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STREAMBED DISTURBANCES DURING AND AFTER RESTORATION OF GLEN CREEK, DENALI NATIONAL PARK, ALASKA

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ABSTRACT: Glen Creek, in Denali National Park, was hand placer-mined from 1906-1941 and then remined with heavy equipment in the 1960s and 1970s. Restoration to re-establish channel and floodplain geometry was performed in the summers of 1991 and 1992. Streambed stability and structure, and macroinvertebrate density and diversity were examined from 1990 (prior to initiation of restoration) through 1995 to quantify disturbance and its duration. Both the physical and biological data indicated that the stream was unstable before restoration, probably due to historical mining throughout Glen Creek. Erosion and deposition occurred throughout the restoration years, as demonstrated by channel degradation, aggradation, and thalweg shifting. The percent fines in the streambed also increased during periods of substantial channel disturbance. By 1994, the channel attained a level of relative stability. Macroinvertebrate numbers were low throughout the study. Densities and diversities of the genera present changed little from before to during restoration. However, two years after restoration was completed and the stream channel stabilized, macroinvertebrate numbers and diversity improved.
KEY TERMS: stream restoration; channel stability; stream cross-sections; pebble counts; percent fines; macroinvertebrates.

INTRODUCTION

Streambed and streambank disturbance and destabilization are common during stream restoration projects. Typically, the effects are ignored within the planning process because the long-term results of restoration are believed to outweigh any deleterious effects caused by the project, and the restoration effects are considered temporary. However, stream functions may be impaired or influenced significantly within and beyond the restorative period from associated effects, such as elevated suspended solids or hyporheic zone disturbance by heavy equipment. To date, little work has been done to quantify the magnitude and duration of disturbance caused by actual restoration activities, and the assumption that the results justify the disturbance, particularly in the short-term, have not been validated. In this paper, we take up that task by describing and quantifying temporal changes to streambed structure and benthic macroinvertebrate populations during and after restoration in a stream that had been placer-mined throughout much of the 1900s in Denali National Park and Preserve.

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STUDY AREA

The 17.2-km² Glen Creek watershed is located within the rugged, low-lying Kantishna Hills of Denali National Park and Preserve, in interior Alaska. Glen Creek watershed is in the continental climatic zone. July temperatures are warmest, averaging 12°C, while January, the coldest month, averages -18°C. Precipitation averages 47.8 cm annually, with 72 percent occurring from June through September. Snow accumulation ranges from 50 to 150 cm. Discontinuous permafrost is found throughout Kantishna Hills.

Basin bedrock geology is faulted and folded quartzite and hornblende schist of the Birch Creek formation. The lower portion of Glen Creek was covered with glacial ice during the middle Wisconsin stage, so that deposited gravel and rocks are mixed with bedrock materials in the alluvial gravels. Glen Creek originates as two forks, south and east of Glacier Peak, a highly mineralized area. The east and west forks flow 1.1 km and 2.4 km respectively, before becoming confluent and flowing another 5.6 km to its mouth.

Glen Creek was hand-mined for gold from 1906-1941. Stream diversion and damming resulted in fines and topsoil being washed away. However, remining with heavy equipment in the 1960s and 1970s resulted in much greater disturbance to the stream and floodplain; extensive and extreme damage occurred from the headwaters of both forks down to the watershed outlet.

RESTORATION

Initial restoration of the study area by the USDI National Park Service (NPS) began in 1988, when the area above the active floodplain was recontoured. In 1991, a two-year project began in which two reaches of the stream channel and floodplain were restored (Fig. 1). Methods developed by Jackson and VanHaveren (1984) were used for channel design, with modifications for subarctic conditions. Their design concept is based upon the premise that a channel in coarse alluvium is stable if discharges and sediment loads can be carried without causing excess streambank or streambed erosion or sedimentation.

