Aquatic Macroinvertebrate Monitoring Results of the 1995 and 1996 Rotenone Treatments of Manning Creek, Utah

Hesperoperla pacifica, a stonefly found in Manning Creek both before and after the 1995 and 1996 rotenone treatments.

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Salt Lake City, Utah

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SPORT FISH RESTORATION

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Photo 1: Station D on upper Manning Creek about 1 mile below Manning Meadow Reservoir. This station has been monitored from 1988 to 1999, providing the longest series of aquatic macroinvertebrate data on Manning Creek. Data from four other stations for shorter time spans also was used in this study.

SUMMARY

Aquatic macroinvertebrate monitoring was conducted on Manning Creek in 1995 prior to treatment with rotenone in 1995 and 1996. This renovation treatment was conducted to prepare Manning Creek for reintroduction of native Bonneville cutthroat trout (*Oncorhynchus clarki utah*). Post-rotenone monitoring was conducted in 1997 and 1999 to evaluate the impacts of the treatments on the aquatic macroinvertebrate community. Items monitored included number of taxa, specific taxa, biotic diversity, and condition indices. Additional aquatic macroinvertebrate samples from 1988 and 1990 were also included in the analysis. Analyses of the results were somewhat complicated by changes in areas sampled, field collection methodologies, laboratories used to analyze samples, and naturally occurring and man-caused changes in the watershed.

Overall the Manning Creek macroinvertebrate community has recovered as the vast majority of taxa were found in post-treatment samples, and post-treatment samples had high diversity and high numbers of taxa. The greatest number of taxa was identified in 1999, although this is probably partially a function of the larger area sampled. Nearly half of the total taxa (49.5%) were identified both pre and post-treatment. The second largest group of taxa (29.5%) was collected only post-treatment. Finally, the smallest group of taxa (21.0%) was collected only pre-treatment. Nearly half of the taxa in the "pre-treatment only group" were missing prior to the actual treatment. In other words, there were almost as many taxa found in 1988 and 1990 missing by 1995 prior to the treatment, as there was taxa found in 1995 that were still missing in 1999 after the treatment. This illustrates the highly dynamic nature of aquatic macroinvertebrate communities.

Many or all of the "missing" taxa could still be present in Manning Creek. The majority of the missing taxa were a very small percentage of the pre-treatment samples, which made them difficult to sample. Comparable numbers could be present and not sampled, due to the small amount of the stream bottom surveyed. Indications are that many of the missing taxa can survive a rotenone treatment. For example, 10 of the 11 taxa found in 1995 that were missing post-treatment were found following rotenone treatments of the Strawberry drainage of Utah (Mangum and Madrigal 1999) or the North Snake Range of Nevada (Appendix B).

Macroinvertebrate diversity indices declined in 1997 following the 1995 and 1996 treatments. The diversity indices increased to pre-treatment levels by 1999. The Biotic Condition Index (BCI – see Winget and Mangum 1979), while primarily designed to monitor organic enrichment and sedimentation, also declined in 1997, which indicated a loss of some of the more sensitive invertebrate species. The upper survey station recovered to pre-treatment BCI levels by 1999. It is believed other land management activities may have prevented the BCI recovery of a downstream station.

Similarities were noted between treatments of the Strawberry and Manning Creek drainages. The most impacted order of aquatic macroinvertebrates was the caddisflies or Tricoptera. Species recovery appears to have been quicker in Manning Creek than in the Strawberry River, however, where 21% of the taxa were still missing after 5 years. While 21.0% of the Manning taxa were not found in post-treatment monitoring, almost half of these missing taxa are from the

1988 or 1990 samples that were not collected in the 1995 pre-treatment sample. Further, the 1999 samples were only 3 years after the last treatment, compared to 5 years at Strawberry. Several of the missing invertebrates may be due to different levels of taxonomic identification between the two laboratories.

A mitigation measure of leaving several fishless tributaries of Manning Creek untreated was applied during the Manning Creek treatment. In addition, the lower concentration (1.5 mg/l Noxfish vs. 3 mg/l Noxfish) of rotenone used, and shorter treatment time (12-18 hours vs. 48 hours) likely reduced impacts to Manning Creek compared to the Strawberry treatments. It should be noted that Manning Creek was treated once a year for two years, while the Strawberry River watershed was treated twice in one year. It appears that leaving fishless headwater and side tributary reaches untreated and using the minimum rotenone concentration and treatment time necessary to achieve treatment objectives is a low cost and reasonably effective mitigation measure which speeds recovery of aquatic macroinvertebrate communities.

Management action to collect and reintroduce aquatic macroinvertebrates into Manning Creek is not recommended. The vast majority of the taxa and overall diversity recovered. General transfer of aquatic macroinvertebrates would be unlikely to contain enough suitable individuals of the uncommon taxa to bolster their populations. Locating and transferring the missing taxa would require considerable expertise and labor in the field. Other factors such as changes in competition due to different community structure also could be responsible for post-treatment differences, which could make transfer of macroinvertebrates ineffective. Since continued monitoring of Manning Creek will be necessary to assess other land management impacts to the aquatic health of this drainage, it is recommended that future aquatic macroinvertebrate samples be checked for re-occurrence of the missing taxa.

INTRODUCTION / PURPOSE

The purpose of this study was to fulfill the monitoring requirements established in the *Environmental Assessment for the Proposed Rotenone Treatment of Manning Creek* (UDWR/USDA Forest Service 1995) and to determine post-treatment status of aquatic macroinvertebrate communities. Items specified for monitoring were aquatic macroinvertebrate species composition and relative abundance. Samples were to be collected prior to treatment and three years after treatment following protocol in the Forest Service Handbook (FSH) 2609.23. A management action was specified that if species were missing from the treatment area, then collections of aquatic macroinvertebrates from nearby drainages were to be made and transplanted into the treatment area.

Sampling intensity was limited by funding and personnel constraints. The data collected are not of sufficient quantity for a rigorous scientific and statistical analysis, and the natural setting with ongoing management actions in the drainage prevent establishing a control area with no confounding variables. Nevertheless, the Manning Creek evaluation is valuable for answering the original objective of the monitoring plan and may be useful for comparison to other areas and for planning future treatments, given the limitations. This project is unique in the long overall time frame evaluated (1988-1999) and the use of diversity and biotic indices. Additional literature has been reviewed to help put results in context and provide information that may be useful in planning future treatments.

METHODS

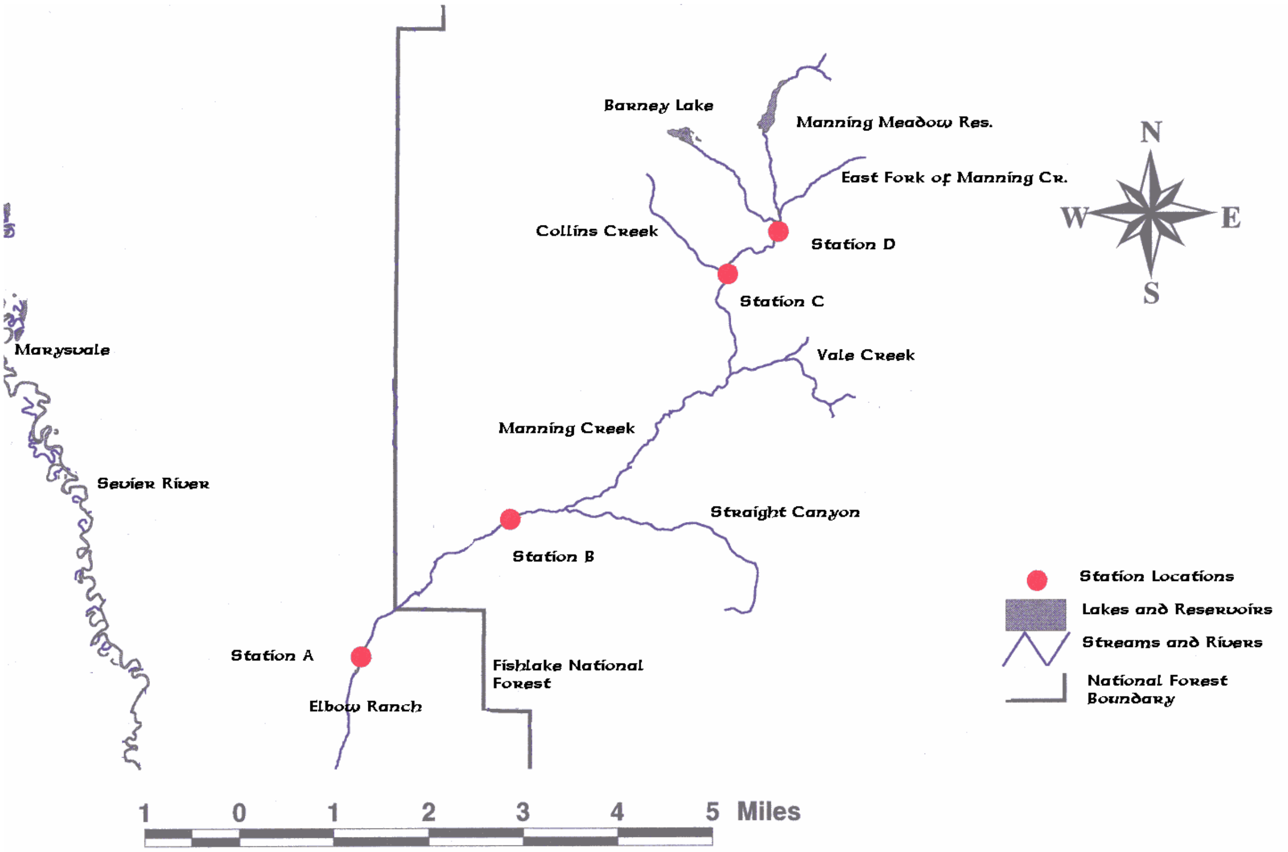
Rotenone Application

Rotenone was applied to Manning Creek and several tributaries in September 1995 and 1996. Liquid emulsifiable rotenone (Noxfish, 5% active ingredient) was primarily used to treat the stream. A total of 13.3 stream miles were treated in September 1995 with 21.4 gallons of liquid rotenone and 50 pounds of rotenone powder (Figure 1; Ottenbacher and Hepworth 1995). Liquid rotenone was applied by drip barrels from 12 stations at roughly one-mile intervals at a target concentration of 0.5 to 1.5 ppm in the stream channel for 12-18 hours. Drips were operated for up to 18 hours until a crew with backpack sprayers covered each given section applying liquid rotenone to backwaters, side channels, and seeps not effectively treated by the drips. A small pond near the bottom of the drainage was treated with powdered rotenone (Cube Root, 5-7% active ingredient).

The Environmental Analysis (EA) specified as a mitigation measure for aquatic macroinvertebrates that “Only areas containing non-native trout would be treated... ...Off stream ponds, bogs, seeps and springs which did not contain fish would not be treated. In addition, substantial portions of the headwaters of the tributaries would not be treated” (UDWR/USDA Forest Service 1995 p. 4, 6). Sections of the stream known to be fishless which were not treated to reduce impacts to aquatic macroinvertebrates included almost the entire length of Collins Creek (1.3 miles), a very short section just below Barney Lake dam, Smith Canyon (much of which is ephemeral), and Straight Canyon (due to natural barriers and dry sections).

