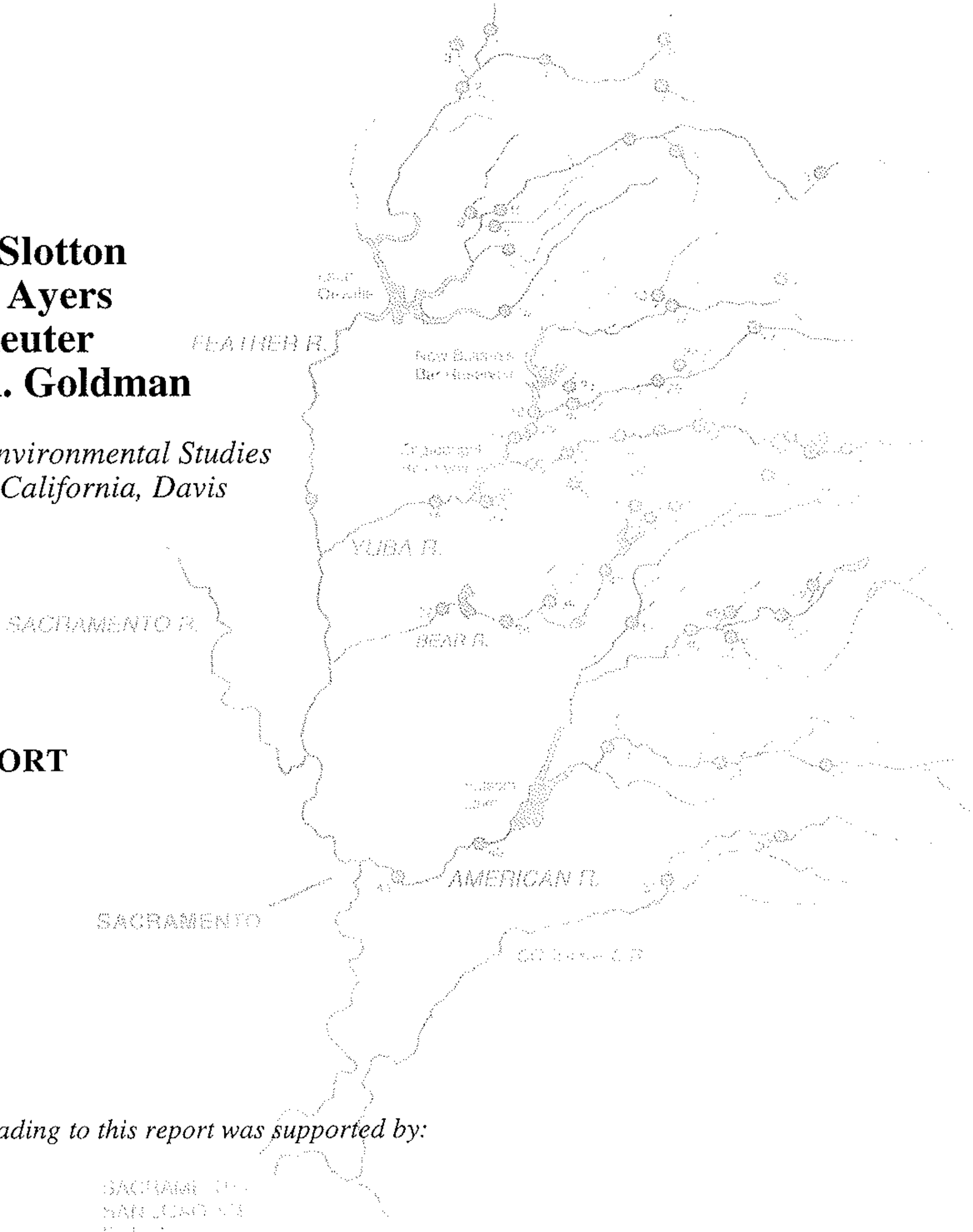
GOLD MINING IMPACTS ON FOOD CHAIN MERCURY IN NORTHWESTERN SIERRA NEVADA STREAMS

(1997 REVISION)



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FINAL REPORT

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ABSTRACT / EXECUTIVE SUMMARY

In this research, we investigated mercury levels in aquatic invertebrates and trout within the historic gold mining region of the northwestern Sierra Nevada, in order to determine the localized biological impacts of mining-derived mercury. These organisms were used as indicators of specifically the bioavailable fraction of mercury, that portion which can enter, transfer through, and be concentrated by the food web. The biota samples were used to determine relative "hot spots" of mercury contamination and to rank the various streams and rivers as to relative bioavailable mercury levels. Trout mercury was investigated also from a health perspective, for comparison with existing mercury guidelines.

Fifty-seven sites were sampled throughout the region during the three years of this study. A clear signature of mining-derived mercury was found, with notably elevated levels in the aquatic food webs of the South and Middle forks of the Yuba River, the mid-section of the Middle Fork of the Feather River, Deer Creek, the North Fork of the Cosumnes River, and tributaries throughout the Bear River drainage. Mercury was low throughout most of the American and Feather River watersheds and in many tributaries away from the most intensively mined stretches of rivers. Elevated mercury regions did not demonstrate a point source signature. Where biotic accumulations of mercury were elevated, this elevation was generally distributed across many miles of stream or river. The elevated bioavailable mercury regions could thus be localized to specific tributaries or series of river miles, but not to highly localized "hot spot" point sources. This is consistent with the historic widespread use of mercury throughout the gold mining region and its subsequent redistribution downstream.

Mercury concentrations in trout, while variable, were found to be uniformly below existing health standards, indicating the lack of a direct health hazard within the region itself. Foothill reservoirs were found to operate as interceptors of bioavailable mercury, in addition to trapping much of the sediment-associated inorganic load. Significantly lower bioaccumulated levels were found throughout the food web below several reservoirs, as compared to upstream. Concentrations of mercury in aquatic indicator organisms increased in a predictable pattern with increasing trophic feeding level. Aquatic invertebrate samples can be used to determine relative mercury presence and bioavailability, to predict mercury levels in co-occurring trout, and to integrate localized bioavailable mercury conditions over the lifetime of the respective organisms.

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ACKNOWLEDGMENTS

We are grateful to the many agency personnel who were generous with their time and conversation and who helped direct our site selection process in the early stages of the project. We also appreciate being provided access to several otherwise difficult to reach sites. In particular, we thank staff of: the Foresthill Ranger District in the American River watershed, the North Yuba Ranger Station in the Yuba River watershed, various stations in the Feather River area, the Yuba Water Agency, the University of California Agricultural Field Station at the lower Yuba River, the Central Valley Regional Water Quality Control Board, and the California Department of Fish and Game. The State Toxic Substances Monitoring Program supplied much parallel and related data and, in large part, provided the basis for this work. Special thanks go to our colleague, Dr. Michael Brett, who played an important role in the development of this project and who provided helpful suggestions throughout the data reduction and interpretation process.

INTRODUCTION: PROBLEM AND RESEARCH OBJECTIVES

Mercury pollution of aquatic systems is a major concern of researchers and regulatory agencies on both a regional and global scale. In its methylated form, mercury is readily concentrated and transferred through aquatic food chains, where it can become a significant neurological toxicant to higher trophic level consumers, including man. The primary pathway into humans is fish consumption. Much of the current mercury research is focused on the pervasive problem associated with low level atmospheric deposition of industrially-derived mercury across wide areas which have low pH and poorly buffered surface waters. In these regions, mercury can accumulate to dangerous levels in fish with even trace level inputs (e.g. the Northeast United States, Southeast Canada, Scandinavia and much of Western Europe). While the high alkalinity waters of the western U.S. render atmospheric sources of mercury relatively insignificant, California has historically been impacted by large-scale bulk contamination of mercury. This has been the result of extensive mercury mining in the Coast Range of Central California, the use of very large amounts of mercury in Sierra Nevada streams and rivers for gold mining, and the subsequent movement of mercury from both of these areas into downstream rivers and lakes, foothill reservoirs, and ultimately the Delta/Bay ecosystem. In this work, we investigated regional patterns of mercury accumulation in aquatic biota collected in the historic and current gold mining region of the northwestern Sierra Nevada. While some attention has been devoted to mercury accumulation in downstream sinks, little or no research has focused on probable upstream source regions associated with current and, primarily, historic use of mercury for gold mining. It has been estimated that over 3 million kilograms of mercury were lost into Sierra Nevada streams in the course of the California Gold Rush (CVRWQCB 1987).

Previous biological sampling efforts in these streams, as part of the State's Toxic Substances Monitoring Program (TSMP 1990, 1991, 1992), have been limited and most of this was done prior to the 1986 floods and the resurgence of small scale mining. Indeed, much of the routine sampling for the TSMP program is conducted on the lower reaches of the stem rivers and in foothill reservoirs. Mining, on the other hand, is concentrated along mid-elevation stretches of northern Sierra Nevada rivers, namely the forks of the upper Feather, Yuba, and American Rivers, the Bear River, Rubicon River, Cosumnes River, and the Mokelumne River. These rivers have been sampled sporadically by the Toxic Substances Monitoring Program (TSMP 1990, 1991, 1992). However, site selection and the species composition of the fish collected indicates that this work was generally carried out in regions well downstream of the reaches where gold mining is prevalent. We feel our data constitutes a valuable contribution to the Program's data base and its objective of identifying human health risks and major sources of toxic substances.

Small scale mining, suction dredging and panning for gold in the northwest region of the Sierra Nevada mountains has increased markedly during the last ten years. This is in part attributable to the recent series of flood runoff years in 1986, 1993, and 1995, which impacted the channel of many rivers in this region and, in the process, exposed new gold. The massive flows occurring at the time of this publication (December 1996 / January 1997) will undoubtedly continue this process. These high flows also exposed and mobilized old mercury. Additionally, current mining activity could potentially introduce additional mercury to the streams as well as disrupt formerly buried historic mercury. This project addresses the status of mercury contamination in northwestern Sierra Nevada gold mining streams, both in terms of on-site biotic mercury accumulation and as potentially ongoing sources of mercury contamination to downstream regions. The primary objectives of the project have been to:

- Determine levels of mercury in stream biota within the region most impacted by historic and current gold mining and demonstrate whether there is significant localized uptake of mercury into the stream food web in the vicinity of major historic and current mining operations.
- Produce data which will help to assess the importance of this region as an ongoing source of mercury to downstream rivers and reservoirs, and rank upstream tributaries in terms of mercury bioavailability.
- Determine whether a human or environmental health hazard exists in relation to trout mercury concentrations in the project area.
- Supplement mercury information collected from other areas of the state.

We believe that all of these objectives were achieved in this work, together with a number of other important scientific findings.

We chose mid-elevation sampling sites from among the main Sierra Nevada gold-mining rivers (Figure 1, Table 1). During the three years of the project reported here (1993-1995), we focused on the region between the Feather River watershed and the American River watershed, including the forks of the upper Feather, Yuba, Bear, and American Rivers. Special attention was given to those areas with high densities of active mining claims. These locations were determined by communication with agency and other personnel familiar with given stretches of river, and through our own reconnaissance. We soon determined that mercury distribution was very widespread throughout this region and the most effective sampling approach was to, as extensively as possible, sample throughout these rivers and their major tributaries. Where possible, samples were collected at or just below actively mined stretches of river, as well as at control sites upstream and/or along unmined stretches.

In this research, we utilized exclusively biotic samples. In-stream aquatic insect species were sampled as bioindicators of relative mercury bioavailability at each of the sites and as surrogates for fish, which were not available at many of the sites. The invertebrate mercury data also provided information on the transfer of mercury through the stream food web. Fish were of interest for their specific mercury concentrations, from a health perspective, as well as also being indicators of relative mercury availability. We chose rainbow trout as one focus of the survey because this species is the dominant vertebrate in many of these rivers, and because mercury bioaccumulation in this species represents perhaps the main vector of human exposure to mercury in this region. Other fish were sampled when available.

Sampled trout were generally representative of individuals taken by fishermen. While a range of sizes and ages were taken, the focus was on three year olds, typically 9-12 inches in length. Trout of this size class dominate angling catches, are the major contributors to in-stream reproductive success of this species, and are the group most heavily relied upon by the Department of Fish and Game in both research and policy making (Harry Rectenwald, Calif. Dept. of Fish and Game, personal communication). Stream aquatic insects were taken from a variety of trophic levels whenever possible, as described below in the methodology section.

The first two years of the work reported here were sponsored by the University of California Water Resources Center. Thirty-five individual sampling sites were studied in 1993 and 1994 and reported on in Slotton *et al.* 1995a. The Sacramento Sanitation District sponsored U.C. Davis follow-up work in 1995, sub-contracted through Larry Walker and Associates. As part of the 1995 continuation work, biota mercury was investigated at 22 additional sites, completing a comprehensive network of 55 sites throughout the Sierra Nevada drainage of the Sacramento River (plus 2 sites on the Cosumnes River of the San Joaquin drainage). The 1995 biological work was conducted in parallel with mercury mass balance and water quality studies which were performed by Larry Walker and Associates. The results of that project are presented in a separate report. The report that follows focuses specifically on the U.C. Davis biological mercury project that was conducted in the gold mining region of the nothwestern Sierra Nevada between 1993 and 1995. This report is a December 1996 revision of the original University of California Water Resources Center publication, including the additional (1995) data and new discussion as appropriate.

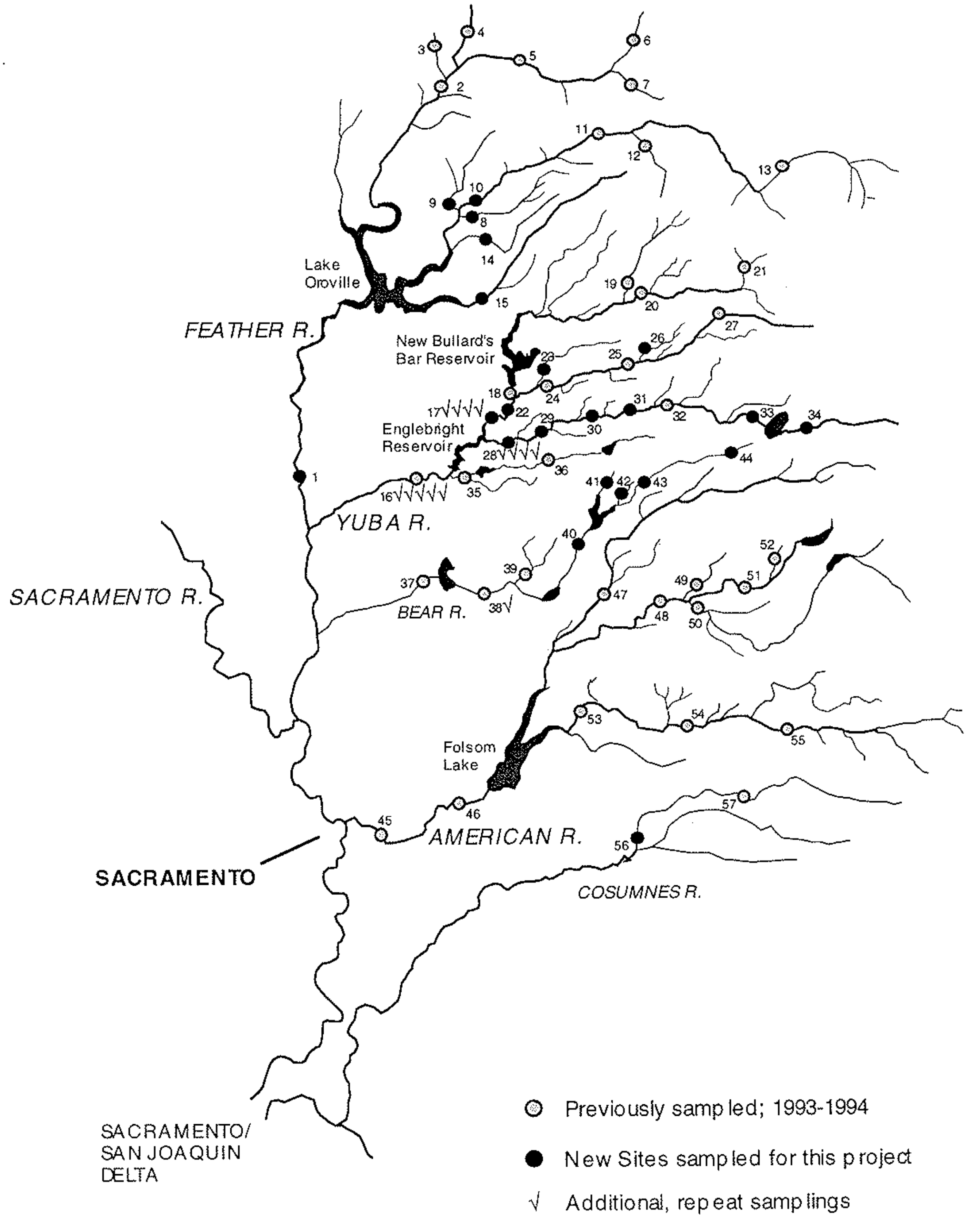


Fig. 1. U.C. Davis Northwest Sierra Nevada Biotic Sampling Sites, 1993-1995

Table 1. U.C. Davis Sierra Nevada Gold Region Biotic Mercury Sites

FEATHER RIVER DRAINAGE

1. Lower Feather River below Lake Oroville, near Live Oak (11/17/95).
2. North Fork Feather River at Belden (10/26/94).
3. Yellow Creek (tributary to N Fk Feather R), 2 miles above confluence (6/11/94).
4. Caribou Branch of North Fork Feather River, 4 miles above confluence (10/27/94).
5. East Branch of North Fork Feather River, 10 miles above confluence with Caribou Branch (10/26/94).
6. Indian Creek, tributary to E Branch N Fk Feather River, 7 miles above confluence (9/27/94).
7. Spanish Creek, tributary to E Branch N Fk Feather River, 2 miles above confluence (9/26/94).
8. South Branch Middle Fork Feather River, at M Fk Feather River (11/21/95).
9. Little North Fork Middle Fork Feather River, at M Fk Feather River (11/21/95).
10. Middle Fork Feather River, 15 miles upstream of Lake Oroville at Milsap Bar (11/21/95).
11. Middle Fork Feather River, 1 mile below Nelson Creek (9/22/94).
12. Nelson Creek, tributary to Middle Fork Feather River, 1 mile above confluence (9/21/94).
13. Upper Middle Fork Feather River, 3 miles upstream of Clio (9/23/94).
14. Fall River, tributary to lower Middle Fork Feather River, 3 miles above confluence (11/20/95).
15. South Fork Feather River above Lake Oroville (11/20/95).

YUBA RIVER DRAINAGE

16. Lower Yuba River below Englebright Reservoir, at University of California field station (12/16/93).
    * Additional, seasonal collections in 1995: (4/24/95, 6/30/95, 8/15/95, 11/16/95, 2/16/96).
17. Combined North and Middle Forks Yuba River, just above Englebright Reservoir.
    * 1995 seasonal collection site #2: (4/24/95, 6/30/95, 8/15/95; no inverts available 11/95 and 2/96).
18. North Fork Yuba River constrained (low) flow beneath New Bullard's Bar Reservoir (3/15/94).
19. Canyon Creek, tributary to N Fk Yuba, just above confluence (11/6/93).

Table 1. (continued)

20. North Fork Yuba River, 2 miles downstream of westmost Highway 49 crossing (11/5/93).

21. Downey Creek, tributary to N Fk Yuba, at Downieville (11/2/93).

22. Middle Fork Yuba River, upstream of Colgate Powerhouse inflow of N Fk Yuba water (11/16/95).

23. Oregon Creek (Middle Fork Yuba tributary) at Middle Fork Yuba (11/9/95).

24. Middle Fork Yuba River, just upstream of Oregon Creek and Highway 49 crossing (10/21/93).

25. Middle Fork Yuba River, 1 mile upstream of Tyler Foote crossing, near Kanaka Creek. (10/19/93).

26. Kanaka Creek (Middle Fork Yuba River tributary), at Middle Fork Yuba River (11/14/94).

27. Middle Fork Yuba River, 1 mile upstream of Plumbago Road (3/24/94).

28. South Fork Yuba River at Bridgeport, just above Englebright Reservoir.
    * 1995 seasonal collection site #3: (4/24/95, 6/30/95, 8/15/95, 11/16/95, 2/16/96).

29. South Fork Yuba River at Highway 49 crossing (11/10/95).

30. South Fork Yuba River at Purdon crossing (11/10/95).

31. South Fork Yuba River at Edward's crossing (10/4/95).

32. South Fork Yuba River 1 mile downstream of Washington (11/12/93).

33. South Fork Yuba River below Lake Spaulding (10/24/95).

34. South Fork Yuba River above Lake Spaulding (10/25/95).

35. Deer Creek below Lake Wildwood, at Mooney Flat Road (12/9/94).

36. Deer Creek at Bittney Spring Road (12/9/94).

BEAR RIVER DRAINAGE

37. Bear River below Camp Far West Reservoir (12/8/94).

38. Bear River between Camp Far West Res. and Wolf Ck confluence, at Hwy 49 (12/7/94, 11/10/95).

39. Wolf Creek, tributary to Bear River, 2 miles above confluence (12/7/94).

40. Bear River below Rollins Reservoir (10/12/95).

41. Greenhorn Creek (Bear River tributary), above Rollins Reservoir (10/13/95).

Table 1. (continued)

42. Steephollow Creek (Bear River tributary), above Rollins Reservoir (10/13/95).

43. Bear River above Rollins Reservoir and flow diversion from S Fk Yuba (10/13/95).

44. Bear River headwaters near Lake Spaulding (10/24/95).

AMERICAN RIVER DRAINAGE

45. Lower American River at Howe Avenue (12/16/94).

46. Lower American River 1 mile below Lake Natoma (12/16/94).

47. North Fork American River in vicinity of Humbug Bar (11/19/93).

48. Middle Fork American River below Oxbow Reservoir (2/25/94).

49. North Fork of the Middle Fork American River, 1 mile above confluence (3/2/94).

50. Rubicon River, tributary to Middle Fork American River, just above confluence (2/1/94).

51. Middle Fork American River at "End of the World" (2/1/94).

52. Duncan Creek, tributary to Middle Fork American River, 3 miles above confluence (11/16/93).

53. South Fork American River, above Folsom Lake (12/16/94).

54. South Fork American River, below Slab Creek Reservoir (12/20/93).

55. South Fork American River, 1 mile upstream of Pacific (4/11/94).

Additional Sites Outside the Sacramento River Drainage

56. North Fork Cosumnes River above M Fk Cosumnes confluence (7/30/95)

57. North Fork Cosumnes River at Mt Aukum Road (12/20/93).

METHODOLOGY

Site Selection

Sampling sites were chosen by a variety of methods. Likely high mercury regions were determined through conversations with employees of the Forest Service, California Department of Fish and Game, regional Water Quality Control Boards, and other agencies, as well as through our own reconnaissance and conversations with miners. Additional sites were chosen upstream and downstream of intensively mined stretches. Additional major tributaries were sampled as possible. Tributaries were sampled for trout ≥ 1 mile upstream of their confluences with main rivers, in order to minimize the importance of migration from downstream and other drainages. Stream invertebrates could be effectively sampled closer to a downstream confluence while remaining representative of the given tributary.

