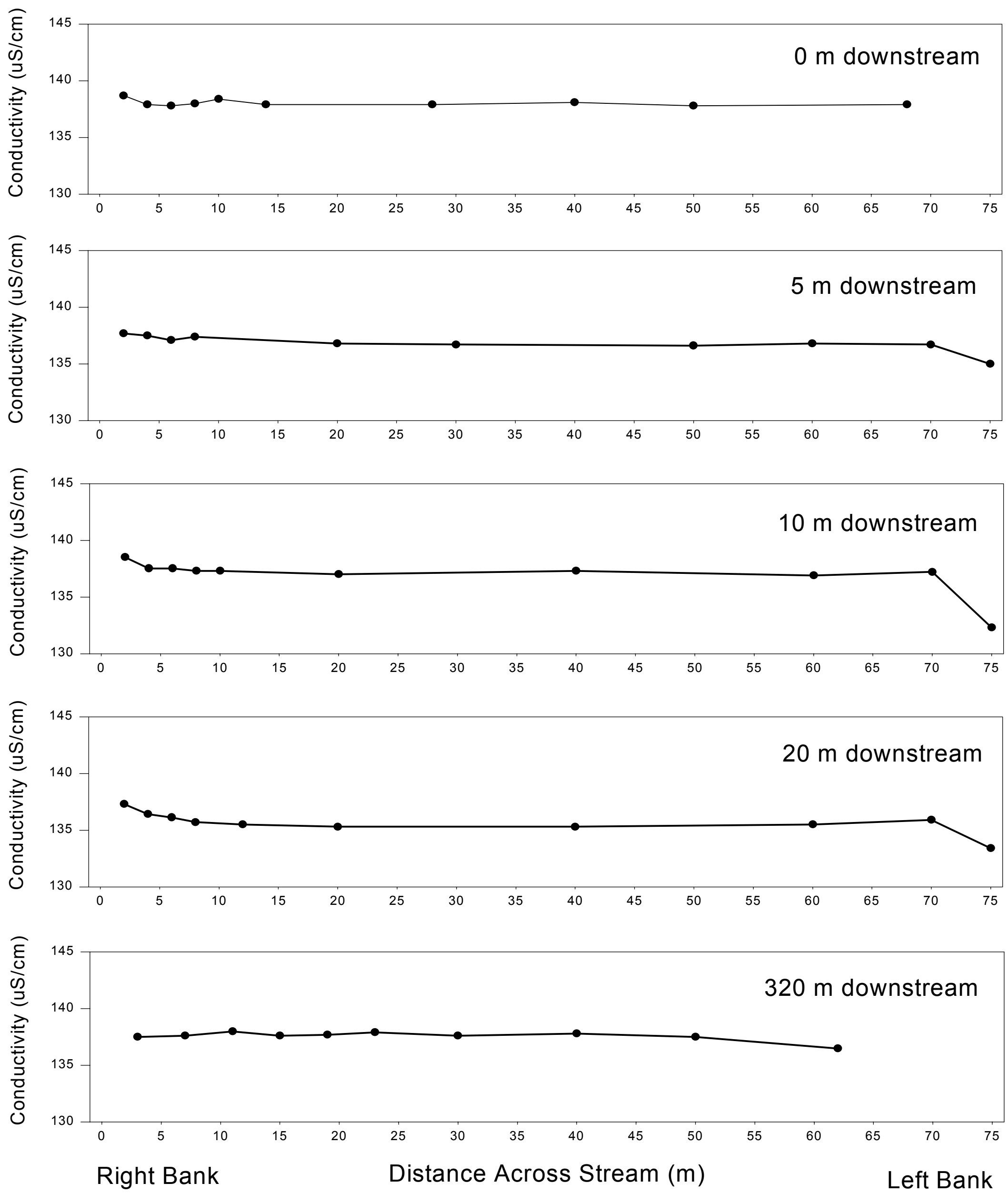


Figure 6. Cross-sectional measurements of specific conductance at various distances downstream from an 8-inch suction dredge in the Fortymile River, Alaska. The dredge was operating approximately 7 m from the right bank at the time of sample collection.

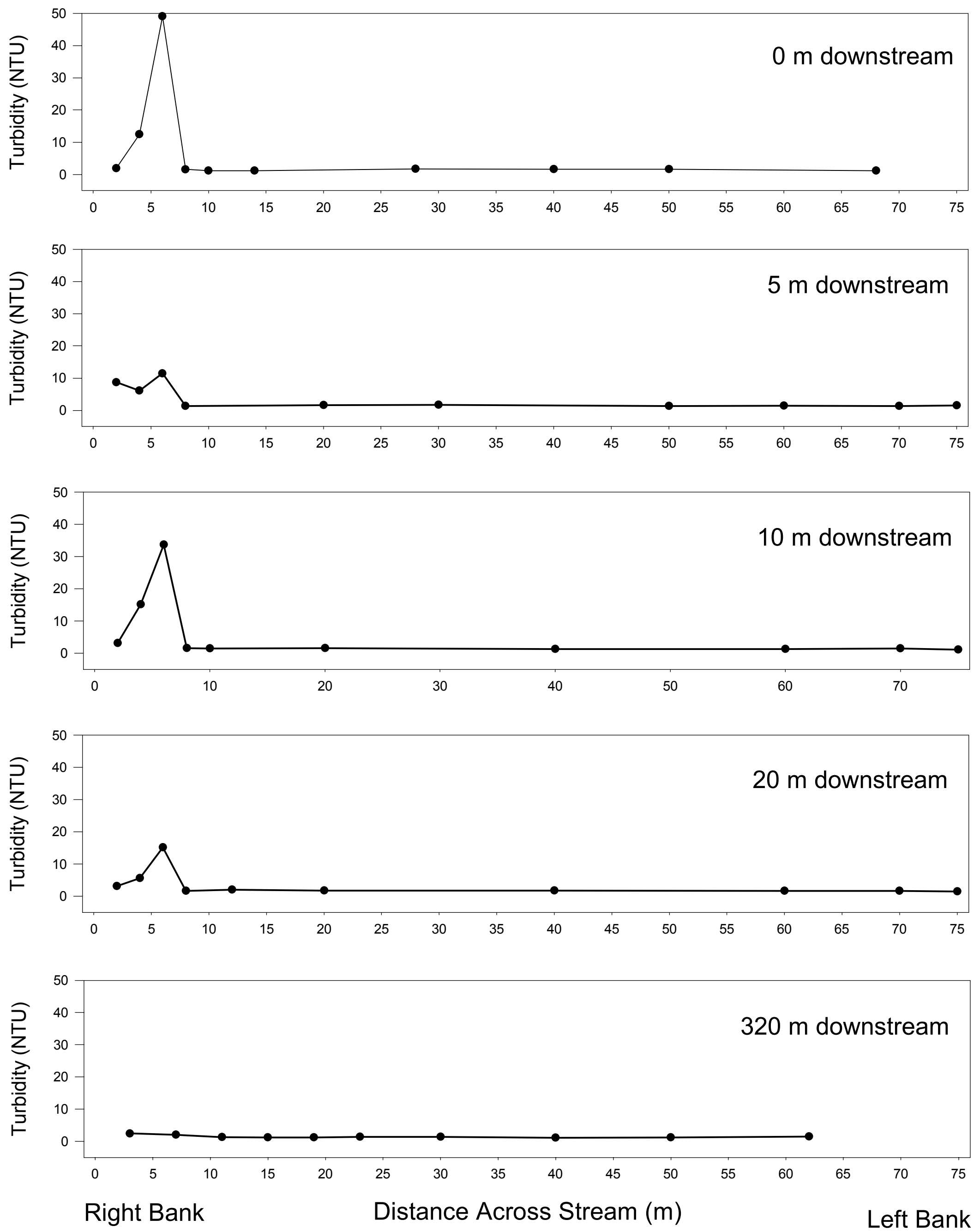


Figure 7. Cross-sectional measurements of turbidity at various distances downstream from an 8-inch suction dredge in the Fortymile River, Alaska. The dredge was operating approximately 7 m from the right bank at the time of sample collection.

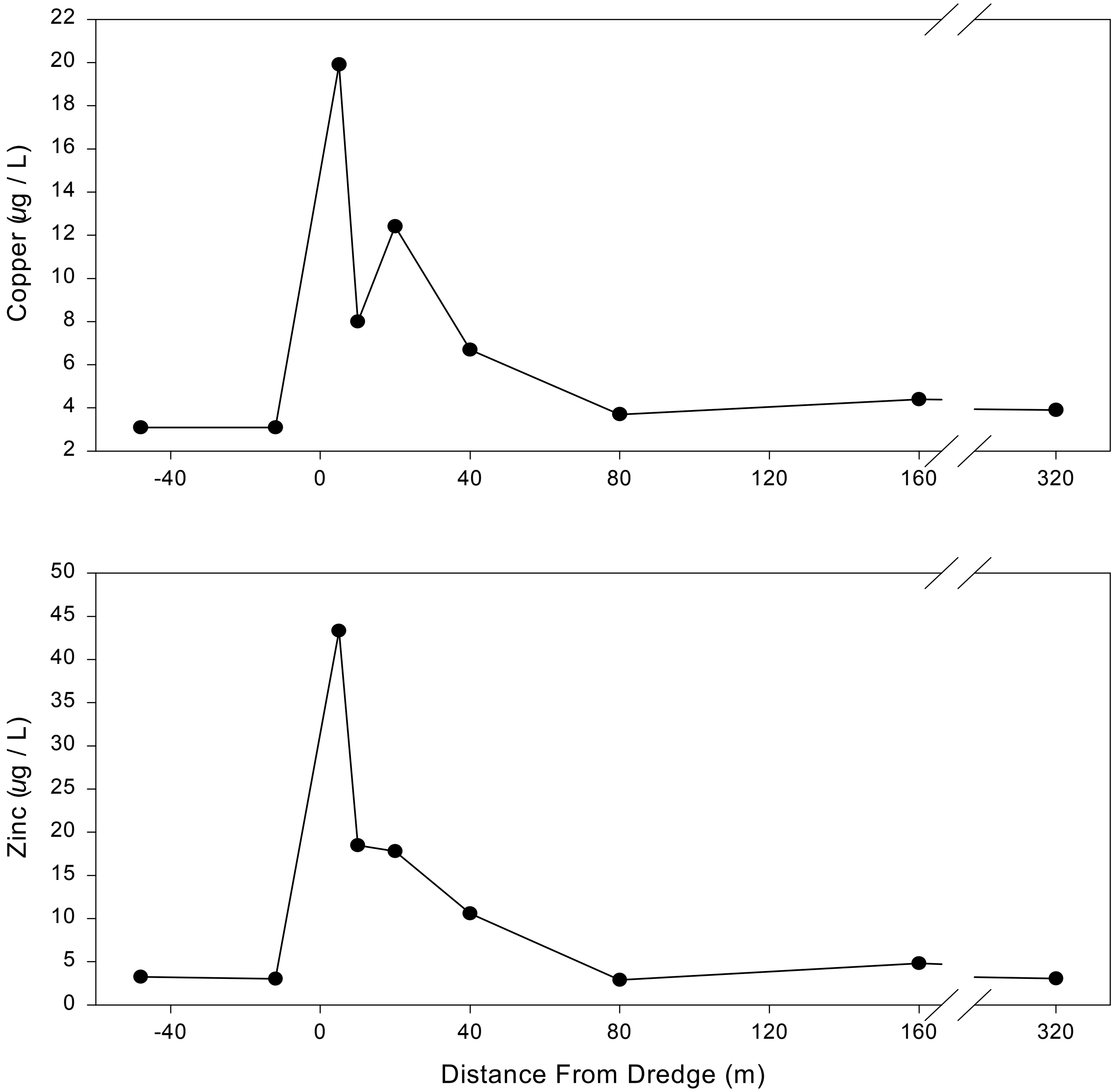


Figure 8. Unfiltered concentrations of Copper and Zinc measured in the Fortymile River, Alaska in relation to operation of an 8-inch suction dredge. Negative values on the x-axis indicate samples collected at locations upstream of the dredge; the dredge was located at zero on the x-axis.

Table 1. Results of heavy metals sampling at the study area. All samples were collected during dredge operation and then filtered. All results in parts per billion.

Date	Time	Location	Mercury	Mercury Average	Zinc	Zinc Average	Arsenic	Arsenic Average	Copper	Copper Average	Lead	Lead Average
13 August 1997	1608	blank	0.200		1.00		0.22		2.6		0.10	
13 August 1997	1645	Upstream	0.371	0.423	2.11	1.99	0.59	0.60	3.7	3.7	0.10	0.10
13 August 1997	1610	Upstream	0.475		1.87		0.61		3.7		0.10	
13 August 1997	1902	Downstream (10 m)	0.212	0.202	2.10	2.34	0.65	0.70	3.6	10.9	0.10	0.12
13 August 1997	1854	Downstream (20 m)	0.200		1.64		0.60		3.2		0.10	
13 August 1997	1846	Downstream (40 m)	0.200		2.67		0.79		17.6		0.14	
13 August 1997	1833	Downstream (80 m)			1.93		0.62		4.5		0.10	
13 August 1997	1822	Downstream (160 m)	0.200		2.80		0.75		18.2		0.14	
13 August 1997	1800	Downstream (320 m)	0.200		2.90		0.76		18.4		0.14	

sampling across either space or time, thus the results of heavy metal sampling are only indicative of likely conditions.

Results from the 1998 analysis of macroinvertebrate tissues suggest that these organisms are capable of concentrating heavy metals. Although the data are preliminary in nature, several metals showed substantially greater concentration in the invertebrates from Polly Creek (mined) than from Alder Creek (reference), including mercury, zinc, molybdenum, and arsenic (Table 2). Other metals, such as copper and nickel, did not exhibit substantial differences between the two sites. The upwelling area identified by the USGS as a potential source of metals in the NF Fortymile did not appear to be influencing metal concentrations in macroinvertebrates. For the metals listed above, nickel was the only metal that showed a substantial increase (Table 2).

Channel Morphology

Site 1- Cross-sectional profiles were mapped to quantify the extent of the dredge piles relative to the width of the river. At Site 1 only the pile created most recently, 0 m downstream of the dredge, was visible with our profile mapping (Fig. 9). At the transects 5 and 20 m downstream of the dredge the piles were visually obvious due to the discolored nature of the excavated material compared to undisturbed riverbed. However, the piles did not appear as distinct "mounds" in the measurements made at these transects. One year since active dredging occurred, the distinct mounds seen in Figure 8 at the 0 m transect are no longer apparent. There is no discernable dredge pile at the 5 and 20 m areas. Figure 9 is based on detailed mapping along the right bank of the river and is drawn to scale to represent the conditions within the streambed relative to the depth of the river in that area. There is a large width:depth ratio for Site 1 as indicated by Figure 10. Discernable dredging activity can be seen within the first 5 m from the right bank. The area that this particular dredge operation effected was about 6% the width of the river.

Site 2a- In August 1997 partial cross-sectional profiles were measured every 5 meters beginning slightly downstream of dredging activity and continuing for 110 meters to map a

Table 2. Heavy metal concentrations in macroinvertebrate tissue from two sites on the NF Fortymile River and two tributatires to the mainstem Fortymile River. Results are from a single measurement at each site. Macroinvertebrates were collected on 28 and 29 June 1998. See text for further description of the sites.

	Mercury ppm	Lead ppm	Zinc ppm	Arsenic ppm	Molybdenum ppm	Vanadium ppm	Magnesium ppm	Copper ppm	Selenium ppm	Nickel ppm
Blank	0.00005	0.002	0.700	0.010	0.100	0.030	0.00004	0.004	0.020	0.040
Alder Creek; Reference	0.09	4.4	140	2.4	2	21	0.37	20	3	12
Polly Creek; Mined	0.20	7.6	350	7.5	32	49	0.57	25	11	12
North Fork Fortymile; Above Source*	0.07	5.4	200	7.4	9	26	0.43	22	16	9
North Fork Fortymile; Below Source*	0.04	5.8	200	7.0	3	21	0.34	27	7	14

* "Source" refers to the location of the upwelling groundwater on the NF that the USGS has identified as a potential source of heavy metals to that river.

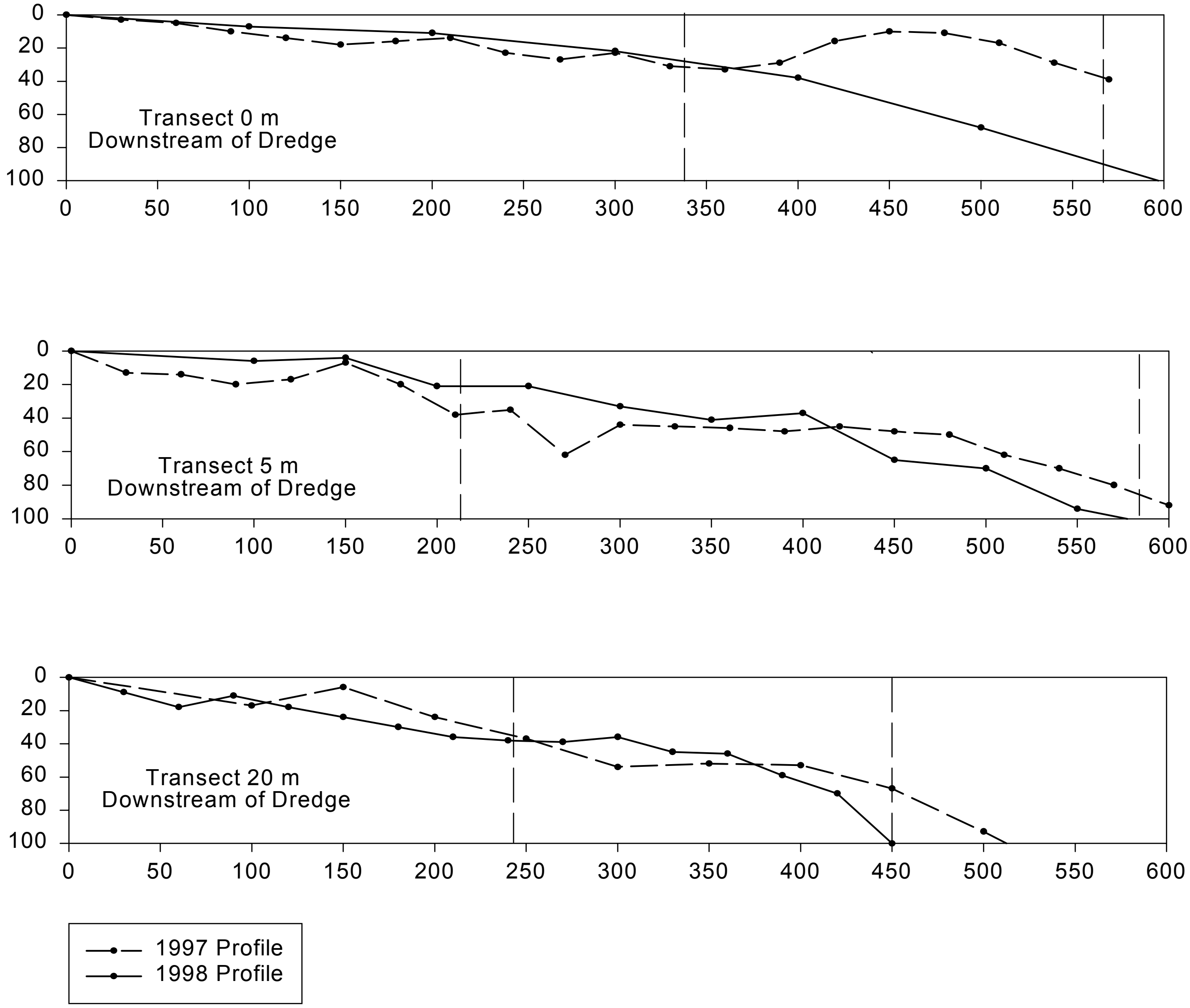


Figure 9. Cross-sectional profile of a portion of the riverbed at three transects various distances downstream of an 8 inch dredge (dotted lines) and riverbed profiles after one year since dredging activity (solid lines) in the the mainstem of the Fortymile River, Alaska (Site 1). Area within the dashed vertical lines is the dredge pile as indicated by visual observation. Profiles are drawn to scale.

