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

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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 and the Chatanika River. 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 for both years. The focus of our work on the Fortymile in 1997 was on an 8-inch suction dredge (Site 1), located on the mainstem and a 10 inch dredge located on the South Fork (Site 2a). Our research in 1998 included (1) resampling the 1997 sites on the mainstem and SF Fortymile to determine recovery after one year, (2) sampling a dredge site on the South Fork to examine for possible spatial variability in the effects of large-scale suction dredging on benthic communities (3) sampling a dredge site on the North Fork Fortymile to determine whether impact and recovery differ from conditions on the South Fork and the mainstem, and (4) again sampling unmined sites on the NF and SF to better document suspected background differences between the two forks in terms of macroinvertebrate communities. In all of the suction-mined sites studied, 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.

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 Fortymile River was small. After one year, dredge piles at Site 1 had largely disappeared following the scouring flows that accompany snow-melt in the Fortymile drainage. However, at Site 2, dredge piles were clearly discernable after one year. Macroinvertebrate abundance and diversity were greatly reduced in the first 10 m below the dredge at Site 1 during 1997, 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 2a. 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 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. An increase in macroinvertebrate density was found in the NF, relative to the SF, and this we attributed to the lower variability of benthic organic matter and greater amounts of periphyton standing crop 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.

The second component of this project is 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 the Chatanika River, known to be popular for recreational dredging. The Chatanika River was sampled at a location north of Fairbanks. 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, EPT richness, or food resources. Results from the Chatanika showed slight downstream decreases in macroinvertebrate density, but all other measures remained similar to those of the reference area. In general, our results are in agreement with other studies that have found only localized reductions in macroinvertebrate abundance in relation to small-scale suction dredging.

Part I - Suction Dredging in the Fortymile River

Introduction

This report describes the results of research performed during 1997 and 1998 to determine the possible impacts of commercial suction dredging on the water quality, benthic habitat, and biota of the Fortymile River, Alaska (hereafter, Fortymile). Also described in this report are the impacts by recreational dredging on the Chatanika River and Resurrection Creek. This is the first study of its kind to describe the effects of suction dredge mining on river ecosystems in Alaska.

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, Chatanika, and Resurrection 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 for both years. The latter two components form the food base for stream herbivores and detritivores and are vital to the production and recovery of aquatic macroinvertebrates. Variations in the sampling method between years are described in the Methods section.

Historically, gold mining occurred throughout the Fortymile basin and several types of operations are still active, including placer mining, hydraulic mining, and suction dredging. Large scale placer mining also occurs in some sections of the Chatanika River and historically in the lower reaches of Resurrection Creek. Our research was limited to investigations on the effects of suction dredging. We addressed two general topics: (1) the effect of relatively large (8-10 inch) commercial suction dredges on ecological conditions in the Fortymile and (2) the general effect of smaller (2-6 inch) recreational suction dredges on benthic habitat and biota in the Chatanika River and Resurrection Creek. Part I of this report presents the results from the Fortymile; Part II describes results of small-scale mining within the recreational mining sites.

Suction dredging typically involves excavating the deeper, largely uninhabited sediments and depositing them on top of the ecologically more 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 available food base.

The impact of commercial suction dredging on benthic organisms was evaluated in 1997 on the South Fork and the mainstem Fortymile River (Fig 1.). One site was also sampled in the North Fork near the confluence of the North and South Forks. In addition to resampling the 1997 mainstem and South Fork dredge sites in 1998, we expanded our sampling to include one dredge site on the North Fork and two additional dredge sites on the South Fork. We also sampled three reference sites unaffected by mining activity on the North and South Forks, including the 1997 North Fork Confluence site. 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 and streams known to have annually repeated, relatively, intense mining occur in the same location. 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. Resurrection Creek contains a section of stream designated for recreational mining activity by the State Department of Fish and Game and the U.S. Forest Service and is located on the Kenai Peninsula in Southcentral Alaska. The Chatanika River has no such designation that we know of, however it appears that mining is restricted to a section of river near Milepost 60 on the Steese Highway. The Chatanika River site is known to receive a sizeable amount of suction dredge activity throughout its available mining season.