Channel and floodplain design criteria are detailed in Karle and Densmore (1994a, b). Briefly, channel design requirements included a streambed capacity to contain a 1.5-year (bankfull) discharge, and a floodplain capacity to contain a 100-year flood. Riprap and gabions were not used since they were considered a hindrance to natural stream restoration. Estimated bankfull discharge from regional estimates was 1.44 $m^3 s^{-1}$; however, a value of 1.83 m^3s^{-1} was used for safety. Manning's equation was employed to identify a variety of channel configurations which would carry bankfull discharge. Shear stress equations were applied

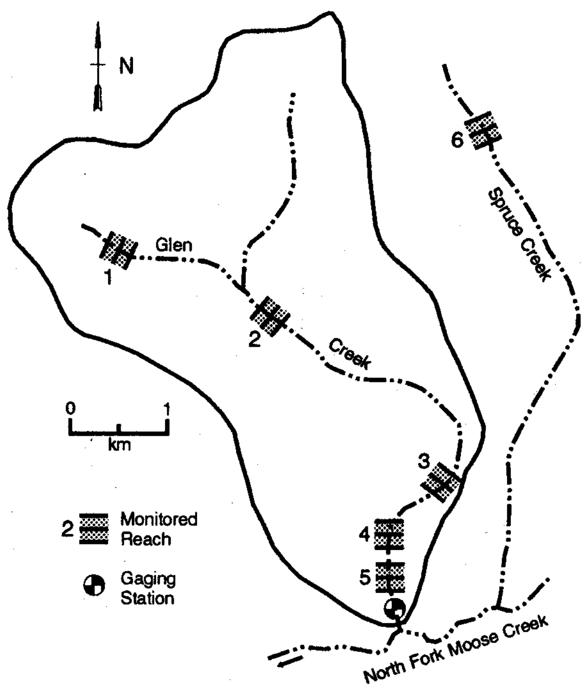

Figure 1. Monitored Reaches for Glen Creek Restoration Study. Reaches 3 and 4 were the Restored Reaches, and Reach 6 on Spruce Creek was the Control Reach.

to the design configurations to determine bed and bank stabilities. Slope and sinuosity were determined based upon regional comparisons.

Once the design parameters were established and surveyed, earthwork took place along two reaches of Glen Creek (Fig. 1) -- a 425-m reach in 1991 (upper study area), and an adjacent 975-m reach in 1992 (lower study area). Most of the work involved recontouring over-steepened floodplains to lower elevations, using shallow slopes to restore natural floodplain processes and retaining the existing channel undisturbed, except for minor bank modifications. However, in one reach, an entirely new 150-m long channel was designed and repositioned in the valley center, away from the valley wall where it was located previously. Excavated gravels were used in some areas to fill settling ponds, old channel beds, and other unnatural depressions. Excess gravels were blended into the valley slope at the floodplain's edge.

MONITORING

Six distinct reaches, each with three or four permanently monumented cross-sections, were established in 1990 (Fig. 1) to document and track streambed structure and macroinvertebrate changes before, during, and after the restoration project. Five monitored reaches were located upstream, within, and downstream of the restoration work on Glen Creek. A monitored reach also was established in an undisturbed section of an adjacent stream, Spruce Creek, against which restoration disturbance results could be compared. Characteristics of all reaches are given in Table 1.

Table 1. Characteristics of Stream Reaches and Permanent Cross-sections Sampled for Particle Size Distributions and Macroinvertebrate Populations.

Reach Number	Reach Type	Elevation	Drainage Area	Channel Slope	Cross-section Width 1	2	3	4
		m	km^2	$m\ m^{-1}$	----------- m -----------			
1	undisturbed	900	2.20	0.0688	6.40	6.10	7.62	--
2	mined	760	11.2	0.0368	6.10	5.49	9.14	--
3	mined, restored 7/91	700	13.8	0.0242	30.48	30.48	29.57	30.48
4	new channel 7/92	670	16.5	0.0224	30.28	30.28	30.28	--
5	mined diversion channel	645	17.2	0.0251	6.71	7.01	7.32	7.62
6	adjacent stream undisturbed	900	2.93	0.0398	8.84	8.84	9.14	9.14

Surveyed cross-sections between permanently monumented points provide a basic technique for describing morphological features and their changes (Emmett, 1974). Accurately surveyed cross-sections provide data for determining stream channel position and bed elevation. Additionally, lateral migration, stream width changes, and streambed aggradation or degradation may be detected. Cross-sections were established for this study and were surveyed once a year, in August or early September, excluding 1993.