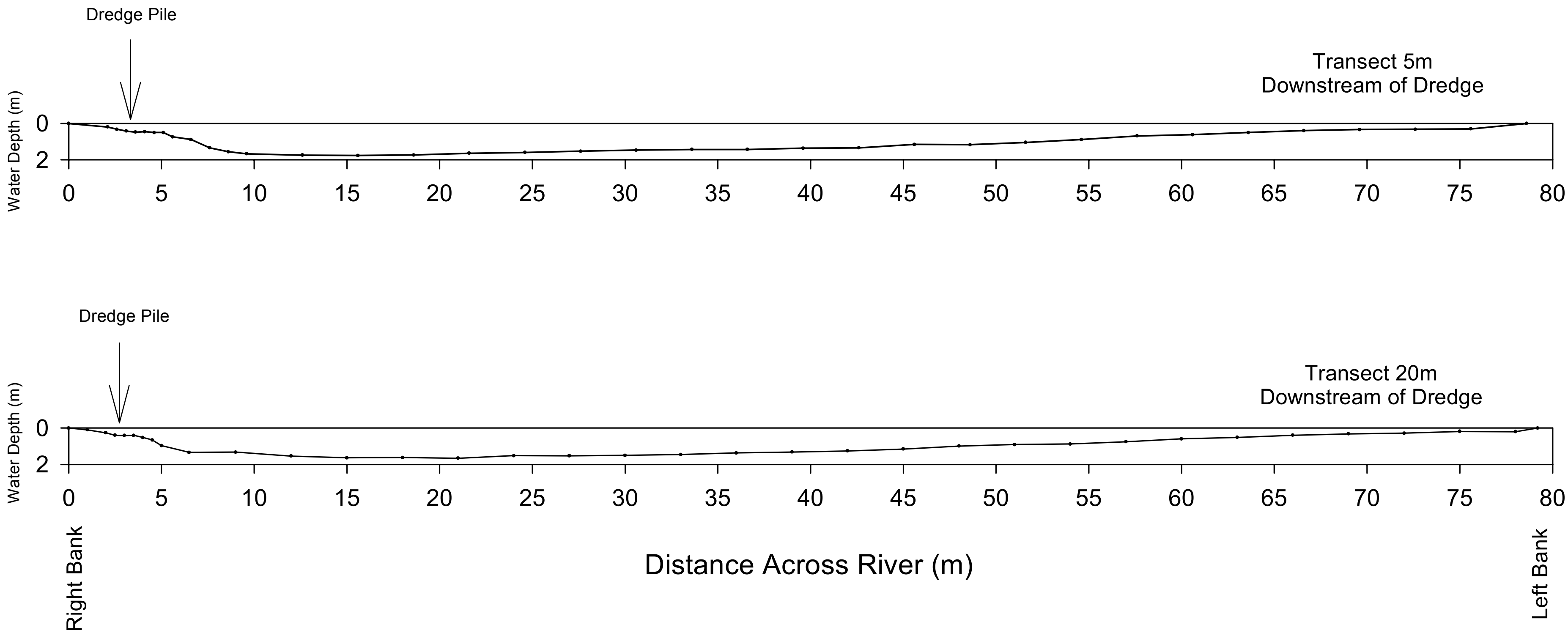


Figure 10. Cross-sectional profiles of the riverbed across two transects 5 m and 20 m downstream of an 8-inch suction dredge in the Fortymile River, Alaska. Profiles drawn to scale. Arrows indicate the approximate location of recently deposited dredge piles.

series of dredge piles along the right bank of the South Fork of the Fortymile (Appendix A). In July 1998 three transects were re-measured to map the change in location of the dredge piles (Fig. 10). The dredge pile at 30 m shows a shift towards the center of the stream, though the overall size essentially remained the same after one year. A profile of the 40 m transect produced similar results. Remaining partial cross-sectional profiles are presented in Appendix A.

Site 2b- In July 1998 a second site on the South Fork was included in our sampling to determine if there are spatial differences in dredging effects on biota. Cross sectional profiles were measured . Full cross-sectional profiles were completed for the "upper" pile in 1998 which had been dredged in September of 1997 (Fig. 11) and partial cross-sections were measured for the upper, middle, and lower locations (Figs. 12 and 13). Easily discernable dredge piles were observed and measured between 0, 5, and 10 m below a reference transect at the upper location for Site 2b. Partial cross-sectional profiles were also measured to determine the longitudinal extent of the upper dredge pile (Fig 12). According to our measurements, the upper dredge pile tapers off at about 35 m. Profiles for the middle and lower dredge areas show another dredge pile beginning between 80 and 100m. The lower dredge pile begins at about 130 m and continues slightly past 140m (Fig 13). The middle and lower dredge areas were mined about 7 days prior to our sampling at Site 2b.

Site 3- Cross-sectional profiles also were measured at Site 3 in the North Fork. Entire width profiles were measured every 20 m along this reach (Fig. 14) and partial profiles were measured at various distances between each full profile (Fig. 15). Dredging was active at the 0 m and 10 m locations and between the 40 and 60 m locations. There is a large width:depth ratio for Site 3. Figure 13 shows the size of the dredge piles relative to the entire width of the river for Site 3. The full width profile measured for Site 3 shows distinguishable channel forms where mining activity had occurred within 10 days of our sampling at 20 m, 60 m, and 80 m though the 80 m location may simply be due to natural bed forms. The lack of obvious dredge piles at the 0 m and 40 m locations are most likely because the dredge pile began slightly upstream of these

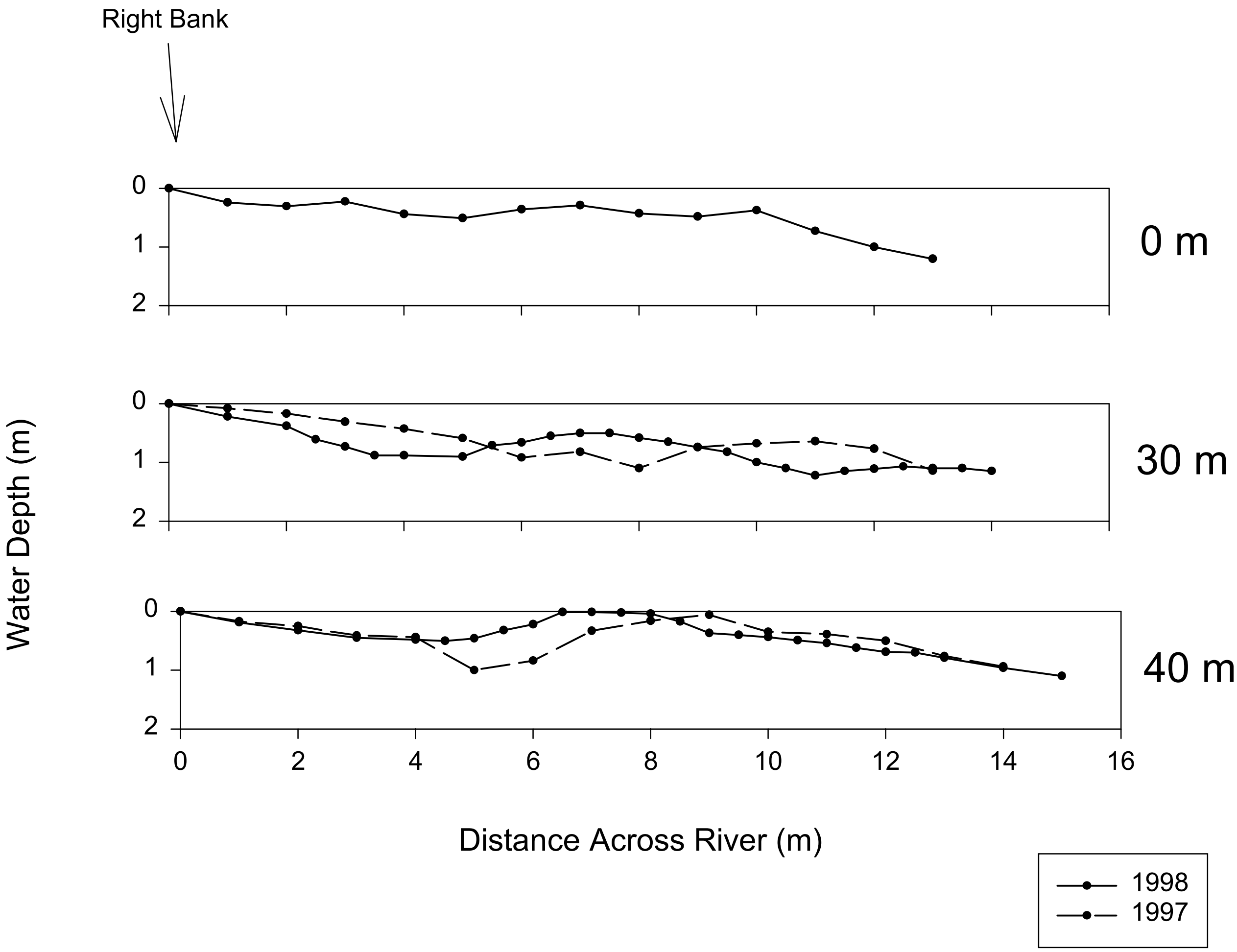


Figure 11. Portion of a cross-sectional profile from an area dredged with a 10 inch suction dredge in the South Fork Fortymile River, Alaska (Site 2a). Profiles are drawn to scale.

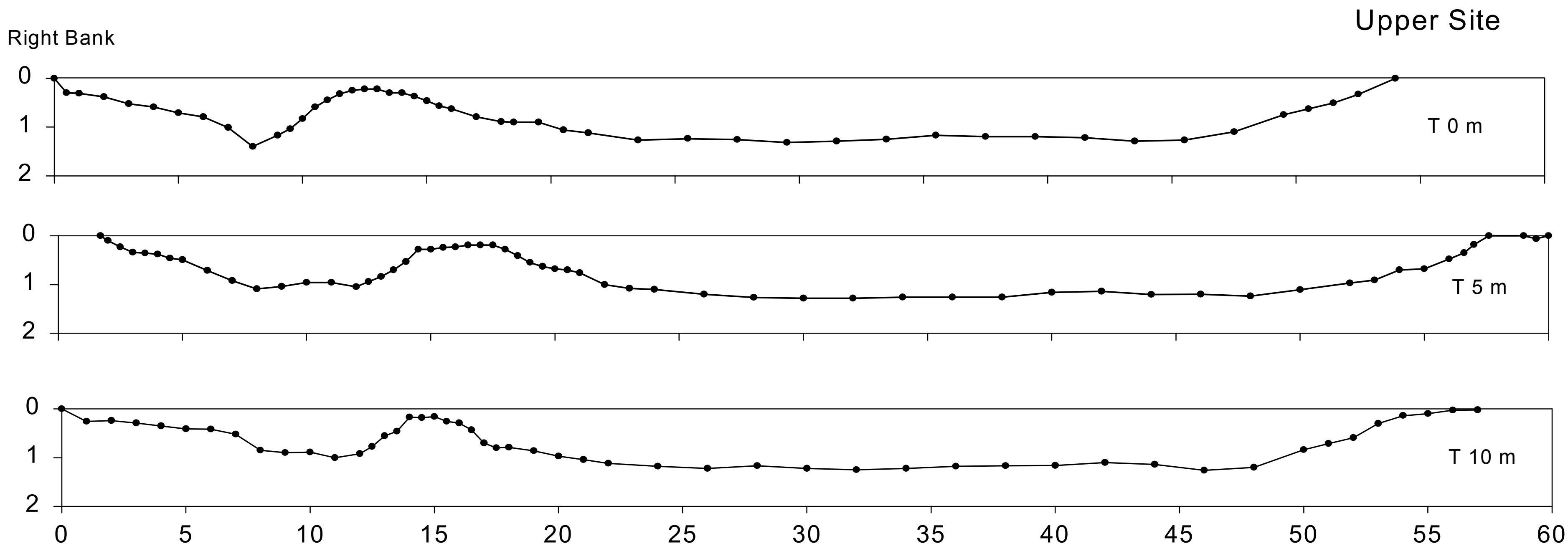


Figure 12. Entire cross-sectional profiles at a site dredged with a 10 inch suction dredge in the South Fork of the Fortymile River, Alaska (Site 2b). Profiles represent the "Upper" site at Site 2b which was dredged in September of 1997. Profiles were measured in July 1998.

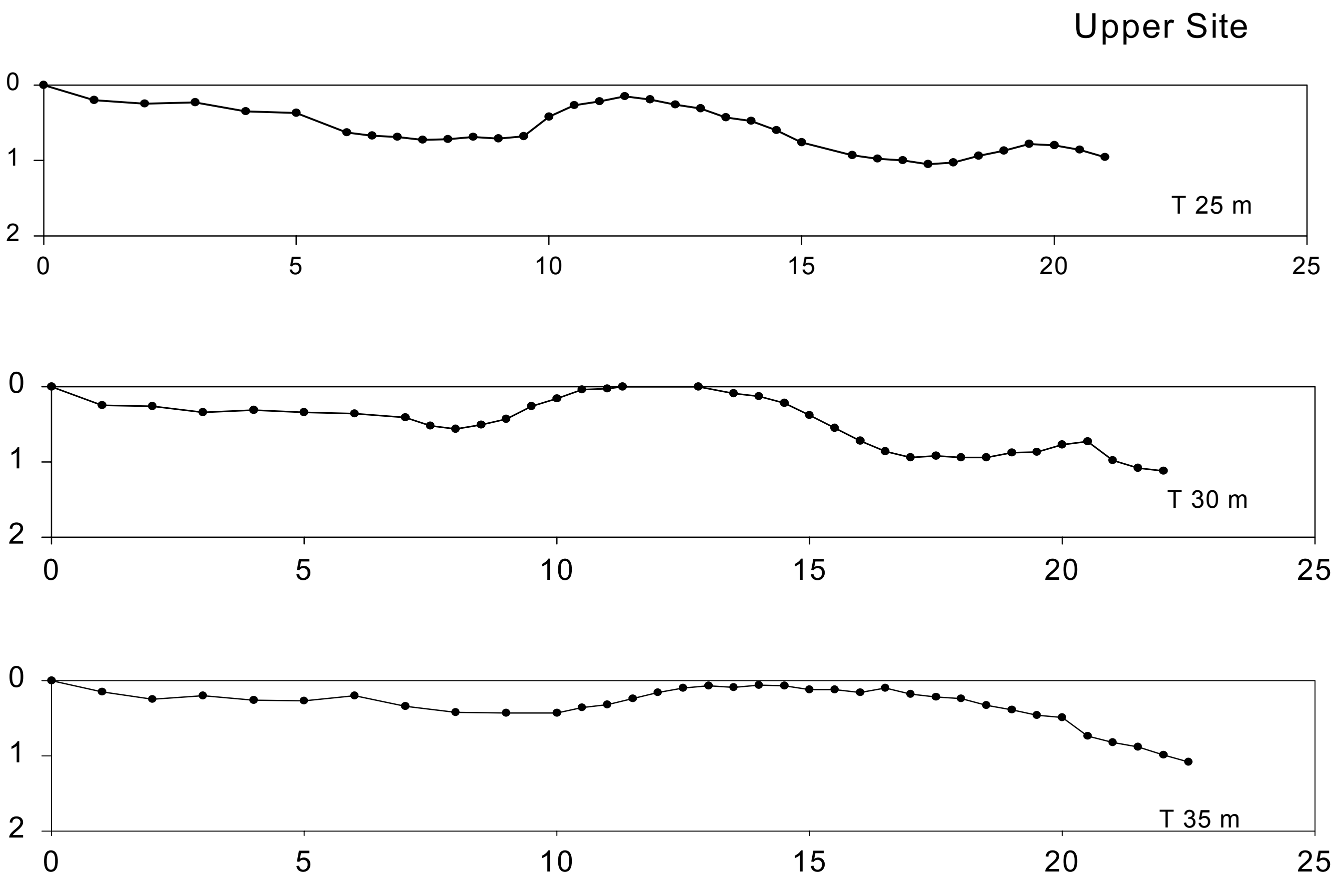


Figure 13. Partial cross-sectional profiles of an area in the South Fork of the Fortymile River dredged with a 10 inch suction dredge. Profiles represent measurement of the "Upper" dredge piles which were dredged in September 1997. Profiles are slightly inflated for water depth to exaggerate dredge piles for better viewing. Dots along profile represent depth measurements.