Collection Techniques

Stream invertebrates were taken from riffle habitat at each of the sites, i.e. from rapids or cobble bottomed stretches with maximal flow, where aquatic insects tend to be most concentrated among the rock interstices. Felt-soled boots were used to permit effective movement in this habitat. Neoprene waders were used when water temperatures were below ~12 °C. Stream invertebrates were collected primarily with the use of a kick screen. A 1.5 mm mesh size was used, trapping invertebrates thicker than this in cross section. One researcher spread and positioned the screen perpendicular to the flow, bracing the side dowels against the bottom, while the other researcher overturned boulders and cobble directly upstream of the screen. These rocks were hand scrubbed into the flow, dislodging any clinging biota. Following the removal of the larger rocks to the side of the stretch, the underlying cobble/pebble/gravel substrate was disrupted by shuffling the boots repeatedly. Invertebrates were washed into the screen by the current. The screen was then lifted out of the current and taken to the shore, where teflon coated forceps were used to pick macro-invertebrates from the screen into jars with teflon-lined caps. This process was repeated until a sufficient sample size of each taxon of interest was accumulated to permit future analysis for mercury. Whenever possible, we attempted to collect consistent samples from the following four invertebrate trophic levels: herbivores, drift feeders, small-item predators, and top insect predators. When present, we took Pteronarcyid stonefly nymphs or a variety of mayfly nymphs for the herbivore trophic level and Hydropsychid caddisfly nymphs for the drift feeding group. Medium to large Perlid stoneflies (either *Callineuria* or *Hesperoperla*) were taken wherever possible to represent the small-item predator insects, while hellgrammites (*Corydalus*) were the preferred top predator stream insect.

Several fish collection techniques were investigated initially, including gill netting, electroshocking, and angling. We determined that angling was the most effective method for taking a cross section of trout sizes from clear, fast moving Sierra foothill rivers and streams. To guard against potentially taking seasonal migrant fish from downstream reservoirs, fish sampling was largely confined to the months of August through December. Stocked individuals were rarely taken and were easily differentiated from native fish by their characteristic fused and bent fin rays. We sampled exclusively native fish for mercury content, with the emphasis on rainbow trout. The attempt was made to collect trout across a range of sizes and ages at each site, permitting the construction of site-specific fish size vs mercury regressions. These relationships were used to normalize trout mercury content at each site to a standard, inter-comparable size of trout. We chose a standard size of 250 g for normalization. This size was typical of 2-3 year old, 9-12 inch long trout which represent the majority of "keeper" fish taken by the angling public. Fish were weighed and measured in the field. At sites where stomach contents were assessed, this was also done in the field. Stomach contents were obtained with a stainless steel scalpel and were removed to an acid-cleaned jar with teflon-lined cap. Items were identified and percent volumes assessed, following standard fisheries sampling protocol.

Sample Preparatory Techniques

Stream insects were analyzed for mercury in homogenized composite samples of multiple whole individuals. Typically, ≥ 10 individuals were composited for each of the trophic levels through small-item predators (stoneflies), and 2-5 individuals of the top predator insect group such as hellgrammites, based on availability. Samples were pooled by taxa into separate jars. The insects were maintained live on ice. Within 24 hours of collection, the contents of each jar were carefully cleaned and sorted. This was accomplished by resuspending the jar contents in a tray of clean water and, with teflon-coated forceps, individually rinsing and shaking each individual insect in the clean water to remove any extraneous material. Insects were keyed to at least the family level, using a variety of aquatic insect texts and manuals (McCafferty 1981, Merrit and Cummins 1984, Pennak 1978, Thorp and Covich 1991) . Trophic feeding category of organisms was determined based on the recommendations of Merrit and Cummins (1984). In uncertain cases, the magnified examination of mouthparts was used to help make this determination. Cleaned insects were placed in well rinsed jars and frozen. At the onset of sample analysis, the jar contents were dried at 50-60 °C for 24 hours and then ground with teflon coated instruments or glass mortar and pestle to a homogeneous powder. The resulting powder was dried a second time to constant weight before analytical sub-samples were taken for digestion. All aquatic insect mercury analytical work was performed with dry powdered sample, both to ensure homogeneity of sample and to enhance mercury detection capacity. Percent moisture was determined on homogenized wet samples from several replicates of each major group, to permit the conversion between wet and dry concentrations.

In contrast to the dry, composite sample insect work, fish mercury was analyzed primarily in muscle tissue on a fresh (wet) weight basis, in accordance with standard practices which focus on the potential health risks of consuming mercury in filet meat (TSMP 1990). Muscle samples were taken from fresh fish at streamside. Fish muscle was sampled from the dorso-lateral (shoulder) region utilized by the California Department of Fish and Game. For each individual fish, the skin over the region was pulled back before the sample was taken with a stainless steel scalpel. Samples of approximately 0.2 g were rolled lightly over a laboratory tissue paper to remove extraneous surface moisture and then carefully placed into pre-weighed, acid-washed digestion tubes with teflon-lined caps. The precise weight of each muscle sample was later determined by re-weighing the digestion tubes with samples, together with empty "blank" tubes, on a balance accurate to 0.001 g. This direct sub-sampling technique reflects fresh weight muscle (filet) mercury concentrations, without introducing potential sources of error associated with homogenization techniques. We have found mercury concentration to be extremely uniform throughout the dorso-lateral region of muscle (Slotton 1991). Thus, direct sub-sampling accurately reflects overall muscle mercury concentration. For cases where liver mercury was also measured, identical procedures were followed. Wet/dry conversions were calculated for trout fillet tissue by determining percent moisture from 10 fillet samples from different fish. These were very similar and the mean value (78.2% ± 1.9%) was used to convert analyzed fresh weight parts per million mercury to a dry weight basis, for direct comparison with the invertebrate dry weight values.

Analytical Methodology

Mercury analytical methodology followed the protocols developed at U.C. Davis (Slotton 1991) and summarized in Slotton *et al.* (1995b). The method combines features of a number of previous techniques, and is notable for allowing excellent reproducibility, low detection levels, high numbers of samples per batch and thus room for high numbers of QA/QC samples, and the ability to re-analyze digests.

The method can be summarized as follows: digestion is performed in teflon-capped pyrex test tubes in a two stage process. Environmental samples are broken down in a 2:1 mixture of concentrated sulfuric acid to concentrated nitric acid, the digest mixture found to be most effective in a comparative study (Sadiq and Zaidi 1983). This first stage utilizes a temperature of 90-100 °C and pressure (sealed tubes) for 1.5 hrs, resulting in clear solutions. In the second stage, also 1.5

hrs, potassium permanganate is added for additional oxidation and digest stabilization. This portion of the digest procedure is performed at 80-95 °C with the tubes refluxing, uncapped. The resulting digests can be diluted or not, depending on the mercury concentrations and required level of detection, and are stable indefinitely, both before and following detection. Detection utilizes typical cold vapor atomic absorption techniques with a mercury lamp of 253.7 nm wavelength. The method differs from standard flow-through systems which reduce the entire digest in a one-time detection. A long path length, minimum volume gas cuvette and holder have been manufactured for positioning in the beam path and a specialized injection port allows direct introduction of reduced mercury in vapor. Reduction of digest mercury is performed inside a 12 cc calibrated syringe on a 2.0 cc aliquot of digest together with 2.0 cc of stannous chloride/hydroxylamine sulfate/sodium chloride reductant. A 6.00 cc airspace is utilized for partitioning of the volatile reduced mercury within the syringe and, after partitioning is complete, this airspace is injected directly into the low volume cuvette mounted in the beam path for detection. The amount of digest and, thus, proportion of sample detected is accurately determined through difference, with the digest tubes weighed to ± 0.001 g both before and immediately after removal of the analytical aliquot. Weight of total digest is initially determined by weighing the empty tube and then the full tube of digest. Level of detection was approximately 0.01 mg kg^{-1} (ppm).

QA/QC was quite extensive, with approximately 16 of the 40 tubes in each run dedicated to this purpose. QA/QC samples in each run included a set of 8 aqueous mercury standards, a minimum of 3 certified reference material samples in an appropriate matrix, and duplicate and spike recovery samples each at a ratio of approximately 10%. QA/QC samples passed through all phases of the digest and were treated identically to analytical samples. Replication was typically $\leq 5\%$ difference between duplicates, recoveries of certified reference materials were uniformly within 20% of certified values, spike recoveries were within 20% of predicted concentrations, and standard curves generally had R^2 values in excess of 0.98.

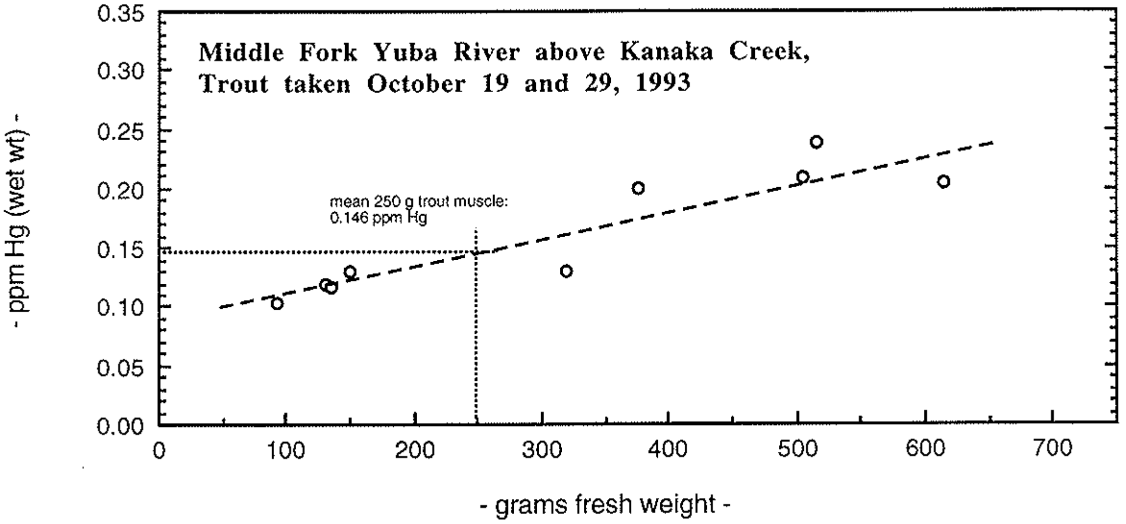
Data Reduction

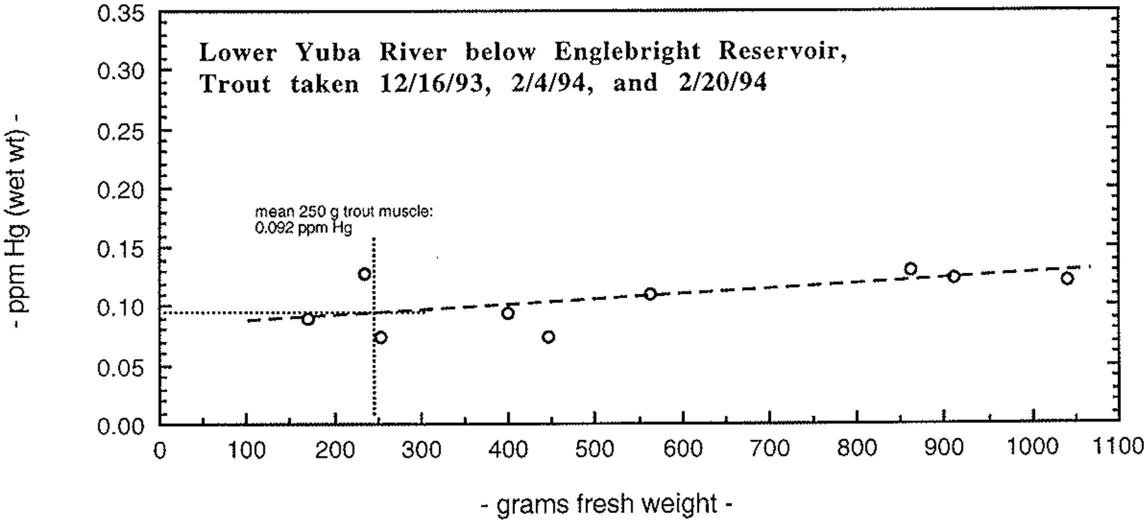
In order to reduce the fish muscle mercury concentration data to a single, inter-comparable number for each site, we developed trout size vs mercury concentration curves for the fish taken at each location. Data for fish weights and corresponding mercury concentrations were plotted for each sample set. Based on a visual line of best fit, a graphic relationship between trout size and mercury concentration was estimated for each site. This approach was taken for the following reasons: (1) obvious outlier individuals could be omitted when they were clearly of different origin than the rest of the fish in a set, typically due to recent migration from an adjoining stream with different mercury bioavailability, (2) fish size vs mercury concentration relations often follow a curvilinear rather than straight line function, and (3) standard polynomial function curve fitting routines tend to wrap the upper portion of these mercury curves, unnaturally, back down toward zero, rather than following the asymptotic, steadily increasing function typical in actual fish vs mercury relations. However, a straight line could generally be fitted to the trout data of most sample sets, within the range of sizes utilized. Examples of this normalization approach are presented in Fig. 2. Map figures for trout represent normalized 250 g rainbow trout filet muscle mercury concentrations. Only samples with sufficient individuals to derive a size:mercury relationship are displayed in the map figures (21 of 24 sites where trout were taken).

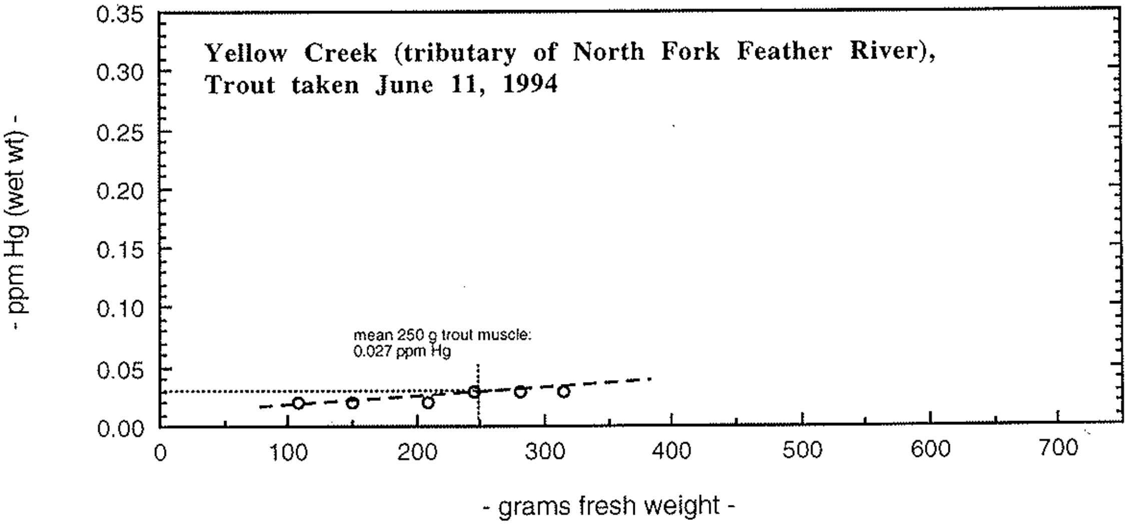
Among the invertebrate samples, some of the trophic levels were well represented by a single genus throughout the majority of sampling sites, while others were represented by different members of the trophic level at different locations. While mercury concentrations for all of the individual samples are presented in the data tables, the summary map figures utilize averaging techniques in several circumstances. In the herbivore trophic level, a distinction is made between consumers of allochthonous (terrestrially derived) vegetation ("shredders") and forms which graze autochthonous, within-stream algae and aquatic plants. The shredder sub-group was dominated by samples of Pteronarcyid stoneflies. Where other shredder groups were present rather than Pteronarcyids, the average mercury level among them is plotted. Grazers of within-stream vegetation are similarly averaged. For plots which utilize only a single value for "herbivores", the average of all shredder and grazer types is used for each site. The drift feeding omnivore trophic level is represented exclusively by Hydropsychid caddisfly larvae, which were widely represented among the sampling sites (44 of the 57 sites). The first order (small item) predator trophic level is represented by Perlid stoneflies at all but 4 of the 50 stations where first order predators were taken. At these 4 stations, the average of all available first order predator samples is used. The second order (large item) predator trophic level is represented most consistently, but not overwhelmingly, by Corydalid hellgrammites, which occurred at 24 of the 33 stations where second order predators were taken. In the second order predator figure, Corydalid hellgrammite mercury is plotted alone in addition to average values for all second order predators. For plots which utilize only a single value for "second order predators", the average of all second order predator types at each site is used.

In order to reduce the often voluminous and varied trophic mercury data to a single, inter-comparable value for each site, tissue concentrations were normalized to an intermediate trophic level for each sampling site. The selection of the specific intermediate trophic level for normalization was arbitrary and does not bias comparisons between sites. The data were normalized by trophic level for each site based on an ANCOVA model of the of tissue mercury concentration vs. relative trophic level and site factors. Additional manipulation of data consisted

Fig. 2. Examples of Fish Size vs Mercury Concentration Normalization







of adding back the model residuals to the trophic level-normalized data for each site. This allowed estimation and expression of the variability (standard deviation, confidence limits) of the trophic level-normalized estimates for each site. The average trophic level-normalized mercury concentration for each site (or drainage) was used as one of several tools in comparing relative biological accumulation of mercury between sites.

RESULTS

In the three years of this study, we were able to sample aquatic biota at a total of 57 different stream and river sites throughout the Sierra Nevada foothill gold region (Figure 1, Table 1). Of the 57 sites, all but the two Cosumnes River sites were within the Sierra Nevada watershed of the Sacramento River. Sampling was generally constrained to the months of September through December for a variety of reasons, including (1) prohibitively high flow in late winter through early summer and (2) frequently low invertebrate biomass at other times of year. In 1993, we focused our sampling efforts on tributaries of the Yuba and American River watersheds, while in the second year of the project we worked mainly in the Feather River, Bear River, and Deer Creek drainages. The third year of the project concentrated on more intensive sampling of higher mercury drainages identified previously. In Table 2, biota mercury data for all sites are displayed both numerically and graphically, on a dry weight basis. Fish data for individual trout are presented in Table 3. The biotic mercury data are also displayed on a regional map, with graphic representations of mercury levels in all main trophic levels superimposed in Figure 3 and the approximated normalized mercury values for the 57 sites shown in Figure 4. Mercury trends within individual trophic categories are displayed in Figures 5-10.

Trout

Trout were sampled in sufficient numbers for statistical analysis at 21 of the 24 stream sites where fish were taken, with a total of 134 fish collected and analyzed for filet muscle mercury. This included 120 native rainbow trout, 11 small brown trout, 1 large brown trout, and 2 mid-sized squawfish. Data for individual fish are presented in Table 3 and are displayed on a regional basis in Figures 9 (dry weight ppm Hg) and 10 (wet weight ppm Hg). On a wet weight (fresh) basis, normalized filet muscle mercury concentrations in 250 g trout varied between 0.03 mg kg^{-1} (ppm) and 0.21 mg kg^{-1}. The normalized values represent the synthesis of data from 4-13 fish from each site. Trout from all sites demonstrated a generally positive size vs mercury concentration relationship, with largest fish typically having the highest concentrations. Highest trout mercury was found at sites along the Middle and South Forks of the Yuba River, and the mid

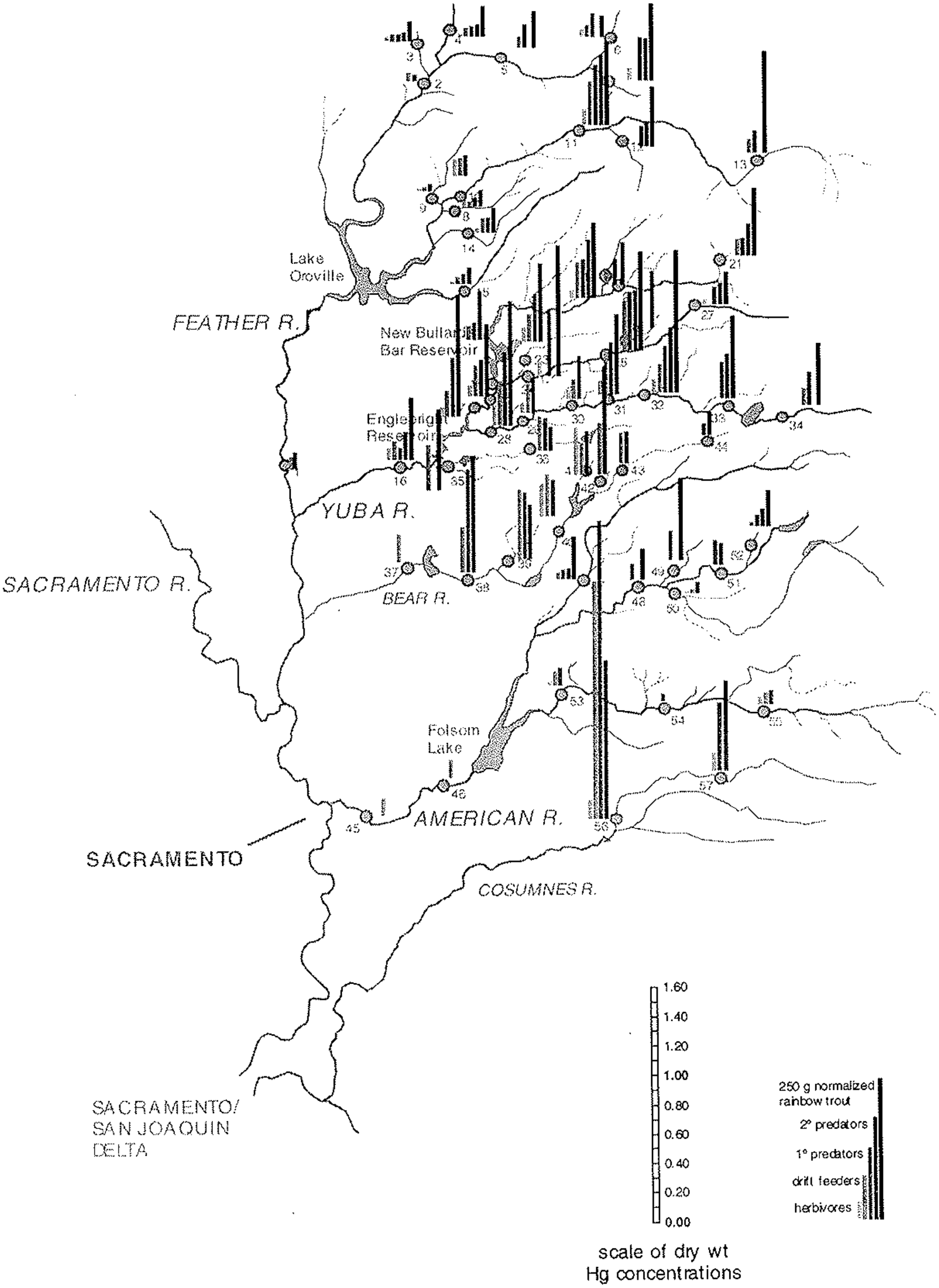


Fig. 3. Superimposed Sierra Nevada biotic mercury data for all major trophic categories