Streambed material composition is a critical factor in controlling channel morphology, downstream sediment supply, macroinvertebrate habitat, and other parameters. Streambed material was sampled to determine particle size changes over time. Size analyses were performed using pebble counts conducted in conjunction with the cross-sectional surveys. The intermediate axis of at least 100 randomly selected particles was measured, and the cumulative size distribution, as a percentage of the number of particles, was determined (Wolman, 1954).

Benthic macroinvertebrates also were sampled and analyzed as bioindicators of aquatic ecosystem health. Unlike most physical and chemical parameters, macroinvertebrates provide an index to stream health over a period of time rather than a single point in time. Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), collectively known as EPT, are most significant in this task. Unimpaired streams typically support a wider diversity of taxa than impaired streams. EPT groups are particularly sensitive to water quality changes. Their numbers reduce markedly as water quality degrades and fine sediment concentrations increase.

Macroinvertebrates were sampled in reaches 2-5 of Glen Creek in 1991, and 1993-1995. Sampling areas were chosen based upon substrate size and riffle areas present to obtain site-specific metrics of the maximum number of macroinvertebrates the system could support. Three to five replicate samples were taken at each site to assess variability within the habitat. Since macroinvertebrate presence, distribution, and abundance numbers vary seasonally, sampling was conducted two or three times a year (from early through late summer). Samples were collected using Surber and modified Surber samplers, and driftnets. Both macroinvertebrate community structure and function were examined. Particulate organic matter (POM) was analyzed from Surber samples collected in 1995 to determine organic matter loads in sediment. POM is an additional measure of ecological health of the system.

RESULTS

Streambed Stability and Composition

Restoration work required operation of heavy equipment, including a D-6 Caterpillar bulldozer, front loader, and 5-ton dump truck, within the floodplain and channel. This disturbance resulted in delivery of visibly-heavy silt loads to Glen Creek. Two specific areas presented special problems. In the upper study area (reach 3), floodplain lowering uncovered fine unprocessed tailings on the right bank adjacent to the stream channel. In the lower study area, construction of the new channel segment (reach 4) passed through an additional section of undersized processed mine tailings, which markedly decreased the average bed material size and effectively eliminated the old bed armor layer that it replaced.

Due to space limitations for this paper, results from all of the reaches are not discussed here. Instead, reach 5 is used in subsequent analyses to evaluate restoration effects because it is located several hundred meters downstream from all of the restoration activity; its location made it theoretically more-affected by *all* of the restoration work than any other reach. In most instances, all other restoration-affected reaches responded similarly to reach 5, in direction of response if not also in magnitude of response. Reach 6, in the adjacent, undisturbed Spruce Creek, is used for comparison to describe and account for "natural" temporal changes in streambed composition.

Survey results for cross-sections 1 through 4 (upstream to downstream) in reach 5 are given in Figure 2. The elevational position of the 1990 streambed in relation to 1991 and other years suggests that the channel was unstable prior to the 1991-1992 restoration. Some erosion occurred in the thalweg between 1990 and 1991. This instability is believed to be at least partially attributable to the earlier floodplain restoration in 1988. While that work was outside of the stream channel, sediment may have been transported to the stream during and after restoration, particularly during periods of floodplain inundation.

However, most of the channel changes occurred following restoration. For example, cross-section 1 (Fig. 2a) shows substantial erosion and deposition from August 1991 to August 1992, with the thalweg moving from the left to the right side of the channel.

