BENTHIC MACROINVERTEBRATE COMMUNITIES IN THE ELWHA RIVER BASIN, 1994-95

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ABSTRACT

Benthic macroinvertebrates were collected in 1994-95 from 26 sites representing four habitat types in the Elwha River Basin to document benthic community structure and to assess the communities in relation to the two hydroelectric dams on the Elwha River. This information will provide a baseline for monitoring changes in the benthic communities that may occur in relation to land use activities and the potential removal of the dams. Our analysis of benthic macroinvertebrate communities in this basin generally indicated good water quality and habitat conditions. Communities were diverse and included numerous taxa classified as sensitive to environmental disturbance. The exception to this finding was in the regulated reach of the Elwha River below the two dams where there was a higher total density of macroinvertebrates due to an increase in midges (Diptera: Chironomidae) and a reduction in mayfly (Ephemeroptera) densities. Macroinvertebrate communities downstream of hydroelectric dams usually differ from communities in free-flowing rivers; the differences vary depending on the design and management of the hydroelectric facility. Although this study was not designed to determine which environmental factors most influenced the biological communities, we noted several environmental differences between the regulated reach and the upstream free-flowing reach. For example, because the dams act as sediment sinks, the median substrate size has increased in the regulated reach. In addition, the near-surface release of water from the two reservoirs has also altered the thermal regime and likely the food resources for benthic macroinvertebrates.

A secondary objective of this study was to assess the adequacy of the present sampling program and make suggestions for future assessments. Our findings demonstrated that the number of samples collected was sufficient to characterize the present communities and to satisfy the study objectives. For future monitoring, fewer benthic samples from each site may provide enough information and reduce the overall cost. Benthic macroinvertebrate communities need to be included in any long-term assessment of the Elwha River Basin because these communities integrate a wide range of physical and chemical disturbances and therefore reflect the overall health of the stream systems. These macroinvertebrates are also a key food resource to many species of fish, including some species of juvenile salmon prior to outmigration.

INTRODUCTION

The formerly free-flowing Elwha River was famous for the diversity and size of its salmon runs; it produced an estimated 380,000 migrating salmon and trout and supported 10 runs of anadromous salmonids, including chinook that exceeded 100 pounds (National Park Service, 1996). After the construction of the Elwha Dam (1912) and the Glines Canyon Dam (1927), more than 70 miles of mainstem river and tributary habitat were lost to anadromous fish production. This loss resulted in a precipitous decline in the native populations of all 10 runs of Elwha salmon and sea-going trout. Sockeye (*Oncorhynchus nerka*), pink salmon (*Oncorhynchus gorbuscha*) and spring chinook (*Oncorhynchus tshawytscha*) are now extinct in the river. Chum salmon (*Oncorhynchus keta*) are down to less than 300 fish per year; steelhead (*Salmo gairdneri*), coho (*Oncorhynchus kisutch*), and summer chinook (*Oncorhynchus tshawytscha*) are presently maintained through hatchery supplementation.

In addition, the dams have altered the ecosystem in several other ways. The normal transport of sediments has been interrupted because the reservoirs effectively act as sinks; as a result, the substrate downstream of the dams gradually coarsened. The release of water from the surface of the reservoirs has increased the water temperature, which is known to affect biological communities; peak summer temperatures downstream of the Elwha Dam have been measured at nearly 70°F. The high temperatures are exacerbated by the industrial water withdrawal at river mile 2.9. Elevated water temperatures, particularly during low snowpack years, are associated with outbreaks of a protozoan gill parasite (*Dermocystidium*) that is associated with fall chinook mortality. The loss of salmon to the Elwha River has also substantially reduced nutrient loading to the spawning grounds due to a lack of carcasses. This loss of the historical nutrient contribution from migrating salmon suggests that the biological communities in the waters upstream of the dams may differ from those that existed prior to the construction of the dams.

In response to the loss of the salmon runs in the Elwha River Basin, President Bush signed the Elwha River Restoration Act in 1992, which began the process of assessing the feasibility of restoring the Elwha River ecosystem. The Elwha Fisheries Technical Group was formed to determine what studies were needed for the Environmental Impact Statement (EIS) and the planning phase of the restoration effort, and for establishing baseline conditions of the watershed prior to restoration. The Lower Elwha Klallam Tribe was asked to assess the aquatic macroinvertebrate communities of the Elwha River. Benthic macroinvertebrates are commonly assessed in environmental studies because they show cumulative effects of present and past conditions, they have low mobility, and their ecological relationships are relatively well understood (Wilhm, 1975; Herricks and Cairns, 1982). In addition, sampling procedures are relatively well developed and a single sampling technique collects a considerable number of species from a wide range of phyla (Mason, 1981).

This macroinvertebrate assessment is essential for the EIS process because it will form the basis for a long-term evaluation of the ecological effects of dam removal and subsequent recovery of biological communities. The primary objective of this study was to document benthic macroinvertebrate community structure in the Elwha River Basin. Site locations permitted an assessment of communities upstream, between, and downstream of the two mainstem dams. A secondary objective was to determine whether the sampling program was adequate for assessing communities and whether there should be changes in future sampling programs.

DESCRIPTION OF STUDY AREA

The Elwha River, the fourth largest river on the Olympic Peninsula, is 45 miles long with 100 miles of tributary streams. It drains a 321 mi^2 area, 83 percent of which is located within the Olympic National Park. The river flows in a northward direction and enters the Strait of Juan de Fuca 5 miles west of Port Angeles, a community of approximately 17,000 people (fig. 1).

Elwha Dam (river mile 4.9) was constructed in 1912 creating Lake Aldwell, a reservoir 2.8 miles long with 8,100 acre feet of water storage. Glines Canyon Dam was completed in 1927 at river mile 8.5; this dam created Lake Mills, which is 2.5 miles long and has a storage capacity of 40,000 acre feet. The two dams were installed without fish passage facilities. Both dams are classified as run-of-the-river systems with water released near the surface; both systems produce hydroelectric power. Because the Elwha River is a glacial system, streamflows have a bimodal discharge pattern: discharge peaks during winter due to winter freshets and again at a lower level in summer from snowmelt (fig. 2). Average monthly flows are highest in early summer; average daily flows are highest in winter.

A comparison of flow and thermal regimes in the nonregulated and regulated reaches reveals that flow regimes are not exceptionally different (fig. 2), probably because the river is managed as a run-of-the-river system. However, thermal regimes do differ. Above the dams, water temperatures exhibit the wide fluctuations that are normal in free-flowing rivers. These fluctuations are lacking in the regulated reaches between and below the dams; in addition, maximum water temperatures during the summer tend to be higher (fig. 3).

Sediments in the Elwha River Basin are dominated by glacial deposits and recent alluvium. Glacial deposits range from clay to boulders and provide much of the material available for transport by the Elwha River and its tributaries. River alluvium deposited since the retreat of the glacier typically consists of sandy gravel, cobbles, and