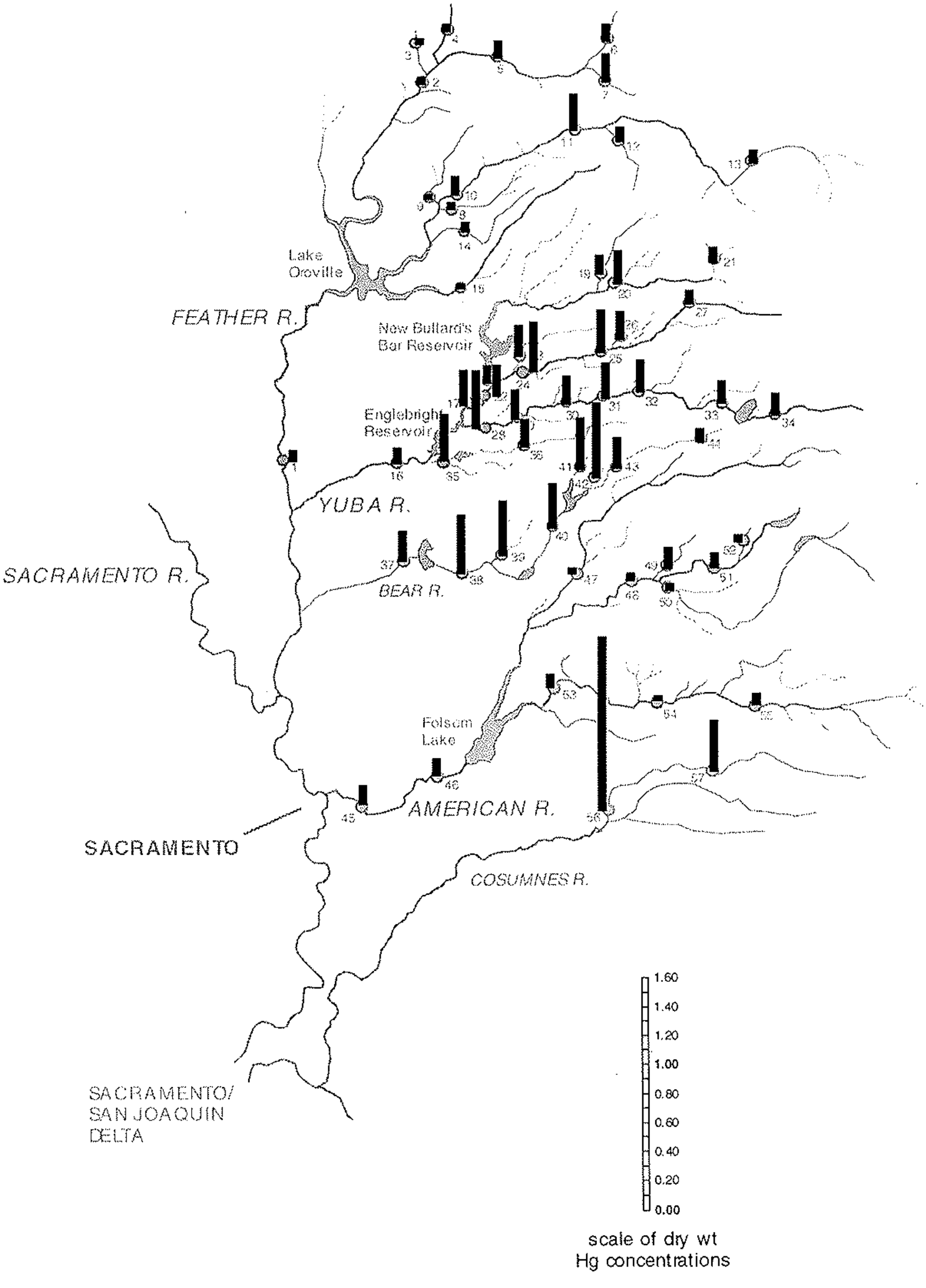


Fig. 4. Trophically Averaged Relative Mercury Levels, For Inter-Site Comparison

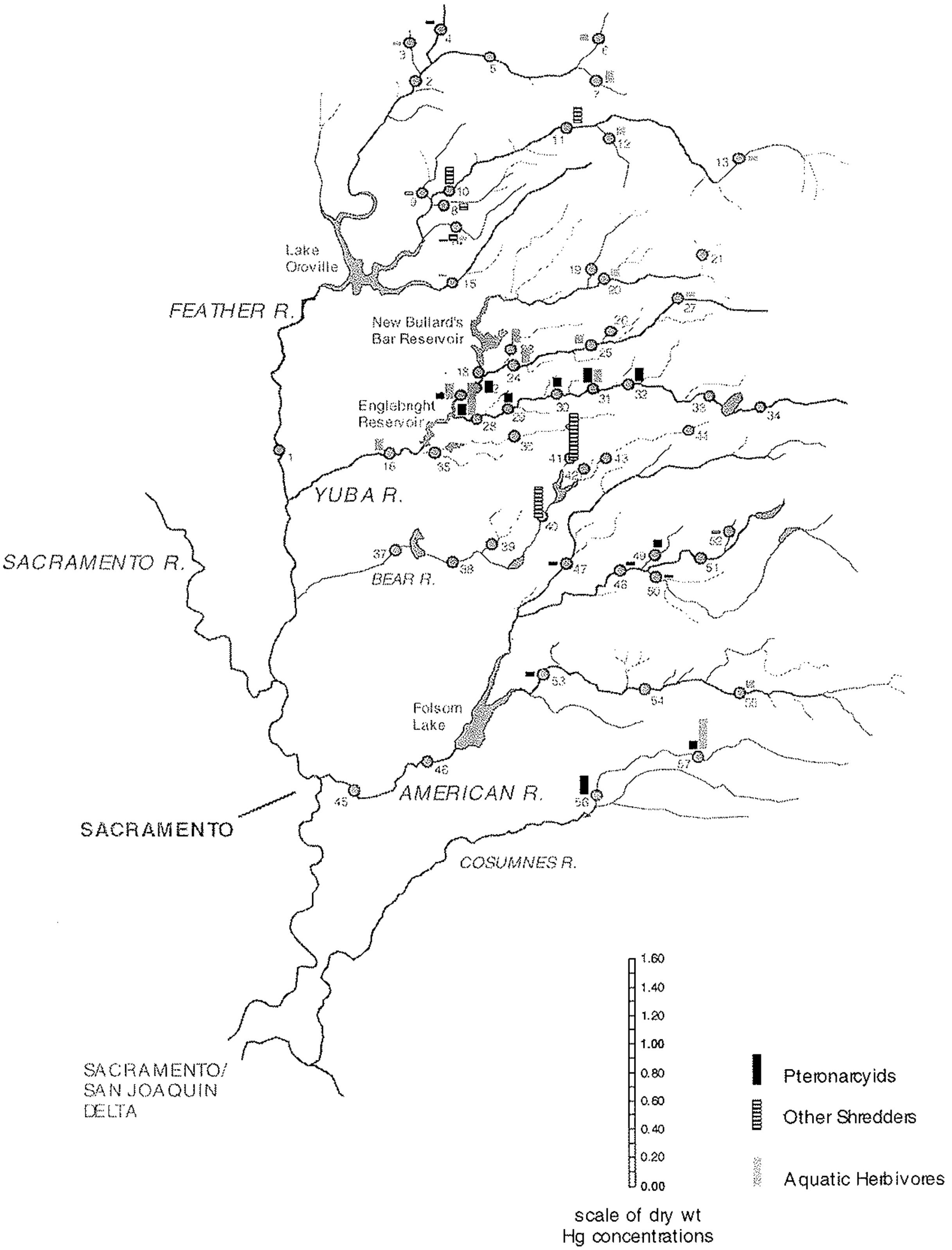


Fig. 5. Mercury in Herbivorous Stream Invertebrates (dry weight ppm)
(Shredders of terrestrial vegetation vs consumers of aquatic plants and algae)

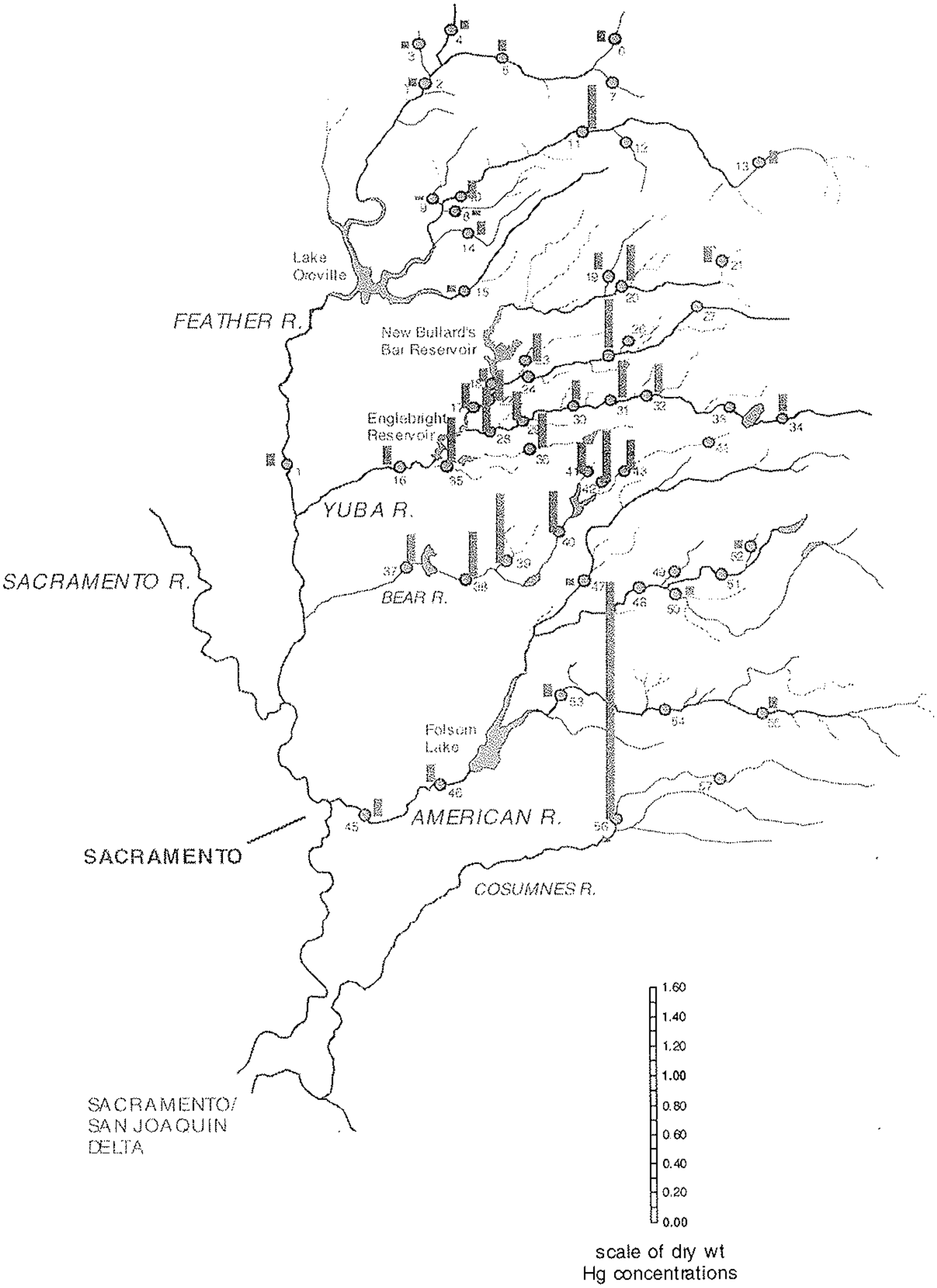


Fig. 6. Mercury in Hydropsychid Caddisfly Larvae (dry weight ppm) (Net-utilizing drift feeders)

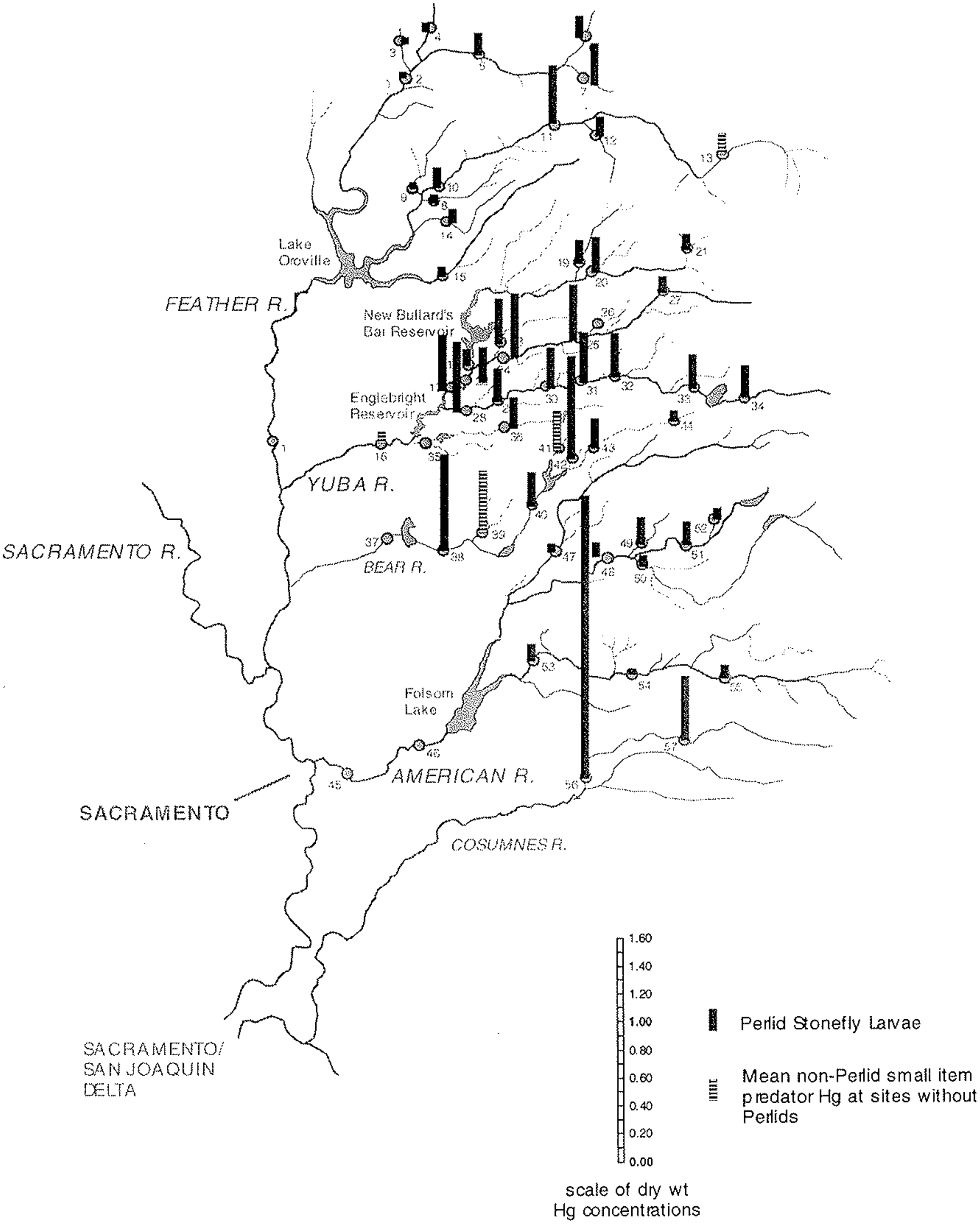


Fig. 7. Mercury in Perlid Stonefly and Other Small Item Predator Larvae
(dry weight ppm)

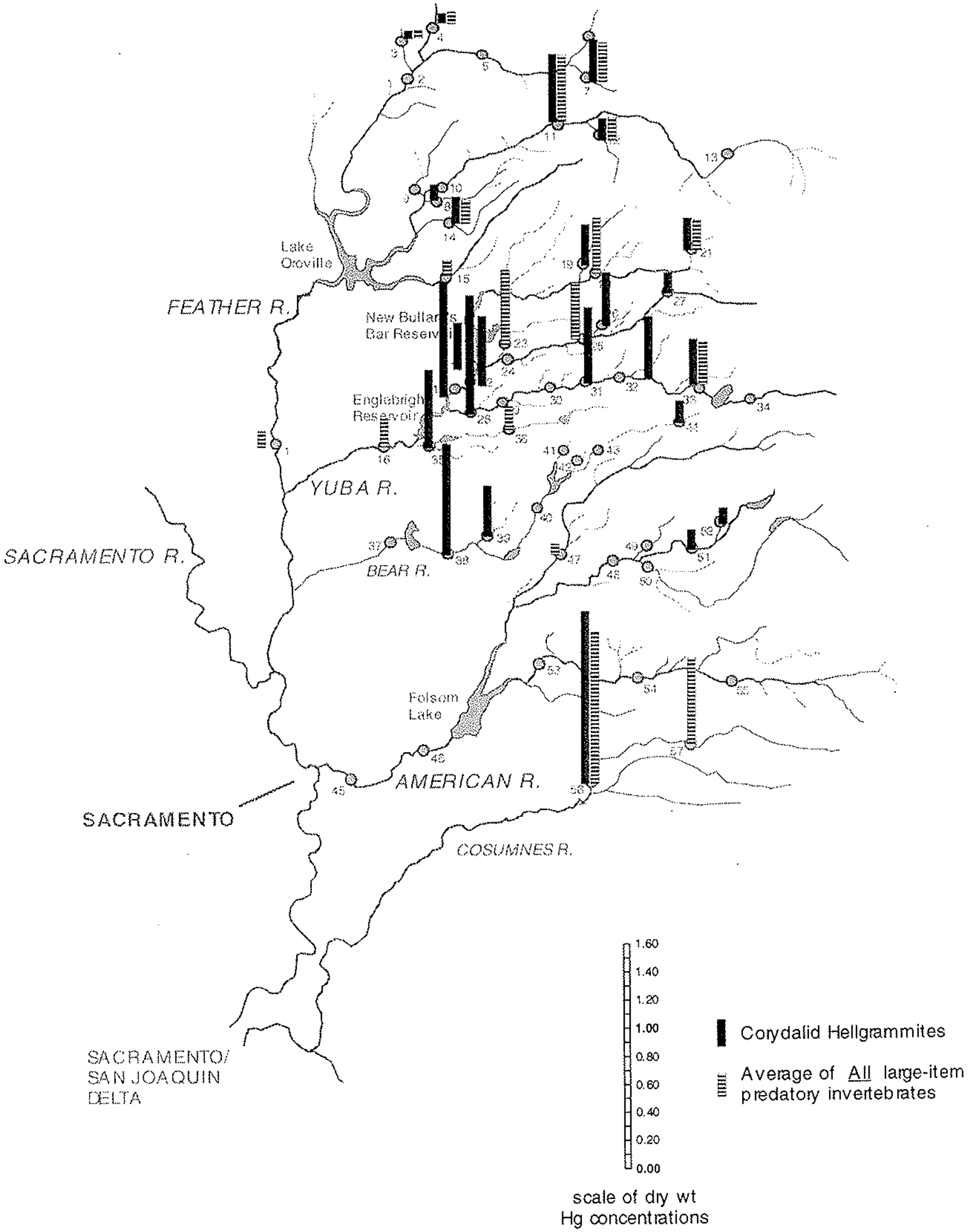


Fig. 8. Mercury in Corydalid Hellgrammite Larvae and Other Large Item Predatory Invertebrates (dry weight ppm)

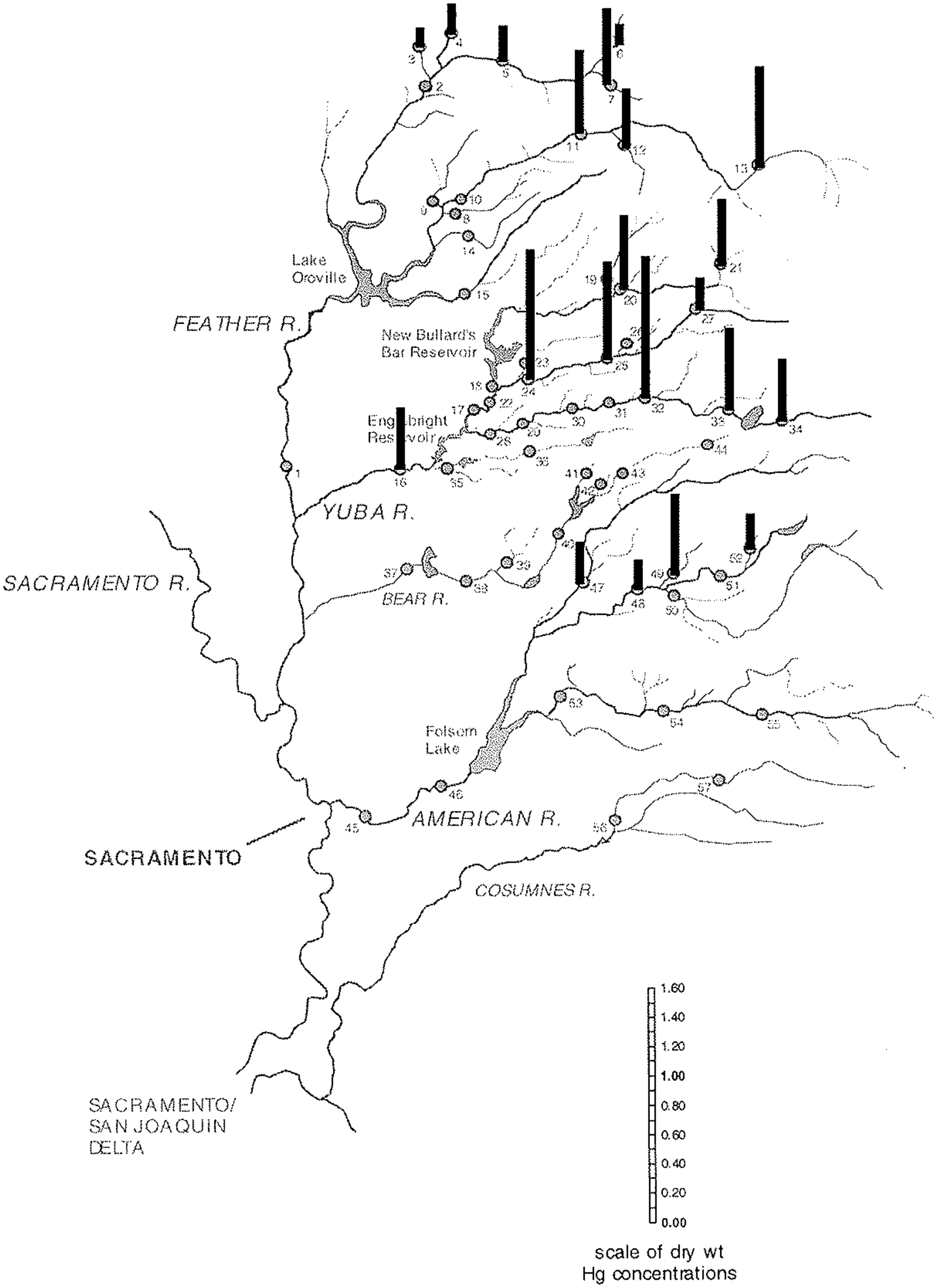


Fig. 9. Mercury in Normalized 250 g Rainbow Trout Muscle
(dry weight ppm, comparable to dry wt invertebrate data)