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, within, and below the dredge location (Fig. 2). Work at this site occurred from 14 through 17 August 1997, under baseflow conditions. Less intensive sampling also was conducted above and below a larger (10 inch) dredge located on the South Fork Fortymile also by a veteran miner (Site 2a), and near the mouth of the North Fork Fortymile (NF, Site 4). Sampling at Site 2a 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 2a 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 2a, the area that had been dredged in 1997 was re-sampled and another location, of different mining history and geomorphic setting, was studied for the first time (2b). During 1998, we also sampled a dredge site located on the NF Fortymile (Site 3) 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). Single measurements' were made at each of 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 macroinvertebrate and periphyton 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 2a, sampling was limited to recent dredge piles located 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 2a, it had been in operation during the preceding week. Finally, the samples from the reference area at Site 2a were used with similarly collected samples from the mouth of the NF to compare conditions in the two forks of the Fortymile River.

In 1998, five macroinvertebrate and periphyton samples were taken from the reference, mined, 20 m, and 40 m locations at Site 1 to determine the extent of recovery after one year. No mining occurred at Site 1 during the 1998 study period. At Site 2a, samples were taken from the reference, 35 m, and 70 m transects. At Site 2b, slightly downstream of Site 2a, samples were taken from three locations that had been dredged along the inside of a meander bend. Ten samples were taken from an "Upper" location that had been dredged in late September 1997. Five samples were taken from two dredged areas slightly downstream of the upper location that had been dredged within the preceding week. We sampled a single dredge site on the NF that had been dredged with a 10 inch dredge within the previous 10 days of our sampling. Samples were taken at locations that had been dredged, no attempt was made to document the downstream extent of mining disturbance at this site because of inconsistent (patchy) dredge operations by the Site 3 dredge operators. Ten samples were taken from a location not affected by mining in the NF, as well as from each of three transects within the mined area. In addition to the dredged locations within the Fortymile basin, ten samples were taken from unmined locations in both the SF and NF near their junction with the mainstem (Sites 4 and 6). A second NP location was sampled on request by the US Geological Survey after an upwelling of groundwater containing arsenic and other heavy metals was located on the North Fork and is described in detail below. Ten samples were taken from this location and were compared to samples taken from upstream of the upwelling.

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 collector 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 NP 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 morphology 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.

All macroinvertebrate sampling was done with a Portable Invertebrate Box (PIB) sampler that was modified for use in water deeper than the height of the sampler. The PIB sampler encompassed 0.093 m2 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 250p.m 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 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 are located in the Stream Ecology Center, Pocatello at Idaho State University.

Periphyton samples were collected from individual rocks located just upstream of each macroinvertebrate sample. 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 cm2) 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 1997 chlorophyll-a content was determined with a spectrophotometer (Gilford

Instruments model 2600). The 1998 chlorophyll-a samples were analyzed using a fluorometer in order to detect very low concentrations. 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 CaCO3/L, regardless of whether or not the dredge was operating. Hardness ranged from approximately 80 to 115 mg CaCO3/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 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 sampling across either space or time, thus the results of heavy metal sampling are only indicative of likely conditions.

Due to the low densities of macroinvertebrates in the dredge plume (and in the Fortymile in general) and the short exposure times, no macroinvertebrates were collected for heavy metal tissue analysis downstream of the suction dredge. However, results from the 1998 analysis of macroinvertebrate tissues suggest that these organisms are capable of concentrating heavy metals at least under conditions of chronic exposure. 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 light color 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 after active dredging occurred, the distinct mounds seen in Figure 8 at the 0 m transect were no longer apparent. There was 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 affected 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 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. 1). The dredge pile at 30 m shows a shift towards the center of the stream, though the overall size remained essentially 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. 12) and partial cross-sections were measured for the upper, middle, and lower locations (Figs. 13 and 14). 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 also were measured to determine the longitudinal extent of the upper dredge pile (Fig 13). According to our measurements, the upper dredge pile tapered off at about 35 m. Profiles for the middle and lower dredge areas show another dredge pile beginning between 80 and l00 m. The lower dredge pile begins at about 130 m and continues slightly past 140 m (Fig 14). 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. 15) and partial profiles were measured at various distances between each full profile (Fig. 16). 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 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, 1997 periphyton AFDM was greatest at the transect upstream of the suction dredge, with a mean value of 1.8 mg AFDM / cm2 (Fig. 17). Periphyton standing crop was reduced by approximately 2-4 fold at the transects downstream of the dredge. The lowest value, >0.5 mg AFDM / cm2, 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. Chlorophyll-a concentrations are reduced to unmeasurable values within the areas dredged and 20 m below the operating dredge. Measured chlorophyll-a concentrations follow the results of periphyton standing crop biomass downstream of the operating dredge. After one year, chlorophyll-a concentrations and periphyton standing crop biomass in the mined area had returned to values near those from the unmined reference location, indicating that periphyton is unaffected by dredging the previous year at this location (Fig 18).