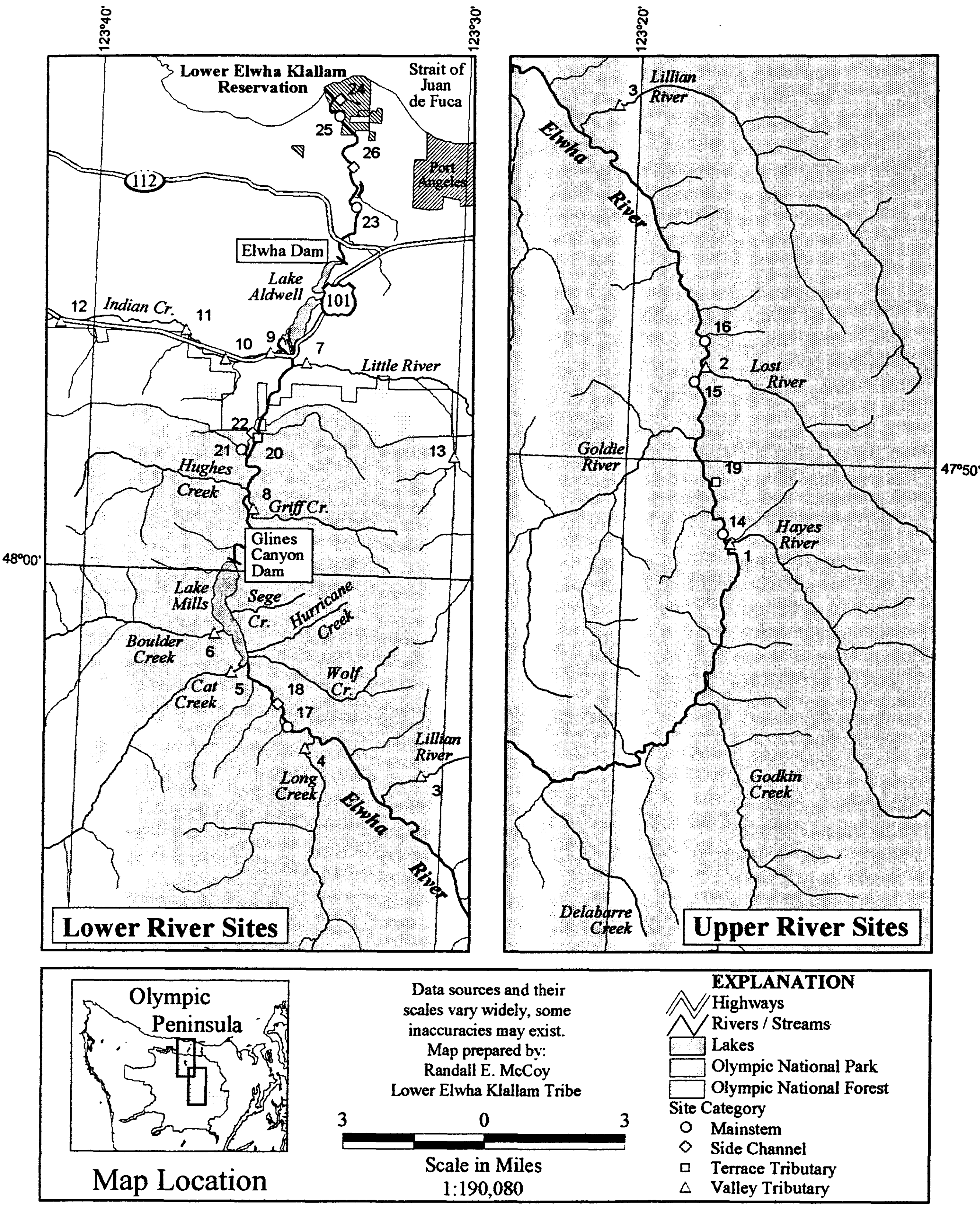

Figure 1. *Benthic invertebrate sites 1994-95*

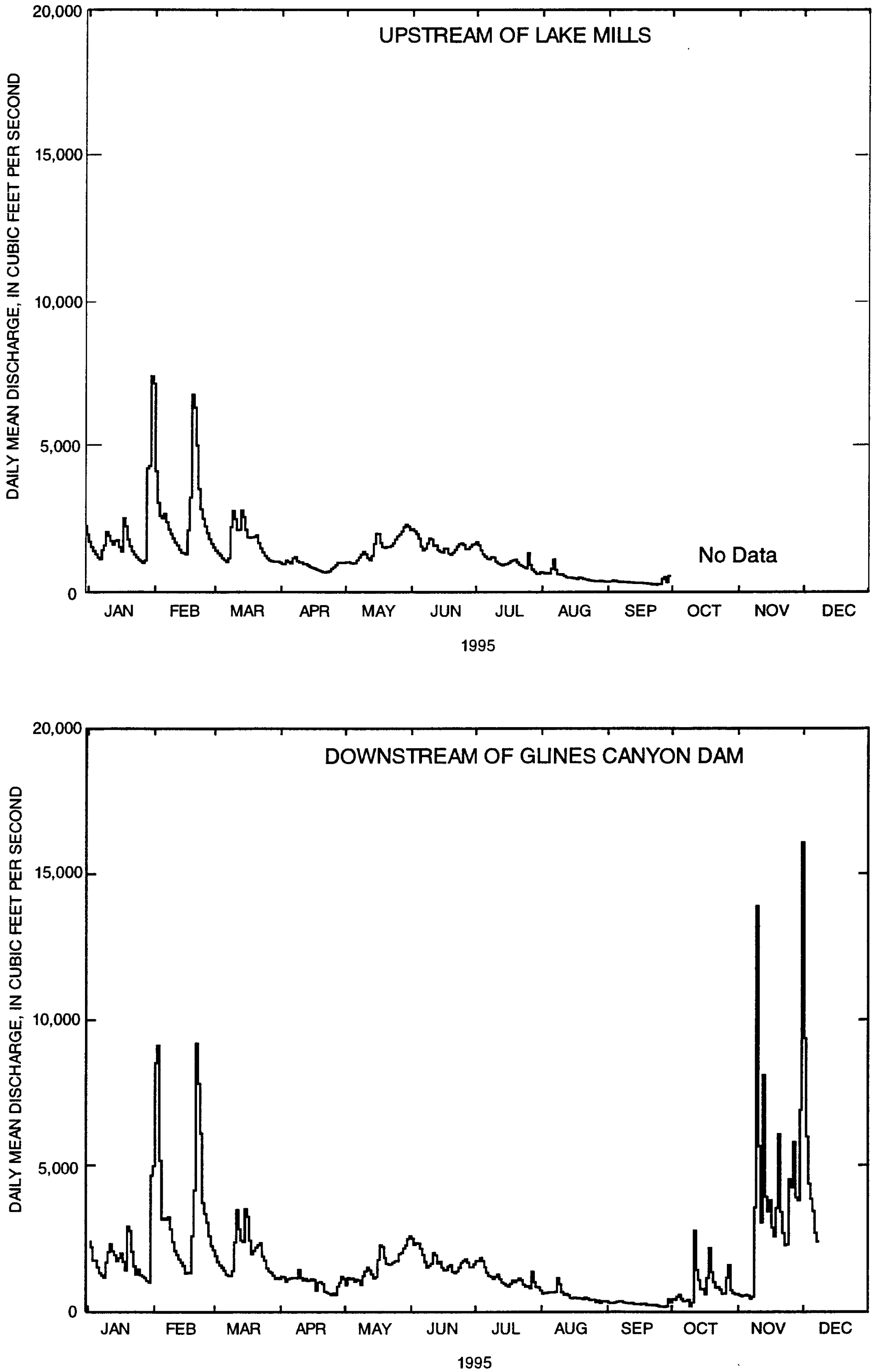

Figure 2.-- 1995 hydrographs of a nonregulated site upstream of Lake Mills and a site between Glines Canyon and Elwha River Dams.

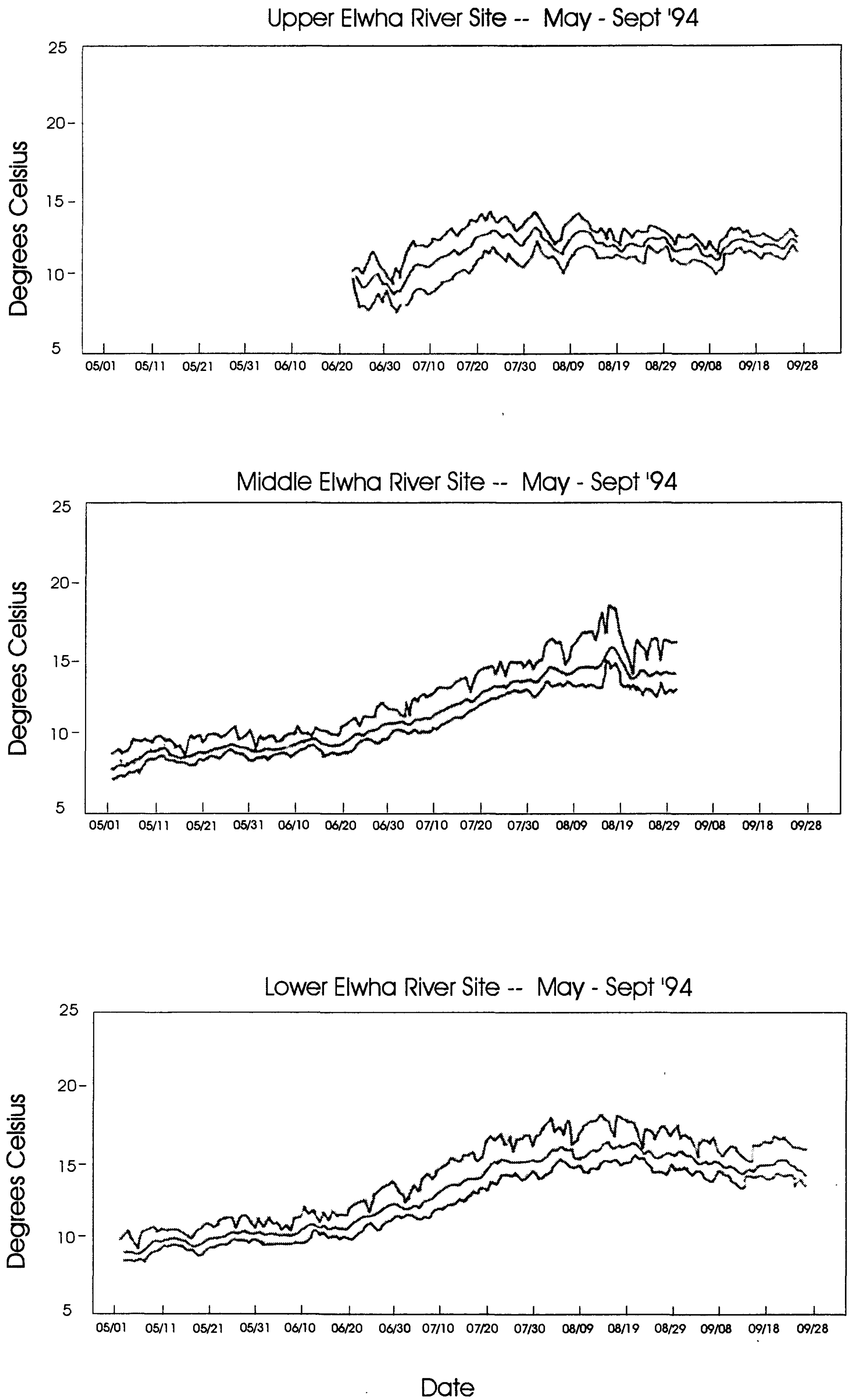

Figure 3.--Annual thermal regimes for three sites on the Elwha River, including above, between, and below the dams. Data are from May to September, 1994

boulders. Sediment eroded from the valley walls is transported by the Elwha River and tributaries. Lower and middle reaches have substantially coarsened since the construction of the dams and the subsequent cessation of sediment transport. If the two dams are removed, a portion of the trapped sediment, estimated at approximately 14.3 million cubic yards (National Park Service, 1996), would be released to the downstream reach of the Elwha River. The release of sediment to the lower reach will alter habitat and the biological communities.

METHODS

The habitat stratification system developed for the South Fork Hoh River (Sedell and others, 1982) was used to establish sampling sites for this study. Sedell and others (1982) used this habitat classification system for examining fish species composition, density, and total fish biomass. Four habitat types were identified: mainstem (MS), mainstem side-channel (SC), valley tributary (VT), and terrace tributary (TT). The rationale for using these habitat types was that each has different physical properties which influence specific species of salmonids in various ways. We established 26 sampling sites in the Elwha River Basin, including sites from each of the four habitat categories. Table 1 lists the sites and their respective habitat categories. Figure 1 shows the location of the various sites within the basin. Because of the seasonal discharge regime, sampling was conducted in late July and early August in both 1994 and 1995.

Sample Collection

Benthic macroinvertebrate samples were collected using a modified Hess sampler equipped with a 250 μm net. Five to 10 replicate samples were collected at each site; the number of replicates depended on the size and complexity of the site. Benthic samples in the valley tributaries, terrace tributaries, and side-channels were collected among several riffles, but because of the size of the mainstem sites, all benthic samples in this habitat category were collected from a single large riffle along the margin of the river. Individual samples were preserved in plastic containers using 70 percent ethanol.

Processing samples in the laboratory included cleaning (separating organic and inorganic debris), sorting macroinvertebrates from the sample, and identification to the lowest practical taxon. This procedure generally resulted in genus/species level identification for many of the mayflies, stoneflies, and caddisflies, while more difficult groups, like the midges and aquatic worms, were identified to higher taxonomic levels. Macroinvertebrates were identified using Merritt and Cummins (1984), Wiggins (1976), and Edmunds and others (1978).