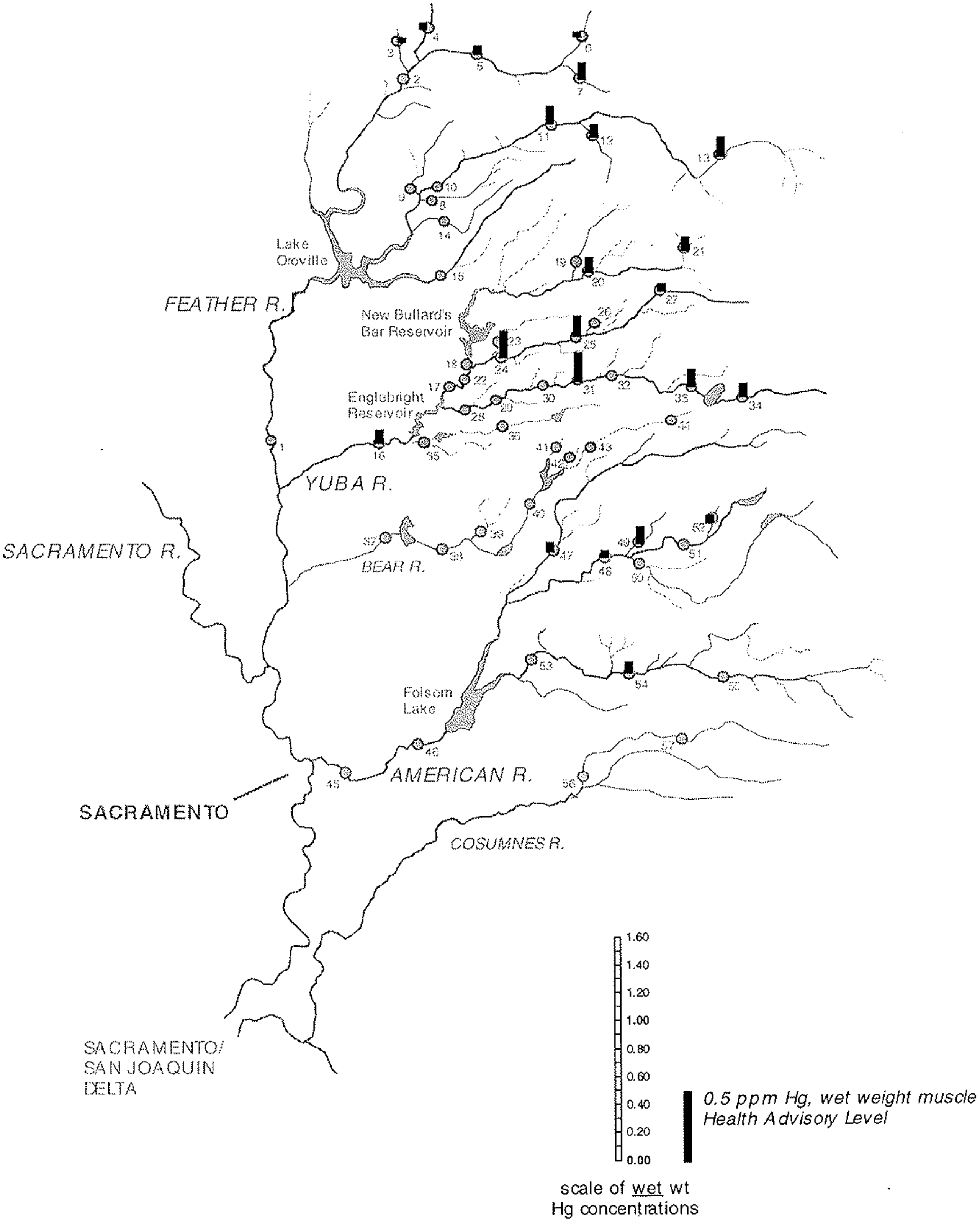
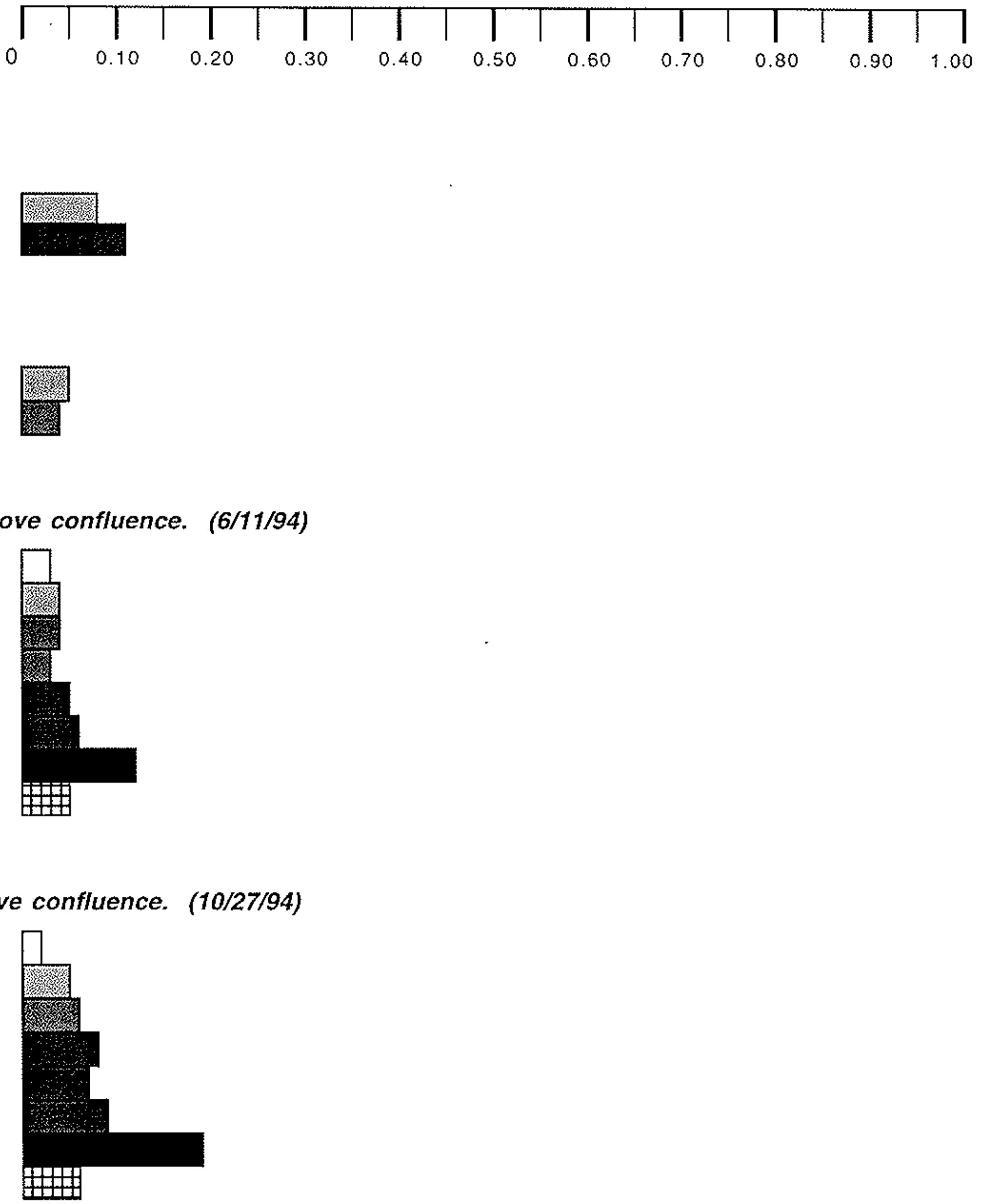


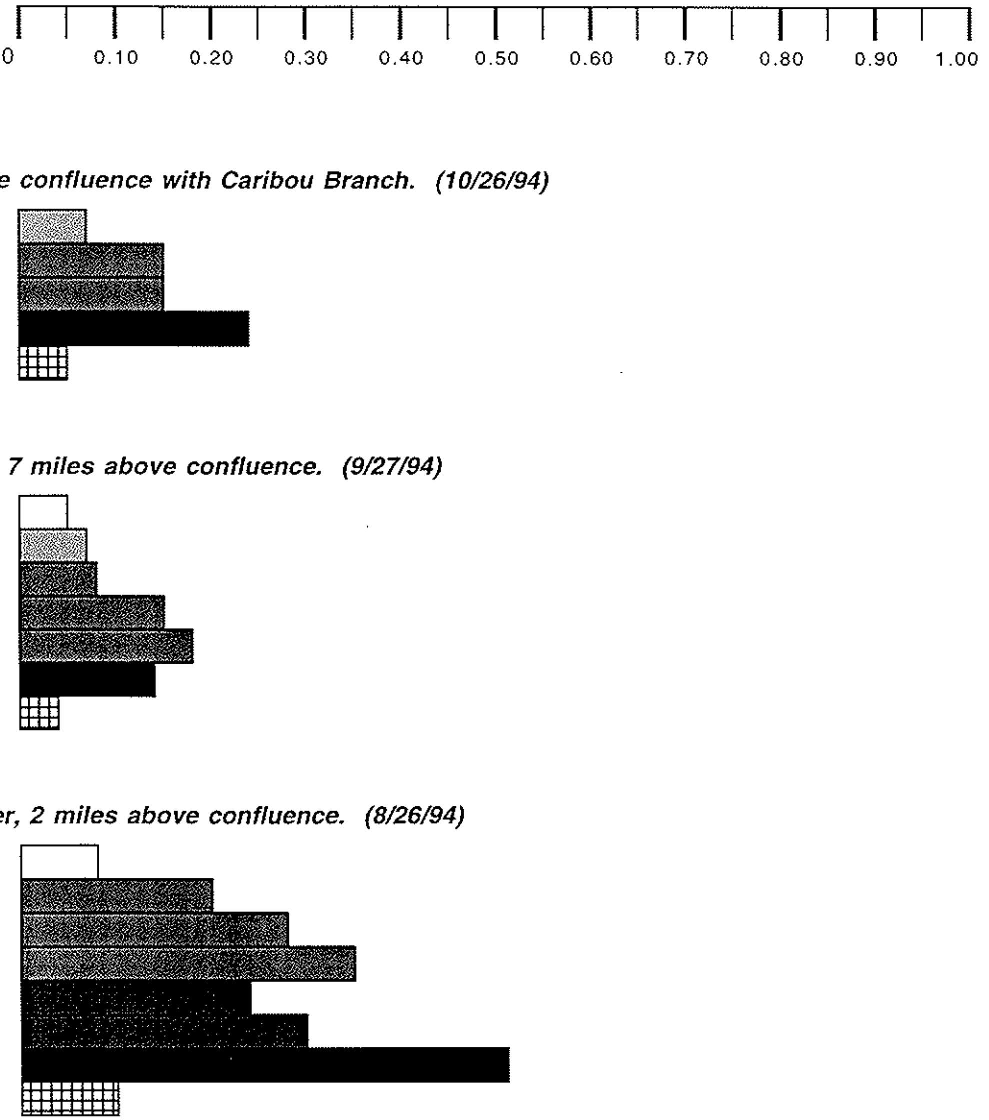
Fig. 10. Mercury in Normalized 250 g Rainbow Trout Filet Muscle
(wet weight ppm, in relation to 0.5 ppm wet weight health advisory level)

Table 2. Biota Mercury Data For All Northwestern Sierra Nevada Project Sites (all as dry wt ppm)



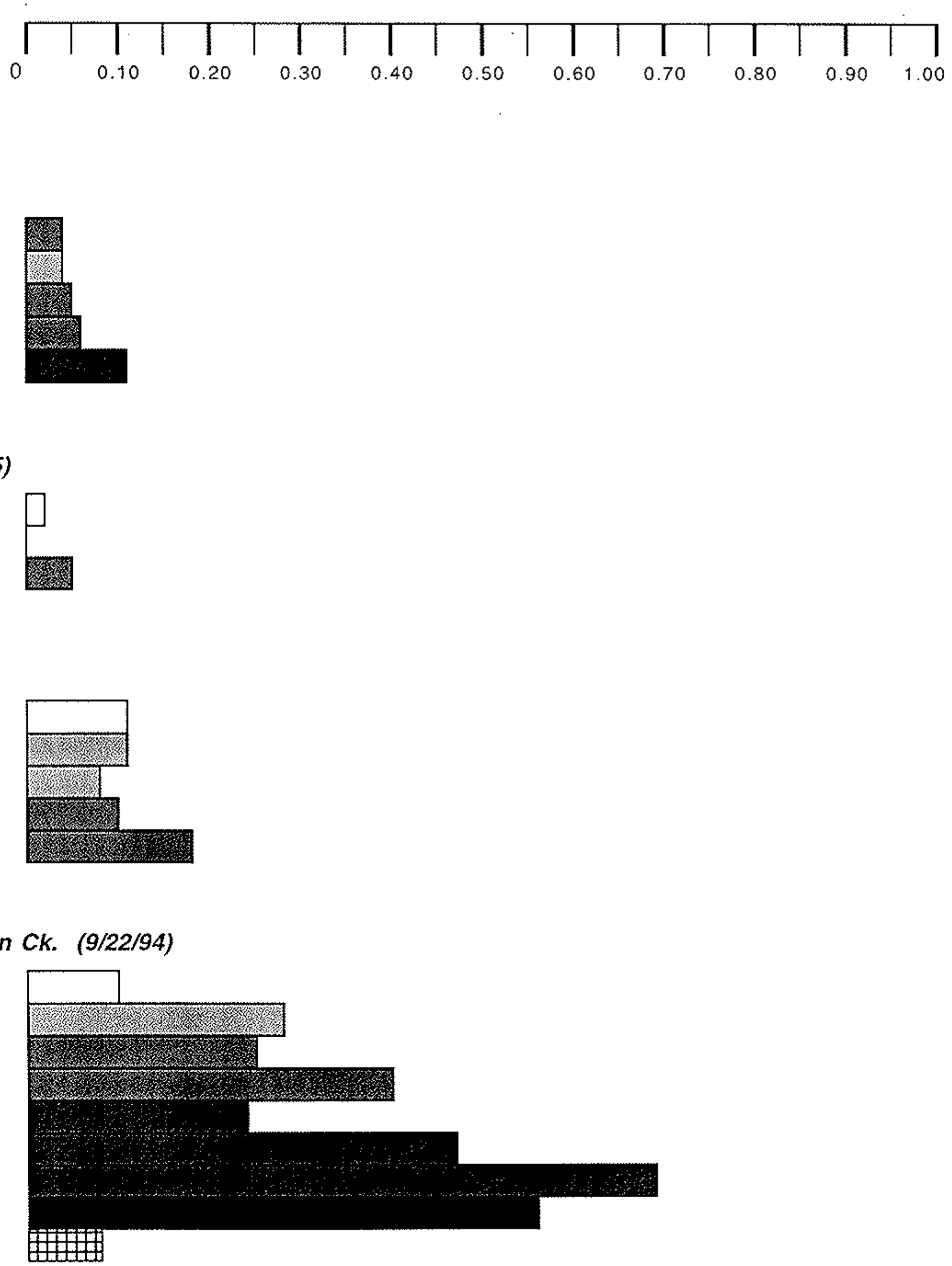
identification	trophic level	Hg
1. Lower Feather River at Live Oak. (11/17/95)		
Hydropsychidae (net caddis)	drift feeder	**0.08**
Gomphidae (dragonfly nymph)	large predator	**0.10**
2. North Fork Feather River at Belden. (10/26/94)		
Hydropsychidae (net caddis)	drift feeder	**0.05**
Perlidae-Gold sp (Callineuria)	small predator	**0.04**
3. Yellow Creek (trib. of North Fk Feather R.), 2 miles above confluence. (6/11/94)		
(Large Mayflies)	herbivore	**0.03**
Hydropsychidae (net caddis)	drift feeder	**0.04**
Rhyacophyllidae (pred. caddis)	small predator	**0.04**
Perlidae (golden stonefly)	small predator	**0.03**
Corydallidae (hellgrammite)	large predator	**0.05**
Tipulidae (cranefly)	large predator	**0.06**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.12***
(trout diet)	(trout diet)	**0.05**
4. Caribou Branch North Fork Feather River, 4 miles above confluence. (10/27/94)		
Pteronarcyidae	leaf shredder	**0.02**
Hydropsychidae (net caddis)	drift feeder	**0.05**
Perlidae-Dark sp (Hesperoperla)	small predator	**0.06**
Gomphidae (dragonfly)	large predator	**0.08**
Corydallidae (hellgrammite)	large predator	**0.07**
Tipulidae (cranefly)	large predator	**0.09**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.20***
(trout diet)	(trout diet)	**0.06**

Table 2. (continued)



identification	trophic level	Hg
5. East Branch of North Fork Feather River,10 miles above confluence with Caribou Branch. (10/26/94)		
Hydropsychidae (net caddis)	drift feeder	**0.07**
Rhyacophyllidae (pred. caddis)	small predator	**0.15**
Perlidae-Dark sp (Hesperoperla)	small predator	**0.15**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.24***
(trout diet)	(trout diet)	**0.05**
6. Indian Creek, tributary to E Branch N Fk Feather River, 7 miles above confluence. (9/27/94)		
Oligoneuriidae (mayfly)	herbivore	**0.05**
Hydropsychidae (net caddis)	drift feeder	**0.07**
Damsefly nymphs	small predator	**0.08**
Perlidae (golden stonefly)	small predator	**0.15**
Rhyacophyllidae (pred. caddis)	small predator	**0.18**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.14***
(trout diet)	(trout diet)	**0.04**
7. Spanish Creek, tributary to E Branch N Fk Feather River, 2 miles above confluence. (8/26/94)		
Ptilodactyllidae (lg aq beetle nymph)	herbivore	**0.08**
Rhyacophyllidae (pred. caddis)	small predator	**0.20**
Damsefly nymphs	small predator	**0.28**
Perlidae (golden stonefly)	small predator	**0.35**
Gomphidae (dragonfly)	large predator	**0.24**
Corydallidae (hellgrammite)	large predator	**0.30**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.51***
(trout diet)	(trout diet)	**0.10**

Table 2. (continued)



identification	trophic level	Hg
8. S Branch M Fk Feather at M Fk Feather. (11/21/95)		
Peltoperlidae (lg/giant)	herb/detritiv	**0.04**
Hydropsychidae (giant)	drift feeder	**0.03**
Perlidae--Callineuria (med/Lg)	small predator	**0.05**
Perlidae--Hesperoperla (lg)	small predator	**0.06**
Hellgrammite (med/lg)	large predator	**0.11**
9. Little N Fk M Fk Feather at M Fk Feather R. (11/21/95)		
Peltoperlidae (med/lg/giant)	herb/detritiv	**0.02**
Hydropsychidae (giant)	drift feeder	**0.00**
Perlidae (lg/giant)	small predator	**0.05**
10. M Fk Feather River at Milsap Bar. (11/21/95)		
Peltoperlidae (med/lg)	herb/detritiv	**0.11**
Hydropsychidae (med)	drift feeder	**0.11**
Hydropsychidae (giant)	drift feeder	**0.08**
Perlidae--Callineuria (lg)	small predator	**0.10**
Perlidae--Hesperoperla (lg)	small predator	**0.18**
11. Middle Fork Feather River, 1 mile below below Nelson Ck. (9/22/94)		
Pteronarcyidae	leaf shredder	**0.10**
Hydropsychidae (net caddis)	drift feeder	**0.28**
Rhyacophyllidae (pred. caddis)	small predator	**0.25**
Perlidae (golden stonefly)	small predator	**0.40**
Gomphidae (dragonfly)	large predator	**0.24**
Corydallidae (hellgrammite)	large predator	**0.47**
Tipulidae (cranefly)	large predator	**0.69**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.56***
(trout diet)	(trout diet)	**0.08**

Table 2. (continued)

identification	trophic level	Hg
12. Nelson Creek, tributary to Middle Fork Feather River, 1 mile above confluence. (9/21/94)		
Limnephilidae (stone case caddis)	herbivore	**0.05**
Perlidae (golden stonefly)	small predator	**0.13**
Corydallidae (hellgrammite)	large predator	**0.15**
Tipulidae (cranefly)	large predator	**0.16**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.40***
(trout diet)	(trout diet)	**0.05**
13. Upper Middle Fork Feather River, 3 miles upstream of Clio. (9/23/94)		
Oligoneuriidae (mayfly)	herbivore	**0.03**
Hydropsychidae (net caddis)	drift feeder	**0.08**
Damselfly Nymphs	small predator	**0.13**
Rhyacophyllidae (pred. caddis)	small predator	**0.16**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.68***
(trout diet)	(trout diet)	**0.07**
14. Fall River (Feather River trib). (11/20/95)		
Pteronarcyidae (med/Lg)	leaf shredder	**0.01**
Mixed Mayflies (lg)	herbivore	**0.03**
Peltoperlidae (lg/giant)	herb/detritiv	**0.05**
Hydropsychidae (giant)	drift feeder	**0.09**
Perlidae-Callineuria (lg/giant)	small predator	**0.09**
Gomphidae (lg)	large predator	**0.13**
Hellgrammite (sm)	large predator	**0.25**
Hellgrammite (med/lg)	large predator	**0.11**