The 1996 treatment was conducted during September 1996 using 12 gallons of liquid rotenone and 50 pounds of powder. It was similar to the 1995 treatment in terms of drip locations, rotenone concentrations, and the length of time treated (Ottenbacher and Hepworth 1996).

Figure 1. Locations of aquatic macroinvertebrate sampling sites on Manning Creek, Piute County, Utah.



Aquatic Macroinvertebrate Sampling

Two stations (B and D) were sampled in 1995 prior to the first rotenone treatment (Figure 1). Three samples were taken at each station using a 250 micron square foot Surber net following standard R-4 Forest Service protocol (FSH 2609.23 and Mangum 1986; see Appendix C). In 1997 stations B, D, and E were sampled. The methodology was the same as the 1995 samples.

In 1999, three years following the final rotenone treatment, stations A, B, C and D were sampled. Station location E from 1997 could not be relocated and was not resampled. The original sampling methodology was used at station D. In addition, all four stations were sampled using a new protocol. It is similar to the old methodology, but eight one-square foot samples were collected and the material was composited into one sample bottle for each station. The 8 samples taken at each station were generally composed of 5 riffle samples, 2 pool tails, and 1 run/glide in an attempt to sample more habitat types and increase the numbers of taxa sampled.

Sampling dates varied among years. The original pre-treatment samples taken in 1995 were collected in August. The 1997 post-treatment samples were collected in June and July. The

1999 post-treatment samples were collected in September. When conducting the analyses of the 1995-1999 data, file data were searched and three previous sample dates, all from station location D, were found and the data incorporated into the analysis. The single 1988 sample was collected in August, and the two 1990 sample dates were collected in July and September. Sampling dates were selected because of work priorities and scheduling conflicts, not a deliberate attempt to conduct sampling at different times.

Laboratory Analysis

The 1988, 1990, 1995, and 1997 samples were sent to the Aquatic Ecosystem Laboratory (AEL) located at Brigham Young University in Provo, Utah. Laboratory analyses procedures are described in Mangum (1997). Appendix C has additional information on laboratory procedures and indices.

By 1999 the AEL was no longer in operation, requiring a change in laboratories. The 1999 samples were sent to the National Aquatic Monitoring Center at Utah State University in Logan, Utah. Methodology is similar but does not include the DAT diversity index.

Office Analysis

A master species list was compiled for all stations and sample dates (see Appendix A for a summary of the list). The study design included 1995, 1997, and 1999 sampling. Samples collected in 1988 and 1990 were also included in the analysis for additional comparisons. The master species list allowed counting of taxa by year and taxonomic structure and comparing pre and post-treatment presence and absence of taxa. The taxa list was compiled exactly as the lab reported. The compiled list has a total of 95 taxa, but the actual number of taxa present may be slightly less, because of overlap of taxonomic classification levels (for example, one taxa might be listed to a genus level in one sample, but the same taxa may be identified to the family level in another sample). The reported density of the taxa in numbers per square meter in the pre-treatment sample was divided by the total number per square meter for that station and multiplied by 100 to convert to a percentage. Other data such as the Biotic Condition Index and various diversity indices were placed into tables for comparison and analyses.

Pre and post-treatment macroinvertebrate data from 4 treated creeks in the North Snake Range in east central Nevada were also compiled for comparison (Appendix B).

RESULTS

Numbers of Taxa

Comparative numbers of organisms identified to each taxonomic level are shown in Table 1 (PR = post-rotenone). The relative numbers of taxa varied from a low of 24 in June 1990 to 46 in 1995, dropped to 41 in 1997, and rose to a high of 57 in 1999. The total number of taxa identified was 95, since some taxa were unique to each year.

Table 1: Total numbers of taxa identified by taxonomic level in Manning Creek samples.

	8/88	7/90	9/90	8/95	7/97	9/99	88-99 total	88-95 total before treatment	97-99 taxa PR (post – rotenone)	% of 1995 taxa PR
Class	3	2	1	1	1	3	4	3	3	100%
Order	3	4	3	7	5	4	8	7	7	85.7%
Family	8	4	3	7	5	16	20	12	17	85.7%
Genus	10	12	13	22	22	31	47	33	38	72.7%
Species	3	5	4	9	8	3	16	12	10	66.7%
Total	27	27	24	46	41	57	95	67	75	76.1%

Variation in numbers of taxa by station and year is shown in Table 2. The numbers dropped slightly in the 1997 post-treatment samples but not much below the September 1990 sample. The numbers of taxa increased in 1999 three years following the rotenone treatment but this is somewhat confounded by the new methodology which sampled a larger area and several habitat types. Taxa numbers declined from the headwaters downstream.

Table 2: Total numbers of taxa identified by station in Manning Creek samples (station locations shown on Figure 1).

Station	8/1988	7/1990	9/1990	8/1995	7/1997	9/1999
E	-	-	-	-	20	-
D	27	27	24	31	23	43
C	-	-	-	-	-	38
B	-	-	-	34	20	29
A	-	-	-	-	-	26

New Taxa Collected After Treatment

Numbers of taxa were compared pre and post-treatment (Table 3). The largest group of taxa was found both pre and post-treatment (49.5%). Interestingly, the second largest group was new taxa that were found only post-treatment (29.5%). The smallest group (21.0%) was found only pre-treatment.

Table 3: Numbers of Manning Creek taxa found pre- and post-treatment 1988-1999 data.

	Number of taxa	Percent of taxa
Pre-treatment only	20	21.0%
Both pre and post-treatment	47	49.5%
Post-treatment only	28	29.5%

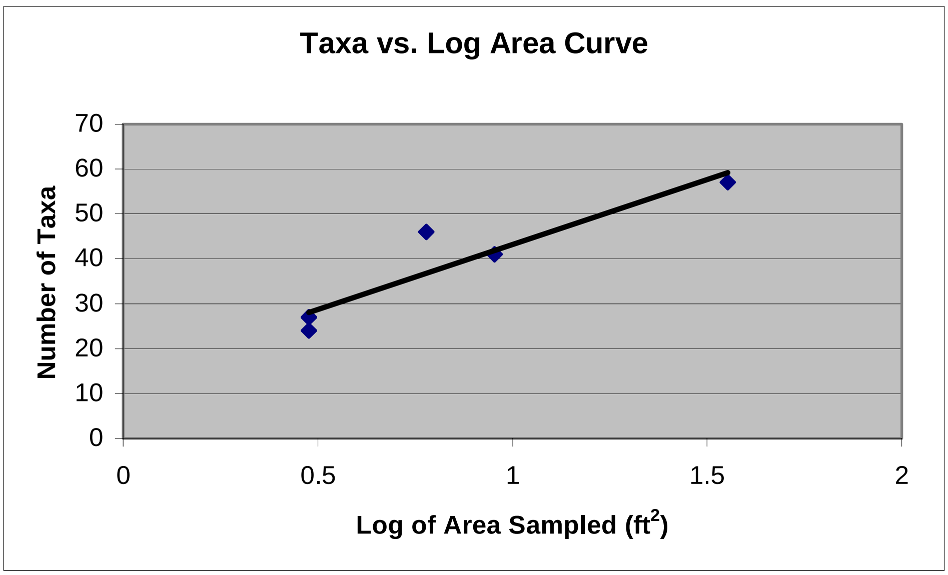
Number of Taxa Collected vs. Sampling Intensity

A larger area was sampled and more taxa were collected in 1999 than in any previous year despite rotenone treatments (Table 4). More taxa were found as an increasingly larger area was sampled. Figure 2 shows a linear relationship between the log of the area sampled and the number of taxa collected. The 1997 sampling date, one year post-treatment, showed a slight decline in taxa numbers, but did not significantly deviate from the linear relationship.

Table 4: Manning Creek sampling intensity by year and number of taxa collected.

Year	Number of stations	Number of samples	Area sampled-ft2	Log of area sampled	Number of taxa collected
1988	1	3	3	.477	27
1990	1	3	3	.477	27
1990	1	3	3	.477	24
1995	2	6	6	.778	46
1997	3	9	9	.954	41
1999	4	35	35.75	1.553	57

Figure 2: Graph of Log of Area Sampled vs. Number of Taxa Collected.



Taxa Compared Among Samples from 1995, 1997, and 1999

When comparing the 1995 pre-rotenone taxa numbers by taxonomic level to post-rotenone numbers, all taxa identified at the Class level were still present (Table 1). At the Order, Family, Genus, and Species level 85.7%, 85.7%, 72.7%, 66.7% of the taxa were present, respectively. Overall 75 of 86 (87.2%) taxa identified in the 1995-1999 samples were found to be present following the rotenone treatments. There were 11 taxa missing from the 1997 and 1999 samples that were in the 1995 samples. The majority of the missing taxa were relatively minor components of the total number of invertebrates. Percentage of the sample for missing species ranged from a low of .075 % to a high of 3.875% (Table 5).

Table 5: Manning Creek 1995 taxa still missing 3 years after final rotenone treatment.

Order	Family	Genus	Species	Percent of sample	Notes: **S**en-sitive	Found in Nevada post-rotenone	Found in Utah post-rotenone
Ephemer.	Heptagen.	Heptagenia		.262%	S	Yes	Y8-12[a]
Ephemer.	Heptagen.	Rhithrogena		.824%	S	-	Y8-12
Plecopt.	Nemourid.	Zapada	haysi	.150%	S	-	Y8-24
Plecopt.	Leuctridae			1.461%	S	Yes	Y8-12
Trichop.	Hydropt.	Leucotrichia		.150%	S	-	Y8-21
Tricop.	Hydropt.	Neotrichia		.262%	S	-	-
Tricop.	Rhyacoph.	Rhyacophila	coloradensis	.075%	S	Yes	-
Tricop.	Limnephi.	Dicosmoecus		.466%	S	Yes	Y8-24
Dipteria	Tipulidae	Antocha	monticola	.262%	-	-	Y8-24
Tricladida	Planariidae	Planaria		3.875%	S	Yes	Y8-12
Lumbricidae				.262%	-	Yes	-

[a] Numbers indicate the time in months post-treatment until the taxa was found in samples.

Taxa Compared Among 1988-1990 and 1997-1999 Samples

There were a total of 9 taxa missing from the 1997 and 1999 samples that were in the 1988-1990 samples (Table 6). The majority of these species were relatively minor components of the total numbers of invertebrates. Percentage of the sample ranged from a low of .090 % to a high of 6.008 %. Eight of the 9 were under 1.0 % and 7 of the 9 were under 0.5 %. Further complicating the comparison of these missing taxa from 1988 and 1990 is that none of them were found in the 1995 samples. In other words, this entire group was already missing before the rotenone treatment.

Table 6: Manning Creek 1988-90 taxa still missing 3 years after final rotenone treatment.