Data Analysis

Benthic Macroinvertebrate Community Structure

For the primary objective of documenting community structure, benthic communities were analyzed using five community metrics: total density (individuals/m^2), richness, EPT taxa (Ephemeroptera, Plecoptera, and Trichoptera), percent dominant taxa, and number of intolerant taxa. Communities also were assessed in relation to the dominance of the major orders of insects. Community metrics used in this study are defined below:

Total Density: Total density is the total number of individuals collected per m^2. Densities are highly variable due to the combination of natural variability and sampling methods; therefore, total densities among sites or basins should be compared using caution.

Richness: This is the total number of taxa collected at a site. The most basic measure of community diversity, richness is considered one of the best measurements available for assessing the health of a benthic community. Streams with a diverse physical habitat and high water/sediment quality tend to have a large number of taxa.

EPT Index: This is the total number of distinct taxa within the aquatic insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). These groups are generally considered intolerant of physical and/or chemical stressors, and therefore their presence indicates good environmental quality.

Percent Dominant Taxa (3): This index is based on selecting the three taxa from a site that are the most abundant, and determining their combined percentage of the total community; this percentage is an indicator of environmental stress. A community with an even distribution of taxa generally indicates high water quality.

Table 1: Benthic macroinvertebrate sampling sites in the Elwha River Basin, 1994-1995. VT=valley tributary; TT=terrace tributary; SC=mainstem side-channel; MS=mainstem.

No.	Site	Site Code	Habitat Category	Stream Order	Elevation (ft.)	Year	Replicates (n)
1	Hayes River abv Elwha River	HAYESRIV	VT	3	1720	1995	8
2	Lost River	LOSTRIV	VT	3	1440	1995	5
3	Lillion River	LILLRIV	VT	2	1050	1994	8
4	Long Creek	LONGCK	VT	3	750	1994	6
5	Cat Creek	CATCK	VT	4	600	1994	8
6	Boulder Creek	BLDRCK	VT	4	600	1994	8
7	Little River	LITTRIV	VT	4	225	1994	7
8	Griff Creek	GRIFFCK	VT	2	400	1994	8
9	Indian Creek @Bridge	INC@BR	VT	3	225	1994	5
10	Indian Creek @Field	INC@FLD	VT	3	325	1994	5
11	Indian Creek @Mill	INC@MIL	VT	3	425	1994	5
12	Indian Creek Upper	INDCKUPP	VT	3	450	1994	5
13	South Fork Little River	SFLITTR	VT	2	1250	1994	8
14	Elwha River below Hayes	ERBEHAY	MS	5	1680	1995	8
15	Elwha River @Riemans Cabin	RIEMCAB	MS	5	1680	1995	8
16	Elwha river @Elkhorn	ELKSTONY	MS	5	1400	1995	8
17	Elwha River @Krause	KRAUSE	MS	5	600	1994	8

Table 1: Benthic macroinvertebrate sampling sites in the Elwha River Basin, 1994-1995. VT=valley tributary; TT=terrace tributary; SC=mainstem side-channel; MS=mainstem.

No.	Site	Site Code	Habitat Category	Stream Order	Elevation (ft.)	Year	Replicates (n)
18	Humes Rance Right Side Channel	HUMERSC	SC	5	650	1994	8
19	Terr. Tributary @Tipp. Campground	TIPPCMP	TT	1	325	1995	5
20	Elwha River Campground Terr. Trib.	TERRTRB	TT	5	500	1994	5
21	Mid Elwha River @Altaire	ALTAIRE	MS	5	400	1994	10
22	Mid Elwha River Right Side Channel by Camp-gound	MIDERSC	SC	5	525	1994	8
23	Elwha River above Diversion	ABOVDIV	MS	5	50	1994	10
24	Lower Elwha River Side Channel Hatchery Outfall	RSCOUTFA	SC	5	25	1994	8
25	Elwha River @Rock	THEROCK	MS	5	25	1994	5
26	Elwha River R.S.C. bel St. Hatchery	RSCSTHAT	SC	5	50	1994	7

Number of Intolerant Taxa: This is the number of macroinvertebrate taxa considered intolerant to physical or chemical disturbance. There are several different published lists of taxa and tolerance values, each using a slightly different scale or rationale for assigning specific values. We relied on the category summarized by Wisseman (1996), which is based on published rankings using organisms from the Pacific Northwest. In general, the more intolerant taxa found at a particular site, the better the quality of the system. Many of the invertebrates in this group are also in the EPT group.

We compared the benthic macroinvertebrate community metrics among the four habitat categories (one site per habitat category) using analysis of variance (ANOVA; P=0.05), with LSMEANS used for multiple comparisons. Pearson correlation was used to determine if any of the community metrics were correlated with stream order or elevation. The differences in the benthic macroinvertebrate communities upstream and downstream of the dams were also examined using some of the same community metrics.

Influence of Sample Size

To assess the effect of sample size, a single site was randomly selected from each of the four habitat categories. We calculated average community metrics ($\pm$2SE) for a randomly selected set of samples from each site; community metrics included total density, richness, EPT, dominant taxa, and the number of intolerant taxa. Average metrics were calculated for one sample up to the maximum number collected and plotted to show the change in values as sample size increased. This analysis provides information on whether increasing the number of replicate samples changes the average value and variance for a particular metric. Because average values are used to compare sites or the same site over time, it is important to know whether sample size influences mean values. It is also important to know whether variance is consistently decreasing as sample size increases or is leveling off at a particular sample size.

Because many of the metrics used to assess benthic invertebrate communities are based upon combining samples from a single site (pooled data), we assessed the influence of increasing numbers of samples in a composite on the individual metric values. Using composite (pooled) data is important because many of the metrics, such as richness, increase with additional samples due to the continual addition of rare taxa. In this report, all community metrics, with the exception of total density, are calculated using composite (pooled) data unless otherwise noted.

RESULTS

Benthic Macroinvertebrate Community Structure

The benthic macroinvertebrate communities in the Elwha River Basin are similar to those of many western glacial-fed river systems. In our study, the communities were dominated by four aquatic insect groups; mayflies (Ephemeroptera), stoneflies (Plecoptera), caddisflies (Trichoptera), and true-flies (Diptera). Other aquatic insect groups collected were aquatic beetles (Coleoptera) and alderflies (Megaloptera). Noninsect groups included aquatic worms (Oligochaeta), snails (Gastropoda), clams (Pelecypoda), leeches (Hirudinea), and water mites (Hydracarina). Overall, between 20 and 30 taxa were collected at each site; 40 to 70 percent of the taxa were in the EPT group (Ephemeroptera, Plecoptera, and Trichoptera). Although the dominance of the EPT taxa is partially a function of the level of taxonomy used in the assessment, it is a common finding in rivers with high water quality and habitat conditions. In addition to composing a large percentage of the number of taxa collected, the EPT taxa also composed a substantial percentage of the overall density of the communities. Diptera, particularly the chironomid midges (Chironomidae) and aquatic worms (Oligochaetea), were also found in high density, depending on the site (table 2).

There are various ways to assess benthic communities in a large river system like the Elwha. The *a priori* decision to collect benthic data from four river habitat types (terrace tributary, valley tributary, side-channel, and mainstem) was based on the premise that the unique characteristics of each habitat may be reflected in different benthic macroinvertebrate communities. The differences in the stream habitats would include environmental variables such as gradient, substrate, cover, and food. We grouped the benthic macroinvertebrate data by these four habitat categories and plotted the mean ($\pm$2SE) for five community metrics (fig. 4). We found no statistically significant differences (ANOVA, $P<0.05$) among the four habitat categories for any of the community metrics with the exception of total density. Total density (individuals/m^2) was significantly different ($P<0.05$) among the four habitat categories (ANOVA, $F_{3,32}=3.25$, $P=0.04$);

Table 2: Summary of benthic macroinvertebrate community metrics in the Elwha River Basin, 1994-1995. VT=valley tributary; TT=terrace tributary; SC=mainstem side-channel; MS=mainstem.

No.	Site	Habitat Category	Density (No./m^2)	SD	Richness	EPT	Mayfly (%)	Stonefly (%)	Caddisfly (%)	Diptera (%)	Other (%)
1	Hayes River abv Elwha River	VT	3,643.6	1,842.4	25	14	44.2	31.8	2.9	8.9	12.2
2	Lost River	VT	2,315.5	564.8	26	18	41.6	27.5	3.5	14.0	13.5
3	Lillion River	VT	1,591.9	644.7	30	21	50.0	5.0	4.8	6.5	33.7
4	Long Creek	VT	928.7	312.5	15	11	41.9	24.1	3.9	29.9	0.2
5	Cat Creek	VT	4,823.0	2,575.3	27	17	5.6	6.6	0.8	78.4	8.6
6	Boulder Creek	VT	4,309.1	1,260.0	26	19	20.0	4.3	1.4	69.5	4.9
7	Little River	VT	2,720.5	1,166.0	26	15	79.2	4.8	3.6	9.1	3.3
8	Griff Creek	VT	2,165.4	749.1	30	21	60.7	11.7	4.6	12.1	10.9
9	Indian Creek @Bridge	VT	2,631.4	1,259.2	30	21	49.3	13.9	6.9	13.6	15.9
10	Indian Creek @Field	VT	4,985.9	1,627.6	23	15	11.0	3.7	4.5	3.6	77.3
11	Indian Creek @Mill	VT	3,090.2	944.9	21	13	28.6	19.9	14.3	4.1	33.1
12	Indian Creek Upper	VT	2,107.7	1,069.3	20	12	4.7	10.1	10.7	6.6	68.0
13	South Fork Little River	VT	1,894.9	746.2	27	17	64.4	5.6	4.7	8.0	17.3
14	Elwha River below Hayes	MS	3,133.7	1,573.7	21	13	73.2	12.6	1.1	9.9	3.2
15	Elwha River @Riemans Cabin	MS	3,304.2	1,289.7	24	13	68.1	19.6	0.5	9.0	2.9
16	Elwha River @Elkhorn	MS	2,755.0	811.4	22	9	79.4	13.3	0.4	5.6	1.2
17	Elwha River @Krause	MS	2,434.5	1,153.1	20	14	62.8	23.3	0.3	13.2	0.4

Table 2: Summary of benthic macroinvertebrate community metrics in the Elwha River Basin, 1994-1995. VT=valley tributary; TT=terrace tributary; SC=mainstem side-channel; MS=mainstem.