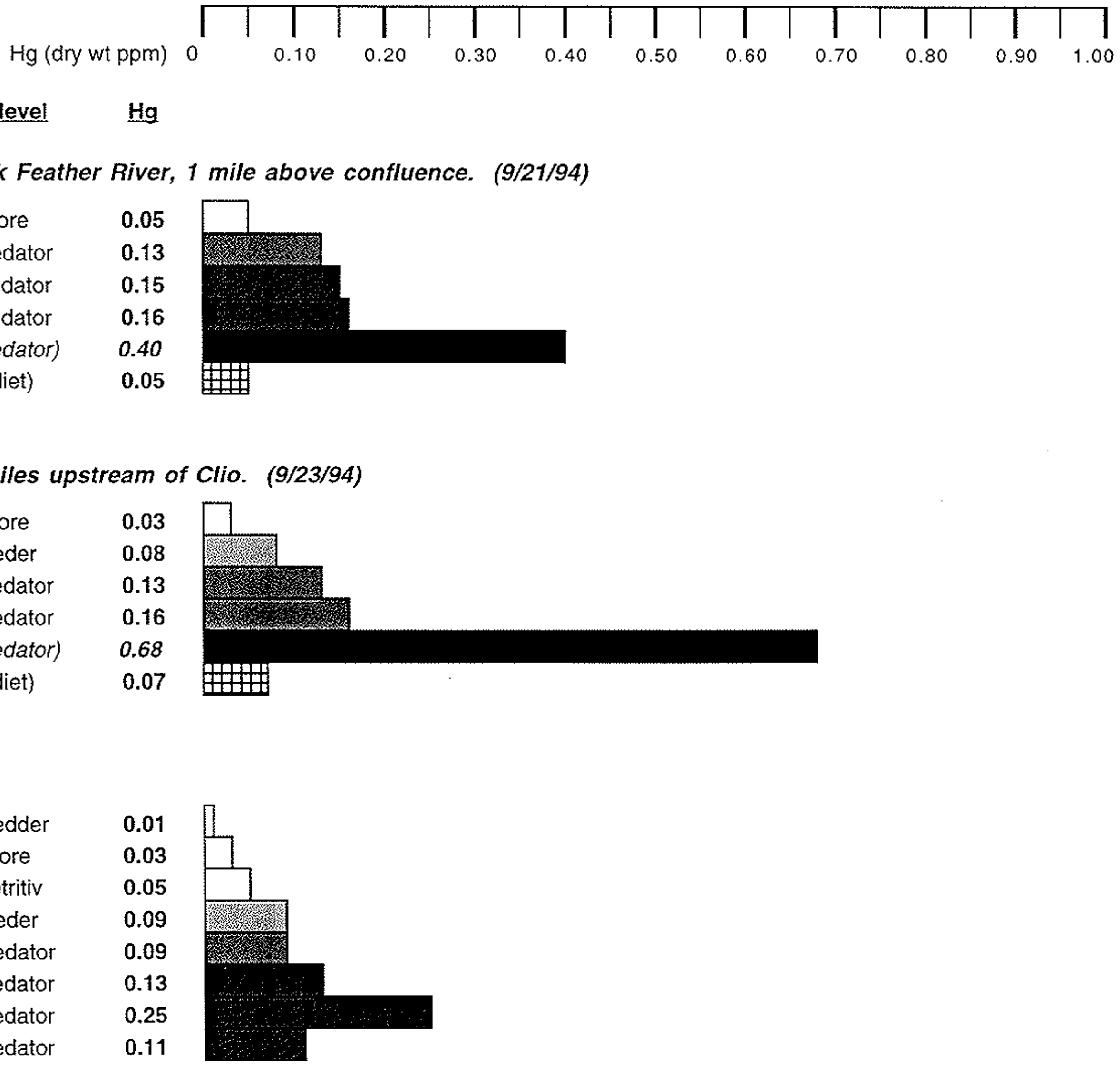
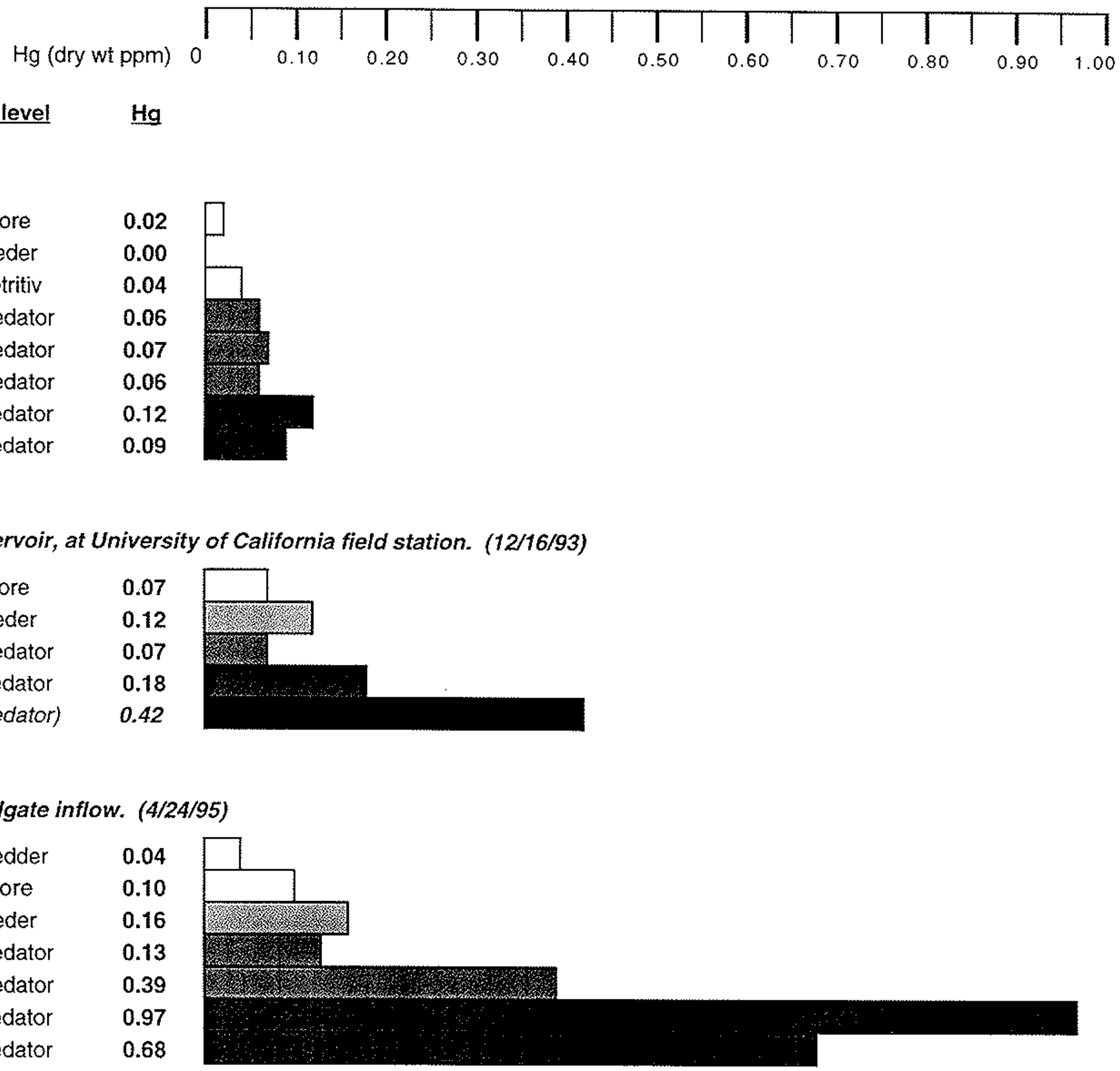


Table 2. (continued)

identification	trophic level	Hg
15. South Fk Feather River. (11/20/95)		
Mayflies (lg)	herbivore	**0.02**
Hydropsychidae (giant)	drift feeder	**0.00**
Peltoperlidae (giant)	herb/detritiv	**0.04**
Perlidae-Callineuria (lg)	small predator	**0.06**
Perlidae-Callineuria (giant)	small predator	**0.07**
Perlidae-Hesperoperla (lg)	small predator	**0.06**
Hellgrammite (sm)	large predator	**0.12**
Hellgrammite (med)	large predator	**0.09**
16. Lower Yuba River below Englebright Reservoir, at University of California field station. (12/16/93)		
Ephemerellidae (mayfly)	herbivore	**0.07**
Hydropsychidae (net caddis)	drift feeder	**0.12**
Perlodidae (stonefly)	small predator	**0.07**
Tipulidae (cranefly)	large predator	**0.18**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.42***
17. North Fk / Middle Fk Yuba River below Colgate inflow. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	**0.04**
Mayflies	herbivore	**0.10**
Hydropsychidae	drift feeder	**0.16**
Perlodidae-sm	small predator	**0.13**
Perlidae-lg	small predator	**0.39**
Hellgrammites-lg	large predator	**0.97**
Hellgrammites-giant	large predator	**0.68**



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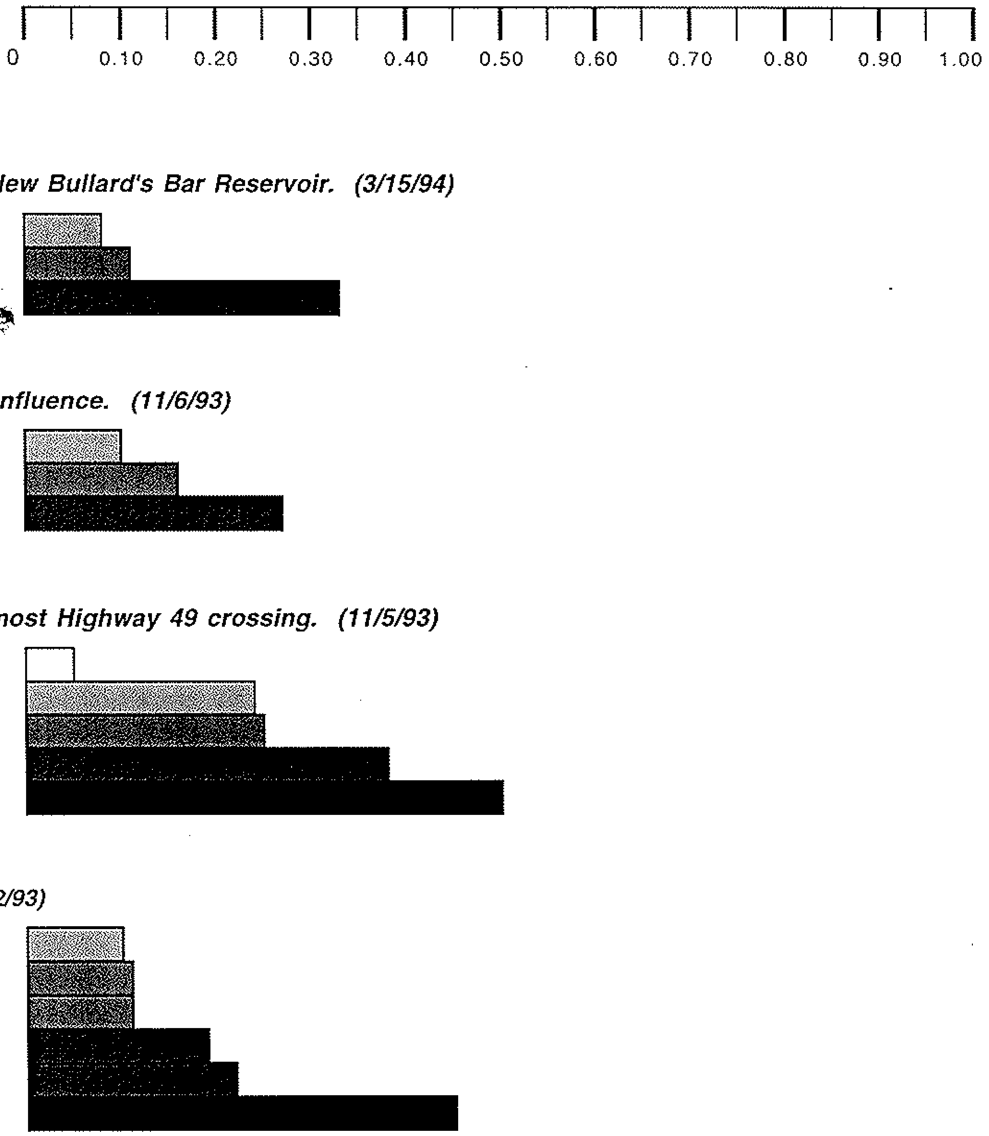
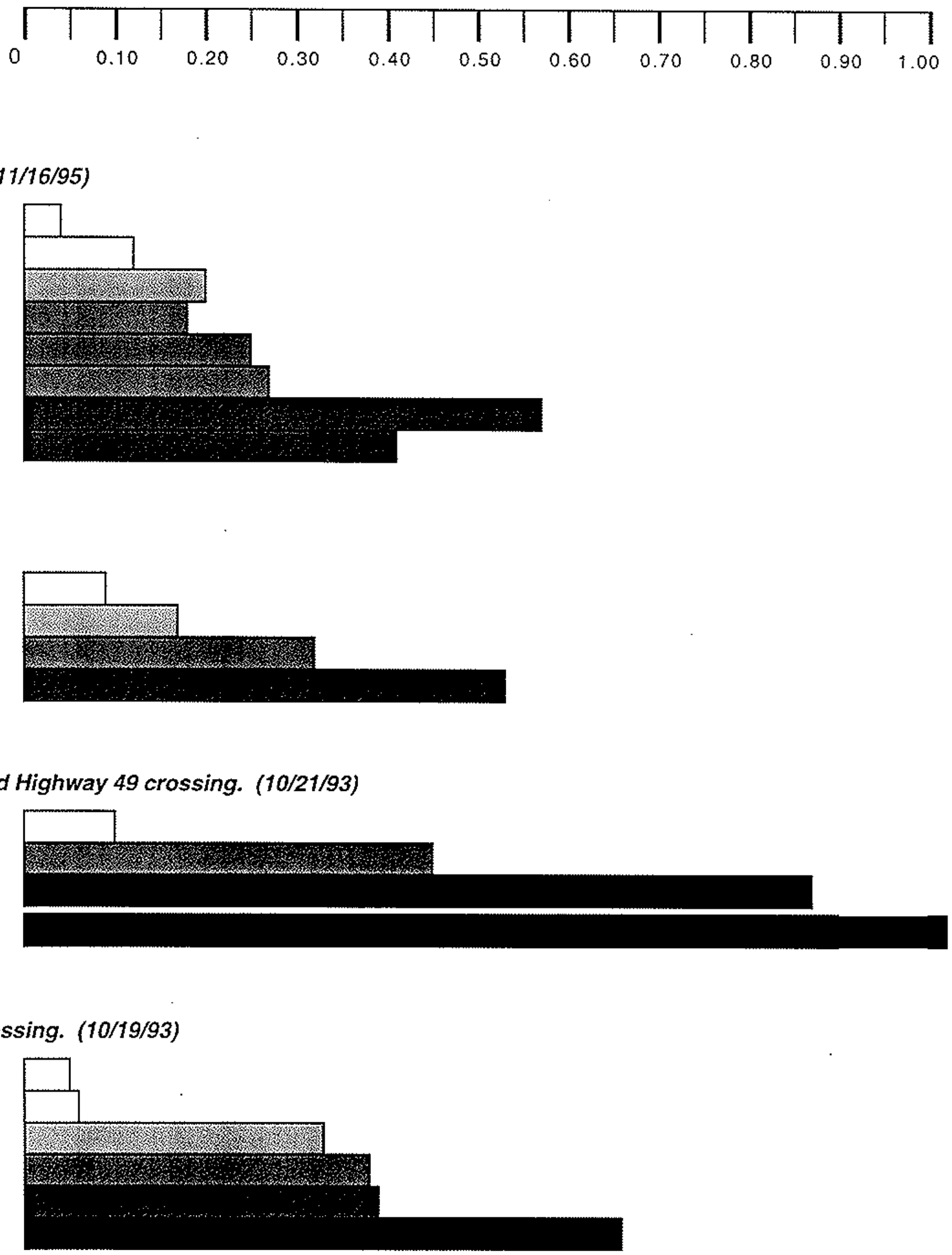


identification	trophic level	Hg
18. North Fork Yuba River constrained (low) flow below New Bullard's Bar Reservoir. (3/15/94)		
Hydropsychidae (net caddis)	drift feeder	0.08
Perlidae (golden stonefly)	small predator	0.11
Corydallidae (hellgrammite)	large predator	0.33
19. Canyon Creek, tributary to N Fk Yuba, just above confluence. (11/6/93)		
Hydropsychidae (net caddis)	drift feeder	0.10
Perlidae (golden stonefly)	small predator	0.16
Corydallidae (hellgrammite)	large predator	0.27
20. North Fork Yuba River, 2 miles downstream of westmost Highway 49 crossing. (11/5/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.05
Hydropsychidae (net caddis)	drift feeder	0.24
Perlidae (golden stonefly)	small predator	0.25
Tipulidae	large predator	0.38
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.50*
21. Downie River, tributary to N FK Yuba, at Downieville. (11/2/93)		
Hydropsychidae (net caddis)	drift feeder	0.10
Perlodidae (stonefly)	small predator	0.11
Perlidae (golden stonefly)	small predator	0.11
Tipulidae (cranefly)	large predator	0.19
Corydallidae (hellgrammite)	large predator	0.22
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.45*

Table 2. (continued)

identification	trophic level	Hg
22. Middle Fork Yuba River, just upstream of Colgate inflow. (11/16/95)		
Pteronarcyidae (sm)	leaf shredder	0.04
Pteronarcyidae (Lg)	leaf shredder	0.11
Hydropsychidae	drift feeder	0.20
Perlodidae (med/Lg)	small predator	0.18
Perlidae (Lg)	small predator	0.25
Damsel nymphs	small predator	0.27
Hellgrammites (sm/Med)	large predator	0.57
Hellgrammites (Lg/giant)	large predator	0.41
23. Oregon Creek at Middle Fk Yuba. (11/9/95)		
Ptilodactylidae (lg)	herbivore	0.09
Hydropsychidae	drift feeder	0.17
Perlidae-Callineuria (med/Lg)	small predator	0.32
Tipulidae (lg)	large predator	0.53
24. Middle Fork Yuba River, just upstream of Oregon Creek and Highway 49 crossing. (10/21/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.10
Perlidae (golden stonefly)	small predator	0.45
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.87*
Mean 250 g Squawfish	*(fish predator)*	*1.87*
25. Middle Fork Yuba River, 1 mile upstream of Tyler Foote crossing. (10/19/93)		
Pteronarcyidae (giant stonefly),1 yr	leaf shredder	0.05
Pteronarcyidae; large (2 yr)	leaf shredder	0.06
Hydropsychidae (net caddis)	drift feeder	0.33
Perlidae (golden stonefly)	small predator	0.38
Gomphidae (dragonfly)	large predator	0.39
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.66*



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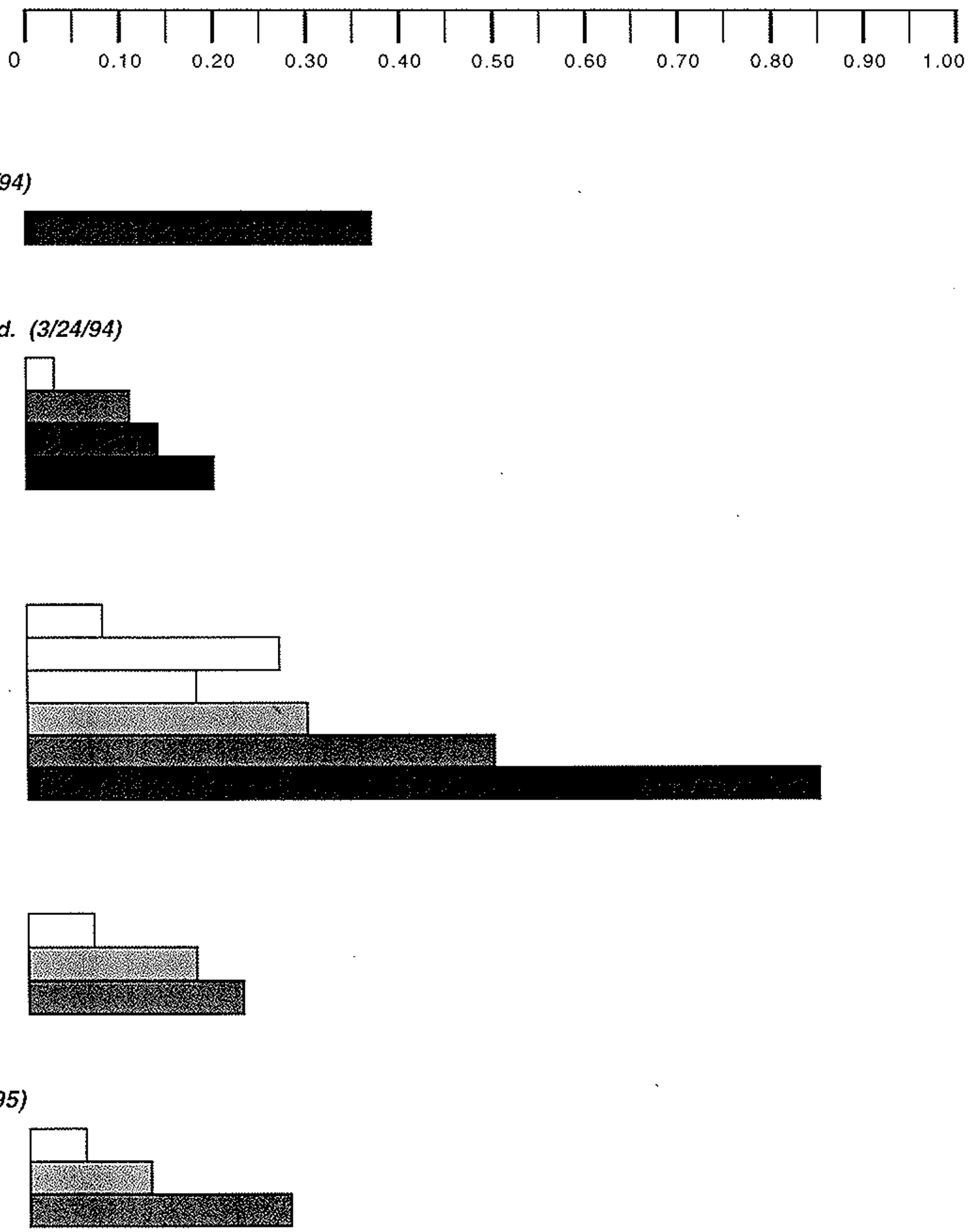
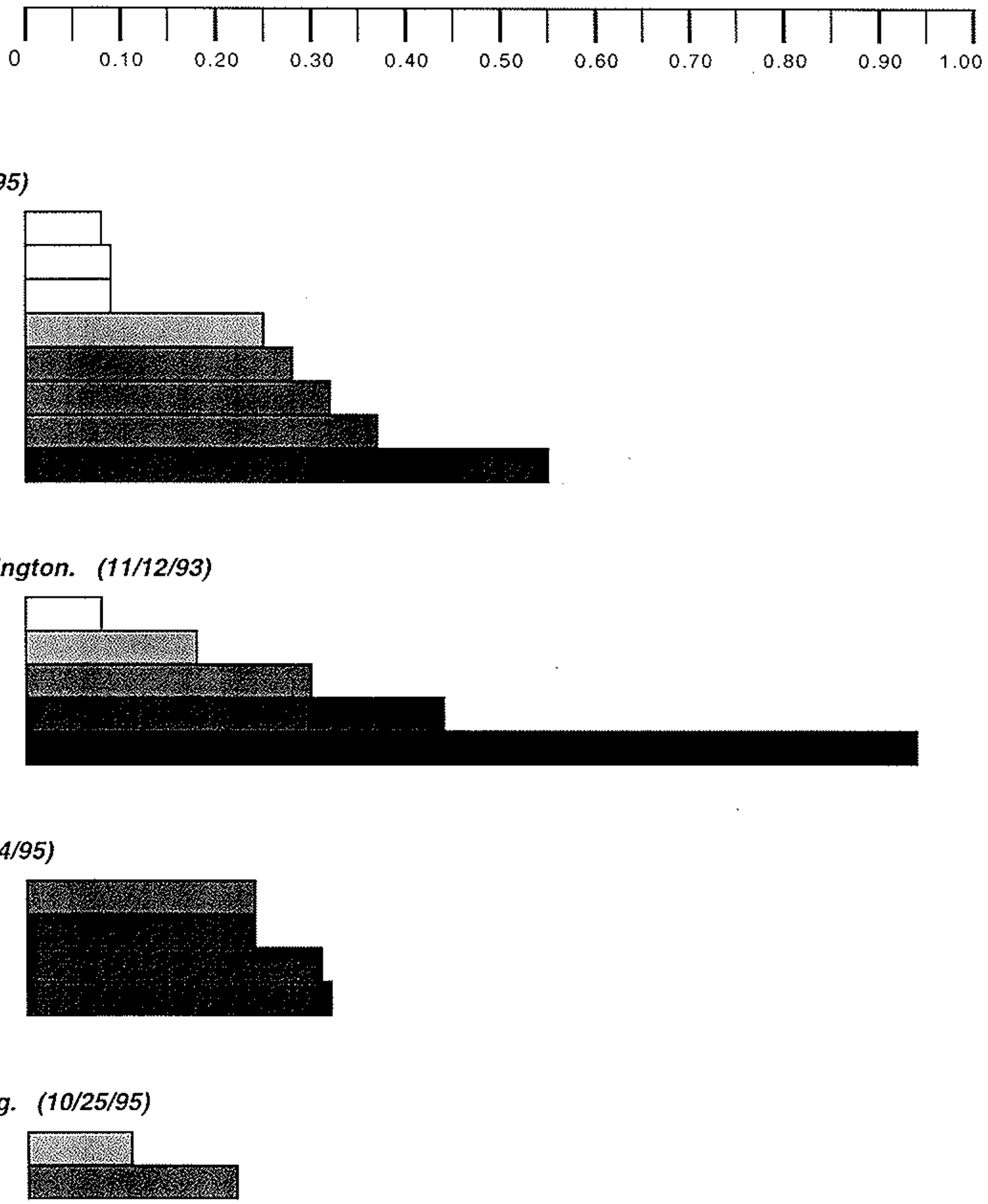


identification	trophic level	Hg
26. Kanaka Ck (Middle Fork Yuba trib) near M Fk Yuba. (10/14/94)		
Corydalidae	large predator	**0.37**
27. Middle Fork Yuba River, 1 mile upstream of Plumbago Road. (3/24/94)		
Peltoperlidae (stonefly)	herbivore	**0.03**
Perlidae (golden stonefly)	small predator	**0.11**
Corydallidae (hellgrammite)	large predator	**0.14**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.20***
28. South Fork Yuba River at Bridgeport. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	**0.08**
Mayflies	herbivore	**0.27**
Ptilodactylidae	herbivore	**0.18**
Hydropsychidae	drift feeder	**0.30**
Perlidae	small predator	**0.50**
Hellgrammites-lg	large predator	**0.85**
29. South Fork Yuba River at Hwy 49. (11/10/95)		
Pteronarcyidae (sm/med)	leaf shredder	**0.06**
Hydropsychidae	drift feeder	**0.18**
Perlidae (med/Lg)	small predator	**0.23**
30. South Fork Yuba River at Purdon Crossing. (11/10/95)		
Pteronarcyidae (lg)	leaf shredder	**0.06**
Hydropsychidae	drift feeder	**0.13**
Perlidae-Callineuria (med/lg)	small predator	**0.28**