Both periphyton standing crop and chlorophyll-a at Site 2a showed little response to dredging in comparison to the upstream reference location in 1997. In 1998, mean chlorophyll-a concentrations were nearly identical at the reference location to those values in 1997; however, mean chlorophyll-a concentrations were greater at each of the dredged locations in 1998 than in 1997 (Fig 19). Periphyton standing crop in 1998 also increased 2-4 fold in the reference and 25 m locations and increased slightly less in the 70 m and 100 m locations after one year (Fig 19).

At Site 2b, periphyton standing crop biomass averaged between 3 and 4 mg/cm2 for all locations regardless of the year in which they were dredged. However, mean chlorophyll-a was 2.5 times greater in the "Upper" location, which had been dredged late in the previous year, than either of the other two nearby locations that had been dredged in 1998. The Upper location was dredged late in the 1997 mining season but sampled only during 1998. The greater amount of chlorophyll-a in the upper location, compared to the other two (1998) dredge piles is most likely due to the additional time of recovery (Fig. 20).

Comparisons between the NF and SF Fortymile were conducted to document differences in background conditions and the potential for recovery of mined areas in two tributaries with different mining pressures within the same basin. Mean periphyton biomass was three times greater in the NF site (Site 4) than in the SF site (Site 6) in 1997. Mean chlorophyll-a concentrations were 4 times greater in the NF than, in the SF for the same year (Fig 21).

Aquatic Macroinvertebrates

Site 1- 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 parts of North America (e.g., Royer and Minshall 1996). A mean of 270 individuals per m2 was collected at the reference site; approximately 370 individuals per m2 were found at the site 160 m downstream of the dredge (Fig. 22). 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 mean number of EPT taxa was 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. 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 (Fig. 23). 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 were sampled in both 1997 and 1998. Macroinvertebrate density and the number of EPT taxa also increased after one year (Fig. 24).

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 m2 (Fig. 25). At the transect 25 m downstream of the dredge, density decreased to approximately 20 individuals per m2 and then increased to about 100 individuals per m2 at the transect 70 m downstream of the dredge. 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 was nearly complete one year after dredging with approximately 20 taxa at each of the transects (Fig. 26). 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. 27).

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 downstream of Site 2a. Site 2b was also used to evaluate the effects of dredging late in the fall on macroinvertebrate composition. In Figures 28 and 29, locations labeled "Upper" represent an area dredged with a 10-inch dredge in late September 1997. Locations labeled "Middle" and "Lower" represent adjacent areas mined within a week of our sampling in July 1998. Comparing Site 2a results with the Upper 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. Mean macroinvertebrate density at the reference location of Site 2a was 26% of the "Upper" location of Site 2b, 40% of the "Middle" and nearly 30% of the

"Lower" locations (Fig 28A). The number of EPT taxa per sample present in the Site 2a reference location were 74% that of the "Upper" location of Site 2b (Fig 29A). Likewise, the number of Diptera present in each sample from Site 2a were 72% those present at Site 2b (Fig. 29B) Diptera comprised between 40 and 80% of the macroinvertebrates per sample at all of our SF sites.