No.	Site	Habitat Category	Density (No./m^2)	SD	Richness	EPT	Mayfly (%)	Stonefly (%)	Caddisfly (%)	Diptera (%)	Other (%)
18	Humes Ranch Right Side Channel	SC	1,575.7	447.1	25	15	64.4	22.5	0.6	10.4	2.2
19	Terr. Trib. @Tipp. Camp-ground	TT	2,332.8	745.3	30	19	17.9	22.8	3.6	23.7	31.9
20	Elwha River Campground Terr. Trib.	TT	1,558.1	597.8	23	14	32.6	23.6	8.1	12.1	23.6
21	Mid Elwha River @Altaire	MS	2,529.7	584.2	28	19	41.3	14.3	3.5	39.9	1.0
22	Mid Elwha River RSC by Campgound	SC	2,045.1	593.5	22	12	28.5	34.3	0.7	30.8	5.6
23	Elwha River above Diver-sion	MS	4,443.8	1,814.5	23	14	10.4	2.9	9.1	76.1	1.4
24	Lower Elwha RSC Hatchery Outfall	SC	1,379.6	808.3	27	18	38.5	22.4	2.5	25.0	11.6
25	Elwha River @Rock	MS	5,042.1	2,761.7	22	14	7.7	1.8	2.1	84.1	4.4
26	Elwha River R.S.C. bel St. Hatchery	SC	1,449.9	592.2	26	16	15.5	18.2	7.5	45.6	13.3

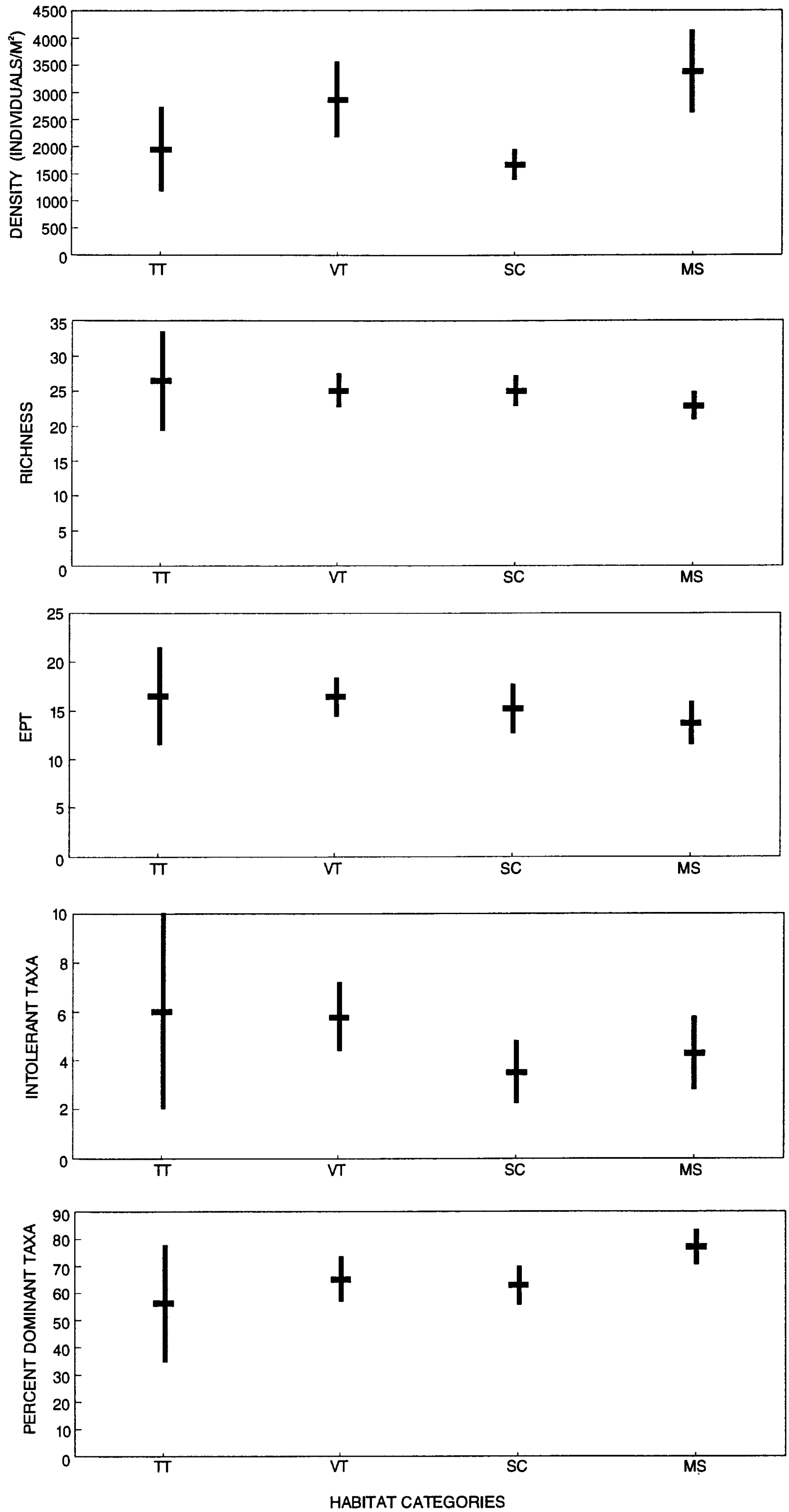

Figure 4.-- Five benthic macroinvertebrate community metrics grouped by four stream habitat categories: terrace tributary (TT), valley tributary (VT), side-channel (SC), and mainstem (MS). Data are presented as $\bar{x} \pm 2$ SE.

multiple comparisons indicated that mean total density was significantly lower in the SC habitat than in either the MS habitat (LSMEANS, P=0.008) or the VT habitat (LSMEANS, P=0.039). Mean density ranged from 1,664 individuals/m^2 in the SC habitat to 3,377 individuals/m^2 in the MS habitat. Average richness and EPT taxa were very similar among the four habitat categories with only a slight decrease from the TT to the MS habitats. Average total taxa ranged from 23 to 26 and average EPT taxa from 14 to 16, indicating that all four habitats provide similar environmental conditions, including physical and chemical habitat, for sustaining a relatively diverse community. There were more intolerant taxa associated with the TT and VT habitats when compared with the SC and MS habitats; percent dominant taxa was greatest in the MS habitat and lowest in the TT habitat.

The composition of benthic macroinvertebrate communities was not significantly different among the four habitat categories, indicating that the organization of these communities may be based on more site-specific habitat features. For example, communities can show a response to stream order or elevation. We used Pearson correlations to determine if either stream order or elevation was correlated with total density, richness, EPT taxa, intolerant taxa, or percent dominant taxa. Results indicated a significant negative correlation ($P<0.05$) between stream order and EPT taxa ($r= -0.45$) and number of intolerant taxa ($r= -0.47$); elevation had a positive correlation with the number of intolerant taxa ($r= 0.54$). Stream order and elevation were not correlated with each other ($P > 0.05$).

The two dams are likely the dominant site-specific factors influencing benthic macroinvertebrate communities in the mainstem of the Elwha River. A common method of assessing the effects of hydroelectric dams on communities is to plot community metrics as a function of longitudinal position along the mainstem of the river from headwaters downstream. These graphs will show natural changes in specific metrics along a river, and whether the location of a dam results in a shift in community structure. Figure 5 shows that communities in the nonregulated reach above Glines Canyon Dam (sites 1 and 14-17, figs. 5 and 6) are relatively similar in total density, richness, EPT taxa, and percent dominant taxa. There was a general decline in intolerant taxa in the nonregulated reach from the headwaters downstream. The benthic macroinvertebrate community directly below Glines Canyon Dam (site 21 in fig. 5) had a slight increase in taxa richness and EPT taxa, and a slight decrease in intolerant taxa. Although the number of EPT taxa changed little below the two dams, the percent contribution of the EPT taxa to the community changed greatly. For example, above the dams the EPT taxa composed between 79 and 93 percent of the community in total numbers of individuals, whereas below the Glines Canyon Dam the percent decreased to 59 percent, and then dropped to 22 and 12 percent below the Elwha Dam. This overall change can be seen in figure 6. The benthic macroinvertebrate community below the Glines Canyon Dam (site 21) showed an increase in the density of chironomid midges (Diptera) and a decrease in the density of mayflies (Ephemeroptera). The other taxonomic groups varied slightly; however, there were no major shifts in their relative densities.

The benthic macroinvertebrate communities downstream of the Elwha Dam (sites 23 and 25) showed a stronger response to the dam than did the communities downstream of the Glines Canyon Dam. Total density increased below the Elwha Dam; both total taxa richness and EPT returned to levels similar to those found upstream of Glines Canyon Dam. The most pronounced change was a shift in the densities of specific taxonomic groups. Downstream of the dams, particularly the Elwha Dam, the communities were numerically dominated by chironomid midges (>75 percent); mayflies (Ephemeroptera) composed a smaller percentage (10 percent). Other differences included a decrease in stoneflies (Plecoptera) and a slight increase in the filter-feeding caddisflies (Trichoptera).

Influence of Sample Size

A secondary objective in our study was to determine whether the number of samples collected in this study was adequate for assessing communities and to make suggestions for future monitoring. To answer the first part of this question, we randomly selected one site from each of the four habitat types and calculated community metrics as a function of increasing sample size (figs. 7-11). The average values for the five community metrics indicated that although there is some variability in the average and variance ($\pm$2SE) with increasing sample size, for all five community metrics the average values do not change greatly as a function of sample size. Although not true for all metrics, there does appear to be leveling of the average values at three to five replicates. Furthermore, for some metrics, there appears to be a decrease in variability as measured by the $\pm$2SE; however, this usually occurs with increasing sample size.