Table 2. (continued)



identification	trophic level	Hg
31. South Fork Yuba River at Edward's Crossing. (10/4/95)		
Mayflies	herbivore	0.08
Pteronarcyidae-sm	leaf shredder	0.09
Pteronarcyidae-lg	leaf shredder	0.09
Hydropsychidae-sm/med	drift feeder	0.25
Perlidae-sm	small predator	0.28
Perlidae-med	small predator	0.32
Perlidae-large	small predator	0.37
Hellgrammite-med	large predator	0.55
32. South Fork Yuba River, 1 mile downstream of Washington. (11/12/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	0.08
Hydropsychidae (net caddis)	drift feeder	0.18
Perlidae (golden stonefly)	small predator	0.30
Corydallidae (hellgrammite)	large predator	0.44
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.94*
33. South Fork Yuba River below Lake Spaulding. (10/24/95)		
Perlidae (m/Lg)	small predator	0.24
Gomphidae (med)	large predator	0.24
Tipulidae (med/lg)	large predator	0.31
Hellgrammites (sm/med)	large predator	0.32
34. South Fork Yuba River 2 miles above Lake Spaulding. (10/25/95)		
Hydropsychidae (giant)	drift feeder	0.11
Perlidae (med/lg)	small predator	0.22

Table 2. (continued)

identification	trophic level	Hg
35. Deer Creek below Lake Wildwood, at Mooney Flat Road. (12/9/94)		
Hydropsychidae (net caddis)	drift feeder	0.30
Corydallidae (hellgrammite)	large predator	0.55
36. Deer Creek at Bittney Spring Road. (12/9/94)		
Hydropsychidae (net caddis)	drift feeder	0.23
Perlidae (golden stonefly)	small predator	0.22
Tipulidae (cranefly)	large predator	0.16
37. Bear River below Camp Far West Reservoir. (12/8/94)		
Hydropsychidae (net caddis)	net collector	0.17
38. Bear River at Highway 49 crossing. (12/7/94)		
Hydropsychidae (net caddis)	drift feeder	0.29
Rhyacophyllidae (pred. caddis)	small predator	0.34
Perlidae-Dark sp (Hesperoperla)	smallpredator	0.69
Corydallidae (hellgrammite)	large predator	0.77
39. Wolf Creek, tributary to Bear River, 2 miles above confluence. (12/7/94)		
Hydropsychidae (net caddis)	drift feeder	0.46
Perlodidae (stonefly)	small predator	0.44
Tipulidae (cranefly)	large predator	0.35

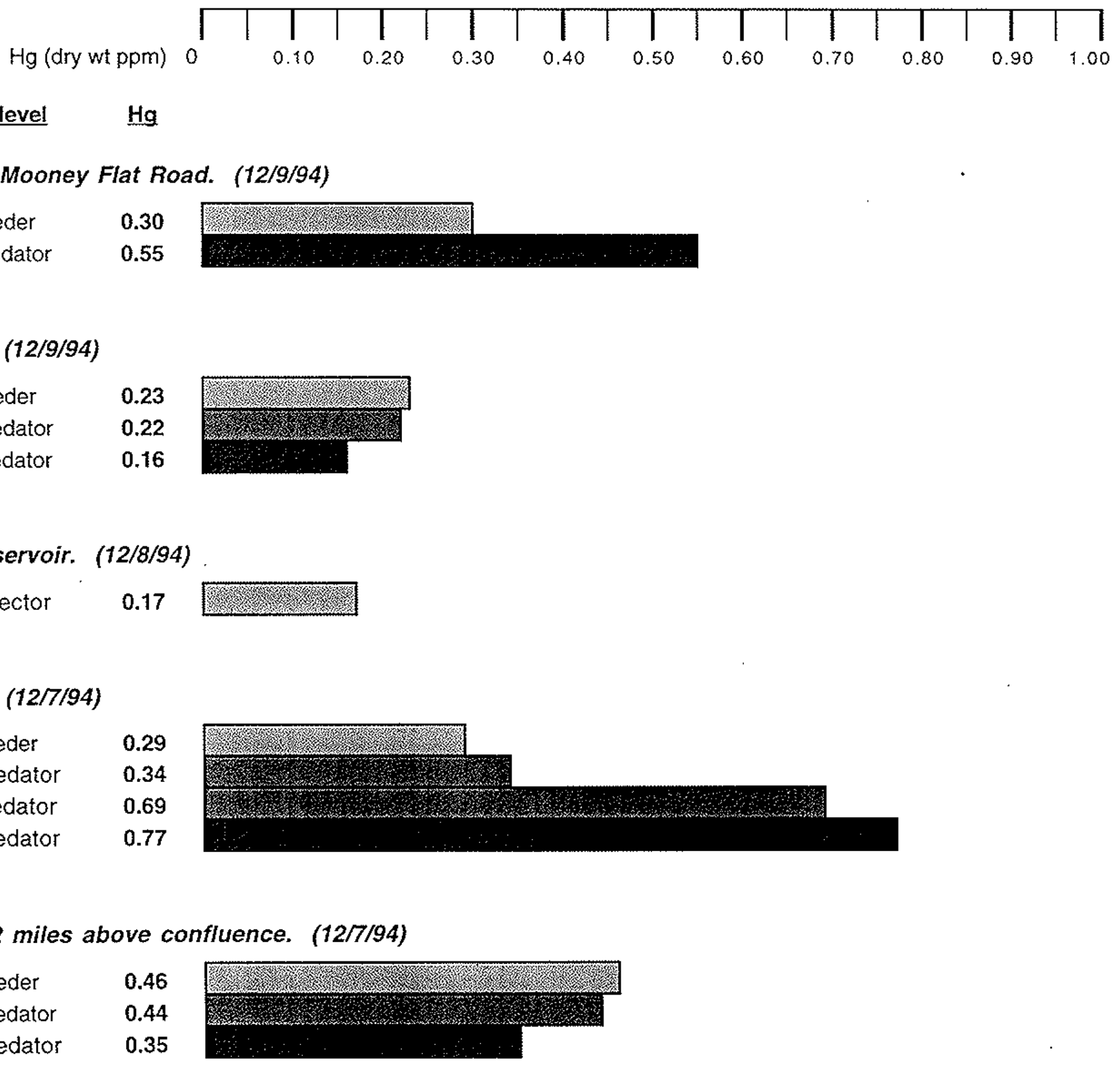


Table 2. (continued)

identification	trophic level	Hg
40. Bear River below Rollins Reservoir. (10/12/95)		
Peltoperlidae (med/lg)	small predator	**0.21**
Hydropsychidae	drift feeder	**0.27**
Perlidae-Hesperoperla (Med/lg)	small predator	**0.24**
41. Greenhorn Creek (Bear River trib). (10/13/95)		
Peltoperlidae (med/lg)	small predator	**0.32**
Hydropsychidae	drift feeder	**0.21**
Damselfly Nymphs	small predator	**0.28**
42. Steephollow Creek (Bear River trib). (10/13/95)		
Hydropsychidae	drift feeder	**0.35**
Perlidae (med/lg)	small predator	**0.74**
43. Bear River above Rollins Reservoir. (10/13/95)		
Hydropsychidae	drift feeder	**0.20**
Perlidae-Callineuria (med/Lg)	small predator	**0.21**
44. Bear River headwaters near Lake Spaulding. (10/24/95)		
Perlidae (med/Lg)	small predator	**0.07**
Hellgrammites (lg)	large predator	**0.15**
45. Lower American River at Howe Avenue. (12/16/94)		
Hydropsychidae (net caddis)	drift feeder	**0.11**

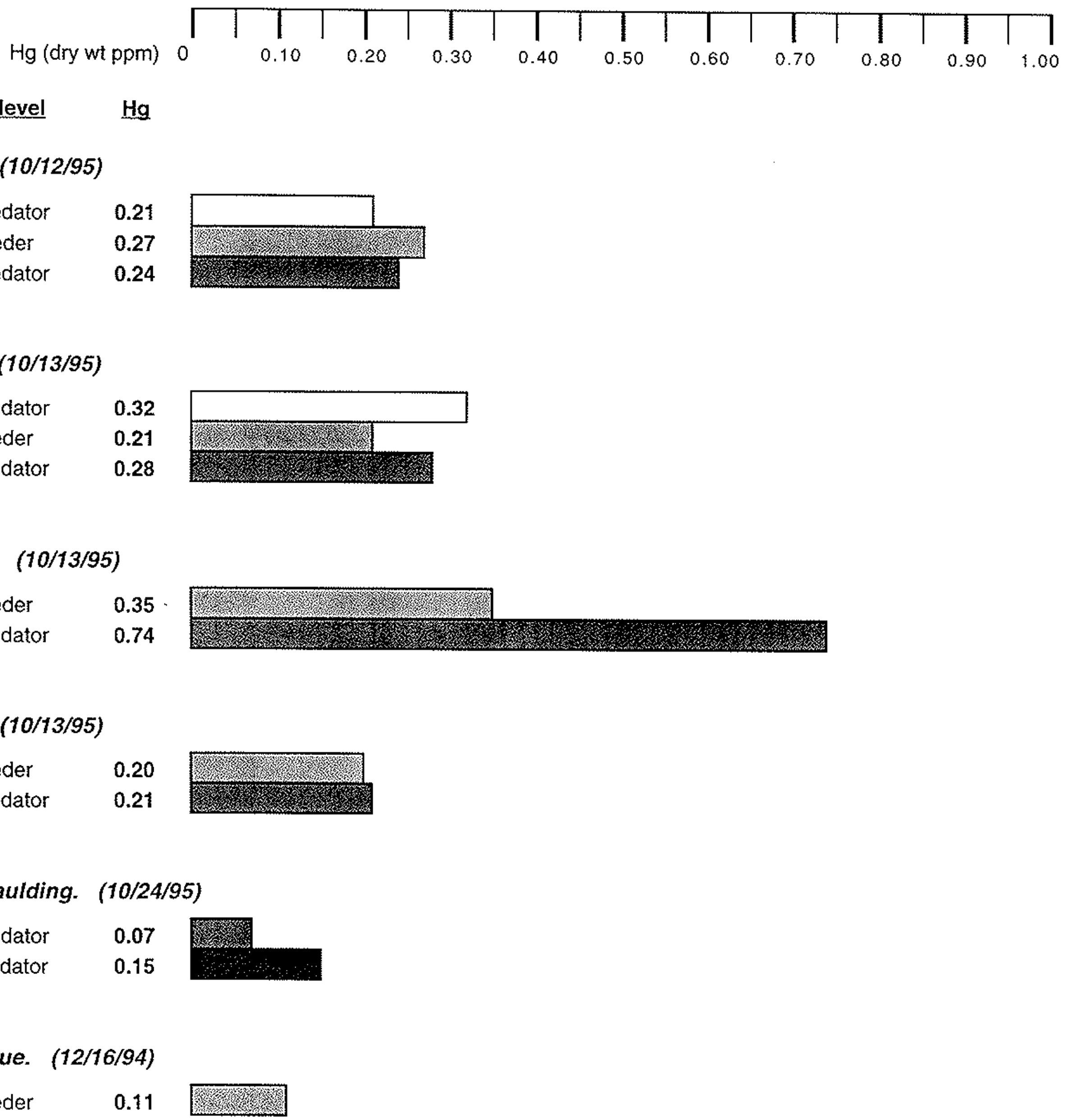
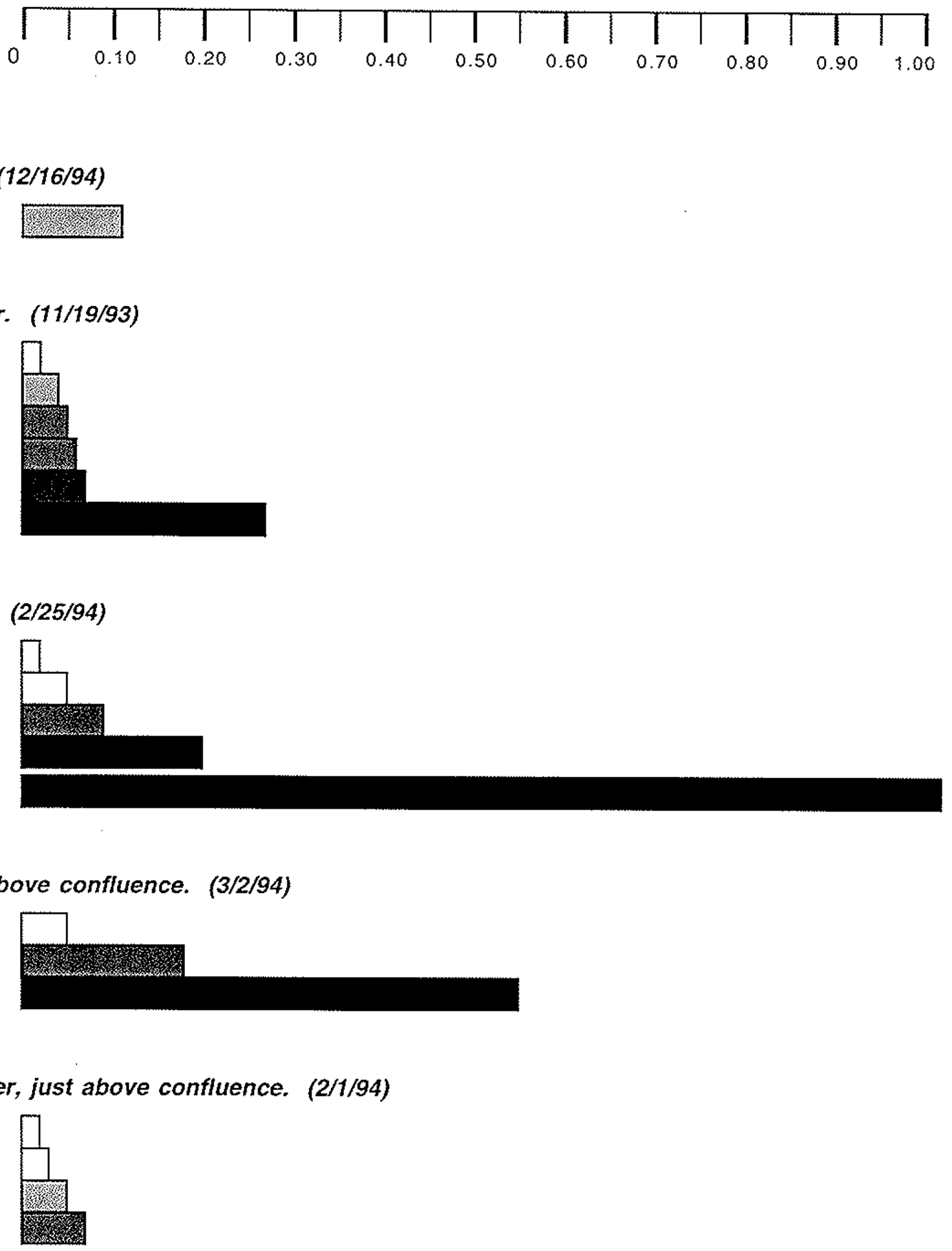


Table 2. (continued)



identification	trophic level	Hg
46. Lower American River, 1 mile below Lake Natoma. (12/16/94)		
Hydropsychidae (net caddis)	drift feeder	**0.11**
47. North Fork American River in vicinity of Humbug Bar. (11/19/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	**0.02**
Hydropsychidae (net caddis)	drift feeder	**0.04**
Perlidae-Gold sp (Callineuria)	small predator	**0.05**
Perlidae-Dark sp (Hesperoperla)	small predator	**0.06**
Gomphidae (dragonfly)	large predator	**0.07**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.27***
48. Middle Fork American River below Oxbow Reservoir. (2/25/94)		
Pteronarcyidae (giant stonefly)	leaf shredder	**0.02**
Perlodidae (stonefly)	herbivore	**0.05**
Perlidae (golden stonefly)	small predator	**0.09**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.20***
950 g Brown Trout (dry ppm)	*(fish predator)*	***1.68***
49. North Fork of the Middle Fk American River, 1 mile above confluence. (3/2/94)		
Pteronarcyidae (giant stonefly)	leaf shredder	**0.05**
Perlidae (golden stonefly)	small predator	**0.18**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.55***
50. Rubicon River, tributary to Middle Fork American River, just above confluence. (2/1/94)		
Pteronarcyidae (giant stonefly)	leaf shredder	**0.02**
Perlodidae (stonefly)	herbivore	**0.03**
Hydropsychidae (net caddis)	drift feeder	**0.05**
Perlidae (golden stonefly)	small predator	**0.07**

Table 2. (continued)

identification	trophic level	Hg
51. Middle Fork American River at "End of World". (2/1/94)		
Perlidae (golden stonefly)	small predator	**0.16**
Corydallidae (hellgrammite)	large predator	**0.14**
52. Duncan Creek, tributary to Middle Fork American River, 3 miles above confluence. (11/16/93)		
Peltoperlidae (stonefly)	herbivore	**0.02**
Hydropsychidae (net caddis)	drift feeder	**0.05**
Perlidae (golden stonefly)	small predator	**0.07**
Corydallidae (hellgrammite)	large predator	**0.11**
Mean 250 g Trout (dry ppm)	*(insect predator)*	***0.24***
53. South Fork American River above Folsom Lake. (12/16/94)		
Pteronarcyidae	leaf shredder	**0.03**
Hydropsychidae (net caddis)	drift feeder	**0.08**
Perlodidae- Osobenus	small predator	**0.07**
Perlidae-Gold sp (Callineuria)	small predator	**0.10**
Perlidae-Dark sp (Hesperoperla)	small predator	**0.14**
54. South Fork American River below Slab Creek Reservoir. (12/20/93)		
Perlidae (golden stonefly)	small predator	**0.04**
55. South Fork American River, 1 mile upstream of Pacific. (4/11/94)		
Heptageneidae (mayfly)	herbivore	**0.03**
Ephemerellidae (mayfly)	herbivore	**0.05**
Ptilodactylidae (lg aq beetle nymph)	herbivore	**0.07**
Hydropsychidae (net caddis)	drift feeder	**0.07**
Perlidae-Gold sp (Callineuria)	small predator	**0.08**
Perlidae-Dark sp (Hesperoperla)	small predator	**0.09**

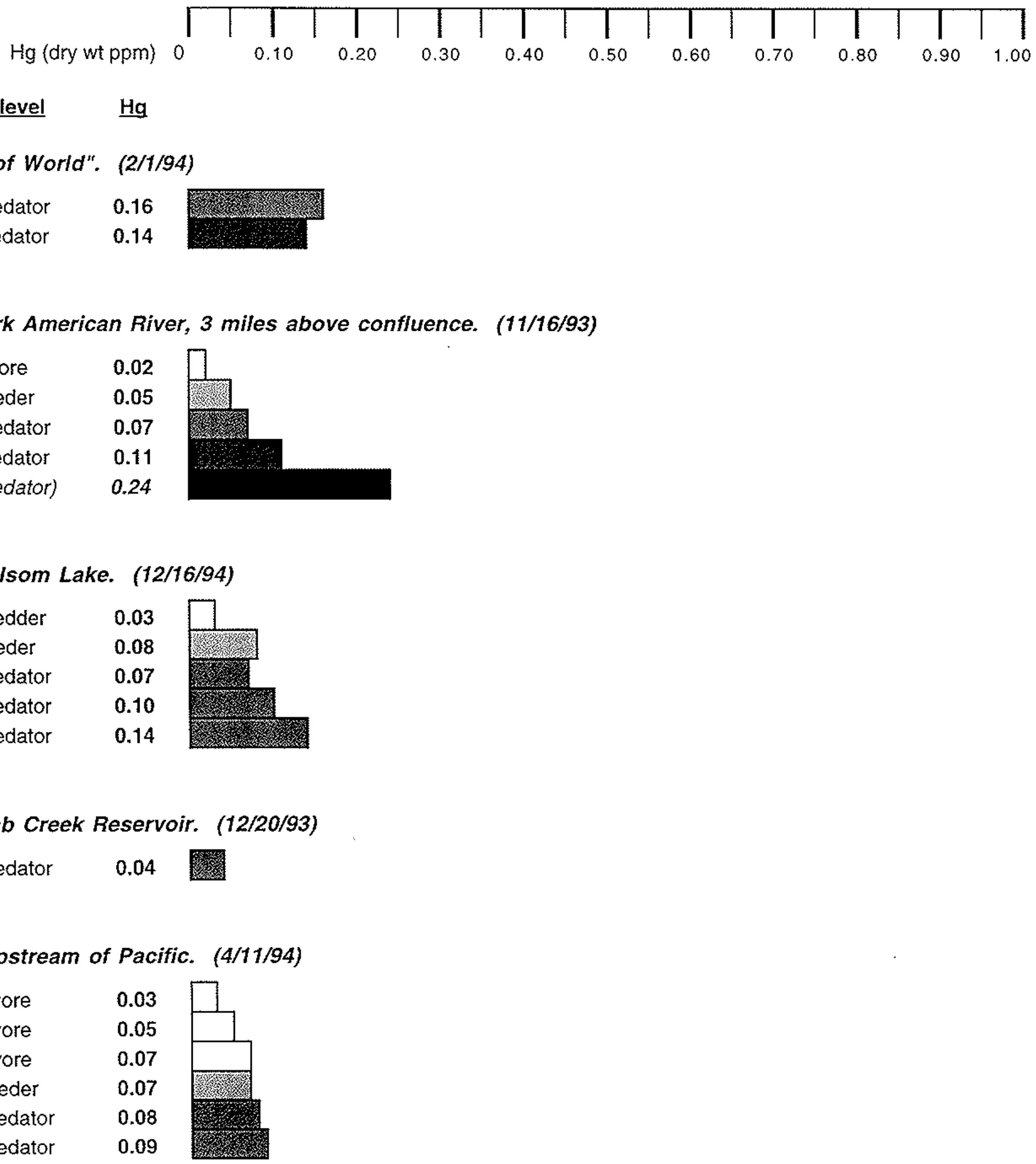
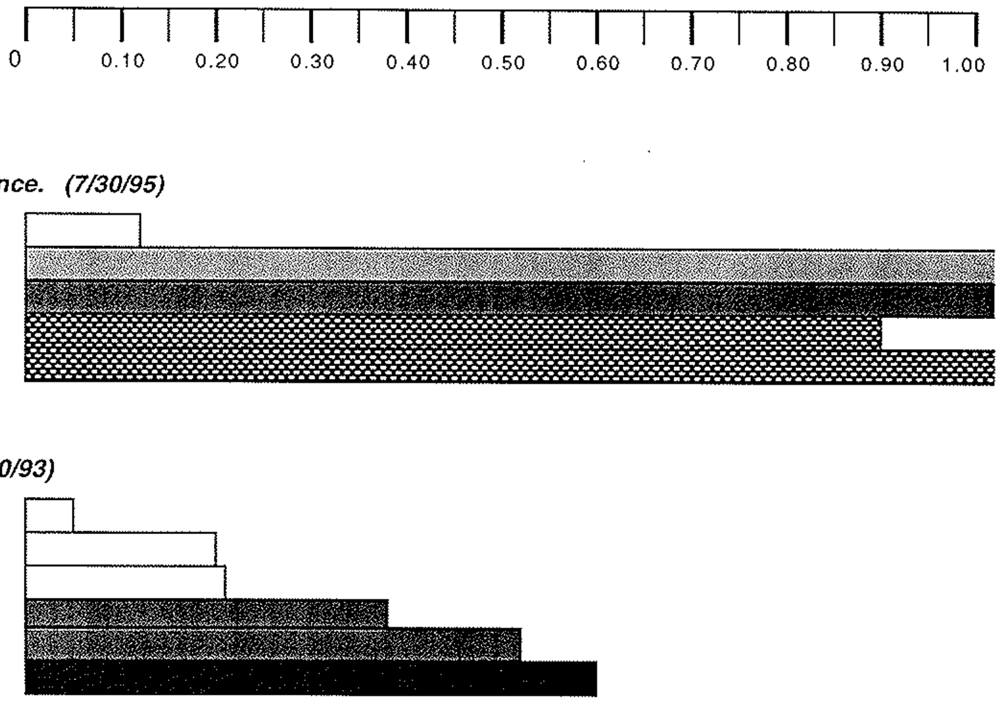