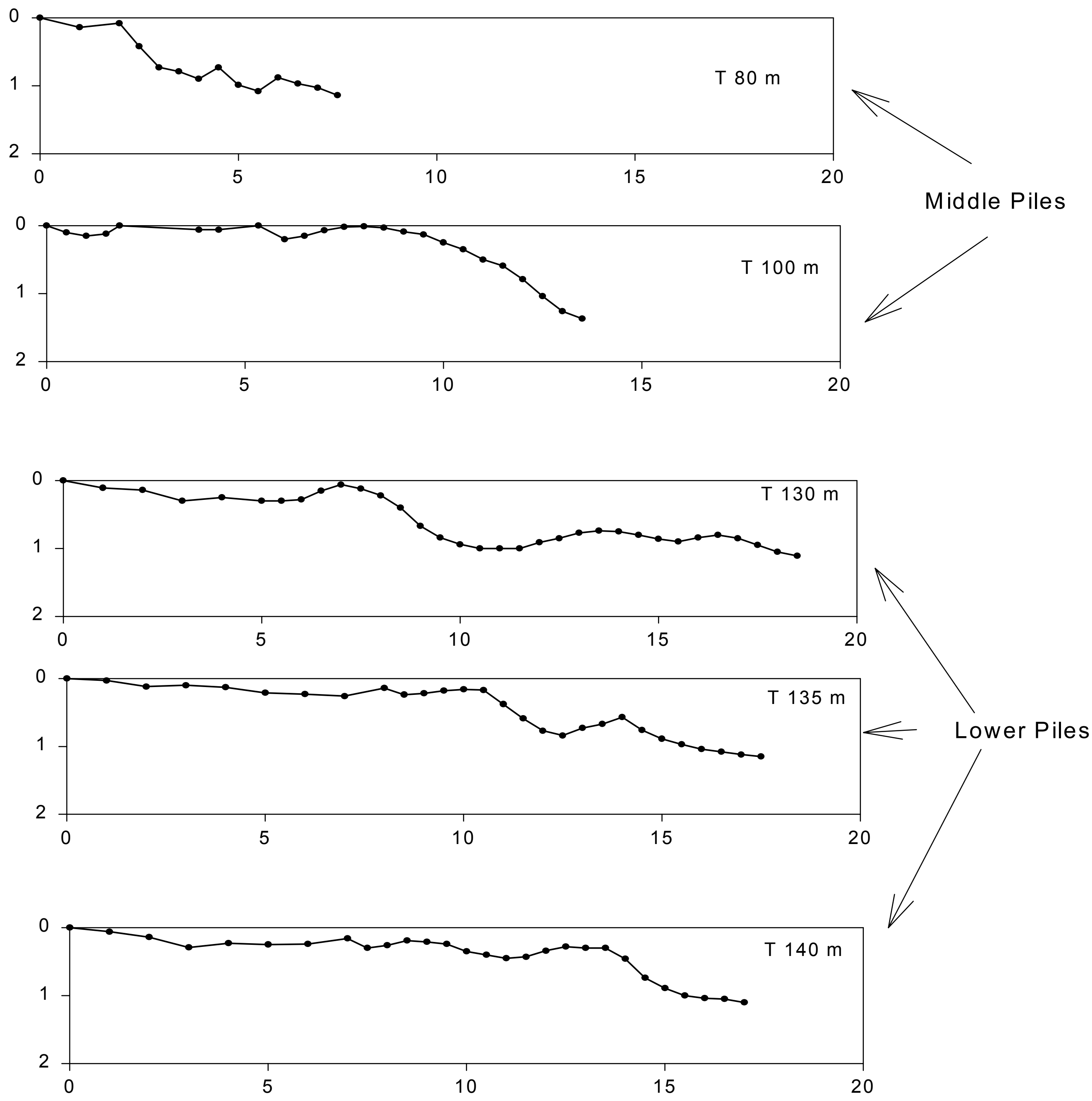


Figure 14. Partial cross-sectional profiles of sites dredged with 10 inch suction dredge in the South Fork of the Fortymile River, Alaska (Site 2b), during summer 1998. Profiles represent both the "Middle" and "Lower" piles. Dots along profiles represent the area at which depth measurements were taken.

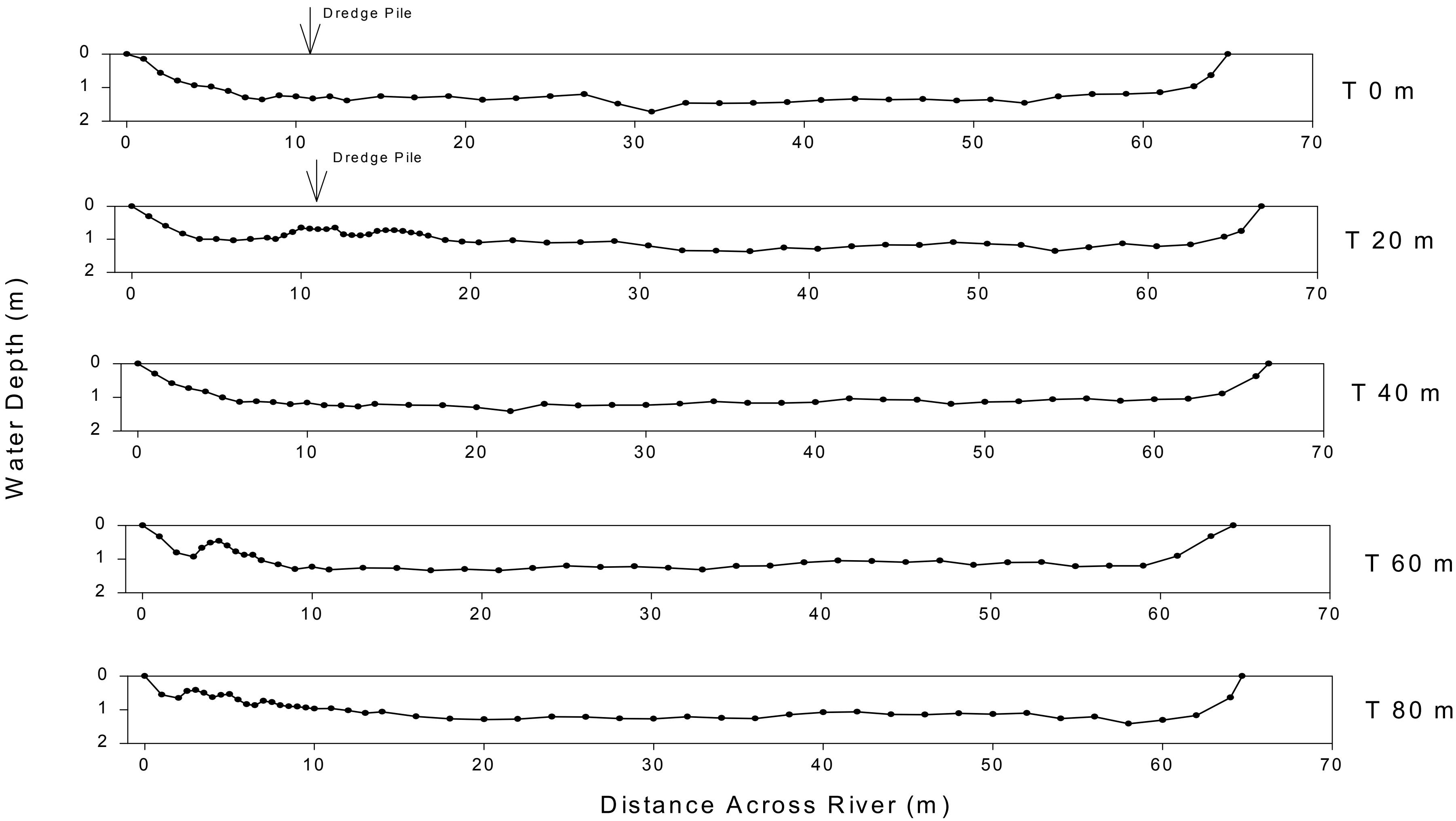


Figure 15. Cross-sectional profiles of the riverbed across five transects downstream of an 8 inch dredge in the North Fork of the Fortymile River (Site 3). Profiles drawn approximately to scale. Arrows indicate the approximate location of recently deposited dredge piles. Points represent locations of depth measurements.

locations. Dredge piles accounted for approximately 15% of the total channel width at Site 3.

The partial profiles show very distinct dredge piles 5 m downstream of mining activity which can be seen nearly 4 m from the right bank. 10 m downstream another relatively distinguishable streambed "rise" is discernable between 4 and 6 m from the right bank. There is no discernable effect on the streambed 15 m downstream of mining activity according to these profiles.

Periphyton Standing Crop

At Site 1 periphyton AFDM was greatest at the transect upstream of the suction dredge, with a mean value of 1.8 mg AFDM / cm^2 (Fig. 16). Periphyton standing crop was reduced by approximately 2-4 fold at the transects downstream of the dredge. The lowest value, >0.5 mg AFDM / cm^2, occurred in the first 10 m immediately below the dredge. Unlike other variables, periphyton standing crop did not appear to recover at subsequent transects downstream of the dredge. At the 320 m transect, for example, AFDM was only 50% of the value measured upstream of the dredge (Fig. 16). At Site 2b, mean chlorophyll *a* was higher in the "upper" location than either of the other two nearby locations. The upper location was dredged late in the 1997 mining season and the greater amount of periphyton is most likely due to the additional time of recovery (Fig. 17).

Aquatic Macroinvertebrates

Site 1 - In general, the short-term influence of the suction dredge on macroinvertebrates appeared to be limited to the first 20-40 m downstream of the dredge. Two locations were examined upstream of the dredge at Site 1, the first was approximately 80 m upstream and the second approximately 200 m upstream. In terms of water velocity and substrate characteristics, the -200 m site was considerably more similar to the habitat downstream of the dredge than was the -80 m site. For this reason, only the -200 m transect was used as the reference for Site 1 .

The abundance of macroinvertebrates at Site 1 was low, relative to large rivers in other

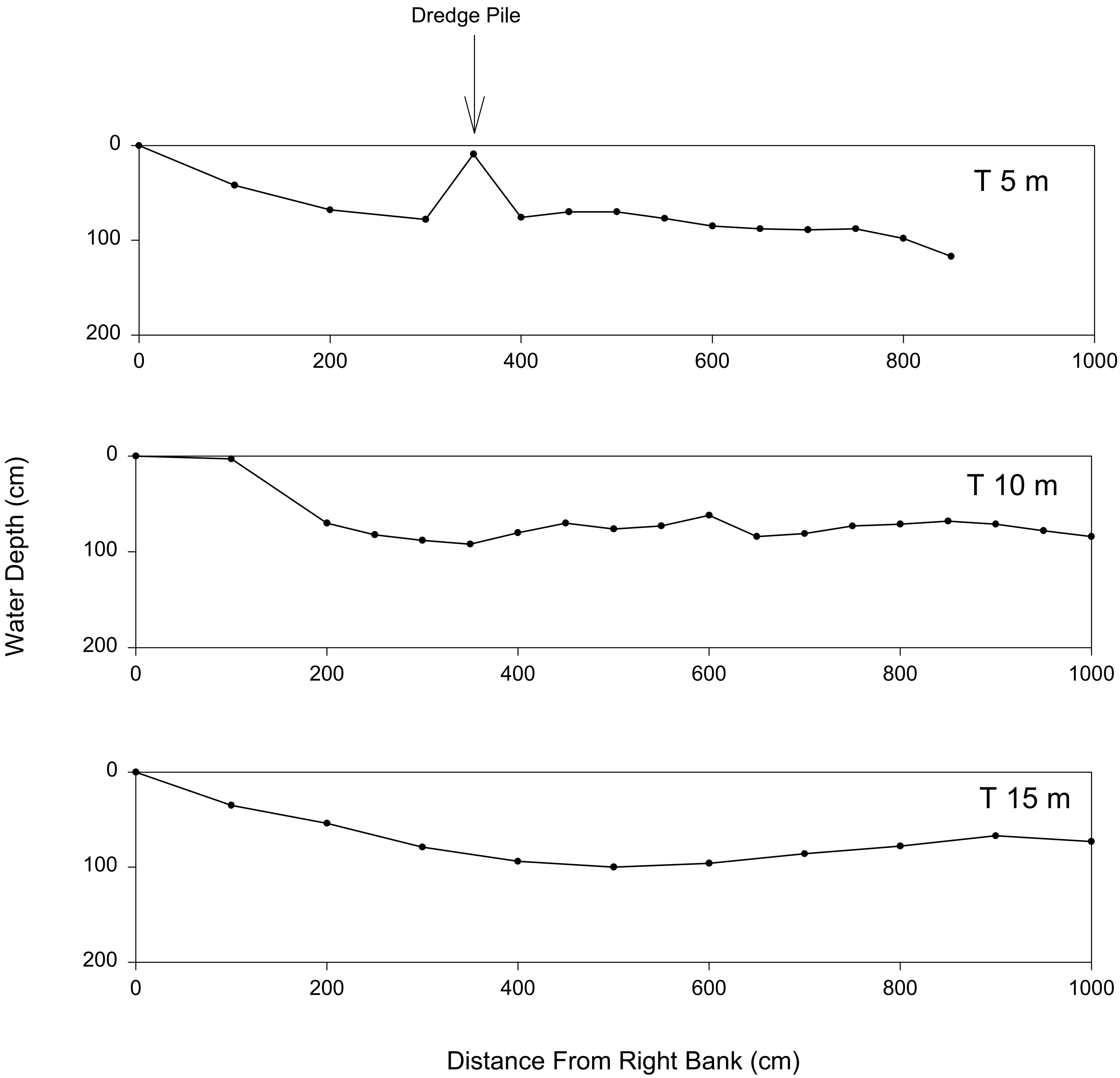


Figure 16. Cross-sectional profile of a portion of the streambed at three transects various distances downstream of a 10 inch dredge on the North Fork of the Fortymile River, Alaska. Arrow indicates the area immediately downstream of the active dredge site. Profiles are drawn to scale.

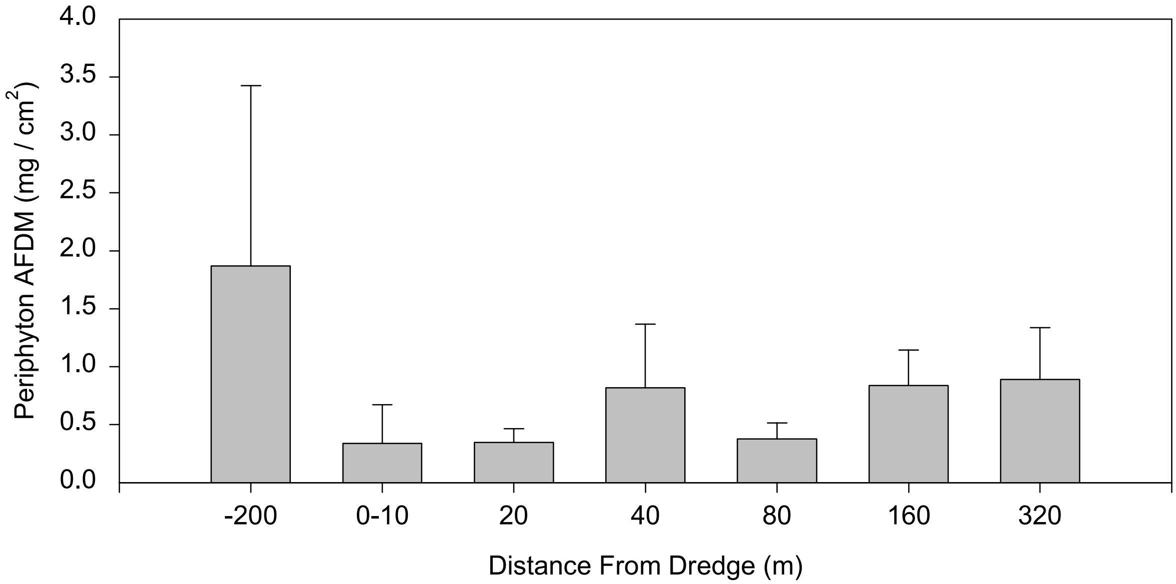


Figure 17. Biomass (as ash-free dry mass; AFDM) of periphyton from samples collected in relation to operation of an 8-inch suction dredge in the Fortymile River, Alaska. Negative values on the x-axis indicate locations upstream of the dredge. Error bars equal one standard deviation from the mean.

parts of North America (e.g., Royer and Minshall 1996). A mean of 270 individuals per m^2 was collected at the reference site; approximately 370 individuals per m^2 were found at the site 160 m downstream of the dredge (Fig. 18). Diversity averaged 6-7 taxa per sample at the reference site and ranged from 1 to 7 taxa per sample at the sites downstream of the dredge. Taxa within the orders of Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) are considered sensitive to habitat degradation and are used commonly in aquatic bioassessment. The number of EPT taxa averaged 5 per sample at the reference site and ranged from <1 to 5 per sample at the sites downstream of the dredge.

The abundance and diversity of macroinvertebrates at Site 1 was greatly reduced in the first 10 m below the dredge, relative to the reference site. Immediately below the dredge (0-10 m) macroinvertebrate abundance was reduced by 97%, number of taxa by 88%, and number of EPT taxa by 92%, relative to the site 200 m upstream of the dredge. The abundance and diversity of macroinvertebrates returned to values seen at the reference site by 80 to 160 m downstream of the dredge

The relative abundance of all taxa collected from the Site 1 in 1997 are presented by transect in Table 3. The order Trichoptera was the most abundant, in terms of richness, with seven genera represented. Five genera of Ephemeroptera and two genera of Plecoptera were collected. Two families of Diptera were found, Simuliidae (blackflies) and Chironomidae (midges). Other groups included: one genus of Coleoptera (beetles), Acarina (water mites), Collembolla (springtails), Oligochatea (aquatic earthworms), and Ostracoda. For all transects, 50% or greater of all taxa were members of the Chironomidae and the Ephemeroptera.

The sampling conducted in 1998 indicated substantial recovery at Site 1 from the dredging that occurred in 1997, in terms of macroinvertebrate diversity. Figure 19 displays the 1997 and 1998 taxa-abundance curves for the reference, 0, 20, and 40 m transects at Site 1. Diversity was notably reduced downstream of the dredge in 1997 (see above) but in 1998 the difference in diversity among the four transects was minimal. For example, at the location 20 m downstream of the dredge macroinvertebrate diversity was approximately 6 taxa in 1997 but 17 taxa in 1998. A similar increase in the number of taxa was observed at all Site 1 transects that

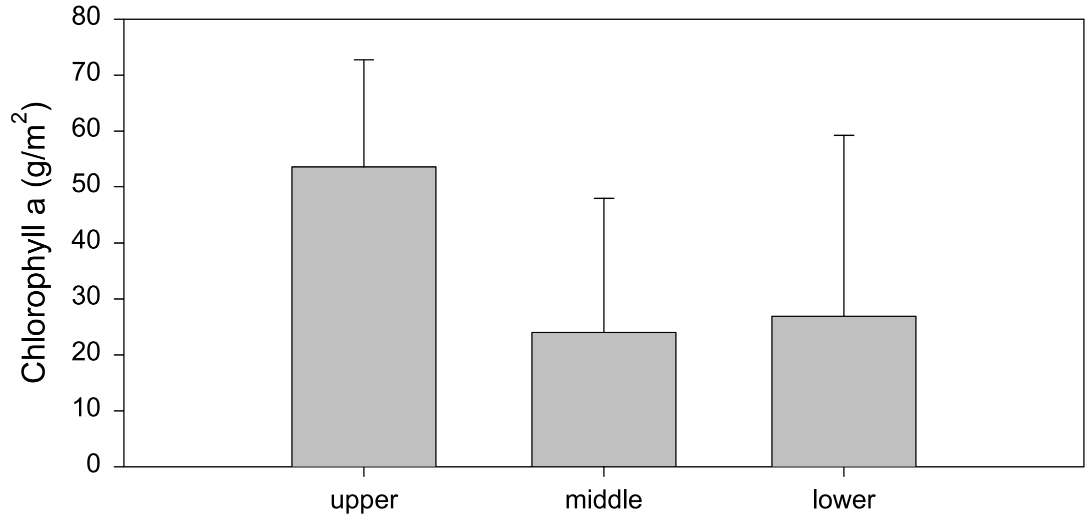


Figure 18. Chlorophyll *a* concentrations of periphyton within a dredged site in the South Fork of the Fortymile River (Site 2b). The "Upper" location was dredged in September 1997, while the "Middle" and "Lower" locations were dredged in July 1998. Error bars represent one standard deviation from the mean.