Order	Family	Genus	Species	Percent of sample	Notes: **C**ommon **R**are **S**ensitive **L**ong life	Found in NV post-rot-enone	Found in Utah post-rotenone
Plecopt.	Perlodidae.	Skwala	parallela	.207%	C, S, L	-	-
Plecopt.	Pteronari.	Pteronarcys	california	.114%	C, S, L	-	-
Trichop.	Hydropt.	Alisotrichia		.797%	C, S	-	-
Tricop.	Limnephil.	Allocosnoecus		.114%	R, S, L	-	-
Tricop.	Rhyacoph.	Rhyacophila	vagrita	6.008%	C, S	Yes	Y8-12[a]
Tricop.	Lepidostom.			.104%	C	-	-
Dipteria	Ceratopogon.			.455%	C	Yes	-
Dipteria	Stratiomyid.	Euparyphus		.090%	C	-	Y9-12
Cl Pelecy.				.311%		Yes	Y8-24

[a] Numbers indicate the time in months post-treatment until the taxa was found in samples.

Overall 6 taxa that were found pre-treatment in any year were not found post-treatment in Manning Creek and were not documented post-rotenone in other nearby rotenone treatments. One of these is likely an artifact of identification to differing taxonomic levels. Four of the remaining 5 were already missing from the 1995 pre-treatment samples. Thus only 1 of the taxa identified immediately prior to treatment is missing from post-treatment samples and has not been documented post-rotenone in other nearby rotenone treatments.

Diversity Indices

The diversity indices included in laboratory results for the Manning Creek aquatic macroinvertebrate monitoring provide a means to judge the impact of the rotenone treatments on the diversity and evenness of the macroinvertebrate community. The 1988 through 1997 samples included the DAT diversity index (Table 7). DAT values for station D were rated good in 1988 and July 1990, but only fair in September 1990. DAT values for station B and D in 1995 were barely in the excellent range. After the rotenone treatments in 1995 and 1996, the DAT values for these stations dropped into the fair range, indicating decreased diversity. The DAT index was not developed for the 1999 samples.

Table 7: DAT diversity index for Manning Creek aquatic macroinvertebrate samples (nlc = no longer calculated).

Station	8/88	7/90	9/90	8/95	7/97	9/99
E	-	-	-	-	10.2	nlc
D	12.8	11.4	8.2	19.5	8.1	nlc
C	-	-	-	-	-	nlc
B	-	-	-	18.8	8.6	nlc
A	-	-	-	-	-	nlc

For station B and D in 1995 Shannon's diversity index values were in the mid-good range (Table 8). After the rotenone treatments in 1995 and 1996, the Shannon's diversity index values for these stations dropped into the fair range. By 1999 the values had recovered to the mid-good range very close to the pre-treatment 1995 values.

For station B and D in 1995 Simpson's index values were .166 and .119, respectively (Table 8). After the rotenone treatments in 1995 and 1996, the Simpson's index values for these stations rose to .334 and .345, indicating decreased diversity. By 1999 the values had recovered or dropped to .137 and .091, which shows diversity comparable to pre-treatment levels.

Table 8: Simpson's and Shannon's diversity indices for Manning Creek samples.

	8/1995		7/1997		9/1999	
Station	Simpson	Shannon	Simpson	Shannon	Simpson	Shannon
E	-	-	.147	2.167	-	-
D	.119	2.515	.345	1.439	.091	2.672
C	-	-	-	-	.108	2.720
B	.116	2.386	.334	1.510	.137	2.369
A	-	-	-	-	.131	2.321

The evenness data for the Manning Creek monitoring is less conclusive than the diversity indices. The evenness index values for station B and D in 1995 were .553 and .680, respectively. After the rotenone treatments in 1995 and 1996, the evenness index values for these stations rose slightly to .662 and .688, indicating a slightly more even community composition. By 1999 the value had dropped slightly at the lower station to .651 but risen at the upper station to .743.

Table 9: Evenness index values for Manning Creek aquatic macroinvertebrate samples.

Station	8/1995	7/1997	9/1999
E	-	0.780	-
D	0.680	0.688	0.743
C	-	-	0.585
B	0.553	0.662	0.651
A	-	-	0.726

Biotic Condition Index (BCI)

The BCI levels ranged from fair to good at Station D from 1988 through 1990. The BCI levels were good at Station D in 1995 but only a high poor at station B near the Forest boundary. BCI values one year after the rotenone treatment declined 7 points to fair at the upper station D, and 4 points at the lower station B. By 1999, three years post-treatment, BCI values at the upper station D had recovered to good, almost the same as pre-treatment. The new station C (0.8 miles downstream) was also in the good range. Station B near the Forest boundary, already in the poor range, declined two more points. The new station A located on State/BLM administered lands near Elbow Ranch had an even lower rating. In all years BCI scores declined progressively downstream.

Table 10: Biotic Condition Index values for Manning Creek stations

Station ID	8/88	7/90	9/90	8/95	7/97	9/99
E	-	-	-	-	70	-
D	81	77	84	80	73	79 pre. meth. 94 composite
C	-	-	-	-	-	79 composite
B	-	-	-	69	65	63 composite
A	-	-	-	-	-	60 composite

Other Indices

Several other indices were evaluated to see if they might provide useful data. Number of organisms and biomass per unit area were analyzed to address relative abundance, as specified in the monitoring plan. The data did not show any relative trend. Sample data from 1997 was very similar to 1995, and the differences between data sets may indicate unintentional bias by different field collectors in site selection, and the time and thoroughness of collecting samples. All other indices checked were inconclusive.

DISCUSSION

Several factors complicated ascertaining whether there had been a complete recovery of aquatic macroinvertebrates in the Manning Creek watershed following rotenone treatment. These included the limited extent of field sampling, turnover in personnel resulting in the inability to relocate one of the sample stations, the increase in area sampled, a change in the field collection methodologies and the laboratory used for analysis in 1999, and differing levels of taxonomic identification of macroinvertebrates by the two laboratories. While the more extensive sampling in 1999 helped find more species, it made comparisons between the 1997 and 1999 results difficult for gauging the temporal rate of recovery. Limited extent of field sampling is inherent in almost all aquatic macroinvertebrate studies. Because of the above factors the study design was broadened to use diversity and biotic condition indices and data from previous samples. The long time frame and use of indices in addition to pre and post-treatment taxa lists makes this study unique compared to previous rotenone studies. With the inclusion of this additional data the results answer the original monitoring objectives and provides useful information for future treatment planning.

Sample Timing

Sampling different times of the year may have complicated the data analyses. Two pre-treatment samples were collected in August, but post-treatment samples were at different times. Some taxa that were found pre-treatment could possibly be missing in the post-treatment samples due to sampling in different life cycle or emergence timeframes. Factors such as the extended hatching periods of some mayflies and stoneflies, or the multiple generations of some taxa within a single year (Hynes 1970) should reduce the impact of variable sample timing, but consistent sampling efforts would have allowed better experimental comparisons.

Numbers of Taxa Collected and Changes in Sampling Intensity

The greatest number of taxa was identified in 1999, although this is probably a function of the larger area sampled. Since the 1997 sampling included one additional station (a 33% increase in sample area) over the two sampled in 1995, the reduced number of taxa in 1997 (41 vs. 46 in 1995) is probably indicative of the temporary loss or reduced numbers of some taxa in the system due to the 1995 and 1996 rotenone treatments. The higher taxa number found in 1999 (57 vs. 41 in 1997) is likely due to the recovery of species from the rotenone treatments over three years and more intensive sampling.

The change in sampling intensity complicated the analyses. Only one station was sampled in 1988 and 1990. These samples were likely a minimum number collected to assess whether the stream met the new Forest Plan standards. This was increased to two stations for the 1995 pre-treatment baseline evaluation, the original headwater high elevation location and a new low elevation station. The new site was likely added to ensure pre-treatment baseline collection of both high elevation and low elevation macroinvertebrate taxa. An additional station was added in 1997. The new 1997 station was dropped in 1999, since it could not be relocated.

A quick review of the 1995 and 1997 monitoring data prior to field collection in 1999 showed a moderate number of missing taxa, so a deliberate decision was made to add two new stations in an attempt to sample as many taxa as possible. One new station was selected just below an untreated tributary. Another was located near the very bottom of the stream just above the fish barrier. In addition, the protocol changed as a result of changing the laboratory used for sample analysis. The recommended new protocol was used at all four stations, although the upper station was also monitored with one set of 3 samples using the old protocol to compare the methodologies. With the new protocol 8 samples are collected at each station. These factors greatly increased the area sampled in 1999.

While the area sampled increased over 10 times from the 1988 and 1990 samples, nearly 6 times from 1995 and almost 4 times from 1997, total samples represented only a small fraction of the total stream bottom (roughly 0.0075% of 9 miles of stream bottom). Because of limited resources, aquatic macroinvertebrate monitoring will always sample a relatively small area.

Although the numbers of taxa collected in samples from both methodologies was compared, the results were inconclusive. At station C the new composite methodology had a fairly high number of taxa. At station D the older methodology actually collected more taxa from good riffle sites than the composite method, which sampled a variety of habitat types. It appears that either methodology is adequate for sampling a majority of the taxa.

The BYU laboratory identified more organisms to the species level, which were later identified to the genus level by the USU laboratory. This is noted by the drop in numbers of taxa at the species level from 1995 and 1997 to 1999, and the corresponding increase in the numbers of taxa identified at the genus level in 1999. This is one reason for the lower percentage of 1995 taxa identified at the species level found post-treatment shown in Table 1.

New Taxa Collected After Treatment

As noted in the results section, 29.5% of the taxa were collected only post-treatment. Mangum and Madrigal (1999) also reported finding species in post-rotenone samples that were not present in the pre-rotenone samples. This may be a result of changes in community composition and dominance, which allowed some of the previously obscure taxa to expand in numbers when the previously dominant taxa were reduced. Other factors that could be responsible are elimination of fish predators and changes in macroinvertebrate predation. Similar results were also found after a rotenone treatment on the Green River, Wyoming. Binns (1967) found ten taxa at his lowest most Green River rotenone monitoring station during the recovery period that were not found pre-treatment. Only two previously uncommon taxa were listed as missing for this same station. Binns (1967) also compared a post-treatment taxa list further down on the Green River within the bounds of the future Flaming George Reservoir to a species list compiled by an earlier researcher. He found 10 families at the conclusion of his post-rotenone sampling (cut off by the filling reservoir), compared to four pre-treatment families reported by the previous researcher.

Natural events can apparently also trigger changes in macroinvertebrate communities, similar to rotenone treatments, resulting in new taxa being found. Hynes (1970) relates two examples of streams that dried up and then refilled which had new species appear for a while and then disappear again, including dytiscid bettles, a *Nemoura* stonefly, and a *Simulium*.

Taxa Compared Among Samples From 1995, 1997, and 1999

There were 11 taxa missing from the 1997 and 1999 samples that were in the 1995 samples (Table 5). The majority of these species were relatively minor components of the aquatic macroinvertebrate community. Their low numbers makes consistent sampling difficult. It should be noted, however, that these were not the only taxa present in low numbers. Other taxa were present in similar percentages that were found post-treatment. Most of the missing taxa in Table 5 are generally known as sensitive taxa requiring clean water conditions.