Table 2. (continued)



identification	trophic level	Hg
56. North Fork Cosumnes River just above M Fk confluence. (7/30/95)		
Pteronarcyidae-sm	leaf shredder	**0.12**
Hydropsychidae-med	drift feeder	**1.62**
Perlidae-med	small predator	**2.02**
Gomphidae	large predator	**0.90**
Hellgrammite-sm	large predator	**1.23**
57. North Fork Cosumnes River at Mt. Aukum Rd. (12/20/93)		
Pteronarcyidae (giant stonefly)	leaf shredder	**0.05**
Ptilodactylidae (lg aq beetle nymph)	herbivore	**0.20**
Perlodidae (stonefly)	herbivore	**0.21**
Perlidae-Dark sp (Hesperoperla)	small predator	**0.38**
Perlidae-Gold sp (Callineuria)	small predator	**0.52**
Gomphidae (dragonfly)	large predator	**0.60**

TABLE 3. Mercury Data From Individual Fish

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
2. Yellow Ck (off N Fk Feather River), 6/11/94				
107 g	197	f	**0.02**	
150 g	230	m	**0.02**	
210 g	257	f	**0.02**	
245 g	270	f	**0.03**	
280 g	285	f	**0.03**	
280 g	288	m	**0.03**	
315 g	297	f	**0.03**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.03***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.12***	
3. Caribou N Fk Feather River, 10/27/94				
75 g	190	m	**0.03**	
115 g	223	f	**0.03**	
120 g	223	m	**0.02**	
210 g	266	m	**0.04**	
240 g	274	m	**0.04**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.04***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.20***	
4. E Branch N Fk Feather River, 10/26/94				
75 g	193	m	**0.04**	
160 g	248	m	**0.03**	
207 g	266	f	**0.04**	
423 g	348	m	**0.05**	
515 g	370	f	**0.07**	
627 g	385	f	**0.12**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.05***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.24***	
5. Indian Ck (Trib, E Branch N Fk Feather River), 9/27/94				
151 g	242	f	**0.03**	
153 g	243	f	**0.02**	
335 g	304	m	**0.03**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.03***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.14***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
6. Spanish Ck (Trib, E Branch N Fk Feather River), 9/26/94				
139 g	241	f	**0.10**	
133 g	238	m	**0.13**	
164 g	250	f	**0.06**	
185 g	258	f	**0.09**	
285 g	298	f	**0.06**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.11***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.51***	
11. Middle Fk Feather River (Below Nelson Ck), 9/22/94				
74 g	195	m	**0.12**	
109 g	223	?	**0.09**	
137 g	238	m	**0.10**	
170 g	245	m	**0.17**	
273 g	294	m	**0.09**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.12***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.56***	
12. Nelson Ck (Tributary to M Fk Feather River), 9/21/94				
60 g	185	?	**0.07**	
160 g	245	m	**0.07**	
230 g	292	f	**0.09**	
305 g	304	f	**0.10**	
340 g	325	m	**0.23**	
430 g	338	f	**0.06**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.09***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.40***	
13. Upper Middle Fk Feather River, Above Clio, 9/23/94				
70 g	176	m	**0.09**	
112 g	210	m	**0.08**	
144 g	222	f	**0.10**	
137 g	224	f	**0.14**	
174 g	245	f	**0.17**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.15***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.68***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
16. Lower Yuba below Engelbright Reservoir,12/16/93				
170 g	235	f	**0.09**	0.11
235 g	274	m	**0.13**	0.09
255 g	272	f	**0.07**	0.08
400 g	314	f	**0.10**	0.09
440 g	329	m	**0.07**	0.08
565 g	370	m	**0.11**	0.06
860 g	408	f	**0.13**	0.09
910 g	417	m	**0.12**	0.08
1040 g	434	m	**0.12**	0.07
normalized 250 g trout muscle (wet wt ppm Hg):			***0.09***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.42***	
20. North Fork Yuba River Near Canyon Creek, 11/5/93				
145 g	236	f	**0.14**	0.16
200 g	270	f	**0.09**	0.08
300 g	306	f	**0.10**	0.10
320 g	314	f	**0.11**	0.13
340 g	311	m	**0.10**	0.07
normalized 250 g trout muscle (wet wt ppm Hg):			***0.11***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.50***	
19. Canyon Creek at N Fk Yuba,11/6/93				
305 g	294	m	**0.11**	0.10
21. Downie River (tributary of N Fk Yuba), 11/2/93				
55 g	176	m	**0.04**	0.04
85 g	195	m	**0.06**	0.04
150 g	239	f	**0.08**	0.06
155 g	243	m	**0.06**	0.05
410 g	356	f	**0.15**	0.13
465 g	348	m	**0.07**	0.06
normalized 250 g trout muscle (wet wt ppm Hg):			***0.10***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.45***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
24. Middle Fork Yuba above Oregon Creek, 10/21/93				
Rainbow Trout				
100 g	204	f	**0.15**	0.12
260 g	260	m	**0.21**	0.19
250 g	278	f	**0.17**	0.20
normalized 250 g trout muscle (wet wt ppm Hg):			***0.19***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.87***	
Squawfish				
370 g	321	m	**0.56**	0.33
480 g	339	f	**0.81**	0.42
25. Middle Fork Yuba above Kanaka Creek, 10/93				
94 g	210	m	**0.10**	0.09
130 g	235	f	**0.12**	0.10
135 g	237	m	**0.12**	0.09
150 g	240	m	**0.13**	0.12
320 g	298	m	**0.13**	0.19
375 g	320	f	**0.20**	0.17
505 g	368	m	**0.21**	(Lost Liver)
515 g	363	m	**0.24**	0.30
615 g	387	m	**0.21**	0.19
normalized 250 g trout muscle (wet wt ppm Hg):			***0.15***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.66***	
27. Middle Fork Yuba above Plumbago Rd, 3/24/94				
270 g	292	f	**0.05**	0.04
380 g	346	f	**0.06**	0.06
580 g	385	m	**0.12**	0.08
710 g	391	f	**0.12**	0.09
730 g	415	f	**0.19**	0.20
normalized 250 g trout muscle (wet wt ppm Hg):			***0.05***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.20***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
32. South Fork Yuba at Washington, 11/12/93				
20 g	112	?	**0.14**	(not analyzed)
70 g	183	f	**0.13**	0.11
70 g	186	?	**0.12**	0.14
85 g	195	?	**0.12**	0.15
90 g	200	m	**0.11**	0.13
90 g	201	?	**0.11**	0.13
90 g	207	f	**0.12**	0.16
100 g	205	?	**0.11**	0.12
135 g	234	m	**0.10**	0.12
140 g	230	m	**0.13**	0.15
150 g	237	f	**0.11**	0.13
230 g	274	f	**0.22**	0.22
310 g	305	f	**0.26**	0.35
450 g	345	f	**0.30**	0.48
normalized 250 g trout muscle (wet wt ppm Hg):			***0.21***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.94***	
33. South Fork Yuba below Lake Spaulding, 10/24/95				
Rainbow Trout				
22 g	131		**0.04**	
75 g	180		**0.06**	
85 g	190		**0.08**	
130 g	228		**0.11**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.12***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.56***	
Brown Trout				
125 g	224		**0.07**	
190 g	248		**0.07**	
34. South Fork Yuba above Lake Spaulding, 10/24/95				
Brown Trout				
99 g	208	f	**0.06**	
101 g	211	f	**0.09**	
155 g	247	f	**0.08**	
189 g	264	f	**0.06**	
normalized 250 g trout muscle (wet wt ppm Hg):			***0.09***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.43***	
40. Bear River below Rollins Reservoir, 10/13/95				
101 g	209		**0.16**	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
47. North Fork American River above Humbug Bar, 11/19/93				
110 g	216	f	**0.03**	0.02
140 g	237	f	**0.05**	0.03
150 g	245	m	**0.03**	0.03
595 g	384	m	**0.15**	0.14
normalized 250 g trout muscle (wet wt ppm Hg):			***0.06***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.27***	
48. Middle Fk American River Below Oxbow Reservoir, 2/25/94				
Rainbow Trout				
295 g	297	f	**0.05**	0.04
330 g	308	f	**0.06**	0.05
335 g	313	f	**0.06**	0.05
385 g	327	f	**0.06**	0.05
385 g	332	f	**0.04**	0.05
400 g	334	m	**0.07**	0.05
normalized 250 g trout muscle (wet wt ppm Hg):			***0.04***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.20***	
Brown Trout				
965 g	452	f	**0.37**	0.67
49. N Fk Middle Fk American River--Middle Fk up to Skunk Ck, 3/2/94				
90 g	211	f	**0.11**	0.08
120 g	227	f	**0.10**	0.08
160 g	247	f	**0.11**	0.07
normalized 250 g trout muscle (wet wt ppm Hg):			***0.12***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.55***	

TABLE 3. (continued)

wt (g)	Length (mm)	Sex	Muscle ppm Hg	Liver ppm Hg
52. Duncan Creek (tributary of Middle Fk American R.), 11/16/93				
Rainbow Trout				
35 g	149	m	**0.02**	0.02
55 g	170	f	**0.02**	0.02
80 g	186	f	**0.03**	0.04
85 g	195	f	**0.03**	0.03
100 g	205	m	**0.03**	0.03
100 g	215	m	**0.04**	0.05
120 g	223	m	**0.03**	0.03
170 g	246	m	**0.04**	0.05
normalized 250 g trout muscle (wet wt ppm Hg):			***0.05***	
normalized 250 g trout muscle (dry wt ppm Hg):			***0.24***	
Brown Trout				
55 g	173	m	**0.03**	0.04
110 g	214	f	**0.04**	0.04
135 g	230	m	**0.05**	0.04
150 g	237	m	**0.04**	0.05
54. South Fk American River Below Slab Creek Reservoir, 12/20/93				
Rainbow Trout				
86 g	197	m	**0.07**	0.06
Brown Trout				
83 g	207	m	**0.06**	0.06

section of the Middle Fork of the Feather River (Site 11). These sites were among those noted in the course of the study as having the greatest current mining activity. They also include some of the historically most intensively mined regions. Low mercury concentrations (≤ 0.06 mg kg^{-1}, normalized) were found in trout from many tributaries of the Feather and American rivers, as well as upstream of the major mining activity along the Middle Fork of the Yuba River. Fish from the North Fork of the Middle Fork of the American River (Site 49) and Spanish Creek (Site 7), a tributary to the North Fork Feather River, were relatively higher in mercury as compared to adjacent sites in their watersheds. When converted to units of dry weight parts per million, the 250 g normalized trout mercury concentrations of this study range from a low of 0.14 mg kg^{-1} to a high of 0.94 mg kg^{-1}. These data are used in Table 2 for comparison with the invertebrate data, which are reported on a dry weight basis.

Several collections of piscivorous squawfish and adult brown trout were made during the course of the study. Being largely fish eaters, these species feed at a higher trophic level, as compared to mid-sized rainbow trout which feed primarily on a mix of aquatic and terrestrial insects. The piscivorous fish contained significantly higher concentrations of mercury than rainbow trout from the same locations (Table 3). At the Middle Fork Yuba River site near Oregon Creek, squawfish contained 0.41 mg kg^{-1} muscle mercury in same sized fish, as compared to rainbow trout which had 0.19 mg kg^{-1} (both on a wet weight basis). At the Middle Fork American River Site below Oxbow Reservoir, a large (965 g) brown trout was taken which had muscle mercury at 0.37 mg kg^{-1}, while a comprehensive sample of rainbow trout from the same river stretch had muscle mercury at only 0.05 mg kg^{-1}. The correlation between trophic feeding level and mercury concentration is also apparent in the data from Duncan Creek (Site 52), the South Fork American River at Slab Creek Reservoir (Site 54), and Sites 33 and 34 on the upper section of the South Fork Yuba River (Table 3). At these sites, samples of small (< 250 g) rainbow and brown trout were taken together. At these sizes, the species are both insectivorous. Mercury concentrations were found to be identical at these sites between the two species.

The relationship between muscle mercury and liver mercury was investigated in the first year of the study. The data are presented together with muscle mercury data in Table 3. Generally, the liver mercury concentrations in these fish were very similar to corresponding muscle mercury levels. Mean liver mercury from 77 rainbow and small brown trout was 97.9% of corresponding muscle mercury concentrations, with a standard deviation of 23.5%. We have found, in other research, that liver mercury is frequently 150-200% of muscle mercury in extremely polluted sites, such as Coast Range lakes and reservoirs in the historic mercury mining district of California (Slotton 1991). These liver data, together with the lower absolute tissue mercury concentrations, indicate a relatively more moderate level of mercury bioavailability in the Sierra gold district as compared to the Coast Range mercury mining districts.

Trout stomach contents were analyzed for mercury at a subset of the sampling sites. These data are displayed in Table 2 together with other trophic mercury data for each site. The food item mercury data was generally reflective of corresponding stream invertebrate mercury levels. In the several cases where food item mercury was considerably lower than corresponding stream invertebrate mercury, it was noted that terrestrial insects dominated the stomach contents. The diets of insectivorous rainbow trout and young brown trout naturally demonstrate temporal shifts in the percentage of terrestrial forms, in conjunction with changes in availability.

Stream Invertebrates

Aquatic invertebrates were taken at each of the 57 sites. Approximately 250 separate invertebrate composite samples were collected, identified, processed, and analyzed for mercury in the research reported here. The sites varied considerably in invertebrate diversity and types present. The most consistently available groups were drift feeding caddisfly nymphs of the family Hydropsychidae (omnivores), stonefly nymphs of the family Perlidae (small-item predators), and hellgrammites of the family Corydalidae (large-item predators). The lowest trophic feeding level of stream invertebrates taken, herbivorous species, were represented by a variety of families, with Pteronarcyid stoneflies being the most frequently taken. A variety of mayfly species represented this trophic level at a number of sites. Additional herbivores included large beetle larvae of the family Ptilodactylidae. The omnivore/drift collector feeding level was represented exclusively by Hydropsychid caddis nymphs, which were widespread throughout much of the region. The invertebrate small-item predator trophic level included Rhyacophyllid caddis nymphs, Perlodid stoneflies, and damselfly nymphs in addition to the Perlid stoneflies which were most generally available. In addition to Corydalid hellgrammite nymphs, the larger-item invertebrate predator trophic level also included large predaceous dipteran larvae of the family Tipulidae and Gomphid dragonfly nymphs.

The invertebrate mercury data are presented in Table 2 and Figures 5-8. The table includes data from each of the samples, while averaging techniques were utilized to derive single trophic level values in the map figures. The averaging methods used are described above in the Methods section. Mercury was detected at ≥ 0.01 mg kg^{-1} (ppm) in all invertebrate samples taken throughout the Sierra Nevada gold country. Inter-site mercury differences were generally consistent among all invertebrate (and trout) trophic levels, with low mercury sites demonstrating low biotic Hg levels throughout the food web and sites with high biotic Hg in one group typically having elevated Hg levels in all co-occurring organisms.

Similar to the trout results, notably elevated mercury in stream invertebrates was found at sites along the Middle and South Forks of the Yuba River, and the Middle Fork of the Feather

River. Also as found for trout, invertebrates from the mid section of the Middle Fork Feather River (Site 11), the North Fork of the Middle Fork of the American River (Site 49) and Spanish Creek (Site 7), a tributary to the North Fork Feather River, were relatively higher in mercury as compared to adjacent sites in their watersheds. Relatively low mercury concentrations (≤ 0.15 mg kg^{-1}, dry weight) were found in all trophic levels of invertebrates from most tributaries of the Feather and American rivers, as well as upstream of the major mining activity along the Middle and South Forks of the Yuba River, similar to co-occurring trout.

Invertebrates were also sampled exclusively at 36 sites where trout were not present in sufficient quantities for adequate collections. These invertebrate-only collections identified a number of additional notably elevated mercury streams, including sites throughout the Bear River watershed mining region (Sites 38-42), the Cosumnes River (Sites 56 and 57), and Deer Creek (Site 35). Other invertebrate-only collections indicated relatively low mercury bioavailability at sites where trout were not present or readily collectable, including the Feather River downstream of Lake Oroville (Site 1), several additional tributaries of the Feather River (Sites 8, 9, 14, 15), the lower American River below Folsom Lake (Sites 45 and 46), the South Fork of the American River (sites 53-55), the Rubicon River (site 50), and the Bear River below Camp Far West Reservoir (site 37). Similar to the reduced mercury results found in fish above the gold mining stretches of the forks of the Yuba River, benthic invertebrate samples of all types from the relatively pristine headwaters sample on the Bear River (Site 44) were far lower in mercury concentration than corresponding samples taken from within and below the major mining elevations (Sites 38-42).

Notably lower invertebrate mercury concentrations were found below many of the foothill reservoirs, as compared to concentrations in similar biota upstream. Specifically, the invertebrates below New Bullard's Bar Reservoir (station 18) were considerably lower in mercury than those collected upstream of the reservoir on the North Fork of the Yuba River (station 20). Hydropsychid net caddis nymphs were 0.08 ppm in their dry weight mercury concentration below the dam, as compared to 0.24 ppm upstream of the reservoir. Perlid stoneflies were 0.11 ppm below, 0.25 ppm above, and Corydalid hellgrammites were 0.33 below vs 0.50 above. Similarly, the invertebrates collected below Englebright Reservoir (station 16) were consistently far lower in mercury than samples collected upstream of the reservoir on the Middle and South Forks of the Yuba River (sites 22, 24, 25, 28-32). On the Bear River, Hydropsychid net caddis larvae ranged from 0.21 to 0.46 ppm Hg (mean = 0.32 ppm) at sites in the mining region above Camp Far West Reservoir (sites 38-42), as compared to 0.17 ppm in extensive, replicate collections from below the dam.

Collections from the Feather River valley site below Lake Oroville (Site 1) and the American River below Folsom Lake (Sites 45 and 46) were similar to samples taken upstream in these relatively low mercury watersheds. Deer Creek was unique in demonstrating significantly higher biotic mercury accumulation below a reservoir (Lake Wildwood) as compared to above (Site 35 vs 36). While both sites were relatively elevated, the higher levels found below Lake Wildwood may result from historic downstream movement of gold mining mercury in this small drainage. The lack of significant modern barriers to downstream mercury migration may be of particular concern on the Cosumnes River (Sites 56 and 57), where the very highest levels of biotic mercury accumulation were observed.

Trophic level relationships to mercury accumulation

A pattern of increasing mercury concentrations in progressively higher trophic levels was found at the majority of sites (Figure 3, Table 2). In Figures 11 and 12 we summarize the food-chain mercury data from 19 sites where trout were sampled, normalized to 250 g rainbow trout muscle concentrations at each of the sites. In Figure 11, the normalized invertebrate data are plotted with 95% confidence intervals for trophic guilds vs trout, and in Figure 12 the dominant single family or genus of each guild is used. The means and confidence intervals are similar with either analysis.

A relatively predictable pattern results, with the highest trophic level stream invertebrates having mercury concentrations approximately half those seen in normalized 250 g trout from the same sites. Among the invertebrates, herbivorous species as a group consistently had the lowest mercury concentrations (averaging 14% of those found in co-existing trout). Low mercury levels in herbivore species was not a function of age and, thus, time of exposure. Similar low concentrations were found in Pteronarcyid stoneflies up to three years old, as well as in annual mayflies. Predaceous invertebrates accumulated considerably higher concentrations. Relatively small predators such as nymphs of Perlid stoneflies, Rhyacophyllid caddisflies, and damselflies had mercury concentrations averaging 38% of the concentrations in corresponding normalized trout muscle, while the largest invertebrate predators, characterized by the large-jawed hellgrammites, averaged 47% of trout concentrations. Hydropsychid caddis nymphs, which were an important component of the invertebrate biomass at many of the sites, averaged 31% of corresponding trout in their mercury levels. This was lower than that of the larger invertebrate predators but considerably higher than the mercury concentrations seen in herbivores, suggesting that these nymphs, which feed by capturing drift in their nets, consume primarily other invertebrates rather than algal material. We believe that relative mercury concentrations in aquatic species may offer a useful tool for determining relative, time-integrated trophic feeding level.

In Figures 13-19, mercury concentrations in different trophic categories and types of invertebrates are plotted against corresponding trout mercury to determine relative correlations.