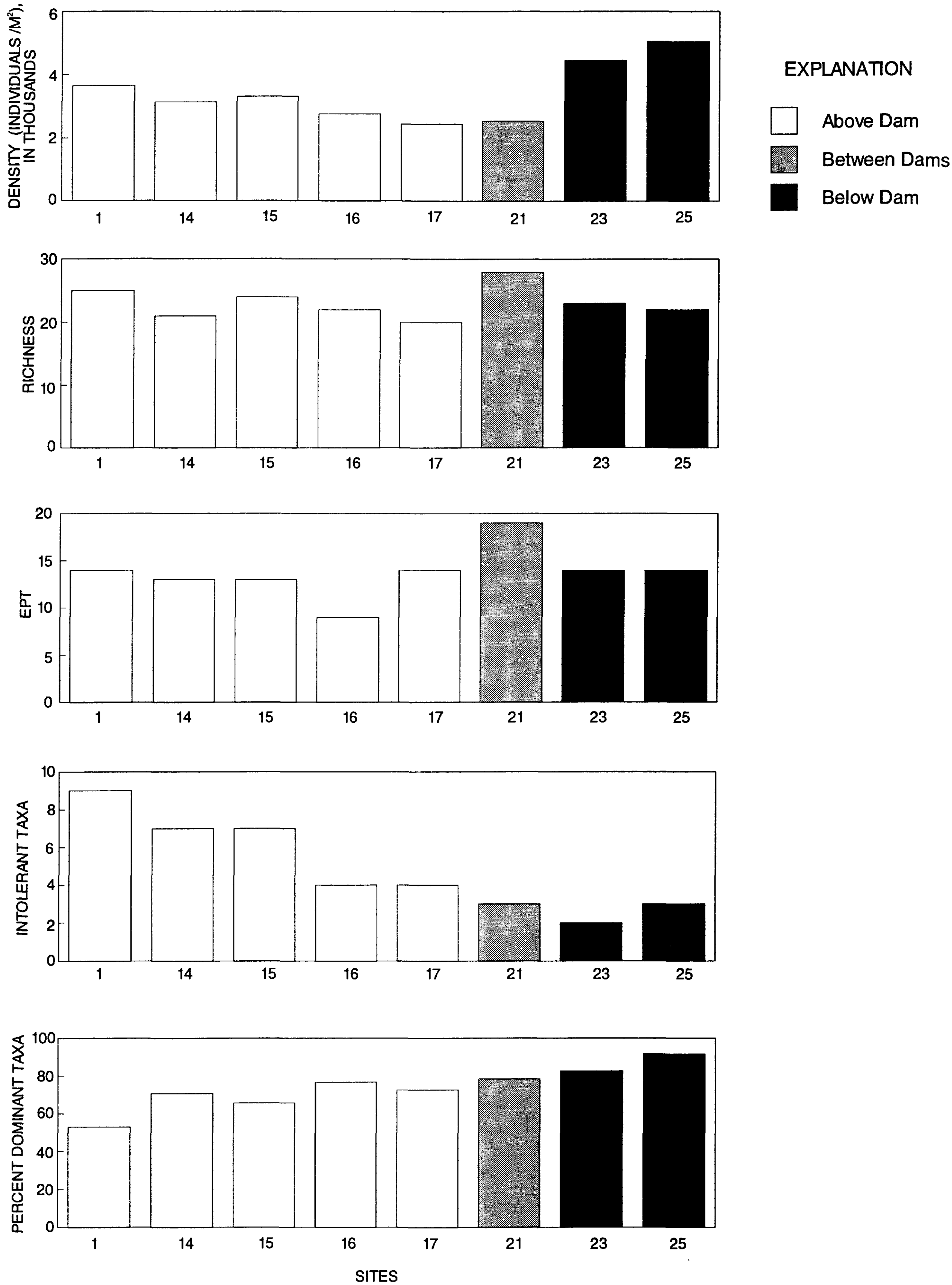

Figure 5.--Five benthic macroinvertebrate community metrics at sites above, between, and below dams in the Elwha River. Sites include 1) HAYESRIV, 14) ERBEHAY, 15) RIMCAB, 16) ELKSTONY, 17) KRAUSE, 21) ALTAIRE, 23) ABOVDIV, and 25) THEROCK. For explanation of site code abbreviations, see table 1.

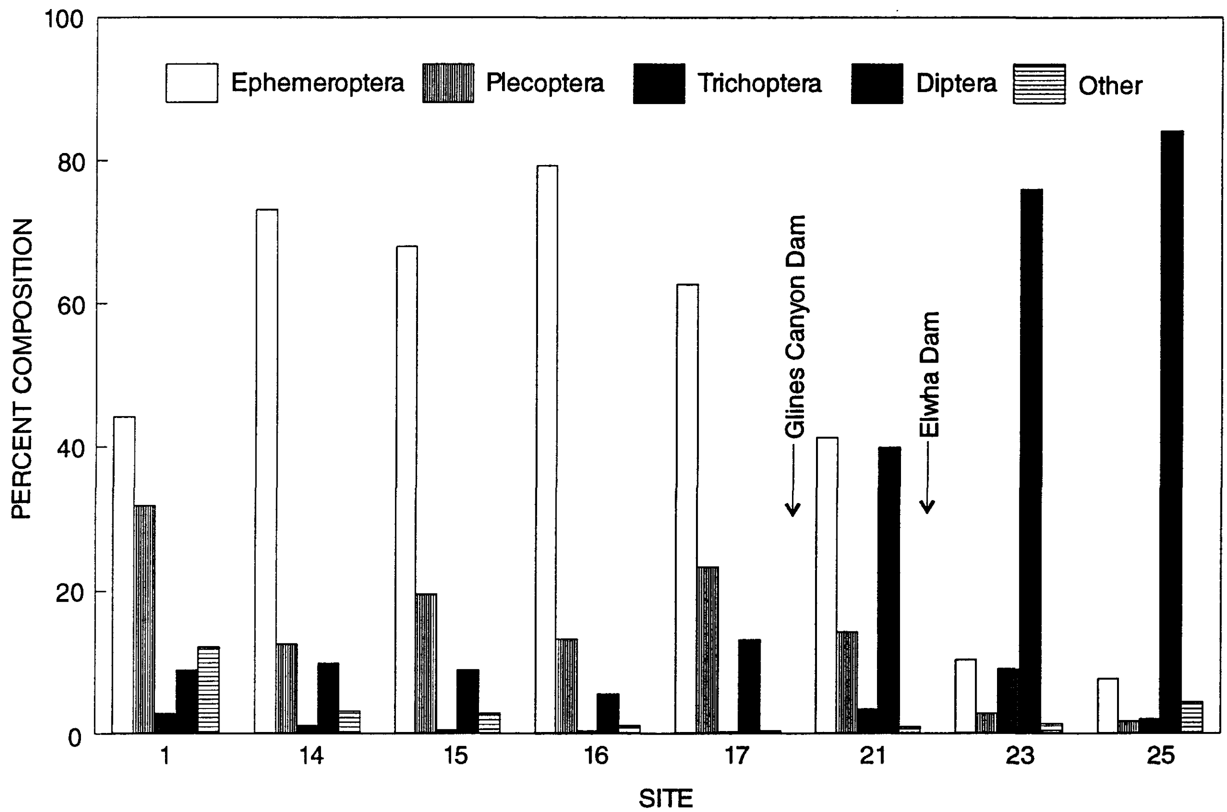

Figure 6. -- Percent composition of major benthic macroinvertebrate taxonomic groups at sites above, between, and below the dams on the Elwha River. Sites include 1)HAYESRIV, 14) ERBEHAY, 15) RIMCAB, 16) ELKSTONY, 17) KRAUSE, 21) ALTAIRE, 23) ABOVDIV, and 25) THE ROCK. For explanation of the code abbreviations, see table 1.

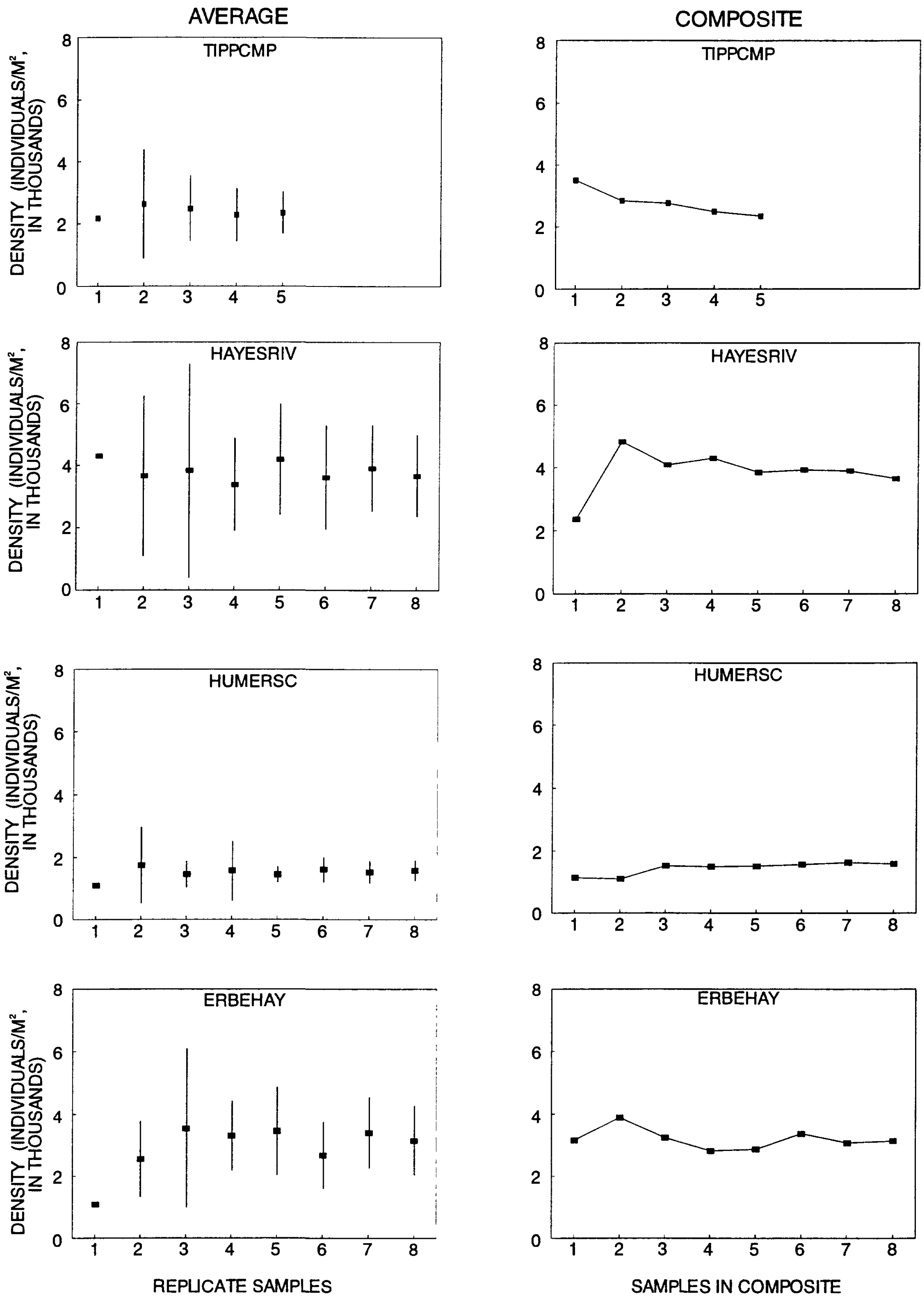

Figure 7.-- Average density (±2SE) as a function of sample size (n) compared to the influence of the number of samples in a composite. The four sites include TIPPCMP, HAYESRIV, HUMERSC, and ERBEHAY. For explanation of site code abbreviations, see table 1.