Table 3. Mean relative abundance (%) of each macroinvertebrate taxon collected from the study site on the Fortymile River, Alaska in August 1997. Data presented by transect.

	Transect						
Taxa	-200m	0-10m	20m	40m	80m	160m	380m
Ephemeroptera							
Baetis	7.0	20.0	11.4	10.2	11.3	4.5	6.2
Cinygma	24.3	20.0	31.1	16.1	15.2	5.7	61.8
Ephemerella	5.6	0.0	0.0	3.3	6.8	16.1	2.2
Metretopus	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rithrogena	0.4	0.0	0.0	0.0	0.0	0.5	0.0
Tricoptera							
Aptania	0.9	0.0	9.1	8.2	6.7	0.0	0.0
Arctopsyche	7.2	0.0	0.0	0.0	3.5	6.1	1.7
Brachycentrus	1.3	0.0	0.0	2.9	6.6	8.0	0.5
Ceralea	0.7	0.0	0.0	0.0	0.6	0.5	0.0
Eobrachycentrus	0.0	0.0	6.1	5.9	3.3	0.0	0.0
Glossosoma	1.4	0.0	0.0	0.0	0.0	0.0	0.0
Psychomyia	0.0	0.0	0.0	1.8	0.0	0.0	0.0
Plecoptera							
Diura	0.4	0.0	0.0	0.0	0.0	0.8	0.0
Plumiperla	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Coleoptera							
Oreodytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diptera							
Simulidae	0.0	30.0	0.0	8.0	0.0	0.0	3.1
Chironomidae	48.1	20.0	42.4	30.3	41.3	50.7	12.2
Others							
Acarina	0.7	10.0	0.0	13.3	2.2	2.0	11.7
Collembolla	0.0	0.0	0.0	0.0	1.3	1.3	0.0
Oligochaeta	1.1	0.0	0.0	0.0	1.3	2.9	0.5
Ostracoda	0.0	0.0	0.0	0.0	0.0	0.8	0.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

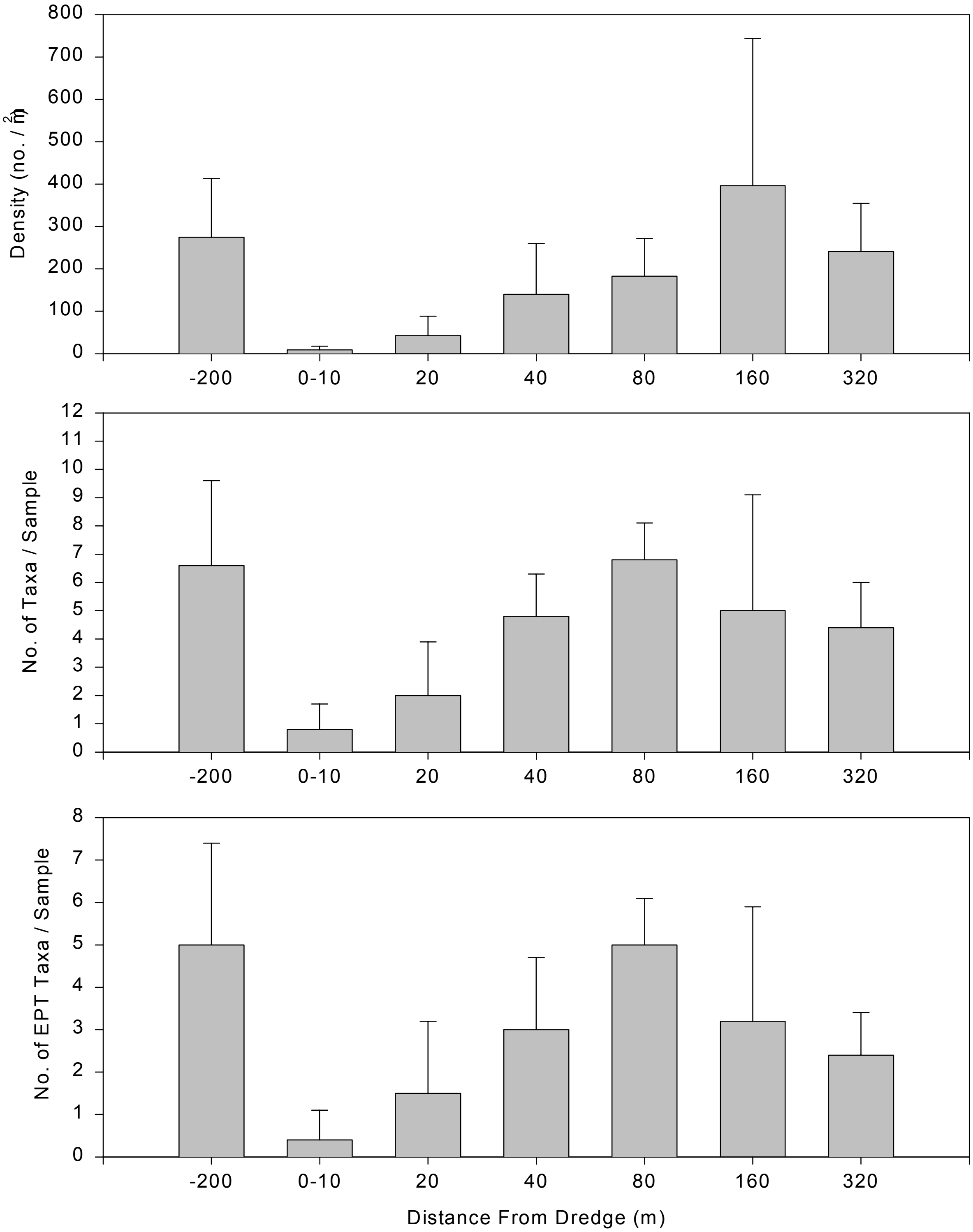


Figure 19. Abundance and diversity of macroinvertebrates from samples collected in relation to operation of an 8-inch suction dredge in the Fortymile River, Alaska. Negative values on the x-axis indicate locations upstream of the dredge. Error bars equal one standard deviation from the mean.

were sampled in both 1997 and 1998. Macroinvertebrate density and the number of EPT taxa also increased after one year (Fig. 20).

Site 2a - Sampling in 1997 revealed patterns at Site 2a similar to those observed at Site 1. Macroinvertebrate density at the reference transect was approximately 200 individuals per m^2 (Fig. 21). At the transect 25 m downstream of the dredge, density had decreased to approximately 20 individuals per m^2 and then increased to about 100 individuals per m^2 at the transect 70 m downstream of the dredge (Fig. 20). The number of taxa at the reference transects was equal for Site 1 and Site 2a and showed a similar downstream pattern at both sites. The number of EPT taxa, however, was considerably less at Site 2a in 1997, although the downstream pattern was the same as that for Site 1. Recovery of macroinvertebrate diversity at Site 2a appeared to be nearly complete one year after dredging with approximately 20 taxa at each of the transects (Fig. 22). One year after dredging with a 10 inch dredge at Site 2a, macroinvertebrate density, richness, and number of EPT taxa also had recovered to pre-mining conditions (Fig. 23).

Site 2b – A second site was established on the South Fork of the Fortymile River in 1998 to evaluate the effects of dredging on a nearby site with different water flow and possibly substrate composition. This site was on the inside bank of a meander bend, about 800 m upstream of Site 2a. Site 2b was also used to evaluate the effects of dredging late in the fall on macroinvertebrate composition. In Figures 24, 25, and 26, sites labeled "Upper" represent an area dredged with a 10 inch dredge in late September 1997. Sites labeled "Middle" and "Lower" represent adjacent areas mined within a week of our sampling in July 1998. Comparing Site 2a results with the Upper (recovered) location of Site 2b revealed that there were in fact differences in macroinvertebrate density between the Upper site of Site 2b and the reference area of Site 2a. (Fig 24b). Mean macroinvertebrate density at the Upper area of site 2b was also greater than the Middle or Lower areas (Fig 24b). Number of macroinvertebrate taxa present was nearly identical

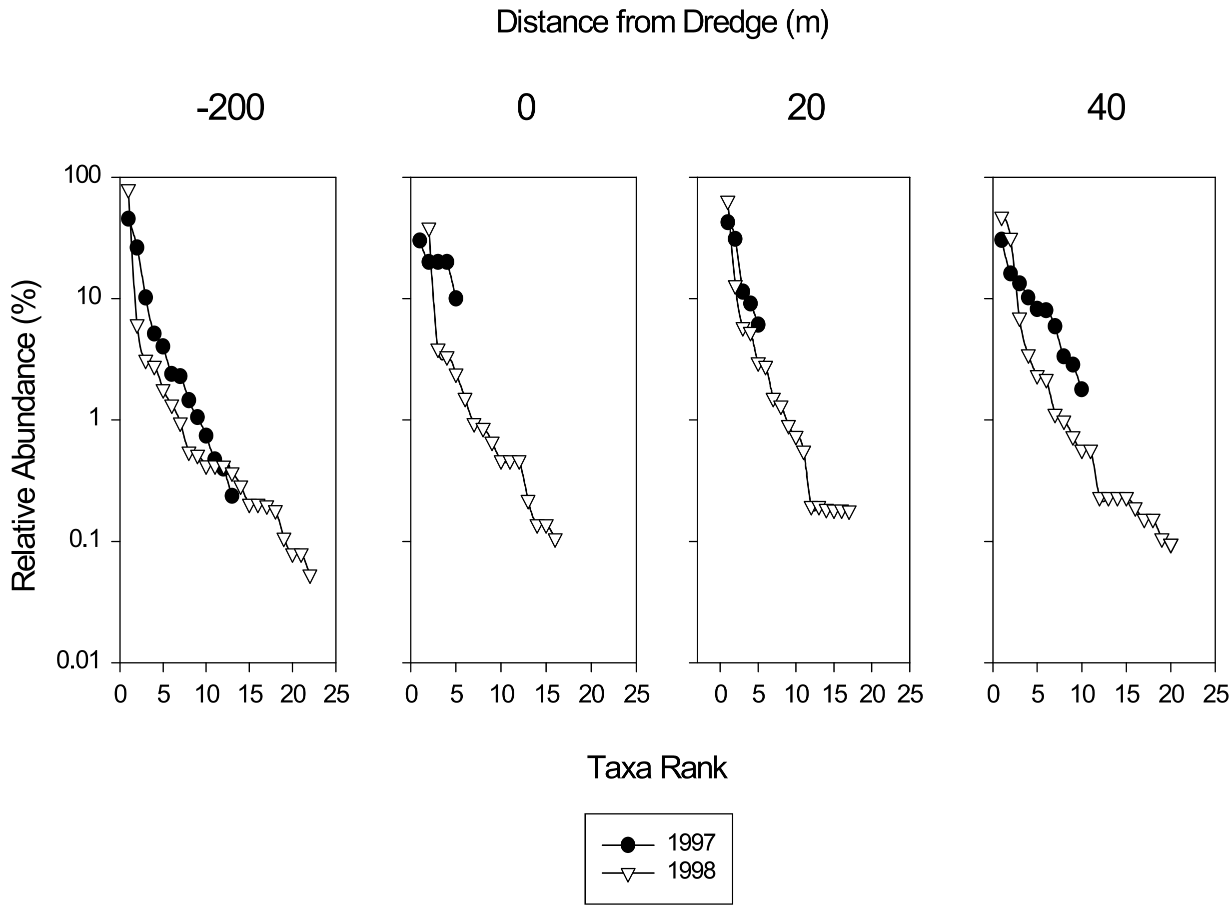


Figure 20. Taxa - abundance curves at Site 1 at four transects sampled in 1997 and 1998. Each graph represents a transect. The y-axis shows the relative abundance of any given taxa and the x-axis shows the rank of each taxa as well as the total number of taxa identified from the transect.

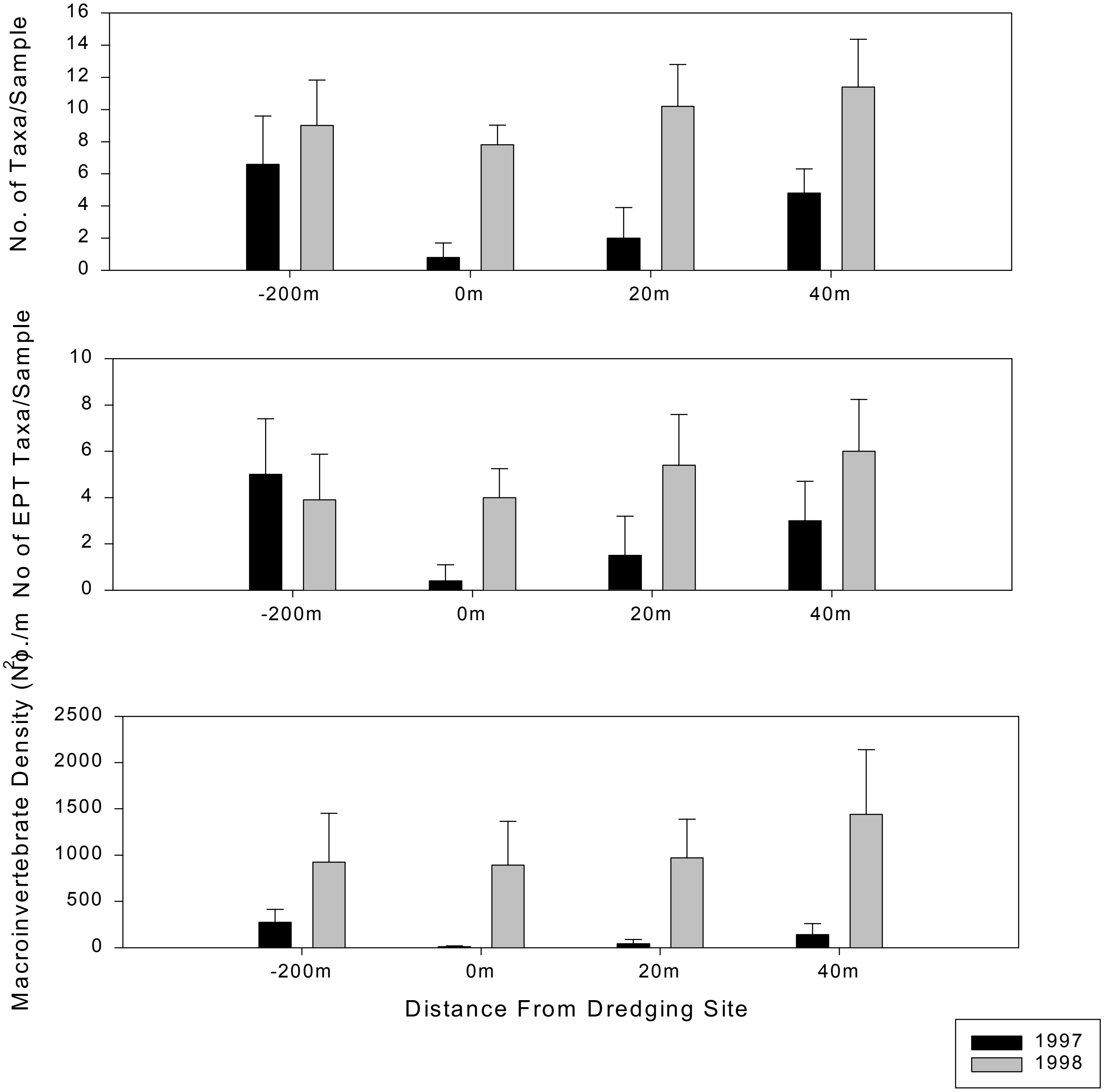


Figure 21. Comparison of 1997 and 1998 data for an area dredged with an 8 inch suction dredge and downstream areas on the Fortymile River, Alaska. Error bars represent one standard error from the mean.