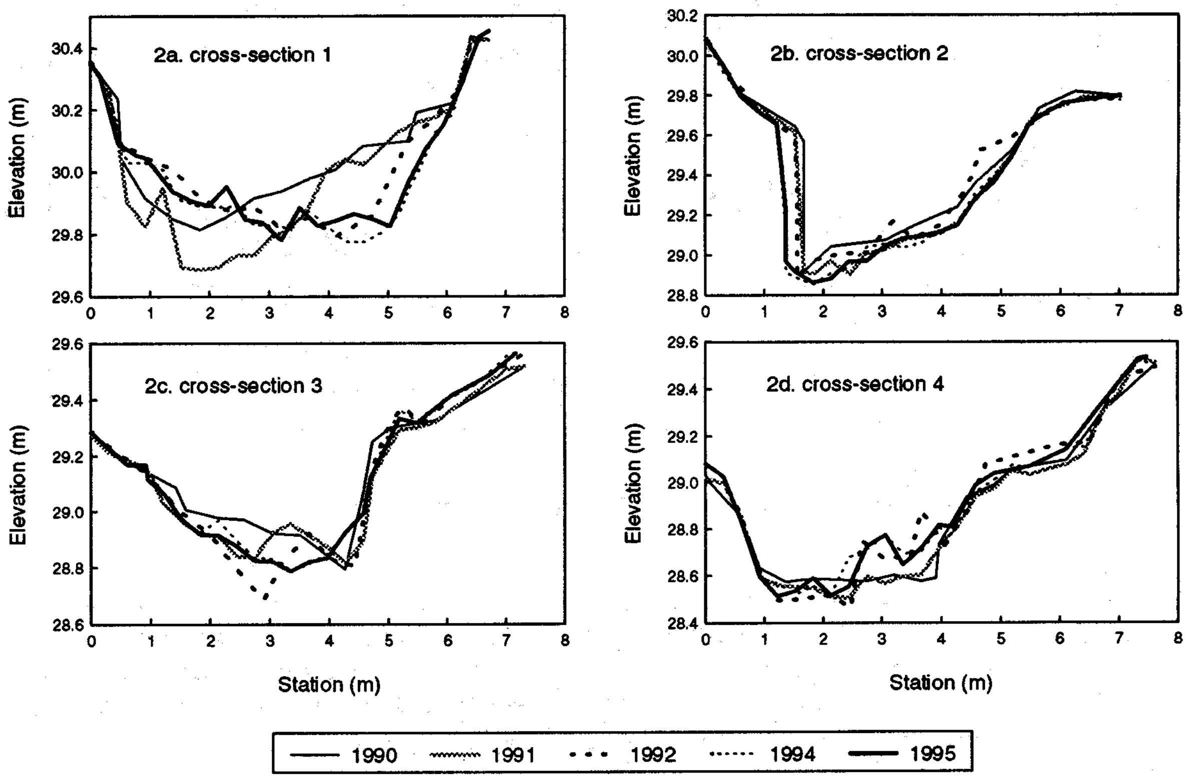

Figure 2. Cross-sections for Glen Creek Reach 5.

Cross-section 2 was stable from year-to-year, particularly from 1991-1992 (Fig. 2b) compared to other cross-sections. However, this stability was not maintained downstream. Additional temporal changes in cross-sections 3 and 4 (Fig. 2c-d) were observed, including thalweg erosion in cross-section 3 (Fig. 2c) and channel deposition in cross-section 4 (Fig. 2d).

Cross-section results for control reach 6 in Spruce Creek (Figs. 3a-d) show much greater stability than reach 5 in Glen Creek. Thalweg positioning did not change from year-to-year within each cross-section, and erosion and deposition were less in reach 6 than reach 5. Cross-section 2 in reach 6 was the most unstable. Pebble counts on control reach 6 also indicate greater stability relative to reach 5 (Fig. 4).