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 0 m, 10 m, and 40 m were compared to a reference location in an unmined area of similar substrate type and water velocity. We were not able to determine the distance downstream affected by dredging 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 all measures except macroinvertebrate density appeared to fully recover within 10 days since dredging. Macroinvertebrate density at the reference location averaged about 1600 organisms per m2 while densities within the mined areas averaged between 1200 and 1400 organisms/m2 (Fig. 30A). Macroinvertebrate taxa ranged from 10 to 12 per sample for all locations (Fig. 30B). Mean numbers of EPT taxa ranged from 5 to 6 per sample (Fig. 30C). Diptera, which comprised the majority of the macroinvertebrate community at all of the sites sampled, ranged from 60 to 80% in the NF sites (Fig. 30D).

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. In 1998 we sampled a different reference location on the South Fork (Site 6, see Fig. 1) that was nearly 500 m upstream of its confluence with the North Fork and compared this data with those from an unimpacted reference site several kilometers upstream on the North Fork (Site 5). We also compared this North Fork reference site to a location downstream of an upwelling of heavy metals noted by the USGS 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/m2 downstream of the upwelling and nearly 1500/m2 upstream (Fig 31A). The number of taxa per sample at all locations ranged from 11 to 12 (Fig 31B). The number of EPT taxa ranged from 5 at the NF and SF reference areas, to 6 at the NF confluence area (Fig 31C). Diptera comprised 60 to 80 % of the macroinvertebrates at all locations (Fig 31D).

Although we did not sample the South Fork confluence site in 1997, there may be some degree of yearly variation in macroinvertebrate populations in the South Fork as seen from comparison of reference conditions from Site 2a (see Fig. 26). In the North Fork however, there appears to be less yearly variation in macroinvertebrate populations in the years that we sampled. Even though taxa richness was similar at the NF and 2a sites in both years, the relative dominance of taxa differed among the sites (Fig. 32). There was a greater difference in the taxa abundance of some taxa between years at the SF reference location whereas there is almost no change in the relative dominance of taxa in the NF site. The difference is seen in the shape of the curves. Table 4 shows that the Chironomidae (order Diptera) comprised over 75% of all the macroinvertebrates present in our samples at Site 4 in 1997 and 82% in 1998. Baetis comprised 0.5% in 1998, and 5.5% in 1997. In the SF Diptera comprised about 34% of the macroinvertebrates in 1997 and about 35% in 1998. However, Oligochaeta (Annelida) comprised 32% of the macroinvertebrates in 1998 and only 8% in a 1997. Baetis, a mayfly, comprised 1.3% of the macroinvertebrates in 1998 and 5% in 1997.

Benthic Organic Matter

Benthic organic matter (BOM) is a primary source of carbon and energy for organisms that live on and within the substrate of the river. In general, the amount of BOM found in the Fortymile was lower than values from many streams in the contiguous United States (see Minshall et al 1982), but are similar to other studies from the interior arctic and subarctic Alaska region (for example, see Miller and Stout 1989).

Site 1- In 1998, mean amounts of BOM within the mined area were slightly lower than those found at the reference and downstream (20, 40 m) areas. BOM at the 20 m location is also much more spatially variable than at the other locations (Fig. 33). This increased patchiness may be a result of the downstream redistribution of BOM from upstream dredged areas.

BOM concentrations at Site 2a in 1997 were similar between reference and mined locations, averaging 5 g per m2 at the reference location and 9 and 11 g per m2 at the 35 m and 70 m locations, respectively (Fig. 34). Mean amounts of BOM in 1997 at the reference area was 15% that of 1998. In 1998, mean BOM at Site 2a ranged from an average of 33 g per m2 at the reference area to 25 and 37 g per m2 at the 35 m and 70 m areas, respectively. BOM at Site 2b ranged from 23 g per m2 at the locations mined in 1998 (Middle and Lower areas) and averaged 53 g per m2 at the location mined in the late fall of 1997 (Upper area). These values were similar to those from 1997 for Site 2a, indicating a yearly variation in BOM of between 15 and 30%. BOM from Site 3 averaged between 6 and 7 g per m2, and showed little difference in average amounts between locations (Fig. 35). However, the coefficients of variation in the mined locations showed considerable variability, particularly at the 35 m location.