The two missing mayflies, *Heptagenia* sp. and *Rhithrogena* sp. are likely present but missed in the field sampling, as both were found 8 to 12 months following the more extensive Strawberry treatments (Mangum and Madrigal 1999). In addition, *Heptagenia* sp. was found following rotenone treatments of the Snake Range, NV (Appendix B). Engstrom-Heg et al. (1978) found the family Heptageniidae to be intermediate to high in rotenone tolerance.

The missing stoneflies *Zapada haysi* and Family Leuctridae are likely present but missed in field sampling. *Zapada haysi* was found 8-24 months and Leuctridae 8-12 months following the rotenone treatment in the Strawberry drainage (Mangum and Madrigal 1999). In addition, Leuctridae was found following rotenone treatments of the Snake Range, NV (Appendix B).

The results of this study are similar to those reported by Mangum and Madrigal (1999) which found Trichopteria to be the order with the most missing taxa following the Strawberry treatments. Two of the missing Manning caddisflies, *Leucotrichia* sp. and *Dicosmoecus* sp., were found by Mangum and Madrigal (1999) 8-21 and 8-24 months following the Strawberry treatments, however, and thus likely were missed in the field sampling of Manning Creek. One of these taxa, *Rhyacophila coloradensis*, was found following rotenone treatments of the Snake Range, NV (Appendix B). Engstrom-Heg et al. (1978) found the genus *Rhyacophila* to be low in rotenone tolerance with an intermediate life cycle and mobility. The final missing caddisfly, *Neotrichia* sp. was not found post-treatment in either the Strawberry or Snake Range, NV sampling.

The missing crane fly *Antocha monticola*, Class Dipteria, Family Tipulidae, found in 1995 is believed to be an artifact from the two laboratories identifying this taxon to different levels, as *Antocha* sp. was found post-treatment in Manning Creek. In addition, *Antocha monticola* was found in samples 8-24 months following rotenone treatment of Strawberry Reservoir tributaries by Mangum and Madrigal (1999). Engstrom-Heg et al. (1978) did find the genus *Antocha* to have a low to intermediate tolerance to rotenone with low mobility and a potentially intermediate to long recolonization time.

One taxa missing from the laboratory results, *Planaria* sp., was missed either by the field sampling or lab analysis. It is visually distinctive and was sighted while conducting the field sampling in 1999, and is known to still be present in Manning Creek. It was also found 8-24 months following rotenone treatment of the Strawberry system by Mangum and Madrigal (1999) and following rotenone treatments of the Snake Range, NV (Appendix B).

The final missing taxa (Class Lumbricidae) might have been missed due to sampling error. An oligochaeta, or aquatic earthworm, it prefers soft substrates and would be more likely to be missed by sampling of gravel riffles. While several pool tails and deep runs were sampled for the composite samples in 1999, the majority of samples were taken in riffles. Class Lumbricidae and Family Lumbriculidae were both found following rotenone treatments of the Snake Range, NV (Appendix B).

To summarize, of the 11 taxa found immediately pre-treatment which were not found post-treatment, 10 of the 11 have been documented following other rotenone treatments. This leaves only 1 of the 86 (1.16%) taxa found immediately before (1995) or after (1997 and 1999) treatment that has not been documented post-treatment in Manning Creek or after other relatively nearby rotenone treatments.

Taxa Compared Among 1988-1990 and 1997-1999 Samples

There were 9 taxa missing from the 1997 and 1999 samples that were in the 1988-1990 samples (Table 6). The majority of these species were relatively minor components of the aquatic macroinvertebrate community. Their low numbers makes consistent sampling difficult. Further complicating the comparison of these missing taxa from 1988 and 1990 is that none of them were found in the 1995 samples. In other words, they were already missing before the rotenone treatment.

Of the Plecoptera, or stoneflies, the 1988-1990 species *Skwala parallela* and *Pteronarcys california* were missing in the post-treatment samples. Engstrom-Heg et al. (1978) found the genus *Pteronarcys* to have a very high estimated rotenone tolerance and high mobility, but with a likely intermediate recolonization time due to its long life cycle.

The largest group of 1988-1990 missing taxa was the Trichoptera, or caddisflies. Four taxa were not found in the 1995, 1997, and 1999 samples that were present in the 1988-1990 samples. These are *Alisotrichia* sp., *Allocosnoecus* sp., *Rhyacophila vagrita*, and the family Lepidostomatidae. The family Lepidostomatidae may be an artifact of differing taxonomic levels of identification, however, as the genus *Lepidostoma* was found post-rotenone. One of the missing Manning caddisflies, *Rhyacophila vagrita* was found by Mangum and Madrigal (1999) 8-12 months following the Strawberry treatments and was also found following rotenone treatments in the Snake Range, NV (Appendix B). Engstrom-Heg et al. (1978) found the genus *Rhyacophila* to be low in rotenone tolerance with an intermediate life cycle and mobility.

The Class Dipteria had two missing taxa from the 1988-1990 samples, the family Ceratopogonidea and *Euparyphus* sp. Ceratopogonidea was found following rotenone treatments in the Snake Range, NV (Appendix B) and *Euparyphus* sp. was found 9-12 months following the Strawberry treatments by Mangum and Madrigal (1999).

The final taxon missing from the 1988-1990 samples was the Class Pelecypoda. It was found 8-24 months following rotenone treatment of the Strawberry system by Mangum and Madrigal (1999) and also following rotenone treatments of the Snake Range, NV (Appendix B).

To summarize, of the 9 taxa found in 1988 and 1990 that were not found post-treatment, 4 of the 9 have been documented following other rotenone treatments. This leaves 5 of the 1988 and 1990 taxa that are not present and not documented after other nearby rotenone treatments. Again, it must be emphasized that all 9 of these taxa were missing prior to the 1995 treatment. This illustrates the highly variable and dynamic nature of aquatic macroinvertebrate communities.

Overall, the results are similar to those found in monitoring of the Strawberry drainage in Utah in that the most impacted order of aquatic macroinvertebrates was Trichoptera. Species recovery appears to have been quicker in Manning Creek than in the Strawberry River, however, where 21% of the taxa were still missing after 5 years. While 21.0% of the Manning taxa were not found in post-treatment monitoring, nearly half of these missing taxa are from the 1988 or 1990 samples that were not even collected in the 1995 pre-treatment sample. Further, the last Manning Creek sample was only three years since the last treatment, at least one of the taxa was known to be missed in field or lab sampling, and two of these taxa may not be missing but instead identified to different taxonomic levels by the two laboratories.

The missing taxa may still be present in Manning Creek. The majority of the missing taxa were only a very small percentage of the pre-treatment samples, which makes them difficult to sample. These taxa could still be present in comparable numbers, but difficult to collect because of their low densities. Most of the missing taxa have survived other rotenone treatments and several of the missing genera were found by Engstrom-Heg et al. (1978) either to be quite tolerant to rotenone or rapid recolonizers after a disturbance due to short life cycles and high mobility.

Diversity Indices

Rotenone treatments likely cause changes in macroinvertebrate community composition, dominance, and evenness. All three diversity indices measured at stations B and D declined after the Manning rotenone treatments, although the evenness index rose slightly. It is possible that the rotenone treatments reduced numbers of species that were dominating the community prior to rotenone treatments thus slightly increasing community evenness. The two diversity indices reported for 1999 (Shannon’s and Simpson’s indices) both showed a recovery to about 1995 levels. Mangum and Madrigal (1999) found not only an immediate change in benthic invertebrate community composition, but also later changes in the dominant taxa during their five-year post-rotenone monitoring period.

Biotic Condition Index

The Biotic Condition Index (BCI) values reported for the Manning Creek samples allow a view of how the rotenone treatment impacted this measure of aquatic health, although changes in other factors such as watershed condition, storm events, land management activities, and road sediment which occurred during the same timeframe would compound the effects and analyses.

Another caution is that the database of environmental tolerances of aquatic macroinvertebrates was developed for factors such as organic enrichment and sedimentation, and taxa tolerance to rotenone may vary from their tolerance to these factors.

The BCI for station D ranged from the high 70s to the low 80s from 1988 to 1995, which is in the upper fair to good range. These scores are among the highest scores sampled on the Fishlake N.F. The BCI declined to 73, or a lower fair rating, in 1997 after the rotenone treatments, which shows a loss of some of the more sensitive species. While this drop is quite likely due to the rotenone application, there was no experimental control and other causes such as increased grazing or storm events cannot be ruled out. The upper station recovered by 1999 to 79, similar to pre-treatment levels. The lower station B was first sampled in 1995 and had a BCI of 69, which is in the poor range. It declined slightly after the rotenone treatments to 65. Unlike the upper station, it declined further to 63 in 1999. Other land management activities may be preventing the BCI recovery of this station.

One interesting result was the differing BCI ratings compared between the two sampling methodologies at station D in 1999. The BCI rating from the composite sample of 8 sub samples (5 riffle, 2 pool tails, and 1 run), while having fewer taxa than any of the three individual samples, had a considerably higher BCI rating (94 vs. 79). One possible explanation is that the composite sample collects more of the relatively infrequent clean water taxa than the older methodology, biasing the score upwards (Vinson personal communication). Stations with low BCI scores did not seem to be as affected, and had comparable ratings using either methodology. In 1999, BCI ratings for stations A, B, and C were based on the composite of 8 sub-samples only.

Comparison to Other Rotenone Treatment Studies

Results of the Manning Creek monitoring study are consistent with other studies of the impacts of rotenone to aquatic macroinvertebrates. Studies of treatments at low rotenone concentrations or with untreated upstream waters generally showed minimal impacts and/or a rapid resurgence of the taxa (Cook and Moore 1969 and Engstrom-Heg et al. 1978). The studies that found greater impacts were generally treatments of longer duration, at higher treatment concentrations, and a more complete treatment of the watershed (Binns 1967 and Mangum and Madrigal 1999). In extreme cases with high exposures to rotenone for extended time periods the fauna was severely reduced (Binns 1967). Even in those areas, numbers of more tolerant taxa and taxa with short generations that survived as eggs increased rapidly, often exceeding numbers of untreated stations within a few months to a year. Absence of both fish and macroinvertebrate predators, and the additional nutrients from the treatment may account for this effect. Several studies noted a succession of dominant taxa during the recovery period (Binns 1967 and Mangum and Madrigal 1999). The majority of taxa seem to recover in about a year with almost all taxa recovering in two. Interestingly, many new taxa may appear after a treatment. The number of new taxa may exceed the number of missing taxa (Binns 1967). Lack of competition from previously dominant taxa or a lack of predators may permit these new taxa to flourish. Perhaps some of these taxa are "disturbance types", requiring some disturbance to allow their numbers to increase to levels where they can be sampled.