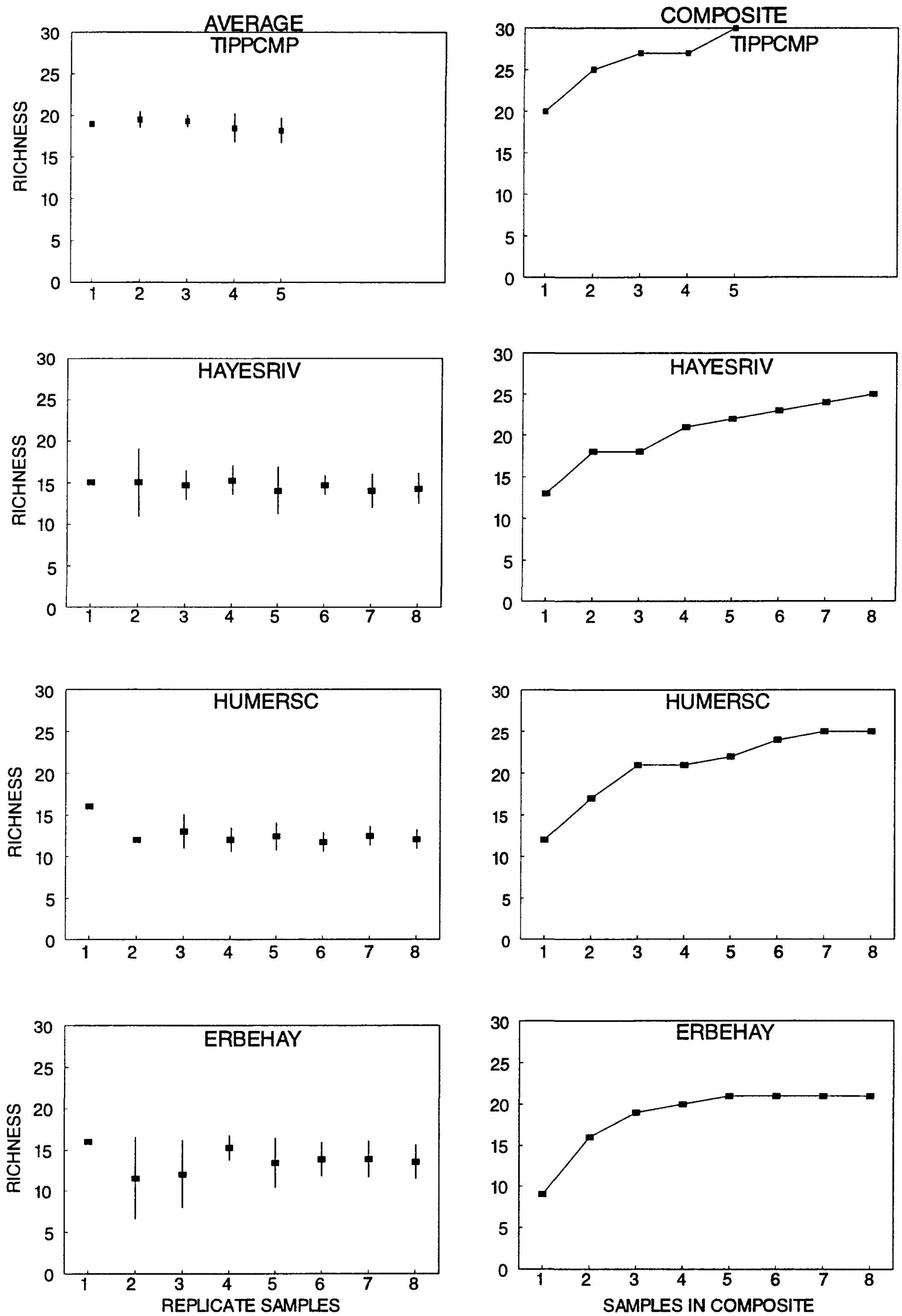

Figure 8.-- Average total richness (±2SE) as a function of sample size (n) compared to the influence of the number of samples in a composite. The four sites include TIPPCMP, HAYESRIV, HUMERSC, and ERBEHAY. For explanation of site code abbreviations, see table 1.

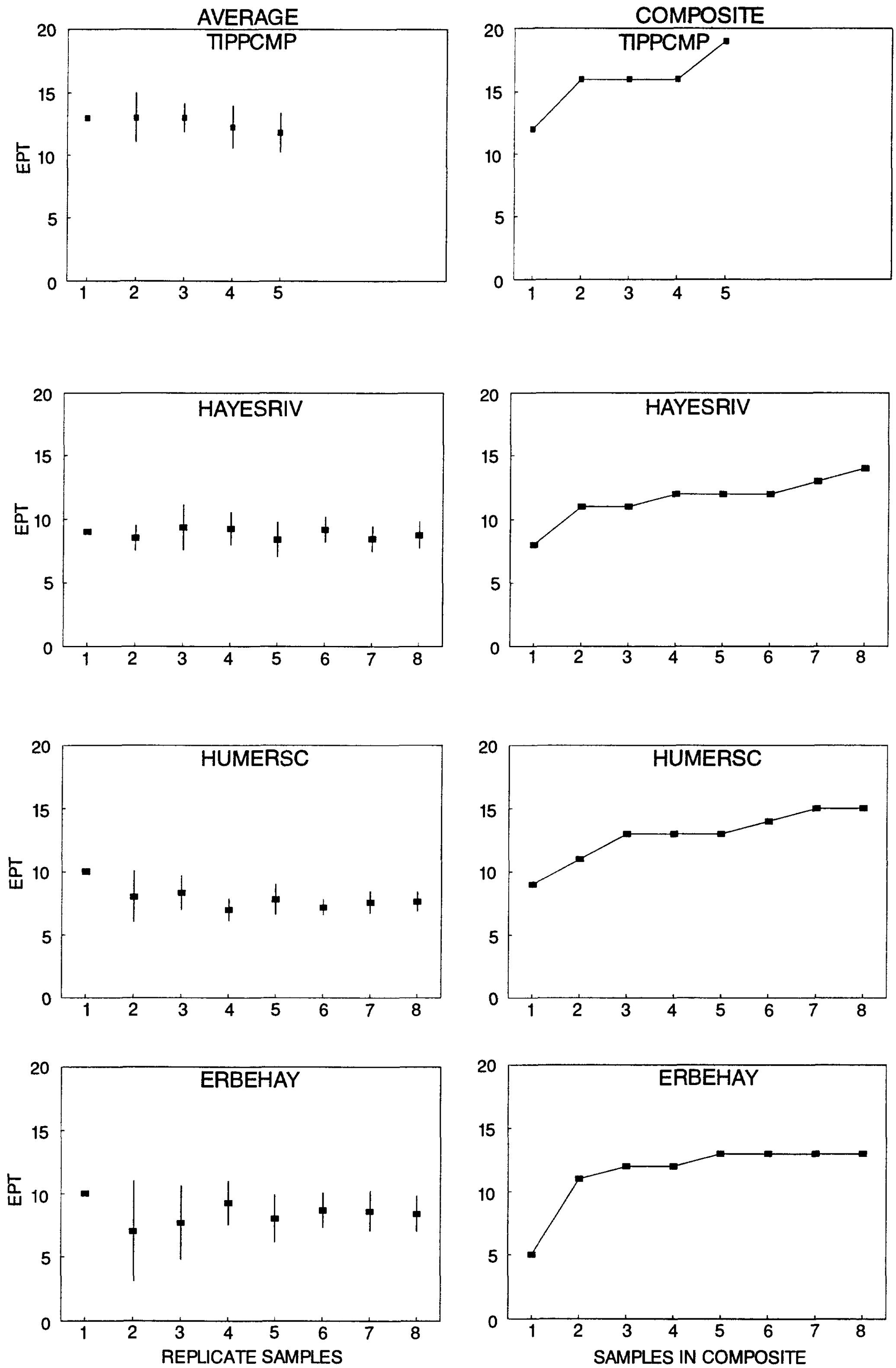

Figure 9.-- Average EPT (±2SE) as a function of sample size (n) compared to the influence of the number of samples in a composite. The four sites include TIPPCMP, HAYESRIV, HUMERSC, and ERBEHAY. For explanation of site code abbreviations, see table 1.