Mean amounts of BOM in both the NF and the SF confluence locations show considerable differences. At the SF confluence site (Site 6), BOM was more spatially variable and averaged more than twice the amount found at the NF confluence site (Site 4, Fig. 36).

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 chronic effects of mining may be 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.

Discussions with local miners indicated that the amount of material in 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 by the dredge will not necessarily be killed. For example, 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. Our results show that in all four of the dredge sites studied, there were substantial changes to the bed morphology where dredging had occurred, but there was no discernable change toward the center of the river. There also did not appear to be any downstream influence on bed morphology by dredged sediments, indicating that dredging strongly influenced immediately adjacent substrates but had little effect beyond, either laterally or downstream of the dredged area. Though no measurements of substrate composition were made directly in the Fortymile, it seems likely that suction dredging has little effect on the size and distribution of bed sediments. Local miners claim that much of the Fortymile River system has been mined in recent history and though this is an unsubstantiated claim, it appears reasonable as we observed no striking differences between sediment compositions within mined areas and those in reference areas particularly in the amount of deposited fines. We did observe that at Site 1, downstream gravels were covered with a fine sediment within the plume caused by the dredge. Given the shallow depth of bedrock and the intense scouring action by ice-flows and spring runoff, it is likely that sediments of all sizes may be well mixed and that fine sediments do not accumulate at the bed surface.

After one year discernable dredge piles remained at one of the two sites studied in both years, though reduced in size and in the South Fork site, shifting toward the stream's center. 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. In many cases the stream channel will return to its pre-dredge condition in a year as a result of river freezing and the succeeding ice-action and springtime flows that accompany 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 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. A detailed study requiring a longer period of time than was available would be required to accurately determine the rate at which macroinvertebrates re-colonized dredged areas. Studies of smaller scale dredging impacts have shown complete recolonization within 30 days of the cessation of mining activity. Given the northern extent of the Fortymile region, the harsh climate and short time available for production and recolonization, the depauperate macroinvertebrate structure, and the likely low quality and quantity of available food resources typical of sub-arctic rivers, recolonization would likely be extended beyond 30 days. It also is possible that the initially low abundance and diversity of macroinvertebrate taxa in the Fortymile would cause rapid recolonization due to the low numbers of organisms required to call an area "substantially recovered". Without detailed recolonization studies for longer periods of time, it is difficult to "guess" at potential times of recovery.

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 and the distance between them, the size of the dredges, the strategy of the dredge operators, and the extent of re-colonization that occurs on the excavated dredge piles. Clearly, the effect of suction dredging will not be the same for all locations in the Fortymile and/or sizes of dredge.

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 23 and 26). 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. However, conditions at these two sites after two years and at sites 2b and 3 after one year could not be determined prior to the termination of the project.

The comparison of conditions in the North Fork versus the South Fork suggests that macroinvertebrate density in this river system may be a function of annual variation in food resources and physical conditions, especially flow and suspended sediment (likely caused by additional mining activity in the SF tributaries). Results from 1997 suggested that greater food abundance (e.g., periphyton and BOM) in the NF corresponded to an approximately 5-fold greater density of macroinvertebrates. These comparisons were made under the assumption that the reference location at Site 2a was representative of the South Fork conditions. However, our 1998 comparison of the North and South Forks, using an undredged site in the SF nearest to the confluence of the two streams (Site 6) and that we believe is more representative of conditions in the tributary, showed no clear difference in biotic conditions between the two sites. The results suggest that conditions may vary markedly among locations and years and suggest that in addition to differences in food resources differences in physical conditions may be important. We suggest that other mining activities within the basin, primarily those in the South Fork tributaries may be important causes of decreased biotic integrity in some years and locations. However, suction dredge mining clearly reduces macroinvertebrate densities, diversity, BOM, and periphyton immediately below dredge activity regardless of the background conditions, though these effects are local and short lived.