Cook and Moore (1969) sampled just above and just below the beginning of a rotenone treatment (Pronoxfish "at a concentration level of not less than 0.50 active ingredient rotenone") in a California stream. Taxa in their study were identified to the order or family level. They found a rapid resurgence of the insect fauna in both riffles and pools after their initial decline to very low levels. By winter population levels dropped to a level similar to untreated waters, but by spring pool habitat had population levels almost twice that of the untreated habitat. The major component of riffle fauna was blackfly larva , caddisflies, and mayflies. Pool habitat was dominated by an eruption of chironomid midge larvae about 6 weeks after treatment. Other taxa were less than 5% of the sample and were not analyzed except for stoneflies, which were virtually eliminated in the treatment zone but recovered to densities comparable to the untreated zone by the next spring.

Engstrom-Heg et al. (1978) describe a treatment of Ten Mile River in New York that was treated three successive times. Samples shortly after the treatments showed that the bottom fauna, dominated by *Hydropsyce* and *Cheumatopsyche* caddisflies and *Paraleptophlebia* mayflies, but also including Chironomidae, Gastropoda, and Oligochaeta, had not been appreciably affected by exposure to 1.0 - 4.75 ppm of rotenone formulation.

Mangum and Madrigal's (1999) study of the Strawberry treatment in Utah (two applications at 3.0 ppm Noxfish for 48 hours) was unique in looking at a longer time frame (5 years post-treatment) than other studies. In addition, the six most important species were analyzed statistically. They found fairly intensive impacts, especially among the Ephemeroptera, Plecoptera, and Trichoptera. Trichopteria was the order with the most missing taxa. Mangum and Madrigal (1999) found that while chironomids and tubificids were adversely affected by the Strawberry rotenone treatments, they recovered to twice their original numbers within one month. Numbers of benthic organisms recovered in 1 to 36 months. Resistance to rotenone was shown by about one-third of the Strawberry taxa. Overall, nearly half of the total taxa recovered after one year, but 21% of the taxa (19 taxa) were still missing after 5 years. They found some new taxa post-treatment. Their study does not note other potential land management or natural impacts that could have affected recovery, however, nor does it note the relative percentage of the missing species in the pre-treatment samples.

Mangum (personal communication) provided previously unpublished data on the BCI scores for the Strawberry treatment. Pre-treatment BCI scores ranged from the mid-70s to high 80s for the four stations, with an average BCI value of 81.25. One month post-treatment the BCI scores had dropped to an average of 56.75, with a range from 51 to 68. The largest drop for any station was from 89 to 51, a total of 38 points. One year post-treatment the BCI ratings averaged 67.75, with a range from 60 to 77. Five years post-treatment the BCI scores averaged 73.75, with a range of 60 to 82. This is still 7.5 points below the pre-treatment average. Post-treatment grazing impacts may have been responsible for the incomplete recovery of the BCI scores. In contrast, the impacts to the BCI ratings were less in the Manning Creek treatment. One year post-treatment the Manning scores had dropped an average of 5.5 points, compared to the 13.5 points noted in the Strawberry treatments.

In contrast to the Manning treatment data, Mangum (personal communication) did find some interesting trends in biomass at the four stations sampled for the Strawberry treatments. Pre-treatment biomass levels were fairly high with an average of 12 gm/m^2, ranging from 8 to 18 gm/m^2 at individual stations. One month post-treatment the biomass had dropped to an average of 3.25 gm/m^2, with a range from 1 to 5 gm/m^2. One year post-treatment the biomass had rebounded to an average of 14.25 gm/m^2, exceeding pre-treatment levels. Five years post-treatment the biomass had dropped to 5.75 gm/m^2, approximately half of the pre-treatment levels. Reasons for the drop in biomass after five years are unknown.

One of the most extensive reviews of a rotenone treatment was Binns' (1967) study. It involved weekly to monthly samples of a 130-mile stretch of the Green River for two years. Most taxa were only identified to the family or genus level. Aquatic macroinvertebrate populations were drastically reduced by the rotenone treatment (formulation concentrations ranged from 2.5-10 ppm), but they began to recover in the upper 30 miles within one month. Fifteen miles downstream from the treatment start the number of taxa, while initially quite reduced, recovered by 14 months. Only one family, the water boatman or Corixidae, was still missing after 2 years. The lower treated area, which was impacted by high rotenone concentrations for several days, was barren until the following spring. By one year invertebrate numbers were equal or greater than they had been before the treatment, however. One interesting observation was that while taxa numbers were considerably reduced immediately after the treatment at these lower stations, peak numbers of taxa were often recorded 12-14 months post-treatment. At fifty-seven miles downstream only Tipulidae was still missing after two years. Around 90 miles downstream about half of the taxa recovered within a year. At the end of two years two previously uncommon taxa were still missing but five new mayfly genera appeared sporadically after the treatment. There was a change of the dominant invertebrates following the treatment with a succession of groups. Dominant groups were still different from the pre-treatment dominant groups after two years.

Potential Survival Mechanisms of Aquatic Macroinvertebrates

Aquatic macroinvertebrates can survive or persist after rotenone treatments as resistant eggs, nymph, larval, or adult stages, in areas of upwelling spring water, in areas with poorly mixed treated water, as mobile air-breathing adults, or they could recolonize by dispersal from nearby refugia. In most cases it is probable that several factors may act at once. Mangum and Madrigal (1999) described possible survival and repopulation mechanisms as resistant egg life stages, instream and side springs which locally diluted the rotenone, incomplete mixing and exposure to rotenone near banks or under rocks, and dispersal of aerial adults. Binns (1967) postulated that repopulation of the Green River could have occurred through physiologically inactive stages such as eggs, surviving nymph, larva or adult organisms, migration from untreated waters, and transport of an organism from outside areas.

The most resistant life stage of many aquatic insects is the egg. Hynes (1970) noted eggs of many aquatic insects could survive dry for many months. He cites an example of several taxa that survived a D.D.T. treatment of a tropical stream, presumably as eggs. Cook and Moore (1969) found a rapid resurgence of insect fauna including simuliids, the first to recover, and then caddisflies and mayflies in riffles and chiromomids in pools after treatment of a California creek. Other than a few large individual caddisfly larva which may have survived the treatment, these insects were early instars indicating recent hatching from eggs. Binns (1967) found there were not any *Ephoron* mayflies upstream of his treatment area, and thus they could not have been reintroduced from untreated areas. Yet this taxon appeared fairly uniformly throughout the treatment area the following summer in its previous habitat. He also found the mayfly *Ephemerella* and midges (Tendipedidae) had a rapid and fairly even recovery distribution supporting recovery from eggs.

According to Hynes (1970) extended hatching periods are common in many aquatic stream insects. Aquatic insects have a variety of life cycles with a few having multiple generations per year, many having one generation per year and some taking more than a year for each generation. Even with species that have annual generations, there may be overlapping generations (Hynes 1970). These factors increase the likelihood that the more resistant egg stages are present over prolonged periods, reducing the impacts of an environmental disturbance (such as drought or flooding). For example, Binns (1967) found the mayfly *Tricorythodes* to be abundant shortly after a rotenone treatment on the Green River. This mayfly has a series of generations each summer, so eggs laid prior to the treatment probably repopulated the area.

Aquatic macroinvertebrates have variable tolerances to rotenone (Engstrom-Heg et al. 1978). Tolerance does not follow taxonomic lines, but may be related to oxygen requirements. Resistant macroinvertebrates include burrowing mayflies of the family Ephemeridae, members of the orders Odonata, Megaloptera, and Coleoptera, and the aquatic isopod *Asellus militaris*. Adult air-breathing coleopterans and hemipterans also were resistant to rotenone. Two rotenone resistant caddisfly genera, *Hydropsyche* and *Cheumatopsyche,* were noted to be tolerant of polluted waters with low oxygen levels. Mangum and Madrigal (1999) found resistance to rotenone in about one-third of the Strawberry adults, nymphs, or larva taxa, including *Paraleptophlebia* and the caddisfly *Hydropsyche*. This is consistent with reports by Engstrom-Heg et al. (1978) for these taxa. Binns (1967) found in a lower treatment area affected by rotenone for an extended time period that taxa such as dragonflies and snipe flies which burrow in the mud were resistant.

Achieving complete fish kills with rotenone is often difficult when aquatic vegetation is common. Binns (1967) discussed the effects of weed beds on the distribution and detoxification of rotenone, and that it might serve as a possible refuge for macroinvertebrates.

Many small insect stages utilize habitat deep in the gravel of streams. For example, a study in southern Colorado found the nymphs of many chlorperlid stoneflies were not available in surface sediments until just before emergence; the authors surmised their use of hyporheic habitat (DeWalt and Stewart 1995). It is possible that the deep zone below the substrate/water interface may provide a refuge from rotenone due to poor mixing/influx of treated water, upwelling groundwater, or binding of the rotenone to soil and clay particles. Suspended clay particles have been found to reduce the effectiveness of rotenone (Gilderhus 1982). Personal observation of a treatment in Hendry's Creek in east central Nevada and Boulder Creek in southern Utah illustrate that water percolating through only a few feet of gravel can neutralize rotenone sufficiently that trout can survive downstream.

As noted by Engstrom-Heg et al. (1978) the most rotenone sensitive taxa tended to have short life cycles, high mobility, and a potential for rapid recolonization. In laboratory tests some of the most sensitive taxa were the mayfly genus *Baetis*, the caddisfly genus *Rhyacophila*, and the blackfly family Simuliidae. Yet all of these taxa were found following treatment in Manning Creek (Appendix A) and in creeks monitored in the North Snake Range of Nevada (Appendix B). These more sensitive insects, which are either mobile or have short life spans, can repopulate depleted areas rapidly through drift, migration, and oviposition. Ephemeroptera are generally considered vulnerable to rotenone, as species of this order generally require clean water conditions. *Drunell grandis* has a relatively moderate range of tolerances, *D. coloradensis* is more narrowly tolerant, and the least tolerant *D. doddsi* is found only in streams with the highest water quality and clean substrates (Winget and Mangum 1996). All three species were found following the rotenone treatment of Manning Creek. Binns (1967) noted that drift from upstream untreated waters may have assisted recovery of his upper treatments stations, where no taxa groups were missing after two years. Hynes (1970) discussed the upstream flight of many winged adults of aquatic macroinvertebrates to oviposit, some moving long distances. This allows upstream dispersal and recolonization from areas of downstream refugia.

Mitigation Measures to Reduce Rotenone Impacts to Aquatic Macroinvertebrates

There are potential mitigation measures that can be taken in some cases to reduce impacts to aquatic macroinvertebrates. For example, a mitigation measure of leaving several fishless tributaries untreated was applied during the Manning Creek treatment. In addition, a lower concentration (1.5 mg/l Noxfish vs. 3 mg/l Noxfish) and a shorter length of time (12-18 hours vs. 48 hours) of treatment were used compared to previous treatments in Utah. These measures appear to have reduced impacts to Manning Creek compared to the Strawberry treatment.