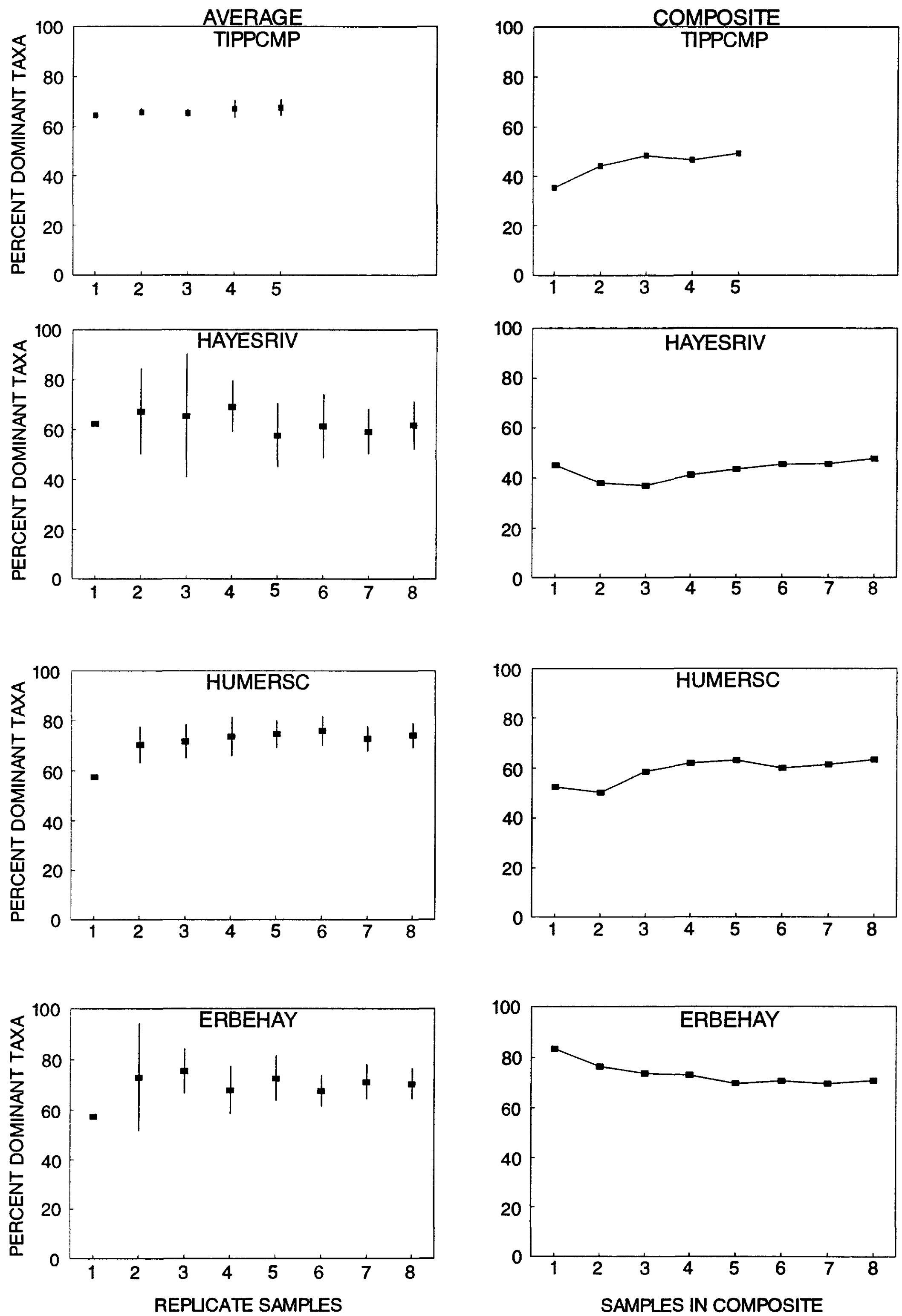

Figure 10.-- Average percent dominant taxa (±2SE) as a function of sample size (n) compared to the influence of the number of samples in a composite. The four sites include TIPPCMP, HAYESRIV, HUMERSC, and ERBEHAY. For explanation of site code abbreviations, see table 1.

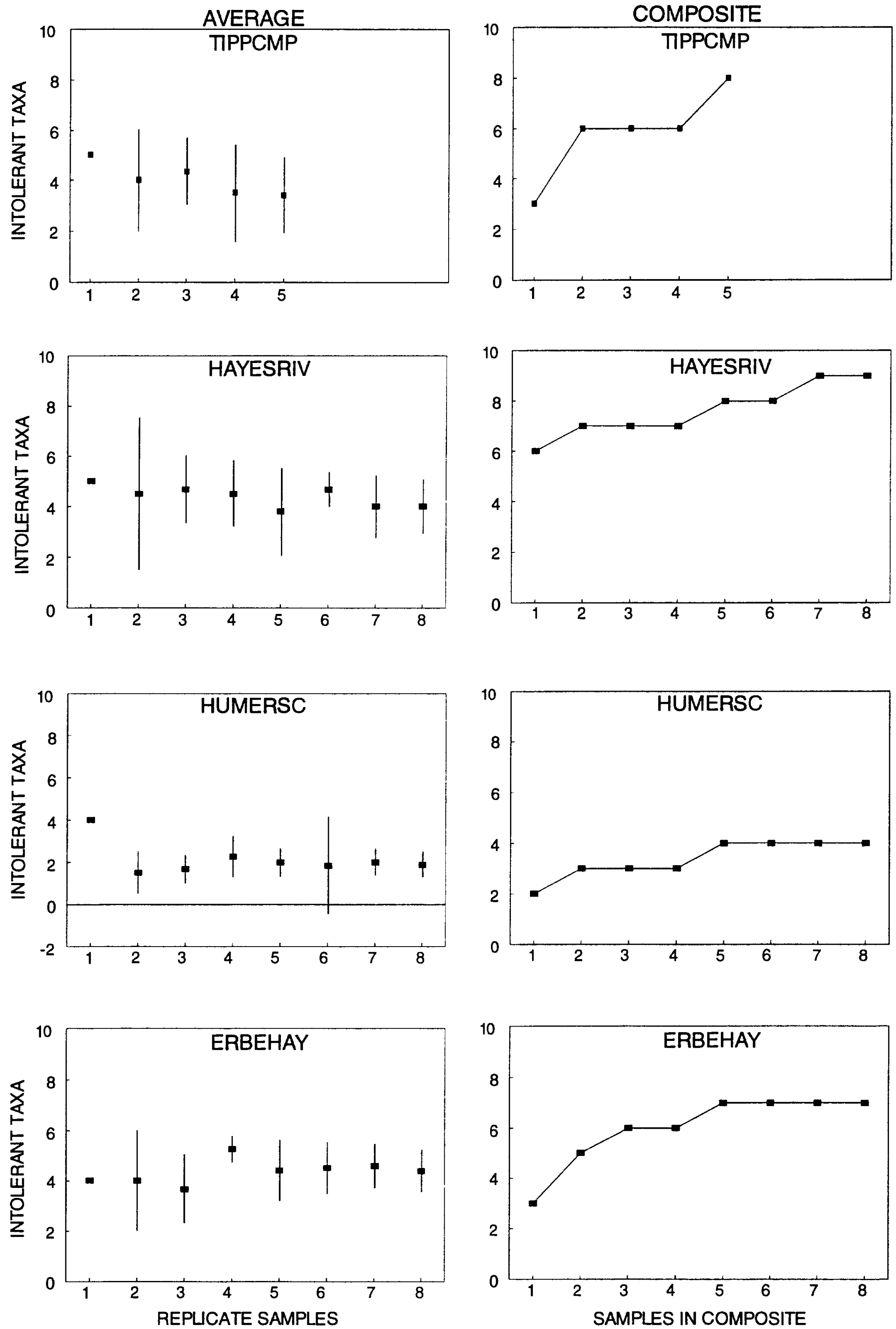

Figure 11.-- Average total intolerant taxa (±2SE) as a function of sample size (n) compared to the influence of the number of samples in a composite. The four sites include TIPPCMP, HAYESRIV, HUMERSC, and ERBEHAY. For explanation of site code abbreviations, see table 1.

The composite data yield somewhat similar results but also provide a more accurate assessment of community structure than average values. For example, collecting a single sample does not provide sufficient information to determine richness at a site. Collecting additional samples will increase the number of taxa collected to a point at which additional sampling will likely not add any new species. One way to assess the influence of increasing sample size on community data is to determine at what sample size the community metric begins to level off. Figures 7 to 11 show the cumulative curves of the various community metrics for each of the four habitat types. For all the metrics measured, values tend to increase with increasing sample size; however, for most metrics there is an initial increase up to a three-sample composite, then either a leveling off or smaller increases with increasing composite size.

DISCUSSION

Benthic Macroinvertebrate Community Structure

With the exception of the sites downstream of the two dams, the benthic macroinvertebrate communities in the Elwha River Basin generally indicate good water and habitat quality. We found no major differences among the benthic macroinvertebrate communities in the four habitat categories (TT, VT, SC, and MS), indicating that this habitat classification, which is based mainly on fish communities, is not appropriate for separating various types of benthic macroinvertebrate communities within a watershed. This may be due partly to problems of scale since invertebrates and fish likely response to different habitat features. The significant correlation of several community metrics with stream order and elevation reinforces this conclusion. Stream order reflects the drainage area of a sub-basin and therefore provides an index of the longitudinal position within the stream network. The communities are correlated with stream order probably because they respond to factors that change with stream order, such as substrate, temperature, food resources, and canopy position of a site.

Comparing the results from our study with others in the area is complicated by the relatively small number of studies and the fact that study methods differ. However, several studies of Olympic Peninsula rivers have found a wide range of macroinvertebrate densities. Benthic invertebrate communities in the Hoh River system have been reported to range from 670 individuals/m^2 (McHenry, 1991) to 15,008 individuals/m^2 (Van Stappen, 1984); our study found from 928 to 5,042 individuals/m^2. The wide range in density values reflects natural variability inherent to benthic invertebrate communities and the variation in collection methods. However, some of the differences between the rivers may be partially related to habitat stability.

Although a variety of factors may be influencing benthic communities in the Elwha River Basin, results from this study indicate that the Glines Canyon and Elwha Dams are the dominant factors controlling the communities in the mainstem of the river. The composition of the benthic macroinvertebrate communities from nonregulated sites was typical for pristine mountain streams; a high percentage of the community consisted of the EPT taxa that generally indicate good environmental conditions. The benthic macroinvertebrate communities downstream of the two dams had higher total densities with a community dominated by chironomid midges, a finding noted in an earlier study by Li (1990). Higher macroinvertebrate densities and higher percent dominance by chironomids in regulated reaches below dams has been demonstrated in other studies (Armitage, 1979; Ward and Standford, 1979; Munn and Brusven, 1991; Munn and Brusven, 1991).