Part II - Recreational Dredging in Resurrection Creek and the Chatanika River

Introduction

Recreational gold mining is a popular activity throughout much of Alaska and suction dredging is a common method used in recreational mining. Recreational dredges are smaller than those examined on the Fortymile and typically have intake lines of 2-6 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 because of the concentrated and repetitive nature of the mining in these areas. 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 on the Chatanika River, located along the Steese Highway north of Fairbanks, in 1998. 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 about May 15 through July 15 of each year. The Chatanika River is not officially designated for mining, but is a popular recreational site with few accessible areas that are open to mining during approximately the same time period.

Our sampling on Resurrection 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 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.

Sampling on the Chatanika River occurred during July 1 and 2, 1998 approximately two weeks prior to the end of the mining season for that region. Because there was no designated downstream mining boundary as there had been for Resurrection Creek, a slightly different sampling regime was used. Samples were taken at approximate distances downstream of last distinguishable active mining location within the river. Transects at "Mined", 50, 100, 150, 300 and 500 m were sampled on two different days. However, an intense rain within the Chatanika basin on the second day caused the river to rise and alter conditions from the first day and therefore the samples beyond 100 m were discarded. Samples from the Mined ("0 m" transec location were taken from representative locations within the entire actively mined area. An area upstream of any active mining was used as our reference location. Substrate measurements were also made to document any changes in substrate size or sorting caused by mining. Approximately 25 stones were chosen at random from near the location of each macroinvertebrate sample. Each stone was measured to the nearest cm and embeddedness was determined. Embeddedness is the portion of stone covered by fine sediments and is an indication of the amount of interstitial filling.

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

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. 37), but ANOVA indicated no significant differences ($p=0.252$). Mean chlorophyll-a was greatest in the mining area and the location immediately downstream, but the differences among the means were not significant ($p=0.182$) (Fig. 37). 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. 37). 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. 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.

The pattern seen with periphyton was not observed for macroinvertebrates in Resurrection Creek. 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. 38). 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. 38).

Results from the Chatanika River showed a trend toward decreasing macroinvertebrate density as well as less variable distribution of those macroinvertebrates with distance from active dredging (Fig 39). Average densities decreased from 6000 per m^2 at the reference location, to 2000 per m^2 150 m downstream of the mined area. The number of taxa per sample was more even among locations, ranging from 10 to 13 taxa per sample. EPT taxa per sample also showed a slight trend toward decreasing numbers downstream of the mined area, ranging from 6 EPT taxa at 150 m, to 8 EPT taxa at the reference area. Mean amounts of BOM were greater within the mined area (10 g/m^2) than within the reference area (6 g/m^2) or the 50 and 100 m areas (7 g/m^2 each) (Fig. 40). Substrate measurements showed little change among locations, ranging from 11 to 15 cm. Substrate embeddedness also averaged 15 to 24 percent (Table 5). The mined areas showed no discernable trends toward any significant change from the reference area.

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 in Resurrection Creek occurred approximately 35 days after suction dredging had ended 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. Results from a concurrent but separate study not funded by the EPA in 1998 also suggest considerable redistribution of BOM downstream of mining areas and reduced numbers of macroinvertebrates (both richness and density) within those mined areas immediately following the end of the mining season (A.M. Prussian, pers. comm.).

The results presented here on the effects of recreational suction dredging on macroinvertebrates are derived from a one-time sampling of only two streams. All of the streams specified in the litigation, plus an additional 13 streams were examined for compatibility with the study design. The two sites presented here represent the best examples of concentrated mining activity we could find and should be considered "worst-case" scenarios because both streams receive considerable mining activity and have relatively well-defined downstream boundaries. The remaining sites suggested in the litigation were either not as intensively mined or do not contain easily identified mining boundaries.

Together with the results of other studies, we suggest that the impacts by small-scale dredging activity are primarily contained within mined areas and persist for about one month after the mining season. However, other studies suggest a high degree of variability among streams in terms of impact caused by small-scale dredges (A.M. Prussian, pers. comm.) confounding our ability to draw broad conclusions for small-scale mining impacts on stream ecosystems in the State of Alaska. Additional study is needed to fully quantify the impact of suction dredge mining on the environment of Alaska before final conclusions are reached regarding the effects of this activity on Alaskan streams and their associated plant and animal communities.

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