Leaving fishless headwaters or side tributaries untreated where feasible would provide source areas for aquatic macroinvertebrates to repopulate treated areas. Downstream drift would be a major factor, but upstream flights by adults to oviposit could result in upstream colonization from lower refugia. Cook and Moore (1969) found a rapid resurgence of insect fauna after a partial treatment of a California creek (4 ½ miles of a 10 mile length), with an untreated zone above the treatment to allow drift of organisms. Cook and Moore (1969) also found a few large individual caddisfly larva after rotenone treatment, which may have indicated drift from the upstream untreated zone. Binns (1967) data seems to support recovery of the caddisfly group Hydropsychidae by downstream movement from untreated upstream waters.

The lowest rotenone concentration and treatment time that will meet treatment objectives will also likely reduce impacts to aquatic macroinvertebrates. Engstrom-Heg et al. (1978), based on their laboratory study of the rotenone tolerance of aquatic macroinvertebrates, felt that a treatment of less than 10 ppm-hours would generally result in only mild and temporary damage to the aquatic macroinvertebrate community. In contrast, they noted that very few immature aquatic insects could survive a 48-hour exposure to 3 ppm of 5% formulation rotenone.

Studies of large treatments have shown more extensive impacts to aquatic macroinvertebrates. If suitable fish barriers can be found or constructed, breaking treatments of large watersheds into smaller treatments carried out over time may reduce impacts to aquatic macroinvertebrates. Treatment logistics are easier for smaller units, which may allow treatment at lower rotenone concentrations for shorter time periods. Further, when larger treatments are broken up, treated waters can be repopulated from untreated waters by macroinvertebrate drift downstream or upstream flights of adults to oviposit.

Detoxification stations are often run at the lower end of a rotenone treatment at a man-made or natural barrier to protect downstream fisheries. This action also may serve to protect downstream aquatic macroinvertebrates. Hynes (1970) notes a variety of adult winged aquatic insects that fly upstream to oviposit. These adults could potentially recolonize upstream waters, thus detoxification is a potential mitigation measure for aquatic macroinvertebrates.

Deciding which streams are suitable for renovation treatment is generally done using fisheries or political criteria, but the decision is often made to treat only a few select streams within a given planning region. This landscape scale pattern of treating individual streams while leaving adjacent streams untreated could potentially act as a mitigation measure by protecting refugia source areas for longer dispersing taxa.

Natural Variation of Aquatic Macroinvertebrate Communities

Evaluations of rotenone impacts on aquatic invertebrates are complicated by the naturally dynamic nature of their communities. Monitoring studies of treatments have generally not included controls for comparison. Without a control, post-treatment observations cannot be entirely attributed to rotenone. For example, Hynes (1970) found large variations in species composition for no apparent reason. He described a nine-year study where composition of the fauna varied considerably among years despite consistent sampling, timing of samples to avoid emergence, and a lack of obvious change in the stream. Seven years into the study *Baetis* became very abundant and several other species quite scarce. This change persisted for two more years. Similarly, nearly as many taxa were missing on Manning Creek over the period 1988-1995 before treatment as there were missing taxa from 1995-1999 after the treatment.

Biomass and numbers of aquatic insects can undergo patterns of seasonal change. Losses are caused by predation and emergence of adults (Hynes 1970). A study in eastern Idaho found large unexplained changes in aquatic macroinvertebrate numbers over 3 years (Platts and Andrews 1980). The declines ranged from 48 to 72%. Numbers of taxa also can be quite variable as shown by an untreated control station on the Green River, Wyoming, which ranged from 7 to 22 groups of taxa (Binns 1967).

Mangum's (1975) study of the Fremont River, Utah, documented high variability in sampling of uncommon taxa. Two stations were sampled three times a year for two years in June, July, and August. Four of the taxa listed were found in only one of the 12 samples (interestingly, all were in the second year). Seven taxa were found in two of the 12 samples. Six of these 7 were only found in one or the other of the two years. The one taxa found in both years occurred at different stations between the years. Similar variability can be seen in Mangum's (1975) data for Duck Creek, Utah.

Aquatic Macroinvertebrates Responses to Natural Short-term Disturbances

Studies showing aquatic macroinvertebrate responses to natural events are often similar to studies showing impacts from rotenone (Binns 1967, Hynes 1970, Mangum 1975, Winget and

Mangum 1979, Richards and Minshall 1992, and Robinson et al. 1993). Aquatic macroinvertebrate samples collected in Nevada during runoff events had low numbers of organisms, low numbers of taxa, and low BCI and diversity indices (personal observation). Aquatic macroinvertebrates adapted to live in the highly variable streamflows common in the Intermountain and Great Basin regions have adapted means to recolonize barren waters after flood events or drought. These same adaptations are useful for surviving or recolonizing streams after rotenone treatments.

Robinson et al. (1993) noted a loss of 10 taxa (almost a third of all taxa) during the spring runoff season of a snowmelt stream subject to high seasonal runoff. The snowmelt stream had more mobile taxa compared to a stable flow groundwater stream. It was suggested that a natural disturbance event on either stream would have little impact in late summer when many aquatic macroinvertebrate populations had emerged.

Hynes (1970) found there was a reduction in the density of fauna where there is seasonal flooding, citing an example from the Provo River, Utah. Mangum (1975) found a reduction in macroinvertebrate numbers in the Grey's River, Wyoming, and the Santa Clara River, Utah, because of scouring from high spring runoff. Binns (1967) found that June runoff severely reduced the number of benthic organisms in untreated areas of the New Fork and Green Rivers, Wyoming.

Hynes (1970) discussed how summer high water flows had reduced the macroinvertebrate fauna in a stream. Cloudburst flood in early August left the streambed barren two weeks later. Macroinvertebrate numbers increased dramatically, peaking about 2 months later, with the initial recovery dominated by Chironomidae and Simuliidae. The Ephemeroptera, Trichoptera, and Plecoptera reappeared more slowly. Binns (1967) found Green River, Wyoming, macroinvertebrates to be adversely affected by late summer flash floods, which reduced populations to only a remnant of pre-flood levels and changed the dominant taxa at one site. While flooding may lead to an upstream decrease of insects, it can increase drift and numbers of insects downstream (Hynes 1970). Downstream drift of aquatic macroinvertebrates can rapidly recolonize lower stream reaches (Hynes 1970).

Low streamflows are another natural factor that affects aquatic macroinvertebrates. Winget and Mangum (1979) describe macroinvertebrate samples from the West Fork of the Duchesne River, Utah, which dropped from 36 taxa to 30 taxa over the course of one year. Analysis showed clean water species were eliminated by drought conditions. Hynes (1970) discussed a rapid resurgence of aquatic macroinvertebrates (Chironomidae) after a drought. Fire is also a natural disturbance that affects aquatic macroinvertebrates. A study in central Idaho showed that wildfire disturbed streams had lower species richness than streams in nearby undisturbed watersheds (Richards and Minshall 1992).

Aquatic Macroinvertebrate Responses to Other Land Management Actions

Mangum (1975) found a reduction in numbers and biomass of aquatic macroinvertebrates in the North Fork of Three Creeks, Utah, likely due to sedimentation from construction. In extreme cases degradation can be a threat to sensitive taxa. Hynes (1970) speculated that a large carnivorous mayfly, which is absent from portions of South Africa, might have been eliminated because of erosion.

In the Provo River, Utah, low numbers of macroinvertebrates were attributed by Mangum (1975) to artificially low winter streamflow and scouring from artificially high summer flows resulting from interbasin water transfers. In the Fremont River, Utah, Mangum (1975) found very low numbers of taxa at the station below Johnson Reservoir, although the number of taxa increased during the summer. Water chemistry, low winter flows, and siltation were likely causes of the depauperate flora at this site.

Recently many of the Fishlake N.F. aquatic macroinvertebrate monitoring stations have been below the Forest Plan standard of a BCI ≥ 75, which is fair. With large percentages of the stations below standards there is likely a widespread reduction in clean water taxa across the Forest. While all the causes of these low BCI ratings are not understood, many are believed to be due to chronic impacts from land management actions. These chronic impacts likely have long-term impacts on community dominance and the taxa present, even if they have not impacted the total number of taxa. Another factor to consider is that recovery of some aquatic macroinvertebrate species after rotenone treatments could be delayed by stress from other past or currant management actions (Mangum and Madrigal 1999). Thus, improving degraded aquatic conditions before a rotenone treatment could improve the post-treatment recovery of aquatic macroinvertebrates.

MANAGEMENT RECOMMENDATIONS

Management action to collect and reintroduce aquatic macroinvertebrates into Manning Creek is not recommended. The vast majority of the taxa have recovered. Post-treatment samples show comparable numbers and diversity of taxa. General transfer of aquatic macroinvertebrates would be unlikely to contain enough suitable individuals of the uncommon taxa to greatly bolster their populations. If factors such as competition from changed community dominance patterns are part of the cause, reintroductions would likely be ineffective. Furthermore, locating and transferring the missing taxa would require considerable expertise and labor in the field. Since continued monitoring of Manning Creek will be necessary to assess other land management impacts to the aquatic health of this drainage, it is recommended that the species lists of future aquatic macroinvertebrate samples should be checked to monitor for the presence of these taxa.

Aquatic macroinvertebrate samples collected for pre-timber harvest baseline data in 2002 should be collected in mid-August. This would help replicate the August pre-treatment sampling period, as no post-treatment samples have been collected in August. This might increase the probability of sampling some of the uncommon taxa.

Monitoring programs of this intensity require a moderate commitment of resources yet have too few samples to allow rigorous statistical analysis. In future rotenone treatments if there are many confounding variables that would complicate an analysis a monitoring study of this intensity may have only limited value. Where several mitigation measures are feasible and are incorporated to reduce project impacts to aquatic macroinvertebrates, studies such as these may not be necessary.

This study and literature sources show the rapid recolonization of aquatic macroinvertebrates from protected refugia. If aquatic macroinvertebrate samples have not ever been collected from the stream, however, it would be advisable to collect baseline samples for future reference.

Monitoring studies can show which taxa are not of general concern and which warrant greater study. For example, the few taxa not found following treatment could be tested under laboratory conditions similar to the Engstrom-Heg et al. (1978) study to determine rotenone tolerance.

While reviewing preliminary findings of this study, Vinson (personal communication) suggested one option for future monitoring is to compare pre and post-treatment taxa while excluding taxa comprising < 5% of the pre-treatment sample, since sampling error rather than rotenone may be the cause for missing these taxa in follow-up sampling dates.

This study demonstrated that leaving fishless headwater and side tributary reaches untreated and using the minimum rotenone concentration and treatment time necessary to achieve treatment objectives is a low cost and reasonably effective mitigation measure that speeds recovery of aquatic macroinvertebrates. Detoxification of downstream waters likely protects additional aquatic macroinvertebrates, which serves as another refugia.

The impacts of rotenone to aquatic macroinvertebrates need to be kept in context. There are probably greater impacts to aquatic macroinvertebrates due to chronic degradation and siltation of large areas of aquatic habitat by other land uses. Concern for aquatic macroinvertebrates is valid. If feasible mitigation measures are incorporated into rotenone treatments for aquatic macroinvertebrates, however, there probably would be greater benefits for aquatic macroinvertebrates by reducing aquatic degradation from other land management uses than from additional actions taken during rotenone treatments.