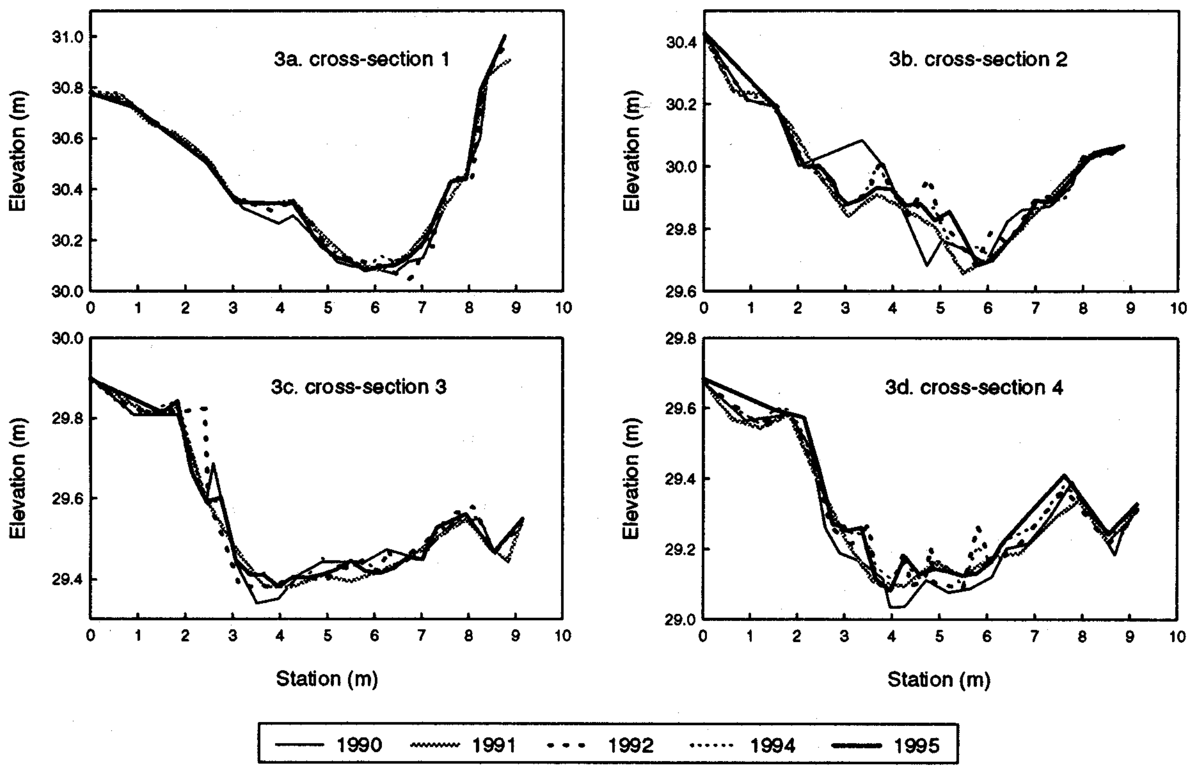

Figure 3. Cross-sections for Spruce Creek Reach 6.

Reach 5 pebble counts (Fig. 4) show results similar to the cross-sections. In reach 5, bed material sizes decreased between 1991 and 1992, especially in the 50 percent and smaller size classes, but by August 1994, the median size of bed materials increased. Streambed composition was very similar for 1994 and 1995 (Fig. 4), as were streambed cross-section elevations (Fig. 2), suggesting that relative stability had been achieved by 1995, if not by 1994.

Fine sediment, often defined as particle sizes less than 6 mm in diameter, is adverse to aquatic habitats (Chapman, 1988). Consequently, pebble count data from reach 5 were tested statistically to determine if fine sediment levels changed over time. Because greater relative stability was present in 1995 in reach 5 than in 1990 (prior to the in-stream restoration disturbances), 1995 was used to represent stable channel characteristics. Thus, each year's pebble count data were compared statistically to 1995 instead of 1990 (typically, posttreatment years would be compared to the pretreatment year). Contingency tables incorporating the number of pebbles less than 6 mm versus the number of pebbles greater than 6 mm were used to compare the frequency distributions within each comparison pair using the likelihood ratio Chi-square statistic (King and Potyondy, 1993). A Bonferroni correction was applied to each group of comparisons to maintain an overall Type-I error rate (Miller, 1991), since more than one year was compared to 1995. Results of the tests are given in Table 2.