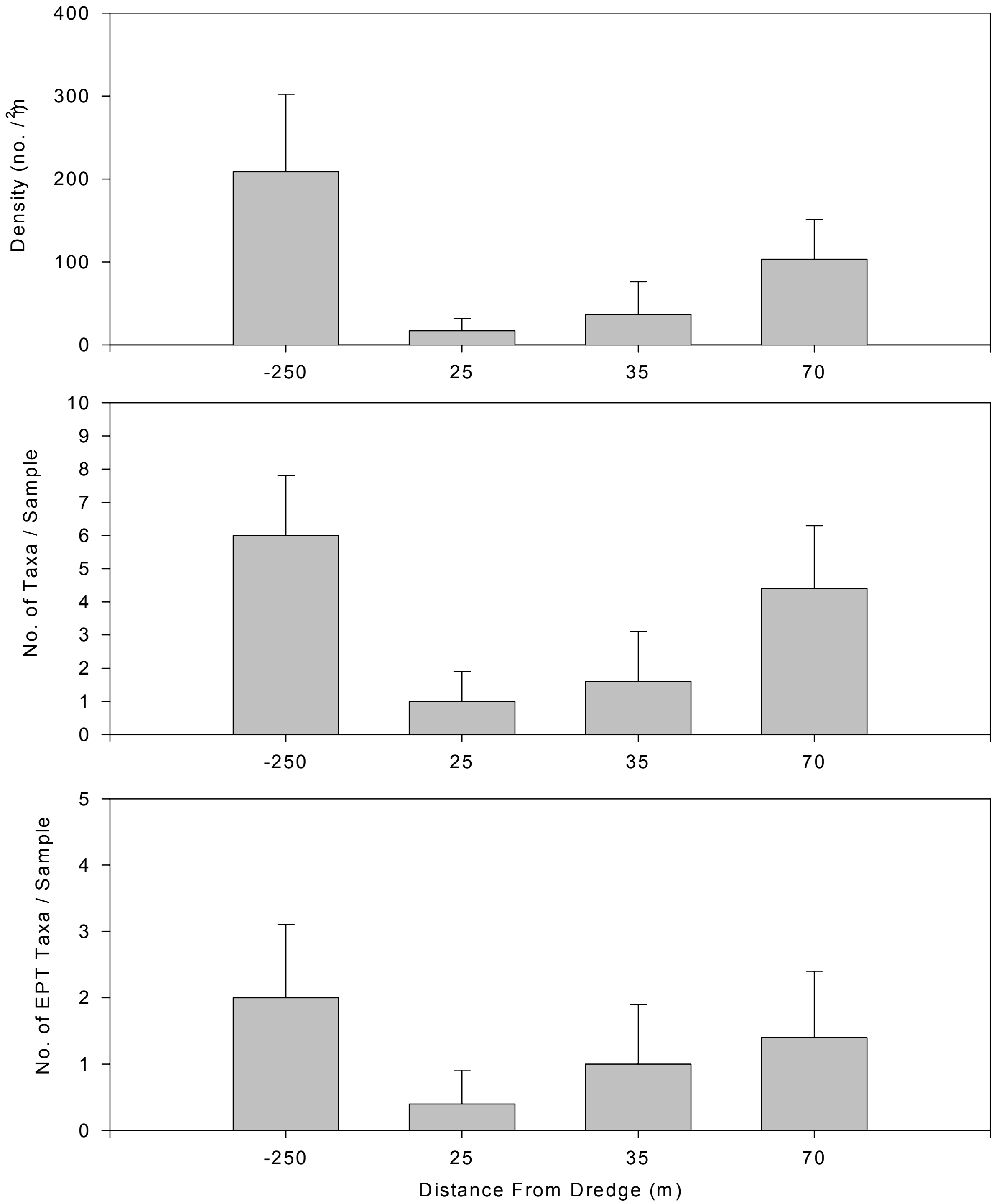


Figure 22. Abundance and diversity of macroinvertebrates from samples collected in relation to operation of a 10-inch suction dredge in the Fortymile River, Alaska. Negative values on the x-axis indicate locations upstream of the dredge. Error bars equal one standard deviation from the mean.

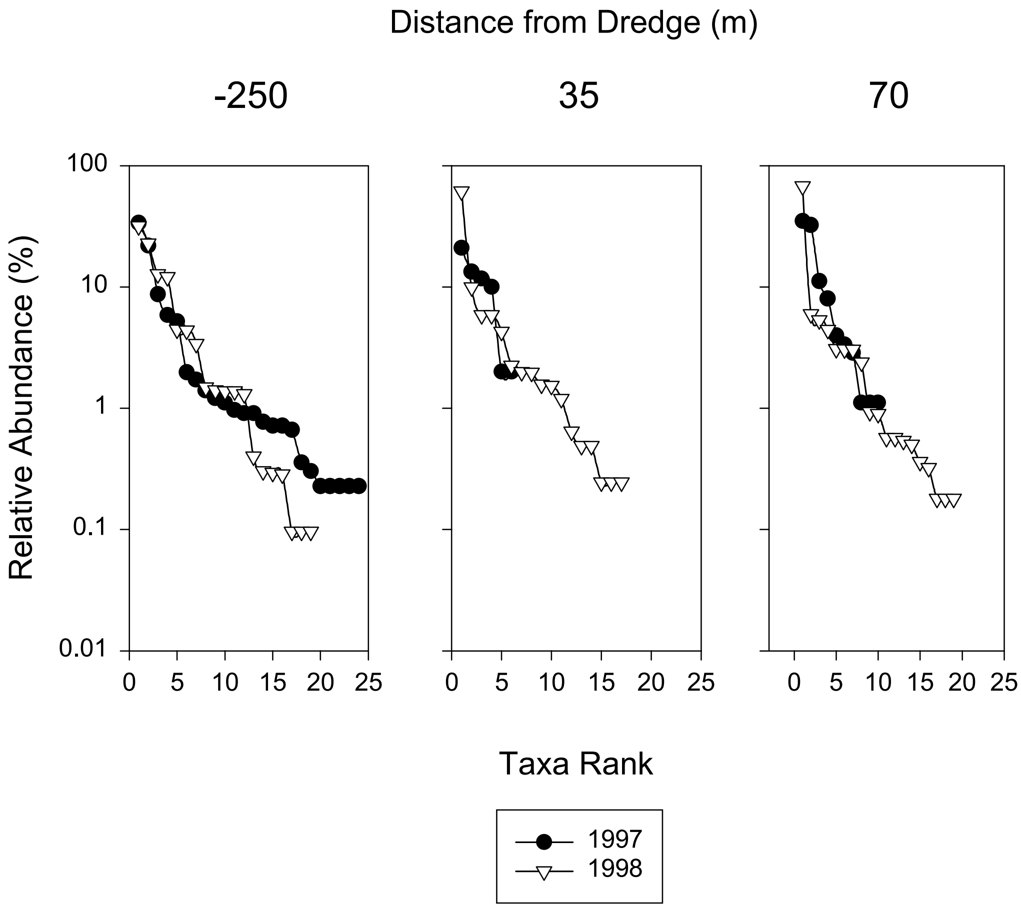


Figure 23. Taxa - abundance curves at Site 2a in the South Fork of the Fortymile River, Alaska, at three transects sampled in 1997 and 1998. Each graph represents a transect. The y-axis shows the relative abundance of any given taxa and the x-axis shows the rank of each taxa as well as the total number of taxa identified from the transect.

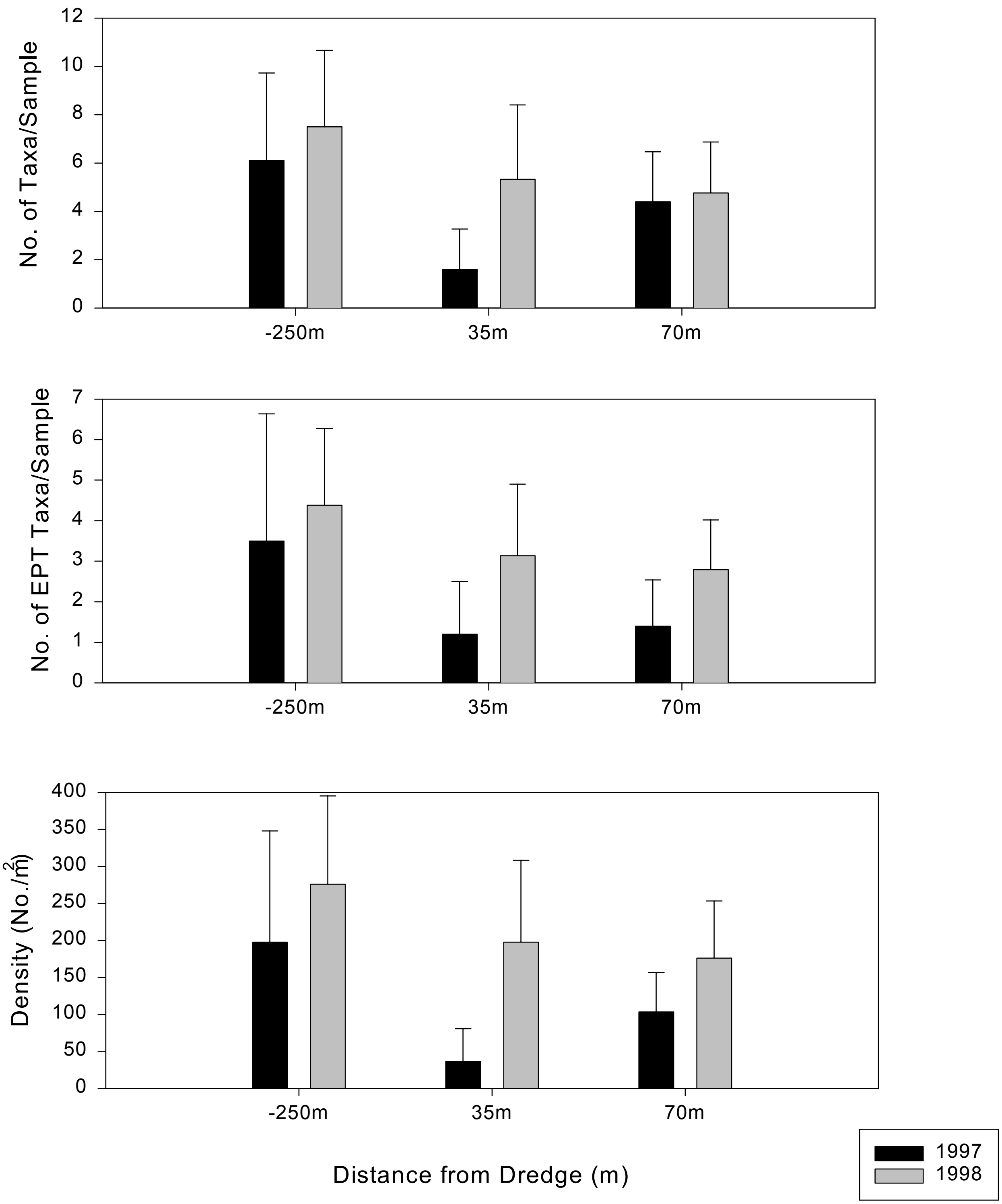


Figure 24. Comparison of 1997 and 1998 data from an area dredged with a 10 inch suction dredge and downstream areas on the South Fork of the Fortymile River, Alaska. Dredging occurred in 1997 only. 1998 data represents the condition of those effected areas after one year. Error bars represent one standard deviation from the mean.

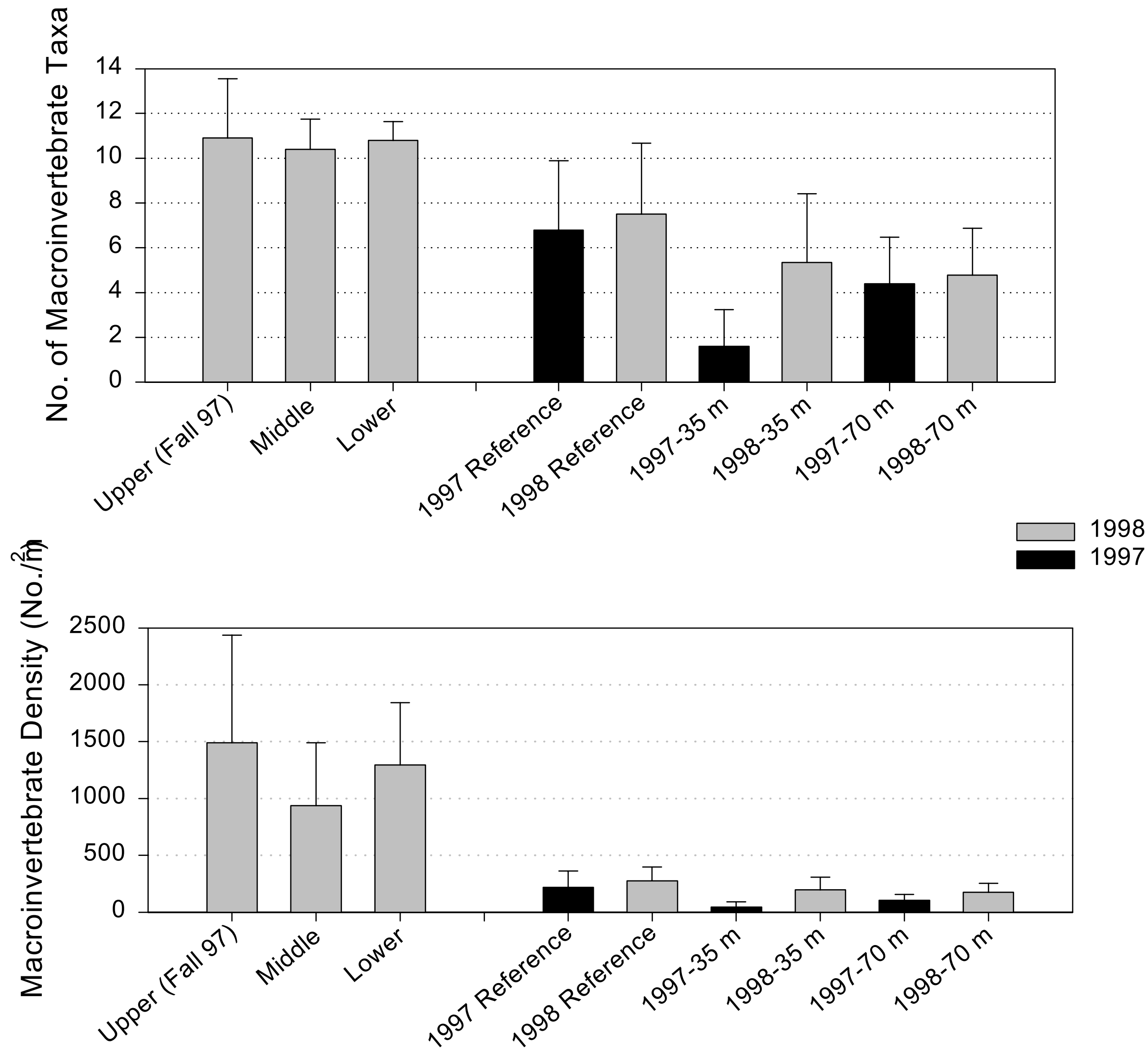


Figure 25. Macroinvertebrate richness and density from two sites mined with a 10 inch suction dredge in the South Fork of the Fortymile River, Alaska. The "Upper" site represents a site mined during late fall 1997, while the "Middle" and Lower" sites represent adjacent sites mined during summer 1998 (Site 2b). The remaining sites represent a nearby area mined only during summer 1997 and its subsequent recolonization after one year (Site 2a).

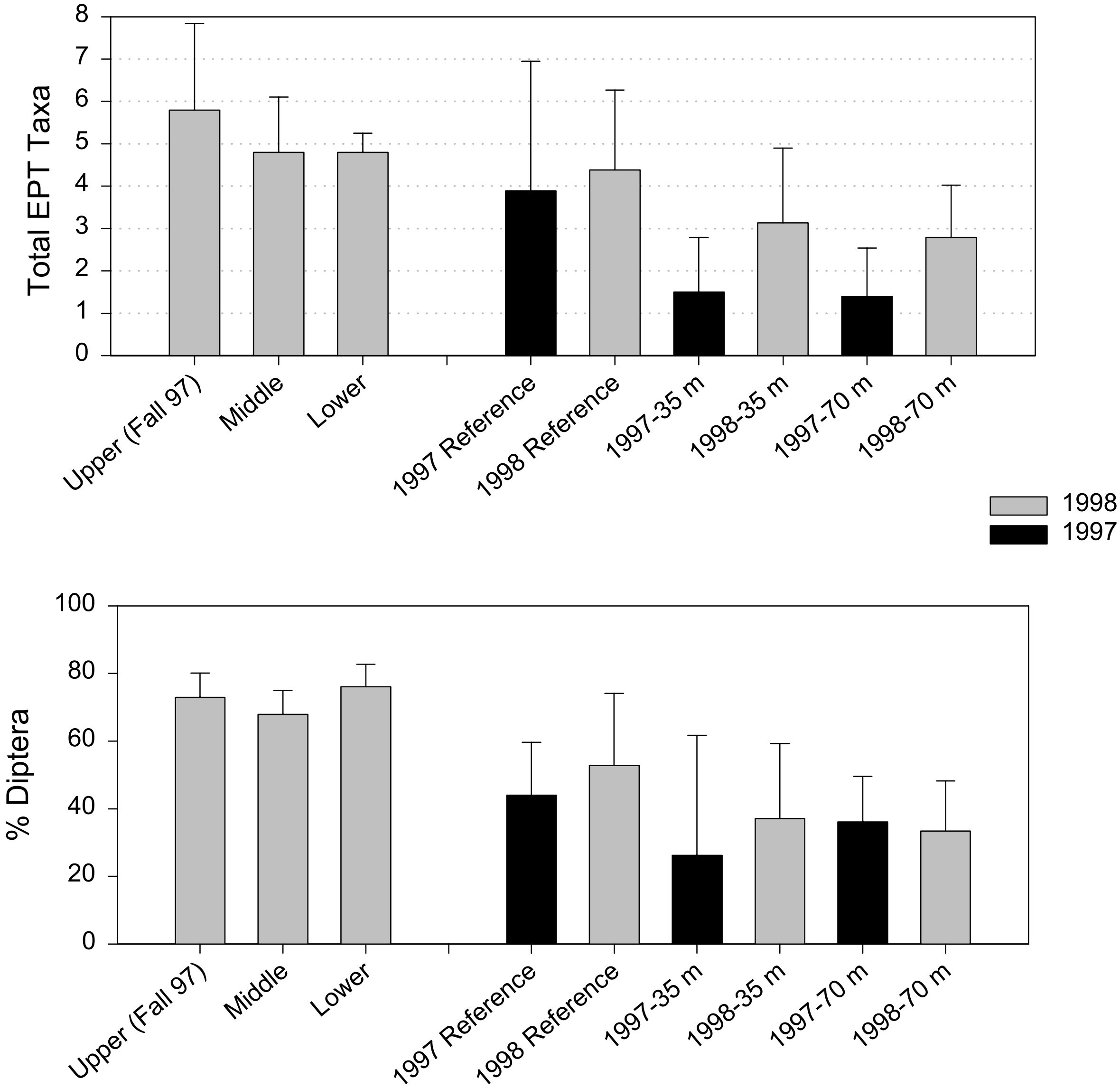


Figure 26. EPT and percent Diptera from two sites mined with a 10 inch suction dredge in the South Fork of the Fortymile River, Alaska. The "Upper" site represents a site mined during late fall 1997, while the "Middle" and Lower" sites represent adjacent sites mined during summer 1998 (Site 2b). The remaining sites represent a nearby area mined only during summer 1997 and its subsequent recolonization after one year (Site 2a).

between Upper, Lower, and Middle sites and was similar for the Site 2a reference areas (Fig 24a). Mean number of EPT taxa present was also similar between Site 2b and the Site 2a reference area (Fig 25a). Additionally, the order Diptera comprised a greater overall percentage of the organisms found in Site 2b than in Site 2a (Fig. 25b). Benthic organic matter was similar between both sites for samples taken in 1998, though the Upper location of Site 2b showed a greater mean concentration of BOM than either the Middle or Lower locations. BOM concentrations were significantly lower at Site 2a in 1997 than in 1998 at all locations downstream of dredging activity (Fig 26).