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Appendix A: Manning Creek Aquatic Macroinvertebrate Summary Species List

Manning Creek, Fishlake National Forest, Richfield Ranger District, Piute County, Utah.
Pre-rotenone: 1988 (1 station), **1990** (1 station twice), **1995** (2 stations)
Post-rotenone: 1997 (3 stations - 1 year following treatments in 1995 and 1996) and **1999** (4 stations - 3 years following treatments in 1995 and 1996)

CLASS	ORDER	FAMILY	GENUS	SPECIES	SUMMARY	
Insecta	Ephemeroptera	Heptageniidae				Post
Insecta	Ephemeroptera	Heptageniidae	Epeorus		Pre	Post
Insecta	Ephemeroptera	Heptageniidae	Epeorus	longimanus		Post
Insecta	Ephemeroptera	Heptageniidae	Heptagenia		Pre	
Insecta	Ephemeroptera	Heptageniidae	Rhithrogena		Pre	
Insecta	Ephemeroptera	Heptageniidae	Cinygmula		Pre	Post
Insecta	Ephemeroptera	Leptophlebiidae				Post
Insecta	Ephemeroptera	Leptophlebiidae	Paralepthophlebia		Pre	Post
Insecta	Ephemeroptera	Ephemerellidae			Pre	Post
Insecta	Ephemeroptera	Ephemerellidae	Drunella			Post
Insecta	Ephemeroptera	Ephemerellidae	Drunella	coloradensis	Pre	Post
Insecta	Ephemeroptera	Ephemerellidae	Drunella	doddsi	Pre	Post
Insecta	Ephemeroptera	Ephemerellidae	Drunella	grandis		Post
Insecta	Ephemeroptera	Ephemerellidae	Ephemerella	coloradensis	Pre	a
Insecta	Ephemeroptera	Ephemerellidae	Ephemerella	doddsi	Pre	a
Insecta	Ephemeroptera	Ephemerellidae	Ephemerella	inermis	Pre	Post
Insecta	Ephemeroptera	Baetidae	Baetis		Pre	Post
Insecta	Ephemeroptera	Siphlonuridae	Ameletus		Pre	Post
Insecta	Plecoptera				Pre	Post
Insecta	Plecoptera	Chloroperlidae			Pre	Post
Insecta	Plecoptera	Chloroperlidae	Sweltsa		Pre	Post
Insecta	Plecoptera	Nemouridae			Pre	Post
Insecta	Plecoptera	Nemouridae	Malenka		Pre	Post
Insecta	Plecoptera	Nemouridae	Zapada		Pre	Post
Insecta	Plecoptera	Nemouridae	Zapada	cinctipes		Post
Insecta	Plecoptera	Nemouridae	Zapada	haysi	Pre	
Insecta	Plecoptera	Nemouridae	Amphinemura			Post
Insecta	Plecoptera	Perlidae	Hesperoperla	pacifica	Pre	Post
Insecta	Plecoptera	Perlodidae			Pre	Post
Insecta	Plecoptera	Perlodidae	Isoperla		Pre	Post
Insecta	Plecoptera	Perlodidae	Megarcys			Post
Insecta	Plecoptera	Perlodidae	Skwala	americana		Post
Insecta	Plecoptera	Perlodidae	Skwala	parallela	Pre	
Insecta	Plecoptera	Pteronarcyidae	Pteronarcys	california	Pre	
Insecta	Plecoptera	Taeniopterygidae				Post
Insecta	Plecoptera	Capniidae			Pre	Post
Insecta	Plecoptera	Leuctridae			Pre	
Insecta	Trichoptera				Pre	Post
Insecta	Trichoptera	Hydropsychidae				Post
Insecta	Trichoptera	Hydropsychidae	Hydropsyche		Pre	Post
Insecta	Trichoptera	Hydroptilidae				Post
Insecta	Trichoptera	Hydroptilidae	Alisotrichia		Pre	
Insecta	Trichoptera	Hydroptilidae	Hydroptila		Pre	Post
Insecta	Trichoptera	Hydroptilidae	Leucotrichia		Pre	
Insecta	Trichoptera	Hydroptilidae	Neotrichia		Pre	
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila			Post
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	acropedes	Pre	Post
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	coloradensis	Pre	
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	hyalinata	Pre	Post
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	vagrita	Pre	
Insecta	Trichoptera	Brachycentridae	Micrasema		Pre	Post
Insecta	Trichoptera	Glossosomatidae	Glossosoma		Pre	Post
Insecta	Trichoptera	Limnephilidae			Pre	Post
Insecta	Trichoptera	Limnephilidae	Allocosmoecus		Pre	
Insecta	Trichoptera	Limnephilidae	Dicosmoecus		Pre	

Insecta	Trichoptera	Limnephilidae	Hesperophylax		Pre	Post
Insecta	Trichoptera	Limnephilidae	Psychoglypha			Post
Insecta	Trichoptera	Lepidostomatidae			Pre	
Insecta	Trichoptera	Lepidostomatidae	Lepidostoma		Pre	Post
Insecta	Coleoptera	Dytiscidae				Post
Insecta	Coleoptera	Elmidae			Pre	Post
Insecta	Coleoptera	Elmidae	Heterlimnius			Post
Insecta	Coleoptera	Elmidae	Optioservus		Pre	Post
Insecta	Coleoptera	Elmidae	Zaitzevia		Pre	Post
Insecta	Diptera	Tipulidae				Post
Insecta	Diptera	Tipulidae	Antocha			Post
Insecta	Diptera	Tipulidae	Antocha	monticola	Pre	
Insecta	Diptera	Tipulidae	Dicranota		Pre	Post
Insecta	Diptera	Tipulidae	Hexatoma		Pre	Post
Insecta	Diptera	Tipulidae	Tipula			Post
Insecta	Diptera	Simuliidae			Pre	Post
Insecta	Diptera	Simuliidae	Simulium		Pre	Post
Insecta	Diptera	Chironomidae			Pre	Post
Insecta	Diptera	Chironomidae	Chironominae			Post
Insecta	Diptera	Chironomidae	Tanypodinae		Pre	Post
Insecta	Diptera	Chironomidae	Orthocladiinae		Pre	Post
Insecta	Diptera	Empididae	Chelifera			Post
Insecta	Diptera	Empididae	Oreogeton			Post
Insecta	Diptera	Ceratopogonidae			Pre	
Insecta	Diptera	Ceratopogonidae	Bezzia		Pre	Post
Insecta	Diptera	Ceratopogonidae	Probezzia			Post
Insecta	Diptera	Psychodiadae	Pericoma		Pre	Post
Insecta	Diptera	Stratiomyidae	Euparyphus		Pre	
Insecta	Diptera	Muscidae				Post
Insecta	Diptera	Dixidae	Dixa			Post
Crustacea	Amphipoda	Gammaridae	Gammarus			Post
Crustacea	Copepoda				Pre	Post
Crustacea	Ostracoda				Pre	Post
Pelecypoda					Pre	
Turbellaria						Post
Turbellaria	Tricladida	Planariidae	Planaria		Pre	
Oligochaeta					Pre	Post
Oligochaeta	Tubificidae				Pre	Post
Oligochaeta	Lumbricidae				Pre	
Arachnoidea	Hydracarina				Pre	Post
Nematoda					Pre	Post
Entognatha	Collembola					Post

Total 95 Taxa

[a] *Ephemerella coloradensis* and *E. doddsi* (1988 and 1990 samples) are synonymous with the current names *Drunella coloradensis* and *D. doddsi,* which were reported both pre (1995) and post-treatment. Total numbers of taxa and other taxa figures have been adjusted accordingly.

Data compiled by J. Whelan from F. Mangum, Aquatic Ecosystem Inventory Macroinvertebrate Analysis Reports for the Fishlake N.F. for 1988, 1990, 1995, and 1997;
and M. Vinson, Aquatic Macroinvertebrate Monitoring Report for the Fishlake N.F. for 1999.

Appendix B: North Snake Range, Nevada Summary Aquatic Macroinvertebrate Species List

Humboldt-Toiyabe National Forests, Ely Ranger District, White Pine County, Nevada
Deadman Creek: 1993 (2 stations pre-rotenone), **1994** (1 year post-rotenone)
Smith Creek: 1996 (5 stations pre-rotenone), **1998** (2 years post-rotenone)
Deep Canyon: 1994 (3 stations pre-rotenone), **1997** (3 years post-rotenone)
Hendry's Creek: 1987 (1 station post-antimycin treatments in 1973 and 1974 but pre-rotenone), **1998** (3 stations - the lower two post-rotenone treatments in 1987 and 1992 and the upper station above all treatments). If the post taxa were only found in Hendry's Creek they are marked PostH since only the lower ½ of the stream was treated in all treatments.

CLASS	ORDER	FAMILY	GENUS	SPECIES	SUMMARY	
Insecta	Ephemeroptera				Pre	
Insecta	Ephemeroptera	Ameletidae	Ameletus			Post
Insecta	Ephemeroptera	Heptageniidae				Post
Insecta	Ephemeroptera	Heptageniidae	Epeorus		Pre	Post
Insecta	Ephemeroptera	Heptageniidae	Heptagenia		Pre	Post
Insecta	Ephemeroptera	Heptageniidae	Cinygmula		Pre	Post
Insecta	Ephemeroptera	Leptophlebiidae				Post
Insecta	Ephemeroptera	Leptophlebiidae	Paralepthophlebia		Pre	Post
Insecta	Ephemeroptera	Ephemerellidae				Post
Insecta	Ephemeroptera	Ephemerellidae	Drunella	coloradensis	Pre	
Insecta	Ephemeroptera	Ephemerellidae	Drunella	doddsi	Pre	Post
Insecta	Ephemeroptera	Ephemerellidae	Drunella	spinifera		PostH
Insecta	Ephemeroptera	Ephemerellidae	Ephemerella	inermis		Post
Insecta	Ephemeroptera	Ephemerellidae	Ephemerella	spinifera	Pre	a
Insecta	Ephemeroptera	Baetidae	Baetis		Pre	Post
Insecta	Ephemeroptera	Baetidae	Cloeon			Post
Insecta	Ephemeroptera	Siphlonuridae	Ameletus		Pre	Post
Insecta	Ephemeroptera	Tricorythidae	Tricorythodes	minutus	Pre	b
Insecta	Plecoptera				Pre	Post
Insecta	Plecoptera	Chloroperlidae			Pre	Post
Insecta	Plecoptera	Chloroperlidae	Sweltsa			Post
Insecta	Plecoptera	Nemouridae			Pre	Post
Insecta	Plecoptera	Nemouridae	Zapada		Pre	Post
Insecta	Plecoptera	Nemouridae	Zapada	cinctipes	Pre	Post
Insecta	Plecoptera	Nemouridae	Amphinemura			Post
Insecta	Plecoptera	Perlidae				Post
Insecta	Plecoptera	Perlidae	Hesperoperla	pacifica	Pre	Post
Insecta	Plecoptera	Pteronaricidae	Pteronarcella			Post
Insecta	Plecoptera	Pteronaricidae	Pteronarcys			PostH
Insecta	Plecoptera	Pteronarcyidae	Pteronarcella	badia	Pre	b
Insecta	Plecoptera	Taeniopterygidae	Taenionema		Pre	
Insecta	Plecoptera	Capniidae			Pre	Post
Insecta	Plecoptera	Leuctridae			Pre	Post
Insecta	Trichopter				Pre	Post
Insecta	Trichoptera	Hydropsychidae			Pre	
Insecta	Trichoptera	Hydropsychidae	Hydropsyche		Pre	Post
Insecta	Trichoptera	Hydropsychidae	Arctopsyche			Post
Insecta	Trichoptera	Hydropsychidae	Arctopsyche	grandis	Pre	Post
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche		Pre	b
Insecta	Trichoptera	Hydropsychidae	Parapsyche			Post
Insecta	Trichoptera	Hydroptilidae			Pre	
Insecta	Trichoptera	Hydroptilidae	Alisotrichia		Pre	
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila			Post
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	acropedes	Pre	Post
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	coloradensis		Post
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	hyalinata	Pre	Post
Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	vagrita	Pre	Post
Insecta	Trichoptera	Brachycentridae			Pre	
Insecta	Trichoptera	Brachycentridae	Brachycentrus		Pre	Post
Insecta	Trichoptera	Brachycentridae	Brachycentrus	americanus	Pre	b
Insecta	Trichoptera	Brachycentridae	Micrasema		Pre	Post