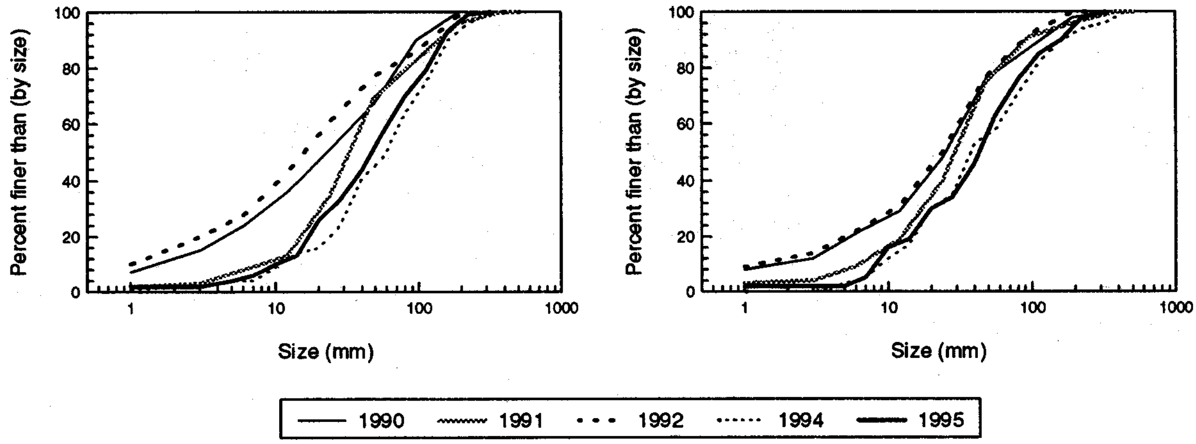

Figure 4. Pebble Count Size Distributions for Reach 5 Glen Creek (left) and Reach 6 Spruce Creek (right).

If the assumption that channel stability had been reached by 1995 is correct, the test results shown in Table 2 provide interesting insight. Only comparisons 1990 vs. 1995 and 1992 vs. 1995 were highly statistically significant (P=0.004 for both comparisons). The 1990 vs. 1995 results indicate that high percentages of fines existed in the streambed in 1990, prior to the major restoration efforts. These fines may have been mobilized and delivered to the stream as a result of the 1988 floodplain restoration efforts and/or historical mining throughout Glen Creek.

Table 2. Fine Sediment Comparisons for Glen Creek.

Comparison	Chi-square Statistic	Corrected Chi-square Probability
1990 to 1995	15.7	0.004
1991 to 1995	0.75	1.552
1992 to 1995	20.8	0.004
1994 to 1995	0.12	2.932

The percent fines in 1991 were not significantly different from those within the more stable 1995 channel, even though restoration took place in reach 3 in 1991. Its effects may not have translated to significant increases in fines in reach 5 for several reasons or combinations of reasons, including: 1) 1991 restoration disturbances simply were insufficient to yield a within-channel response because floodplain restoration work, rather than channel disturbance, dominated that year; 2) a within-channel response occurred, but reach 5 was far enough downstream from reach 3 so that the sediment had not yet been transported to reach 5, or it had been transported to reach 5 but was too dispersed to be observed; or 3) the fine unprocessed tailings uncovered in the right bank of the reach during restoration were not as problematic as expected.

Fine sediment differences again became significantly greater in 1992 compared to 1995. A new channel was constructed in reach 4 (the upstream reach closest to reach 5), creating extreme disturbance within the new channel and the surrounding floodplain. Downstream sedimentation was especially heavy during and after channel construction -- up to 5 cm of fine sediment lined the affected channel. In addition, while the channel was designed so that bed material would not begin incipient motion until bankfull flow was attained, as the 1992 project phase neared completion, Glen Creek experienced a moderate flood event. Peak discharge was calculated to be 4.7 m^3s^{-1} for the August 5 event (the 5-year flood discharge was estimated at 4.4 m^3s^{-1}). As a result, much of the undersized bed material uncovered during channel construction was transported downstream. Thus, the increases in streambed fines were not surprising. By 1994, Glen Creek streambed had undergone a shift toward a more stable situation, dominated by larger-sized materials, and particle sizes were not significantly different from those measured in 1995.

Macroinvertebrates

Numbers of EPT genera collected with Surber samplers varied widely in Glen Creek; 2 to 13 genera were collected per site. However, all sites showed improvement over time, based on increases in EPT genera represented and organism densities. Again, because of space limitations, discussions of macroinvertebrates are limited to findings from reach 5.