Site 3- We sampled a single dredge site on the North Fork in which a 10 inch dredge was operated by an experienced miner and was actively dredged within 10 days prior to our sampling. This site consisted of three dredged areas, one beginning at the head of our study reach (T0), the second stretching the length between 10 and 20 m from the T0 location (T10), and the third encompassing the distance between 40 and 60 m (T40) from the T0 location. The mined areas at 10 m and 40 m were compared to two reference locations. Two reference locations were used to compare reference locations themselves. We were not able to determine the distance downstream that dredging affected because of inconsistent dredge operations by the North Fork miners which were caused by relatively high flows over the duration of our sampling. The study reach chosen here allowed us to determine the short term recovery (>10 days) of these dredged areas in the North Fork. Our results suggest that within the time since dredging, all measures except macroinvertebrate density appeared to fully recover within 10 days since dredging (Fig 27). Macroinvertebrate density at the reference location averaged about 1600 organisms/m^2. Dredged locations averaged between 1200 and 1400 organisms/m^2. Benthic organic matter concentrations also were consistent throughout the study locations (6-7 g/m^2) suggesting that food resources for macroinvertebrates had fully recovered to pre-mining conditions (Fig 27).

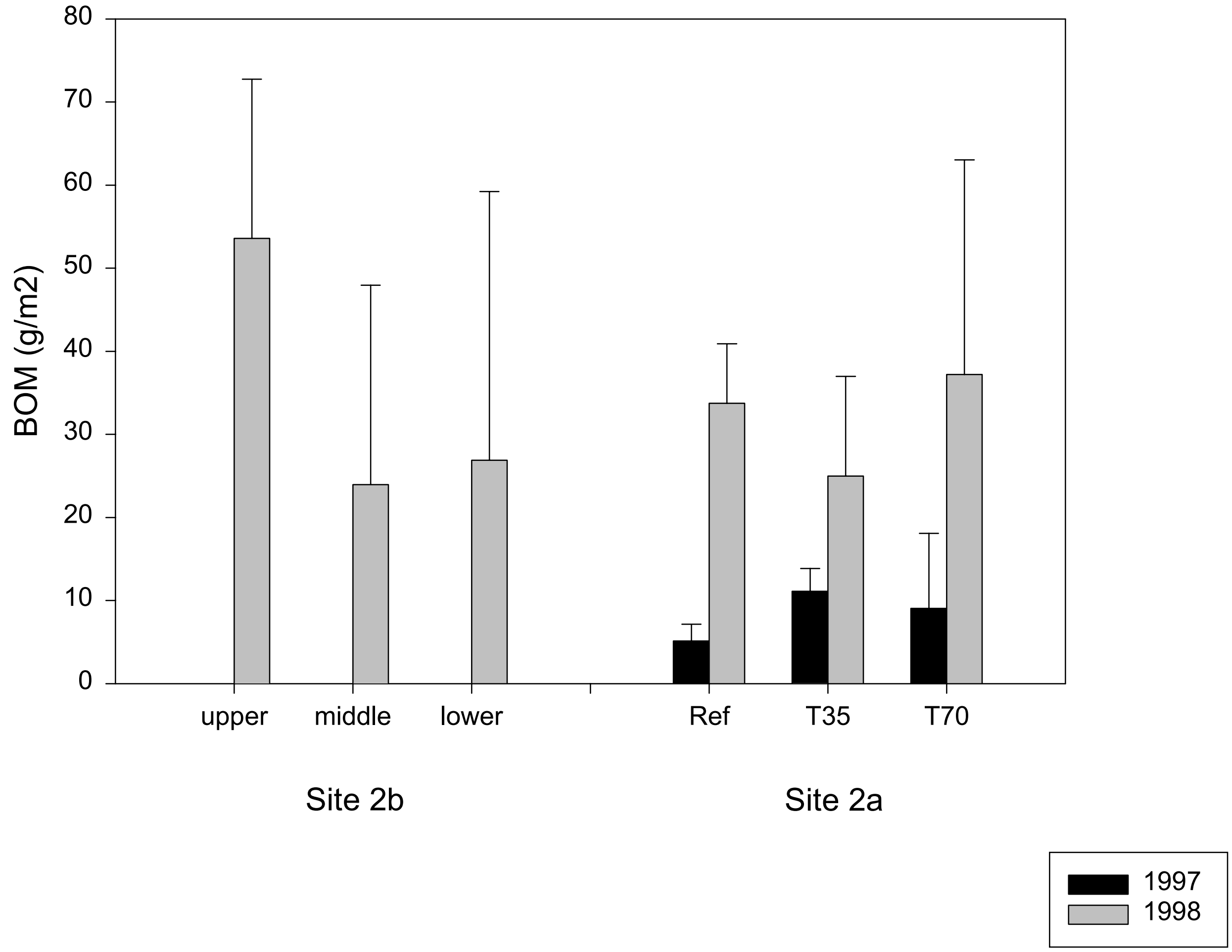
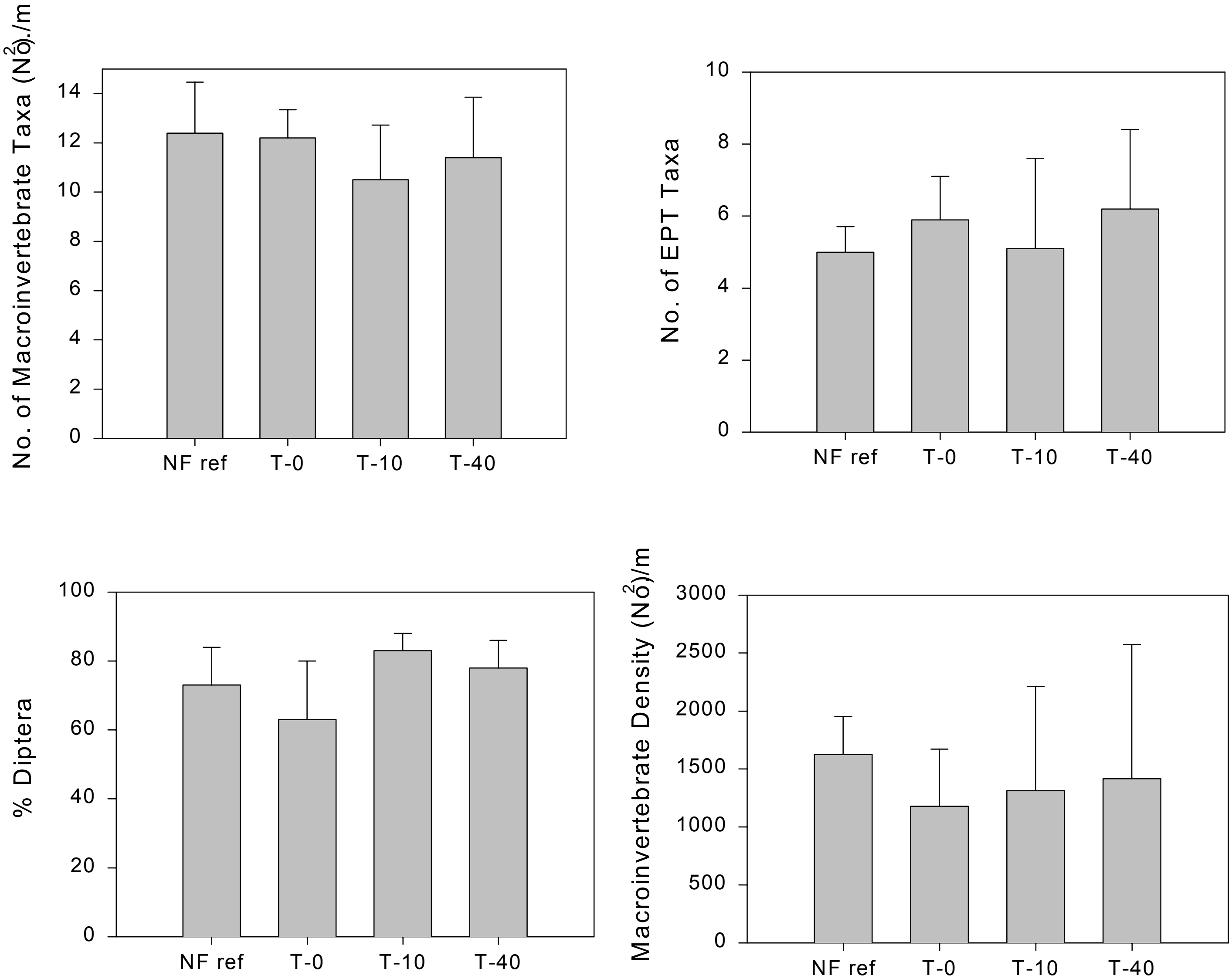


Figure 27. Benthic organic matter at two locations on the South Fork of the Fortymile River, Alaska mined with a 10 inch suction dredge. Bars represent BOM for two years (1997 and 1998). "Upper", "Middle", and "Lower" bars represent data from one location taken in 1998 (Site 2b) only. "Ref", "T35", and "T70" represent data from a location mined in 1997 and its subsequent recovery after one year (Site 2a).

North Fork / South Fork Comparison- Comparisons between the North Fork and South Fork were made to determine if the South Fork macroinvertebrate populations were depauperate due to degraded water quality from increased mining activity on the South Fork itself and some of its major tributaries. Initial results presented in a previous report (February 1999) indicated that this was the case when reference areas from Site 2a were compared to North Fork confluence sites in 1997. In 1998 we sampled a different reference location on the South Fork that was closer to the actual confluence (Site 6, see Fig. 1; nearly 500 m upstream of its confluence with the North Fork) and compared this data with similar results from an unimpacted reference site several kilometers upstream on the North Fork (Site 5). We also compared this North Fork reference site to a downstream location noted by the USGS to be high in heavy metal concentrations near the confluence of the North and South Forks (Site 4).

The upwelling of heavy metals between Sites 4 and 5 appears to have little effect on macroinvertebrate populations in the North Fork. The number of taxa, number of EPT taxa, and overall relative abundance of Diptera are nearly identical for both Sites 4 and 5. Macroinvertebrate density was nearly $2500/m^2$ downstream of the upwelling and about $1500/m^2$ upstream. The only measure that appeared to be affected by heavy metal concentrations was the percentage of Simulidae (Fig 28).

Comparing Site 5 and Site 6, we found no differences between macroinvertebrate density, number of EPT taxa, number of overall taxa, or the relative abundance of Diptera (Fig 29). Mean benthic organic matter concentration was, however, greater in the South Fork than in the North Fork (Fig 30). Although we did not take samples at the South Fork confluence site in 1997, there may be some degree of yearly variation in macroinvertebrate populations in the South Fork when comparing reference conditions from Site 2a (Fig. 22). In the North Fork however, there appears to be less yearly variation in macroinvertebrate populations in the years that we sampled (Fig. 31). According to the species abundance graph used to compare relative abundance among years for Site 4, 19 taxa were present in 1997 while 24 taxa were present in 1998. Though this figure does not depict which taxa were most abundant, Table 4 shows that over 80% of all the macroinvertebrates present in our samples at Site 4 were in the order Diptera



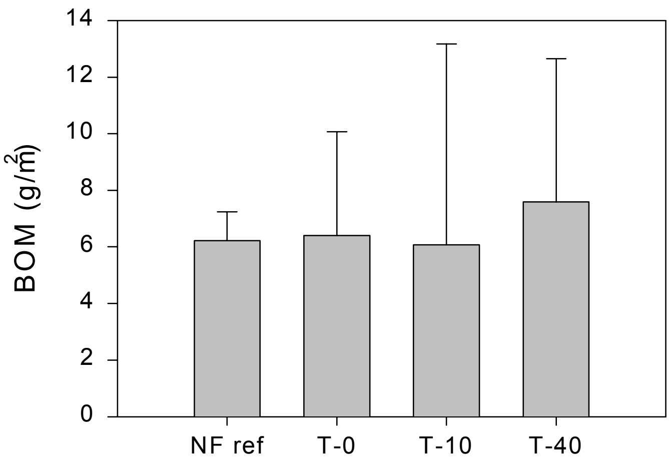


Figure 28. Comparison of variables measured in the North Fork of the Fortymile River, Alaska (Site 3). Error bars equal one standard deviation from the mean.

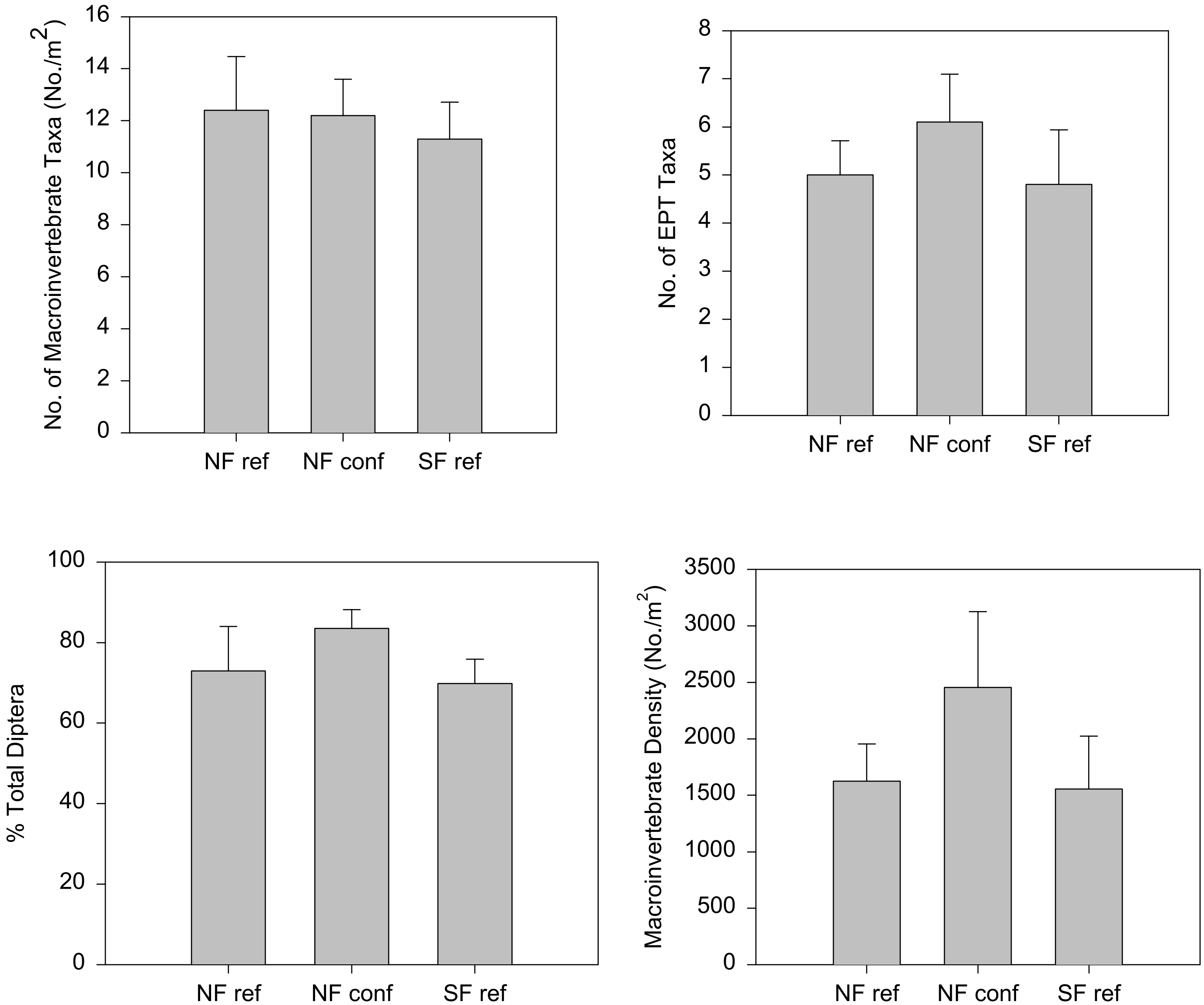


Figure 29. Comparisons between two sites on the North Fork and a single site on the South Fork of the Fortymile River, Alaska.

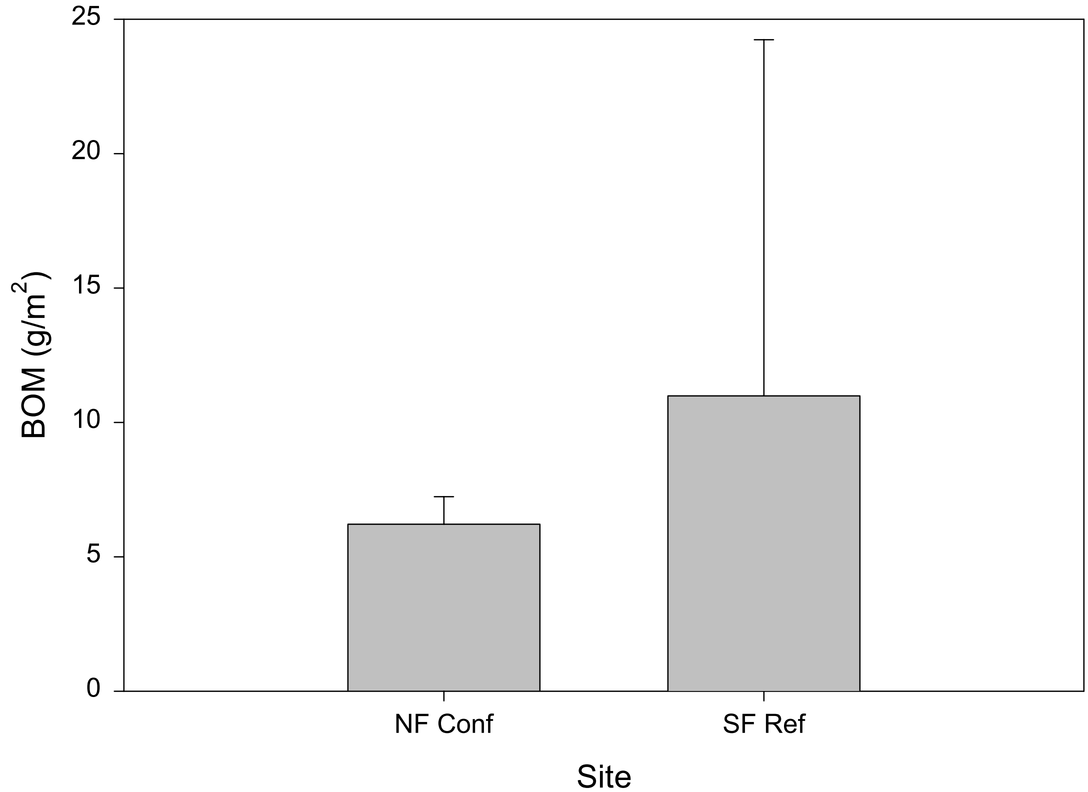


Figure 30. Comparison of benthic organic matter (BOM) concentrations between the North Fork and the South Fork of the Fortymile River, Alaska. Error bars represent one standard deviation from the mean.