Although our study was not designed to determine the degree to which different factors influence the benthic macroinvertebrate communities in the regulated reach, changes in biological communities below a dam are commonly attributed to some combination of alterations in physical habitat, trophic dynamics, flow fluctuations, and thermal regimes. Li (1990) reported that the Elwha River below the Elwha Dam has filamentous algae in some areas; aquatic plants, including filamentous algae, moss, and macrophytes, are known to provide physical habitat for many benthic macroinvertebrates, thereby enhancing their populations (Decamps and others, 1979; Dudley and others, 1986). Mauer and Brusven (1983) reported greater chironomid densities in moss habitat compared to mineral habitat; thus, the chironomids below the Elwha dams may be able to capitalize on the increase in habitat provided by the filamentous algae. In addition, the bed material in the regulated reaches of the Elwha River consists of significantly larger particle sizes (average is cobble-sized or larger) than those found in the nonregulated reaches. A shift in substrate composition can also greatly influence the composition of the benthic macroinvertebrate community and densities of particular species.

Regulated systems can alter the overall trophic structure of a river thereby changing the competitive advantage of particular species. Both of the dams on the Elwha River system release water from the surface of the reservoirs. The implication is that plankton in the reservoir are released to the regulated reach and therefore are a potential food source for macroinvertebrates in the river, possibly contributing to the slight increase in the population of the caddisfly *Arctopsyche* in the regulated reach below the Elwha Dam. This genus is a filter-feeder: it spins silk nets on the surface of rocks and filters food from the water column. The increase in the chironomid population may also be related to the increase in food supply.

Numerous studies have demonstrated that sudden fluctuations in flow below dams are partially responsible for altered benthic communities (Anderson and Lehmkuhl, 1968; Statzner and Higler, 1985). However, because the dams on the Elwha River are run-of-the-river systems, the river does not undergo the severe fluctuations associated with many power peaking systems. Figure 2 demonstrates the overall low impact of the flows in the regulated downstream system. Therefore, the flow regime in this system is not likely a major factor influencing the communities.

Water temperature is considered one of the dominant variables influencing benthic macroinvertebrate communities in regulated rivers (reviewed by Ward and Stanford, 1982). Temperature is a critical factor in insect development; deviations in the thermal regime can alter important environmental cues required for egg development (Lehmkuhl, 1972), hatching (Britt, 1962), larval development and synchronous emergence (Lutz, 1968), and fecundity (Vannote and Sweeney, 1980). The reduction in density of some species below the dams may be related to an alteration in thermal cues required for a particular life cycle stage. Munn and Brusven (1991) demonstrated that the thermal regime in the regulated Clearwater River below Dworshak Dam in Idaho differed substantially from nonregulated rivers and that this was an important factor in the reduction in EPT taxa. In the Elwha River, Li (1990) reported that water temperatures below the dams differed from the nonregulated reach above the dams and concluded that temperature could be a major controlling factor on the benthic communities. Water temperature data from the Elwha River system indicate that there is less variation in water temperatures below the dams and that during the summer the water temperature is higher. This altered thermal regime may be partially responsible for the shift in the benthic invertebrate community in the regulated reaches.

In sum, although the benthic communities in the regulated reaches of the river differed from the communities in the nonregulated reach above the reservoirs, differences were not as extreme as is sometimes seen. For example, although there was a shift in the density and percent dominance by particular taxa, there was no substantial change in taxa richness or EPT taxa. The change in percent dominance of specific taxa is not uncommon in regulated rivers (Munn and Brusven, 1991); however, it is somewhat unusual to maintain the same number of taxa or number of EPT taxa (Radford and Hartland-Rowe, 1971; Trotzky and Gregory, 1974; Munn and Brusven, 1991).

Influence of Sample Size

The first step in designing a study is to define an objective, which determines the design of the sampling program, including methods of collection, number of replicates, and methods of analysis. We collected five to ten replicate samples at each site; the number of samples per site depended on the physical complexity of the site. Results from our study indicate that we collected a sufficient number of samples to satisfy the primary objective of describing the macroinvertebrate communities in the Elwha River Basin. Depending on the goals of the Elwha River restoration project, future studies could likely reduce the number of replicate samples needed at some of the sites. This conclusion is based on our analysis of the effect of sample size and composite sample size on community metrics. Results indicated that for the community metrics used in this report, the same conclusions could be reached using a minimum of five samples. For both of the methods used (sample size and composite size), many of the community metrics began to level off at approximately five samples, although there was some variability depending on the metric. Most stream studies collect three to five replicate samples regardless of the objective (Resh and McElravy, 1993) because for many benthic macroinvertebrate studies, the objective is to describe the benthic community using various community metrics and to occasionally use statistical analysis to determine relationships between benthic communities and environmental variables in the watershed (for example, water chemistry or habitat). The number of replicates collected depends on the interpretations to be done with the data, the magnitude of differences to be detected, and the type of analysis to be performed (Norris and Georges, 1993).

If a future goal is to be able to detect small changes in biological metrics, as is the case in many effluent permit situations, then it will be necessary to reassess the number of samples needed because this will greatly affect the power of any statistical test used. However, for most studies the goal is to describe the benthic macroinvertebrate communities with some level of confidence and to use the data to determine the relationships between community metrics and specific chemical and physical variables.

CONCLUSIONS AND NEED FOR FUTURE STUDIES

There were no major differences among the four habitat categories in relation to benthic invertebrate communities, but there were differences in the structure of the communities directly downstream of the two dams. These differences included a general shift from a diverse community with an even distribution of taxa to a community dominated by chironomids. This information will provide a baseline for monitoring changes in the benthic communities that may occur in relation to land use activities and the potential removal of the dams. A secondary objective of this study was to assess the adequacy of the present sampling program and make suggestions for future assessments. Our findings demonstrated that the number of samples collected was sufficient to characterize the present communities and to satisfy the study objectives. A number of suggestions for future studies are outlined below.

* Continue to use benthic macroinvertebrate communities for monitoring the health of the Elwha River Basin.

Benthic macroinvertebrate communities are the most commonly used biological group for monitoring the environmental conditions of streams. Although any combination of taxonomic groups and level of biological organization can be used to assess the biological health of an aquatic ecosystem, benthic macroinvertebrate communities are commonly used for a number of reasons. They show cumulative effects of past conditions and there is substantial information about their ecological relationships (Wilhm, 1975; Herricks and Cairns, 1982). Future monitoring could focus on a subset of the sites used in this study and monitor every 1 to 3 years, depending on the specific objective of the program. The frequency of collection would depend on present land use changes or predictions of future changes if there is any reason to believe that there have been any physical or chemical disturbances.

* Reduce the number of replicate benthic samples to five per site.

Results from this study indicate that the collection of five replicate samples will permit an adequate assessment of the benthic invertebrate communities, along with reducing the overall cost per site. This is based on the finding that little community information was gained from more than 3 to 5 samples, a common finding among other studies. However, if there is interest in determining a specific level of change in a community metric at a predetermined level of significance, then the full data set included in this report needs to be reassessed for determining the sampling size required.

* Collect environmental data to augment the information gained from the benthic macroinvertebrate communities.

Although collecting data on benthic macroinvertebrate communities is a strong monitoring tool, it can be very useful also to collect some basic environmental data. The environmental variables selected depend on the specific goals of the program. In the case of the Elwha River Basin, physical parameters would optimally include water depth, water velocity, substrate, substrate embeddedness, percent fines, gradient, percent instream/riparian cover, water temperature, and any other features believed to be critical at a particular site.

* Collect additional data on the lower Elwha River below the dams.

If the dams are removed, the lower reach below the dams will likely be modified from its present status. This reach needs to be examined in more detail in relation to the present communities, potential changes in habitat, and the withdrawal of water from the reach. It may be useful to establish long-term monitoring of sediment transport (suspended and bedload) and detailed mapping of changes in physical habitat.

* Design and implement a study on the effect of salmon carcasses on the nutrient dynamics and community response in the Elwha River.

If the dams are removed, the status of the stream communities throughout the basin may change dramatically due to a shift in nutrient dynamics. In most river systems nutrients enter the system upstream from various sources and are transported downstream where they affect the stream community by increasing primary productivity and therefore secondary productivity. The return of salmon to the basin will increase the nutrient input to the upper system, thereby increasing primary and secondary production, which will enhance the food supply for emerging salmon. A useful study would be to determine the natural changes that will occur in the ecology of the spawning streams due to nutrient enrichment from salmon carcasses.

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Appendix A. Benthic macroinvertebrate taxa collected from the Elwha River Basin, 1994-95.

Phyla	Class	Order	Family	Genus/Species
Arthropoda	Insecta	Ephemeroptera	Baetidae	Baetis
			Ephemerellidae	Caudatella
				Drunella coloradensis
				Drunella doddsi
				Ephemerella
			Heptageniidae	Cinygmula
				Cinygma
				Epeorus
				Rithrogena
			Leptophlebiidae	Paraleptophlebia
			Siphlonuridae	Ameletus
			Tricorythidae	Tricorythidae
		Plecoptera	Capniidae	
			Chloroperlidae	
			Leuctridae	
			Nemouridae	Nemoura
			Nemouridae	Malenka
			Peltoperlidae	Yoroperla
			Perlidae	Calineuria
				Claasenia
				Hesperoperla
			Perlodidae	Isoperla
				Megarcys
				Setvena
			Pteronarcyidae	Pteronarcys
		Trichoptera	Brachycentridae	Micrasema
			Glossosomatidae	Glossosoma
			Hydropsychidae	Arctopsyche
			Hydropsychidae	Parapsyche
			Limnephilidae	Dicosmoecus
				Ecclisomyia
				Limnephilidae
			Polycentropodidae	Polycentropus
			Psychomyiidae	Tinodes
			Rhyacophilidae	Himalopsyche
				Rhyacophila
		Diptera	Blephariceridae	
			Ceratopogonidae	
			Chironomidae	
			Deuterophlebiidae	
			Dixidae	
			Empididae	
			Pelecorhynchidae	
			Psychodidae	
			Simuliidae	
			Tabanidae	
			Tipulidae	

		Coleoptera	Elmidae	Narpus
		Megaloptera	Sialidae	Sialis
	Hydracarina (water mites)			
Annelida	Oligachaeta (aquatic worms)			
	Hirudinea (leaches)			
Mullusca	Bivalvia (clams)			
	Gastropoda (snails)			