Insecta	**Trichoptera**	**Glossosomatidae**	**Glossosoma**		**Pre**	**Post**
Insecta	**Trichoptera**	**Limnephilidae**			**Pre**	**Post**
Insecta	**Trichoptera**	**Limnephilidae**	**Dicosmoecus**			**Post**
Insecta	**Trichoptera**	**Limnephilidae**	**Ecclisomyia**		**Pre**	
Insecta	**Trichoptera**	**Limnephilidae**	**Limnephilus**		**Pre**	**b**
Insecta	**Trichoptera**	**Limnephilidae**	**Hesperophylax**		**Pre**	**Post**
Insecta	**Trichoptera**	**Limnephilidae**	**Oligophlebodes**		**Pre**	
Insecta	**Trichoptera**	**Lepidostomatidae**	**Lepidostoma**		**Pre**	**Post**
Insecta	**Trichoptera**	**Philopotamidae**	**Doliphilodes**		**Pre**	**Post**
Insecta	**Trichoptera**	**Polycentropodid.**	**Polycentropus**		**Pre**	
Insecta	**Trichoptera**	**Psychomyiidae**	**Tinodes**			**PostH**
Insecta	**Coleoptera**	**Curculionidae**				**Post**
Insecta	**Coleoptera**	**Dytiscidae**			**Pre**	
Insecta	**Coleoptera**	**Elmidae**			**Pre**	**Post**
Insecta	**Coleoptera**	**Elmidae**	**Cleptelmis**			**PostH**
Insecta	**Coleoptera**	**Elmidae**	**Heterlimnius**			**Post**
Insecta	**Coleoptera**	**Elmidae**	**Narpus**			**Post**
Insecta	**Coleoptera**	**Elmidae**	**Optioservus**		**Pre**	**Post**
Insecta	**Coleoptera**	**Elmidae**	**Zaitzevia**		**Pre**	**Post**
Insecta	**Diptera**					**Post**
Insecta	**Diptera**	**Atherceridae**	**Atherix**			**PostH**
Insecta	**Diptera**	**Tipulidae**				**Post**
Insecta	**Diptera**	**Tipulidae**	**Antocha**			**PostH**
Insecta	**Diptera**	**Tipulidae**	**Antocha**	**monticola**	**Pre**	**b**
Insecta	**Diptera**	**Tipulidae**	**Dicranota**		**Pre**	**Post**
Insecta	**Diptera**	**Tipulidae**	**Hexatoma**		**Pre**	**Post**
Insecta	**Diptera**	**Tipulidae**	**Tipula**		**Pre**	**Post**
Insecta	**Diptera**	**Simuliidae**			**Pre**	**Post**
Insecta	**Diptera**	**Simuliidae**	**Prosimulium**			**Post**
Insecta	**Diptera**	**Simuliidae**	**Simulium**			**Post**
Insecta	**Diptera**	**Chironomidae**			**Pre**	**Post**
Insecta	**Diptera**	**Chironomidae**	**Chironominae**			**Post**
Insecta	**Diptera**	**Chironomidae**	**Tanypodinae**		**Pre**	**Post**
Insecta	**Diptera**	**Chironomidae**	**Orthocladiinae**		**Pre**	**Post**
Insecta	**Diptera**	**Empididae**			**Pre**	**Post**
Insecta	**Diptera**	**Empididae**	**Chelifera**		**Pre**	**Post**
Insecta	**Diptera**	**Empididae**	**Hemerodromia**		**Pre**	**Post**
Insecta	**Diptera**	**Ceratopogonidae**			**Pre**	**Post**
Insecta	**Diptera**	**Ceratopogonidae**	**Bezzia**		**Pre**	**Post**
Insecta	**Diptera**	**Ceratopogonidae**	**Probezzia**			**Post**
Insecta	**Diptera**	**Psychodiadae**	**Pericoma**		**Pre**	**Post**
Insecta	**Diptera**	**Stratiomyidae**	**Caloparyphus**			**Post**
Insecta	**Diptera**	**Stratiomyidae**	**Euparyphus**		**Pre**	**b**
Insecta	**Diptera**	**Muscidae**				**Post**
Insecta	**Diptera**	**Muscidae**	**Limnophora**		**Pre**	**b**
Insecta	**Diptera**	**Dixidae**	**Dixa**		**Pre**	**Post**
Insecta	**Hemiptera**	**Corixidae**				**Post**
Crustacea	**Amphipod**				**Pre**	
Crustacea	**Amphipoda**	**Hyalellidae**	**Hyallela**	**azteca**		**Post**
Crustacea	**Copepoda**				**Pre**	**Post**
Crustacea	**Ostracoda**				**Pre**	**Post**
Gastropoda	**Basommatoph.**	**Planorbidae**				**Post**
Gastropoda	**Lymnaeidae**	**Lymnaea**				**Post**
Gastropoda	**Planorbidae**				**Pre**	**b**
Pelecypoda					**Pre**	**Post**
Pelecypoda	**Veneroidea**	**Sphaeriidae**	**Pisidum**			**Post**
Turbellaria						**Post**
Turbellaria	**Tricladida**	**Planariidae**	**Planaria**		**Pre**	**Post**
Oligochaeta					**Pre**	
Oligochaeta	**Tubificidae**				**Pre**	**Post**
Oligochaeta	**Lumbricidae**				**Pre**	**Post**
Oligochaeta	**Lumbricidae**	**Lumbriculidae**				**Post**
Oligochaeta	**Haplotaxida**	**Tubificidae**				**Post**
Arachnoidea	**Hydracarina**				**Pre**	**Post**
Nematoda					**Pre**	**Post**
Entognatha	**Collembola**					**Post**

[a] *Ephemerella spinifera* is synonymous with the current name *Drunella spinifera*.

[b] These taxa were found (most within 24 months) following two rotenone applications in the Strawberry River basin, UT (3 mg/l Noxfish for 48 hours each) in 1990 (Mangum and Madrigal 1999).

Data compiled by J. Whelan from F. Mangum, Aquatic Ecosystem Inventory Macroinvertebrate Analysis Reports for the Humboldt N.F. (Ely Ranger District) for 1987, 1994, 1996, and 1997; and M. Vinson, Aquatic Macroinvertebrate Monitoring Report for the Humboldt-Toiyabe N.F. (Ely Ranger District) for 1998.

Appendix C: Additional Methods Information on Sampling and Indices

Aquatic Macroinvertebrate Sampling

Standard R-4 Forest Service protocol (FSH 2609.23; Mangum 1986): Three similar riffle sites within a 100-foot stream section are selected for sampling. At each site a 250 micron Surber frame is placed over the gravel/cobble substrate with the net on the downstream side. Rocks within the frame are hand scrubbed and the current carries the macroinvertebrates into the net. After the larger rocks are scrubbed the underlying gravel within the frame is stirred by hand to a depth of 3-4 inches. The net is then inverted into a pan containing a saturated saline solution to help float organisms to the top for easier collection. Larger, heavier items such as caddisfly cases are collected separately and placed in a sample bottle. The sample is gently stirred and the saline solution is poured through a sieve several times. Finally, the sample in the sieve is placed in the sample bottle and preserved in an alcohol solution. Additional data is collected at each station including alkalinity, sulfate, gradient, and substrate composition, which are used to calculate the Biotic Condition Index (BCI).

Laboratory Analysis

The samples are sub-sampled by placing them in a 1-liter beaker over an automated sub sampler with 8 pans. One to eight pans are selected for processing and 250-300 organisms picked from the sample. The Diversity and Taxa Index (DAT) is calculated while picking the macros from the sample. The macroinvertebrates are keyed to species when keys are available (generally mayflies), and others generally to genus, but some groups are keyed only to family, class, or order. The BCI and other diversity indices are then calculated.

The DAT is developed while identifying macroinvertebrate taxa in a petri dish. The dish is moved so no organism is counted twice, tracking numbers of organisms, and the numbers of series, which is a change in the species type. The dominance value is then the number of series divided by the numbers of organisms (Mangum 1986). Finally, the number of taxa in the sample is multiplied by the dominance value to obtain the DAT. Values of 0-5 indicate poor diversity, 6-10 fair diversity, 11-17 good diversity, and 18-26 excellent diversity.

Two other diversity indices are reported for the 1995 through 1999 samples. These are Shannon’s and Simpson’s diversity indices. Shannon’s diversity index values from 0-1 indicate poor diversity, 1-2 fair diversity, 2-3 good diversity, and >3 very good diversity. This index increases as the numbers of species increases and the distribution of individuals among species becomes more even (Mangum 1997).

The Simpson’s index ranges from 0 to 1. It gives the probability that two individuals drawn from random from the population belong to the same species (Mangum 1997). Thus higher values reflect a community with lower diversity.

The evenness index is a measure of the distribution of taxa in the community. If all species in a community are equally abundant the index is at a maximum value approaching one. As the community becomes less even the index decreases towards zero (Mangum 1997).

The Biotic Condition Index (BCI) developed by Winget and Mangum (1979) incorporates water quality (sulfate and alkalinity), stream habitat (substrate and gradient), and a database of environmental tolerances of aquatic macroinvertebrate taxa. It is calculated by dividing the predicted community tolerance quotient based on the water quality and stream habitat by the actual community tolerance quotient. Advantages of the BCI is that it is sensitive to different types of stress, gives a linear assessment of conditions from unstressed through all levels of stressed, and it evaluates a streams condition against its own potential (Winget and Mangum 1979). A BCI rating above 90 is considered excellent, 80-90 good, 72-79 fair, and below 72 poor.