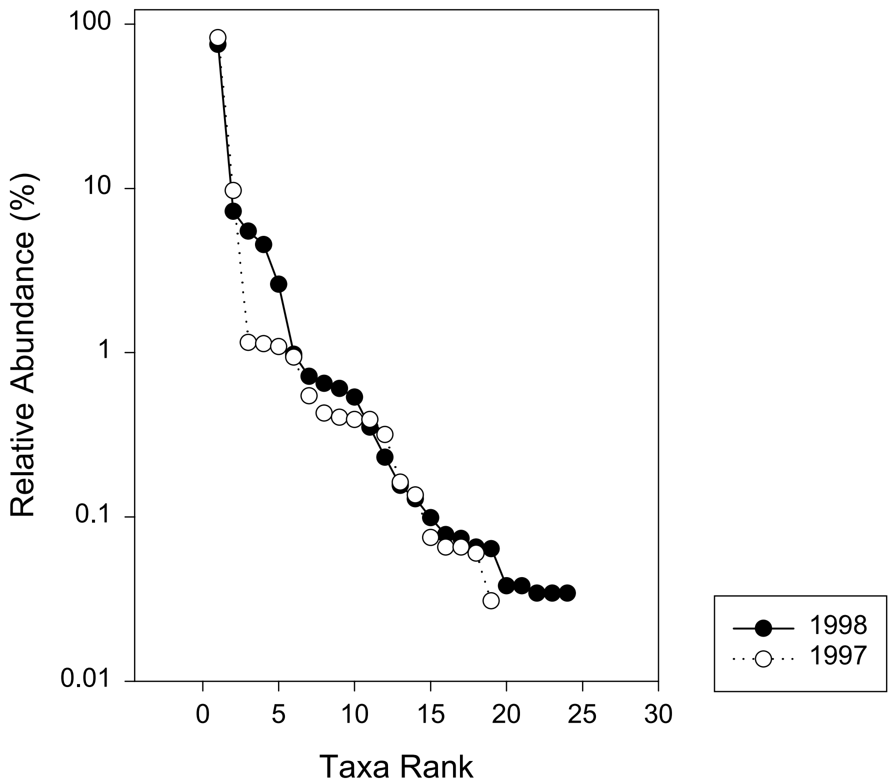


Figure 31. Taxa abundance curves for an unmined reference site on the North Fork of the Fortymile River, Alaska. Curves represent two consecutive years. The y-axis shows the relative abundance of any given taxa and the x-axis shows the rank of each taxa as well as the total number of taxa identified from the location.

Table 3. Relative abundances of macroinvertebrate taxa for two consecutive years at a single reference site (Site 4) in the North Fork of the Fortymile River, Alaska.

TAXA	1998 Mean Rel Abun	1997 Mean Rel Abun
Ephemeroptera		
Baetis	5.49%	0.55%
Ephemerellidae	2.61%	
Ephemerella		1.16%
Ameletus	0.72%	0.94%
Cinygmula	0.65%	1.09%
Stenonema	0.60%	
Acentrella	0.54%	
Siphlonurus	0.03%	
Epeorus	0.06%	
Metretopus		0.14%
Trichoptera		
Brachycentridae, small	0.13%	
Brachycentrus		0.40%
Psychoglypha	0.07%	
Limnephilidae, small	0.04%	
Ceraclea	0.03%	
Neophylax		0.43%
Arctopsyche		0.07%
Plecoptera		
Perlodidae (Small)	0.04%	
Zapada		0.39%
Chloroperlidae (small)		0.07%
Suwallia	0.07%	
Alloperla		0.03%
Coleoptera		
Helophorus	0.16%	
Diptera		
Chironomidae	75.21%	82.61%
Simulidae	8.22%	0.39%
Probezzia	0.08%	
Phoridae	0.03%	
Unknown Diptera		0.48%
Other		
Acarina (mites)	4.55%	9.70%
Oligochaeta	0.35%	0.06%
Nematoda	0.23%	1.13%
Harpactacoida	0.10%	

in 1997, whereas in 1998 this dropped to 75%. We used Site 4 to compare macroinvertebrate populations between years because: (1) it is the only North Fork location in which we have two consecutive years of data, and 2) our results from the arsenic upwelling portion of the study showed no evidence of the arsenic contaminated water having an effect on macroinvertebrate populations (Fig. 28). In fact, macroinvertebrate densities were greater in the supposed "affected" area than in the reference area. The only measure that showed a difference possibly due to heavy metal contamination was the relative abundance of the order Simulidae. Simulidae were accounted for nearly 40% of the macroinvertebrates in the reference site and less than 10% in the confluence site.

Discussion

The primary effect of suction dredging on water chemistry of the Fortymile River, as detected at Site 1, was increased turbidity, total filterable solids (TFS), and copper and zinc concentrations downstream of the dredge. Turbidity and TFS were substantially elevated downstream of the dredge and the plume of sediment-laden water created by the dredge was visually obvious. But, although the plume was visually dramatic it was spatially confined to within 160 m (= 525 ft.) of the dredge and was restricted to the portion of those days that the dredge was operating. Furthermore, the effect of the plume was limited to approximately 7% of the width of the river. The results from this sampling revealed a relatively intense, but very localized, decline in water clarity during the time the dredge was operating. Wanty et al. (1997) reported turbidity values of 19 NTU 30.5 m (100 ft) downstream of a 10 inch dredge located below Wilson Creek on the North Fork Fortymile River. Values returned to near background levels (3.7 NTU) within the next 30.5 m but remained slightly above background levels (2.2 - 2.3 NTU) as far as 150 m downstream (furthest sampling transect). Turbidity values downstream of an 8 inch dredge operating in the same vicinity were lower because less sediment was being disturbed and the sediments were coarser and hence settled more rapidly. The 19 NTU at 30.5 m is comparable to the value we found at 20 m at Site 1.

Wanty et al. (1997) examined dissolved metal concentrations 60.8 m (200 ft) downstream of a 10-inch and an 8-inch dredge and found no difference between the sides and center of the dredge plume. In our study, dissolved metals displayed no clear pattern in relation to the dredge suggesting the increased concentrations of total copper and total zinc at Site 1 were likely a result of metals associated with the sediments excavated by the dredge. As the metal-laden sediments were transported downstream and deposited on the riverbed, total copper and zinc concentrations declined. By 80 m downstream of the dredge, copper and zinc concentrations were similar to those measured upstream of the dredge (see Fig. 8). These results suggest the need for examining heavy metal accumulation on the riverbed, rather than instantaneous measures of heavy metal concentrations in the water column. The examination of heavy metal concentrations in aquatic macroinvertebrates indicated that at some locations, such as Polly Creek, the effects of mining are being reflected in the physiological condition of the biota. However, the degree to which metals within the tissues of the macroinvertebrates may influence life-history or other biological traits is unknown. In general, this approach (examining macroinvertebrates) is worth pursuing with a more intensive sampling effort and a greater number of sites.

Discussions with local miners indicated that the intensity of the plume is, in part, a function of the type of sediment that is being excavated from the riverbed. Thus, the impact of suction dredging on water clarity and heavy metal concentrations may be greater or lesser than that reported here, depending on the type of material being excavated. In general, the observed decrease in water clarity was unlikely to have altered ecosystem function in that area of the Fortymile. However, the increased sediment load and rapid reduction in light could cause aquatic organisms to drift (Allan 1995:221-237, Wiley and Kohler 1984), resulting in reduced macroinvertebrate abundance and/or delayed re-colonization of dredge piles. The effect of suction dredging on the abundance of drifting macroinvertebrates was not addressed in the present study, but drifting is likely an important mechanism in the interaction between macroinvertebrate abundance and suction dredging. In particular, organisms capable of drifting may be displaced, but not killed, by the dredging activities. Those organisms that are entrained in the dredge will not necessarily be killed. Griffith and Andrews (1981) examined >3,600 organisms and reported less than 1% mortality for macroinvertebrates entrained through a 3-inch suction dredge.

The cross-sectional profiles indicate the impact of the dredge piles relative to the width of the river was small (see Fig. 10). Assuming widths of 2 m for the dredge pile and 80 m for the river, the dredge pile would represent 2.5% of the river width. In addition to a small spatial effect, the temporal duration of the dredge piles appeared short. For example, although recently deposited, the dredge piles 5 m and 20 m downstream of the dredge at Site 1 were not detectable in the detailed maps of the right bank (see Fig. 10). It is intuitive that unconsolidated, artificially deposited rock piles in a river would be unstable and ephemeral. Thomas (1985) studied suction dredging in a stream in Montana and reported that spring flows eliminated dredge piles created along the stream margin. Likewise, Somer and Hassler (1992) examined the effect of suction dredging in two northern California streams and observed that dredge piles existed only seasonally and did not persist beyond springtime high-flows. Based on our observations and results, it appears likely that the dredge piles at the locations we examined will remain in place no longer than 1 to 3 years and that in many cases the stream channel will return to its pre-dredge condition following river freezing and the succeeding ice-action and the springtime flows that accompany and snow-melt in the Fortymile drainage.

The abundance and diversity of aquatic macroinvertebrates at a given site are closely related to the size, stability, and surface complexity of the substrata at that site (e.g., Minshall 1984, Hart 1978). In addition, the magnitude of the impact a particular disturbance has on a macroinvertebrate community may be mediated by substrate size; small rocks are more easily tumbled (i.e., disturbed) than are larger rocks (Gurtz and Wallace 1984). Thus, the effect that suction dredging has on the macroinvertebrate community of the Fortymile depends on the characteristics of the substrata being disturbed. The rate at which dredge piles are re-colonized also will depend on stability of the individual substratum. Clearly, the effect of suction dredging will not be the same for all locations in the Fortymile and/or sizes of dredge.

As with water clarity, the effect of suction dredging on macroinvertebrate abundance and diversity at the locations we examined was confined spatially to a relatively small area downstream of the dredge. Other researchers also have documented the localized nature of suction-dredge effects (Somer and Hassler 1992, Harvey 1986, Thomas 1985), although each of these studies was conducted using smaller, recreational dredges. In the present study, both abundance and diversity were notably reduced for 10 m downstream of the dredge at Site 1. By 80 m below the dredge, however, abundance and diversity appeared unaffected by the dredge plume. Site 2a displayed a similar pattern, although the sampling was more spatially limited. The short-term, downstream impact of suction dredging on macroinvertebrates probably was limited to the same area in which the dredge plume was visible. Therefore, the percent of the riverbed being affected by the dredge was small: approximately 7% of the width for <80 m downstream. The cumulative effect of suction dredging on the biota of the Fortymile cannot yet be assessed fully, but likely will depend on the number of dredges operating concurrently, the size of the dredges, the strategy of the dredge operators, and the extent of re-colonization that occurs on the excavated dredge piles.

The results from 1998 indicate that substantial recovery of the macroinvertebrate community occurs within one year after suction dredging. At both Site 1 and Site 2a, the transects dredged in 1997 showed, in 1998, taxa abundance curves very similar to the reference transects (see Figures 12 and 14). Although suction dredging is a very intense, local disturbance to benthic organisms, the biological and chemical effects of suction dredging do not appear to extend for more than a year.

The comparison of conditions in the North Fork versus the South Fork Fortymile suggests that macroinvertebrate density in this river system may be a function of food resources. Previous results had suggested that greater food abundance (e.g., periphyton and BOM) in the NF corresponded to an approximately 5-fold greater density of macroinvertebrates. However, our 1998 comparison of the North and South Forks does not provide the same explanation. It appears that the greater concentration of mining activity in the SF has affected macroinvertebrate density but not macroinvertebrate diversity at the sites we examined. The lack of a difference in macroinvertebrate diversity between the two forks supports the conclusion that the effects of suction dredging are limited, spatially, to areas immediately downstream of an operating dredge.

Part II - Recreational Dredging in Resurrection Creek

Recreational gold mining is a popular activity throughout much of Alaska and suction dredging is a common method used in recreational mining. The recreational dredges are smaller than those examined on the Fortymile; recreational dredges typically have intake lines of 2-4 inches in diameter. Despite the relatively small size of the dredges, streams that are popular with hobbyists may experience a more intensive mining disturbance than do larger rivers such as the Fortymile. Part II of this report describes the results of our research into the effects of recreational suction-dredging in several Alaskan streams.

Methods

This research was conducted on Resurrection Creek located on the Kenai Peninsula in 1997 and 1998. Additional sites in 1998 included Cooper Creek, also on the Kenai Peninsula, and the Chatanika River northeast of Fairbanks. Resurrection Creek is designated as a recreational mining site by the State of Alaska and the U.S. Forest Service and is open to recreational dredging from May 15 through July 15 of each year. The other sites are not officially designated for mining, but are popular recreational sites with few accessible areas and are open to mining during the same time period as Resurrection Creek.

Our sampling was conducted on 22 August 1997; approximately 5 weeks after recreational dredging in the Resurrection Creek had ended for the year. The general design was similar to that described above for sampling on the Fortymile. Four locations were sampled: (1) within the reach of stream that suction dredging is permitted, (2) approximately 500 m upstream of the dredged area, (3) approximately 35 m downstream of the dredged area, and (4) an area >500 m downstream of the dredged area. In each of these locations, five macroinvertebrate samples and three periphyton samples were collected. Water samples were collected only at the location within the dredged area, but as active dredging was not occurring, these samples are indicative of conditions in the stream as a whole. All samples were collected, preserved, and processed as described above for samples from the Fortymile River. In 1998, sampling included only macroinvertebrates and periphyton.

One-way ANOVA was used to test for statistically significant differences among the four locations in Resurrection Creek. Prior to analysis, the data were transformed using either natural log (X) or arcsin(square root (X)) as appropriate (Zar 1984). Pairwise comparisons were conducted using the Tukey HSD test.

Results and Discussion

At the time of sampling, total alkalinity, total hardness, and specific conductance in Resurrection Creek were 29 mg $CaCO_3$ / L, 69 mg $CaCO_3$ / L, and 110 μS / cm, respectively. Mean benthic organic matter (BOM) ranged from approximately 15 to 30 g / m^2 among the four sampling locations (Fig. 31), but ANOVA indicated no significant differences (p=0.252). Mean chlorophyll-a was greatest in the mining area and the location immediately downstream of the mining area, but the differences among the means were not significant (p=0.182) (Fig. 31). Periphyton AFDM showed a pattern similar to chlorophyll-a, with the greatest mean values in the mined area, but here too the differences were not significant (p=0.064) (Fig. 31). The reach of Resurrection Creek in which suction dredging occurs is bordered by a campground and numerous foot trails along the stream. The riparian canopy along that section of Resurrection Creek appeared reduced, relative to areas downstream, by the activities associated with recreational mining (e.g., stream-side camping). The reduced riparian shading (= increased solar radiation) may be responsible for the trend towards greater periphyton AFDM and chlorophyll-a observed in the mined area and the location immediately downstream of the mined area. Additionally, these results suggest that activities other than the actual dredging, such as long-term camping, firewood collection, trampling of vegetation, etc., also may have an impact on streams open to recreational suction dredging.

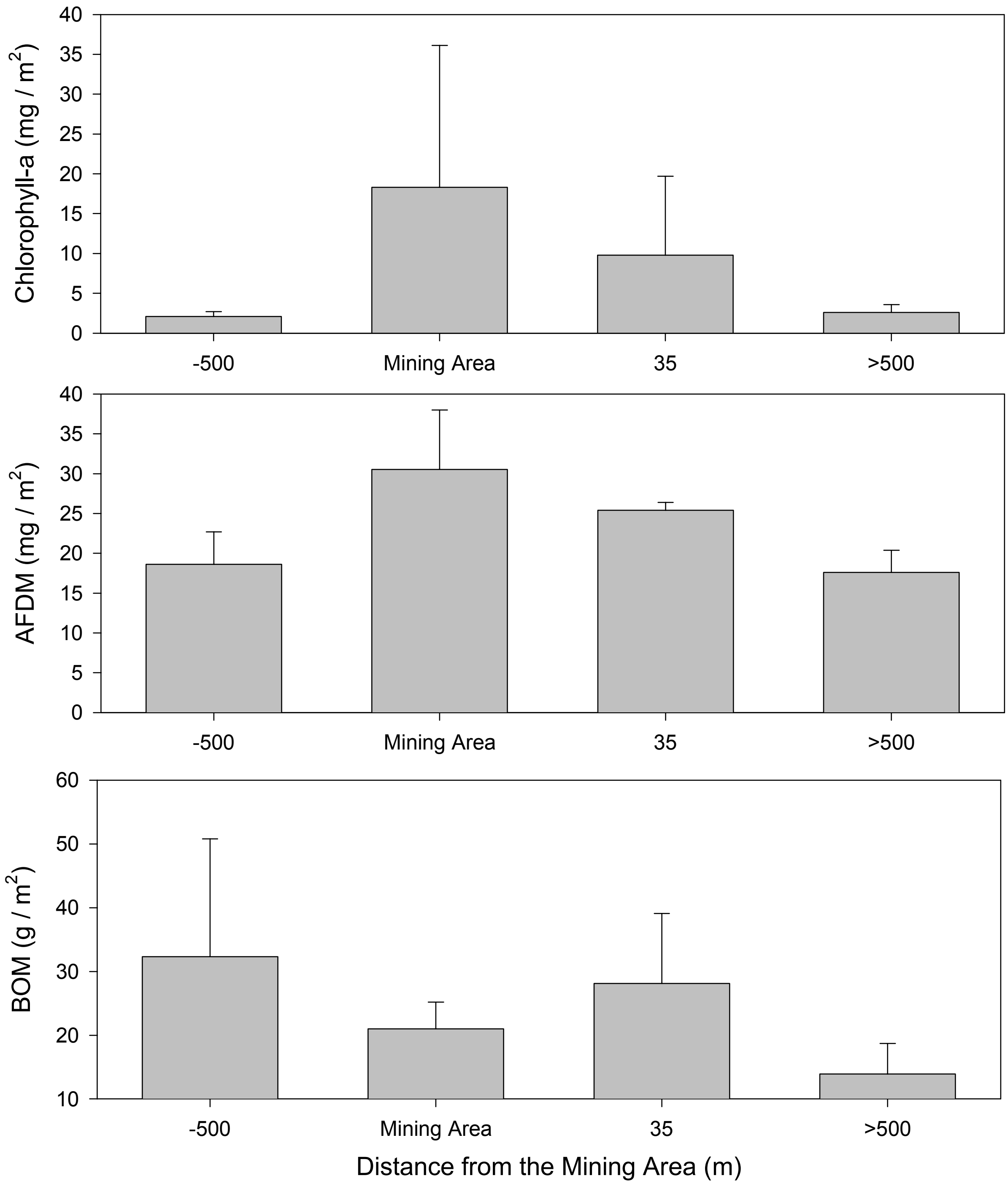


Figure 32. Periphyton chlorophyll-a and AFDM and BOM at four locations in Resurrection Creek in relation to recreational suction dredging. Error bars equal one standard deviation from the mean, n=3 for chl-a and AFDM; n=3-5 for BOM. Negative values on the x-axis indicate locations upstream of the mining area.