Organism densities were low in reach 5 of Glen Creek from June through August 1991, with the lowest densities in July 1991 during restoration. Density numbers improved in August 1991 following completion of that year's restoration and in June 1993, a year after establishment of the new channel upstream in reach 4. Both 1994 and 1995 data indicated improvement in macroinvertebrate densities and diversity. This improvement coincides with the improved physical streambed conditions found and described previously for 1994 and 1995.

A notable progression of change occurred in reach 5, with regard to the functional groups over time. All Surber samples were dominated by individuals of the collector functional feeding group throughout the study. However, shredder numbers changed significantly through 1995, as the streambed stabilized and the percent fines dropped. For example, in September 1994, the samples in reach 5 were composed of 42 percent collectors, 36 percent filter feeders, 20 percent predators, and 2 percent shredders. In September 1995, collectors continued to dominate, but the shredder group increased to 26 percent. This large percentage increase may be due to upstream riparian improvements (Karle and Densmore, 1994a, b) in the form of willow and alder plantings which increased organic inputs into Glen Creek, since low shredder densities indicate poor riparian conditions. POM analyses using ANOVA with Tukey's a posteriori and multiple comparison tests with a P-value of 0.05 indicated significant differences between most of the Glen Creek sites and Spruce Creek.

Macroinvertebrate data from all reaches in Glen Creek suggest that a recovery process has taken place. Unfortunately, it is impossible to determine whether the recovery is the result of restoration activities or natural recovery processes occurring since the cessation of mining within Glen Creek and its tributaries. However, streambed stability and composition data also suggest that recovery has been taking place since the restoration efforts were initiated; thus, restoration is believed to have had substantial influence in hastening the natural restoration of macroinvertebrate communities.

DISCUSSION

Streambed stability and composition responded rapidly and predictably to the restoration activities. The most significant responses corresponded to the most significant disturbance -- new channel construction. Glen Creek was not in a stable state at the initiation of monitoring, prior to the 1991 and 1992 restoration activities. However, as restoration proceeded and additional channel length was returned to a more stable condition, streambed stability improved and the percentage of fines in the streambed decreased. Two years after the new channel was constructed, reach 5 had become fairly stable. Thus, restoration impacts on the streambed characteristics appeared to have been fairly short-lived.

Macroinvertebrate populations did not seem to be affected during the restoration activities themselves. Densities and diversities may have been depressed so much by past mining activities that the actual restoration processes had little additional effect on populations. While the streambed and biological data do not show cause-and-effect, there is a strong suggestion that macroinvertebrate improvement was dependent upon increased streambed stability. Apparently, some minimal threshold of channel stability (following restoration) was required before macroinvertebrate population improvements became obvious. Once that threshold level was achieved, more amenable conditions may have enhanced survival and reproduction. It was not until 1994, and especially 1995, that the stream channel attained a level of stability, and macroinvertebrate densities and diversity correspondingly improved.

Major disturbances to channel characteristics, whether from past activities or restoration, appear to have significant impacts on macroinvertebrates. However, once conditions improve, macroinvertebrates seem to respond quickly. Therefore, even though restoration may result in extreme in-channel disturbance, if effective, restoration can quickly return the stream to a biologically-improved condition.

CONCLUSION

Physical channel characteristics and macroinvertebrate density and diversity measurements collected before, during, and after channel and floodplain restoration in a stream in central Alaska were analyzed to determine the magnitude and duration of disturbance caused by restoration activities. Short-term restoration effects were evident from physical streambed characteristics; however, stable stream conditions were achieved two years after restoration was completed. Changes in macroinvertebrate numbers and diversity were not obvious during restoration compared to pre-restoration data, probably because the populations were depressed before restoration began due to past mining. Two years after restoration, insect densities and diversity improvements were obvious. This improvement coincided with the period when the streambed stabilized and bed material shifted to larger particle sizes. Had restoration not taken place, the deleterious effects of past mining probably would have continued into the long-term. Restoration resulted in only short-term deleterious conditions, and the rapid improvement in stream conditions certainly suggests that the short-term disturbances attributable to channel and floodplain restoration were justified.

DISCLAIMER

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