The pattern seen with periphyton was not observed for macroinvertebrates. Mean density was 3,700 individuals per m^2 in the mined area, and ranged from 4,300 to 4,500 individuals per m^2 in the other three locations, although the variability was large and the differences not significant (p=0.581) (Fig. 32). Total taxa richness from about 17 to 19 among the four locations (p=0.811). The number of EPT taxa was not significantly different among the sites (p=0.415), although the mean values increased from 9.5 at the upstream location to 11 taxa at the most downstream location (Fig. 32). Based on density, taxa richness, and EPT richness, there was no difference in the macroinvertebrate community between the mined area and the locations downstream. The relative abundance of Plecoptera (stoneflies) was significantly greater at the two downstream locations than in the mined area (p=0.037) (Fig. 32). However, if the observed reduction was a result of recreational suction mining, downstream recovery was rapid (i.e., by 35 m).

In general, other studies on the effects of recreational suction dredging have reported only localized reductions in macroinvertebrate abundance (Somer and Hassler 1992, Harvey 1986, Thomas 1985). Studies that examined temporal recovery have found that macroinvertebrates return to pre-dredging densities within 30-45 days (Harvey 1986, Thomas 1985). Our sampling occurred approximately 35 days after suction dredging had ended in Resurrection Creek for the year. Thus, it is not surprising that the abundance and diversity of macroinvertebrates was not significantly different between the mining area and the locations downstream.

The results presented here on the effects of recreational suction dredging on macroinvertebrates are derived from a one-time sampling event on Resurrection Creek. Therefore, we are not able to draw broad conclusions regarding the impact of suction dredging on small streams in Alaska. Using the data presented here, we have revised and expanded (spatially) our study of recreational dredging in small streams (Prussian 1999).

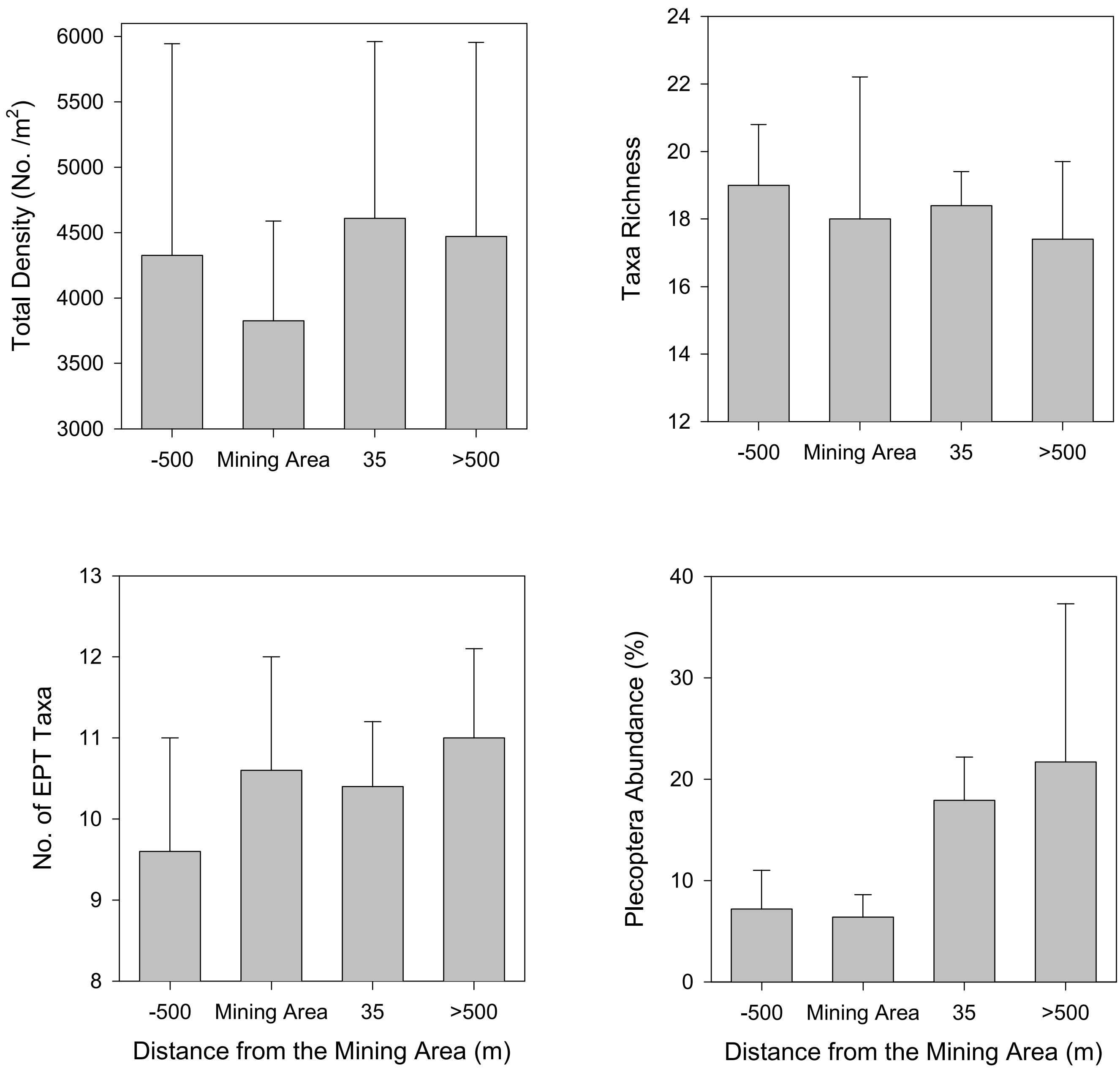


Figure 33. Macroinvertebrate metrics calculated from samples at four locations in Resurrection Creek in relation to recreational suction dredging. Error bars equal one standard deviation from the mean, n=5. Negative values on the x-axis indicate locations upstream of the mining area.

Acknowledgments

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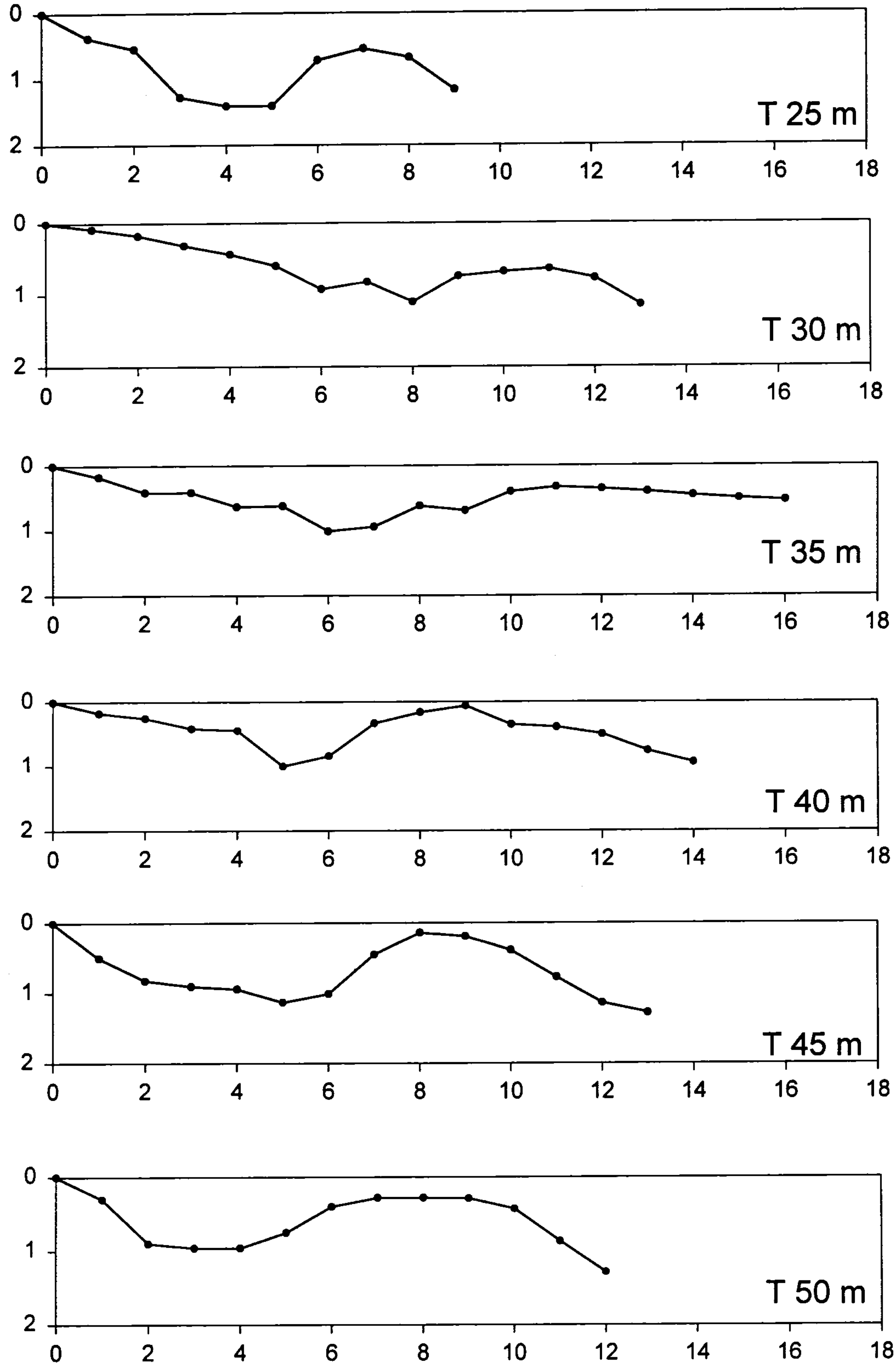
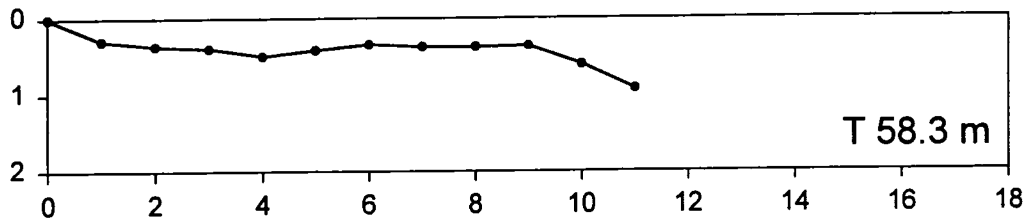
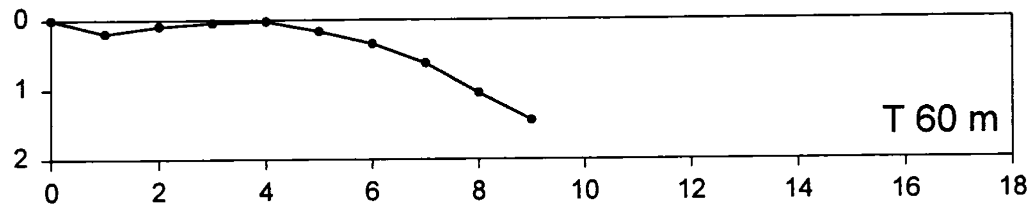
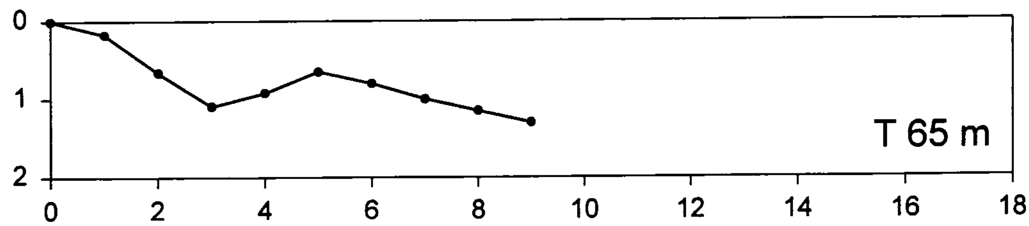
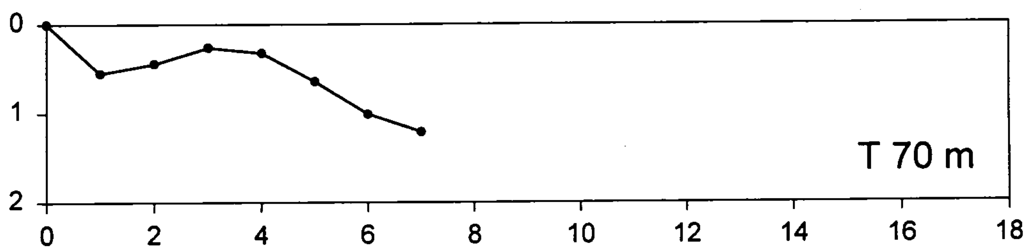


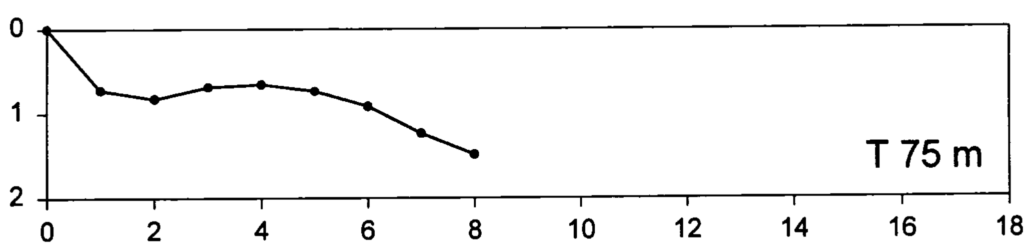
Appendix A. Cross-sectional profiles of Site 2a measured in August 1997. T-numbers within each graph represent distance downstream from active dredging, though some transects had been dredged prior to our sampling.

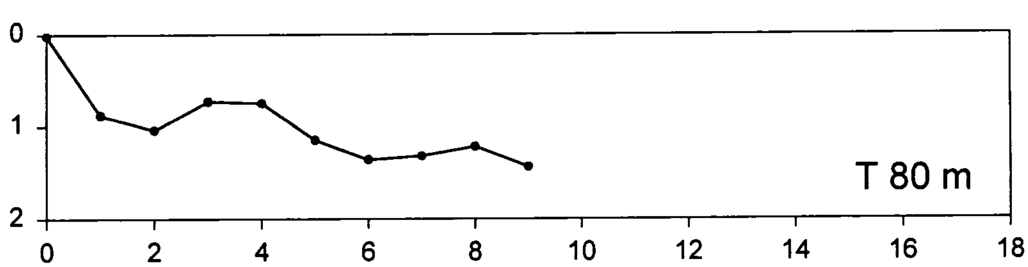












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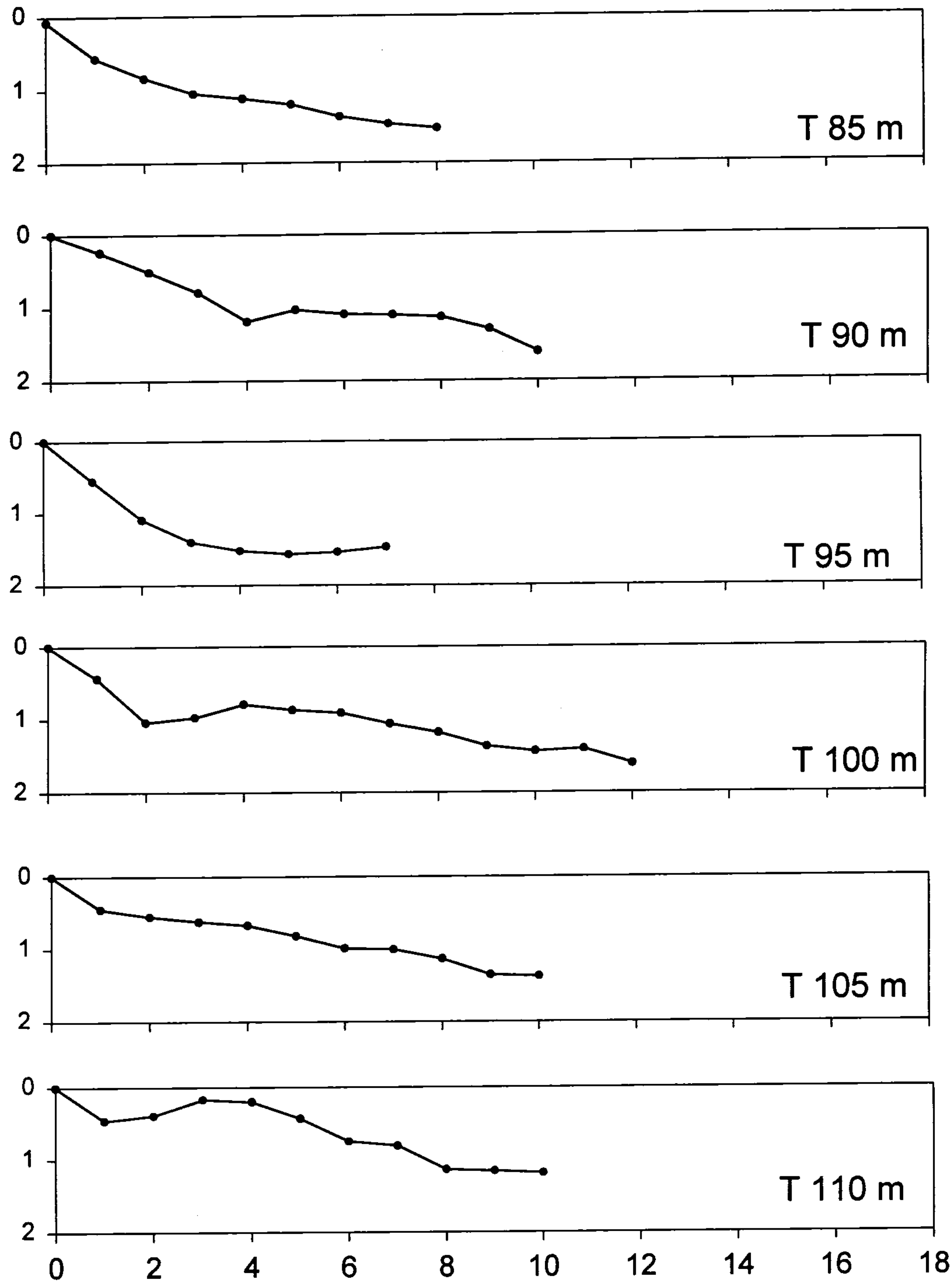

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