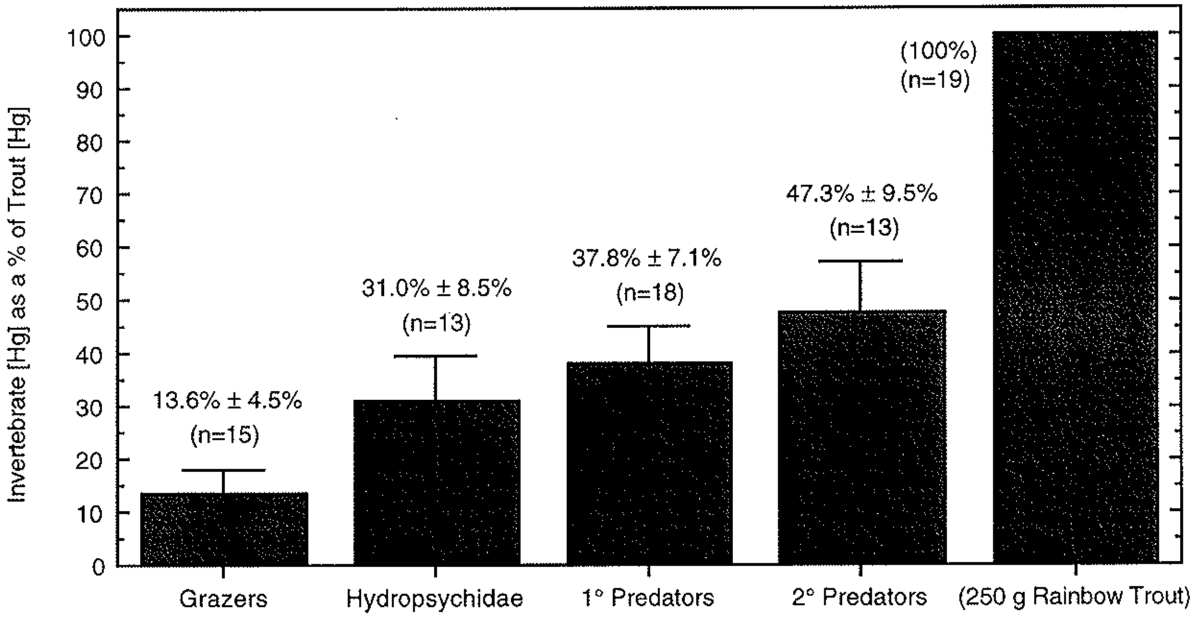


Fig. 11. Mercury in Invertebrate Trophic Groups--As a Proportion of Corresponding Fish Mercury, Among Sites With Sampled Fish

In units of dry wt parts per million Hg, together with 95% confidence intervals

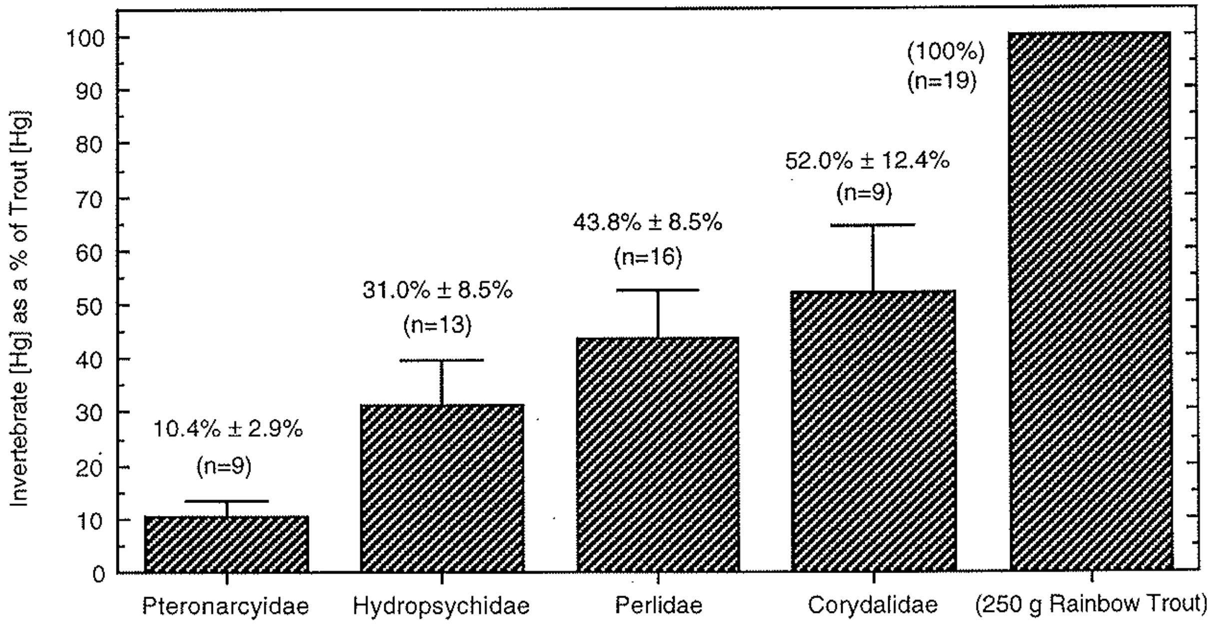


Fig. 12. Mercury in Individual Invertebrate Families--As a Proportion of Corresponding Fish Mercury, Among Sites With Sampled Fish

In units of dry wt parts per million Hg, together with 95% confidence intervals

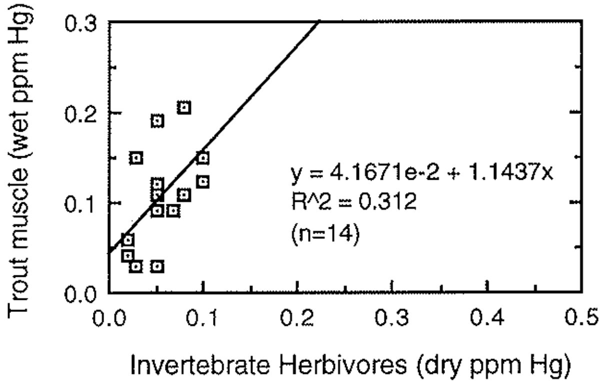


Fig. 13. Invertebrate Herbivores vs Trout

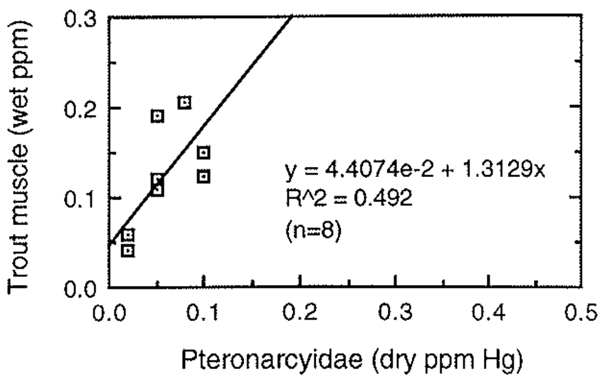


Fig. 14. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Trout

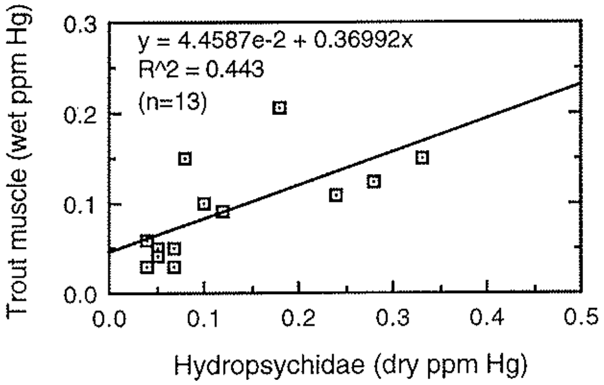


Fig. 15. Hydropsychidae (Net Collector Caddis) vs Trout

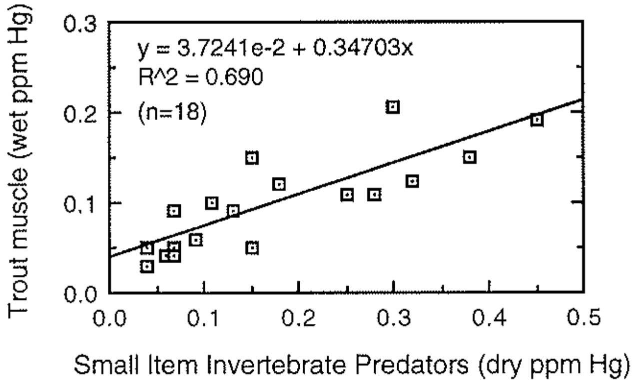


Fig. 16. Small Item Invertebrate Predators (Perlid Stoneflies, etc.) vs Trout

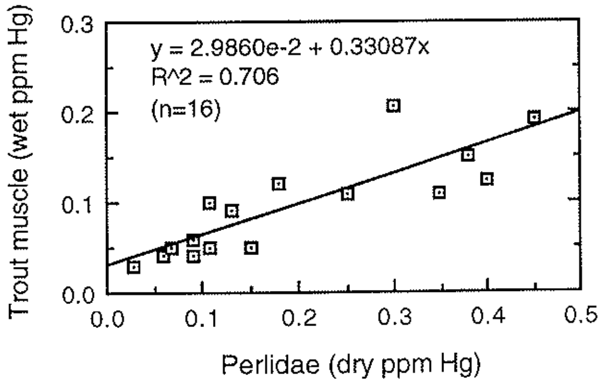


Fig. 17. Perlid Stoneflies vs Trout

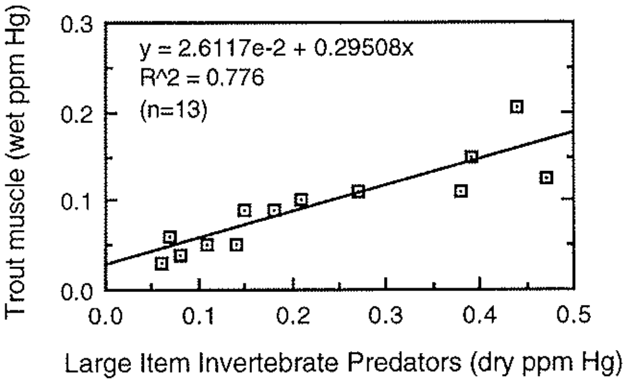


Fig. 18. Large Item Invertebrate Predators (Hellgrammites, etc.) vs Trout

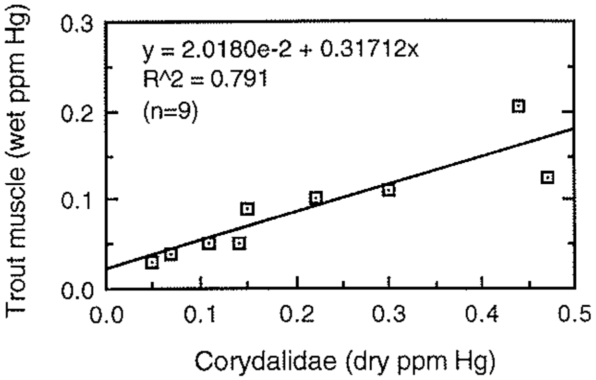


Fig. 19. Corydalid Hellgrammites vs Trout

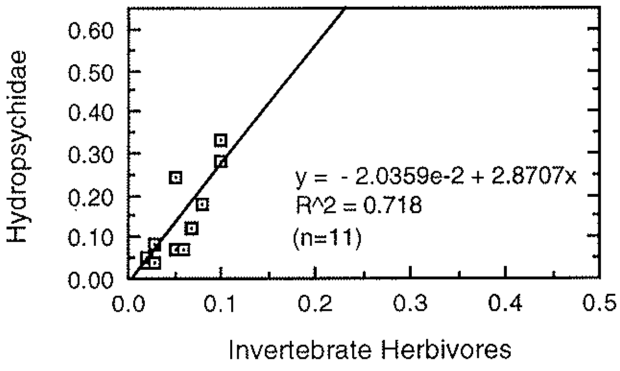


Fig. 20. Invertebrate Herbivores vs Hydropsychidae (Net Collector Caddis)

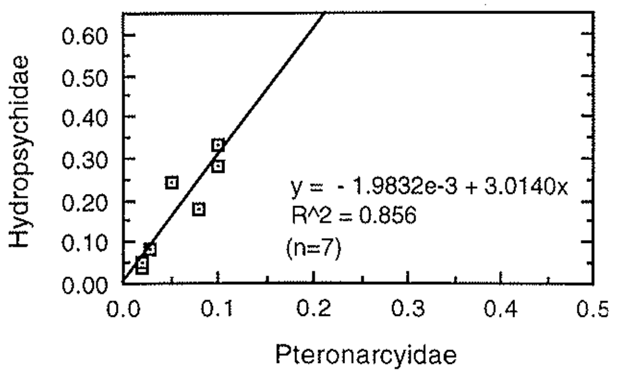


Fig. 21. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Hydropsychidae (Net Collector Caddis

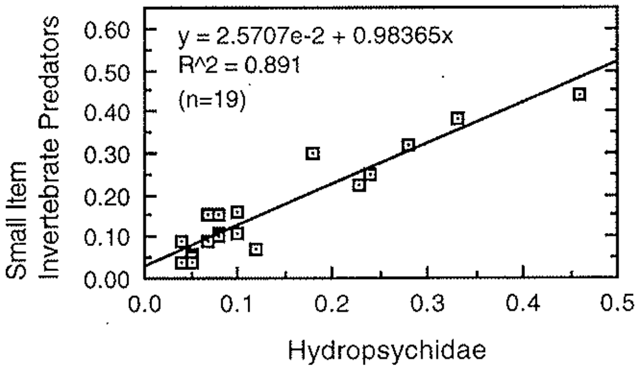


Fig. 22. Hydropsychidae (Net Collector Caddis) vs Small Item Predators (Perlid Stoneflies, etc.)

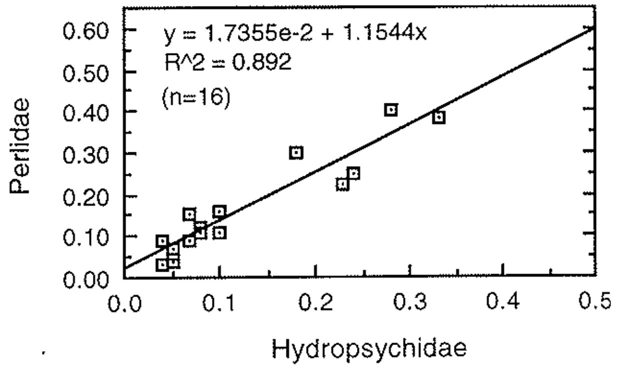


Fig. 23. Hydropsychidae (Net Collector Caddis) vs Perlidae (Predaceous Golden Stoneflies)

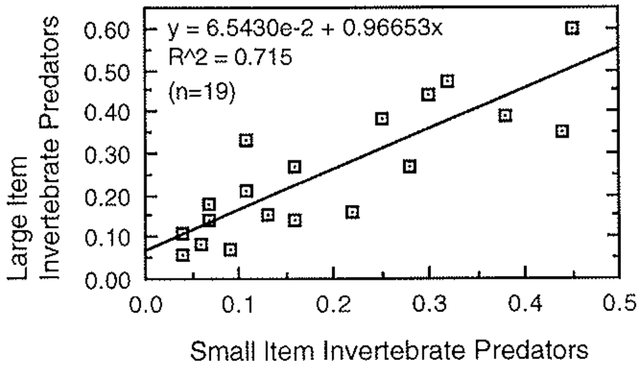


Fig. 24. Invertebrate Small Item Predators (Perlid Stoneflies, etc.) vs Large Item Predators (Hellgrammites, etc.)

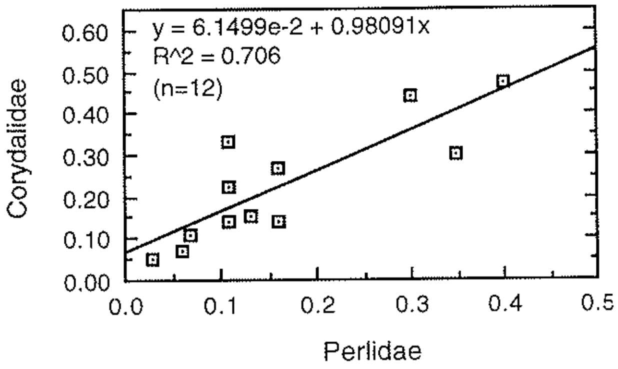


Fig. 25. Perlid Stoneflies vs Corydalid Hellgrammites

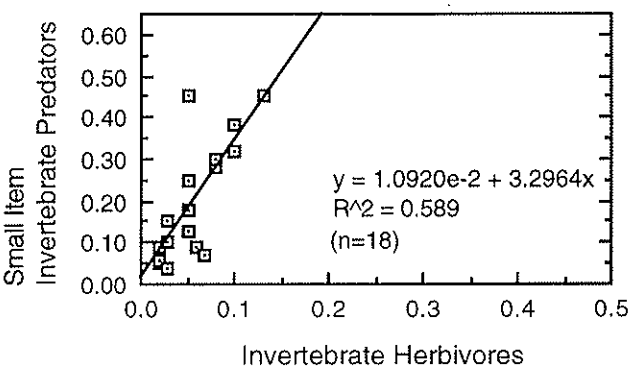


Fig. 26. Invertebrate Herbivores vs Small Item Predators (Perlid Stoneflies, etc.)

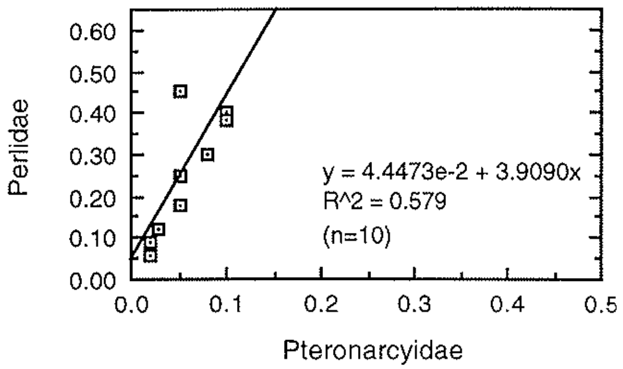


Fig. 27. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Perlidae (Predaceous Golden Stoneflies)

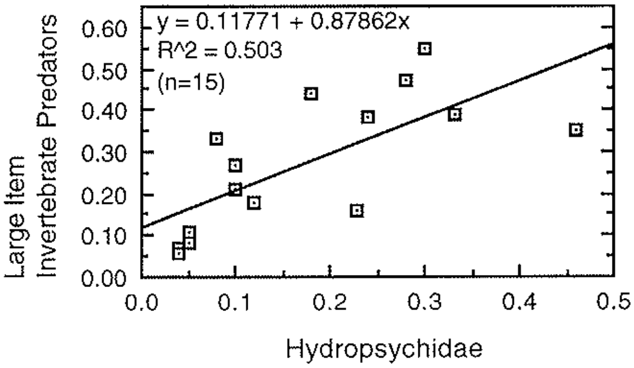


Fig. 28. Hydropsychidae (Net Collector Caddis) vs Large Item Invertebrate Predators (Hellgrammites, etc.)

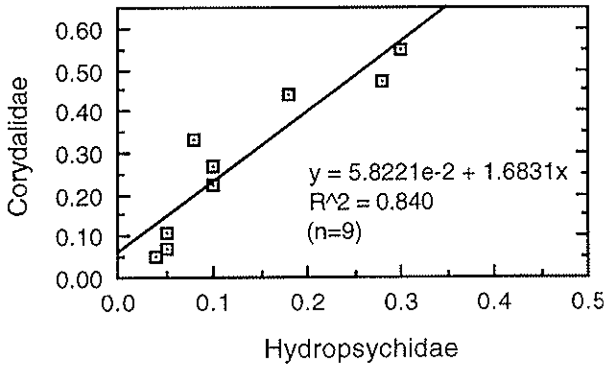


Fig. 29. Hydropsychidae (Net Collector Caddis) vs Corydalidae (Hellgrammites)

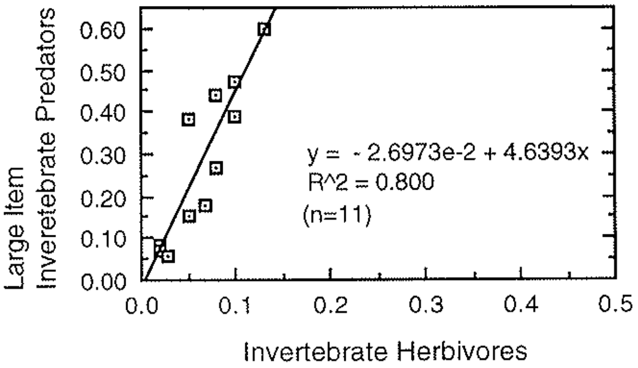


Fig. 30. Invertebrate Herbivores vs Large Item Predators (Hellgrammites, etc.)

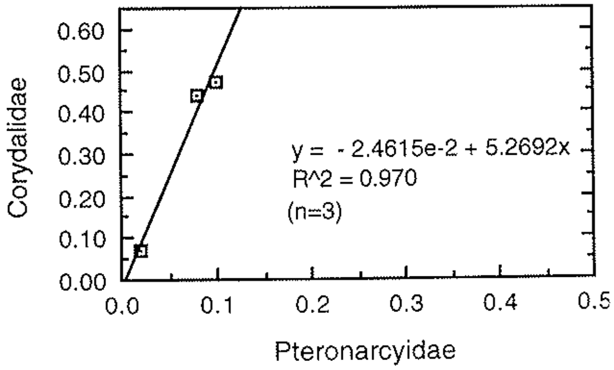


Fig. 31. Pteronarcyidae (Giant Herbivorous Stoneflies) vs Corydalidae (Hellgrammites)

Interestingly, the R^2 correlation coefficients between invertebrates and trout taken from the same sites increased steadily with increasing invertebrate trophic feeding level. Herbivores, as a group, demonstrated the weakest correlation with corresponding trout ($R^2 = 0.31$). Hydropsychid caddis nymphs had a stronger correlation ($R^2 = 0.44$). Small predaceous invertebrates such as Perlid stoneflies had considerably tighter correlations with trout ($R^2 = 0.69$), while the highest trophic level invertebrates, characterized by Corydalid hellgrammites, demonstrated the strongest correlations with corresponding trout ($R^2 = 0.78$). Correlations between individual invertebrate family or genus and trout (figures 11, 14, and 16) were generally not significantly stronger than those using grouped trophic guild members, though this may be partially a function of lower sample size for particular invertebrates.

In Figures 20-31, correlations in mercury concentration between invertebrates are plotted, first between adjacent trophic feeding levels (Figures 20-25) and finally between more distantly separated groups (Figures 26-31). As a set, these inter-invertebrate correlations were all quite high. R^2 correlation coefficients of 0.72-0.98 were found between adjacent trophic levels (Figures 20-25) and coefficients of 0.50-0.97 were found between non-adjacent but co-occurring trophic levels (Figures 26-31).

Biotic time series data

A series of 5 separate collections were made throughout 1995 and early 1996 at 3 index stations, to address the question of potential seasonal shifts in biotic mercury accumulation. Data are presented in Table 4. These sites corresponded to those also used for the intensive temporal series of water collections by Larry Walker and Associates, and were all adjacent to Englebright Reservoir. One site was located below the reservoir on the Lower Yuba River (Site 16), while the other two were situated immediately above the reservoir along the two major inflowing tributaries. Site 17 was an index station located just below the Colgate powerhouse on the Middle Fork Yuba River. The Colgate powerhouse is where the majority of flow from the North Fork Yuba River is diverted into the Middle Fork, piped from the bottom of New Bullards Bar Reservoir. The North Fork flow typically dominates the total flow at this point, though releases can be erratic. The final index station (Site 28) was located along the South Fork Yuba River at Bridgeport, just above Englebright Reservoir.

Sampling for this temporal series of invertebrate bioindicator collections occurred on April 24, June 30, August 15, and November 16 in 1995, and February 16, 1996. Composite collections of 3-7 different types of benthic invertebrates were made on each of the five dates at the lower Yuba site (16) and the site on the South Fork Yuba (28). However, at Site 17 below the Colgate powerhouse, only Hydropsychid caddisfly larvae were present on the August sampling

Table 4. Biota Mercury Data For Time Series Samplings at Above/Below Englebright Reservoir Index Stations

identification	trophic level	Hg (dry wt ppm)
16. Lower Yuba River at UC field station --1993 (12/16/93)		
Ephemerellidae (mayfly)	herbivore	0.07
Hydropsychidae (net caddis)	drift feeder	0.12
Perlodidae (stonefly)	small predator	0.07
Tipulidae (cranefly)	large predator	0.18
Mean 250 g Trout (dry ppm)	*(insect predator)*	*0.42*
16. Lower Yuba River at UC field station. (4/24/95)*		
Mixed Mayflies	herbivore	0.050
Hydropsychidae	drift feeder	0.140
Perlodidae-sm	small predator	0.113
Perlidae-giant	small predator	0.132
Tipulidae-lg	large predator	0.490
*16**. Lower Yuba River at UC field station. (6/30/95)*		
Mayflies	herbivore	0.018
Hydropsychidae	drift feeder	0.082
Perlodidae-tiny	Tiny Stoneflies	*(<0.01)*
Hellgrammite	large predator	0.231
*16***. Lower Yuba River at UC field station. (8/15/95)*		
Mayflies	herbivore	0.080
Hydropsychidae-sm/med	drift feeder	0.122
Hydropsychidae-lg	drift feeder	0.129
Beetle larvae	small predator	0.082
Perlodidae-sm/med	small predator	0.095
Perlidae-Callineuria-lg	small predator	0.108
Hellgrammite-med	large predator	0.273

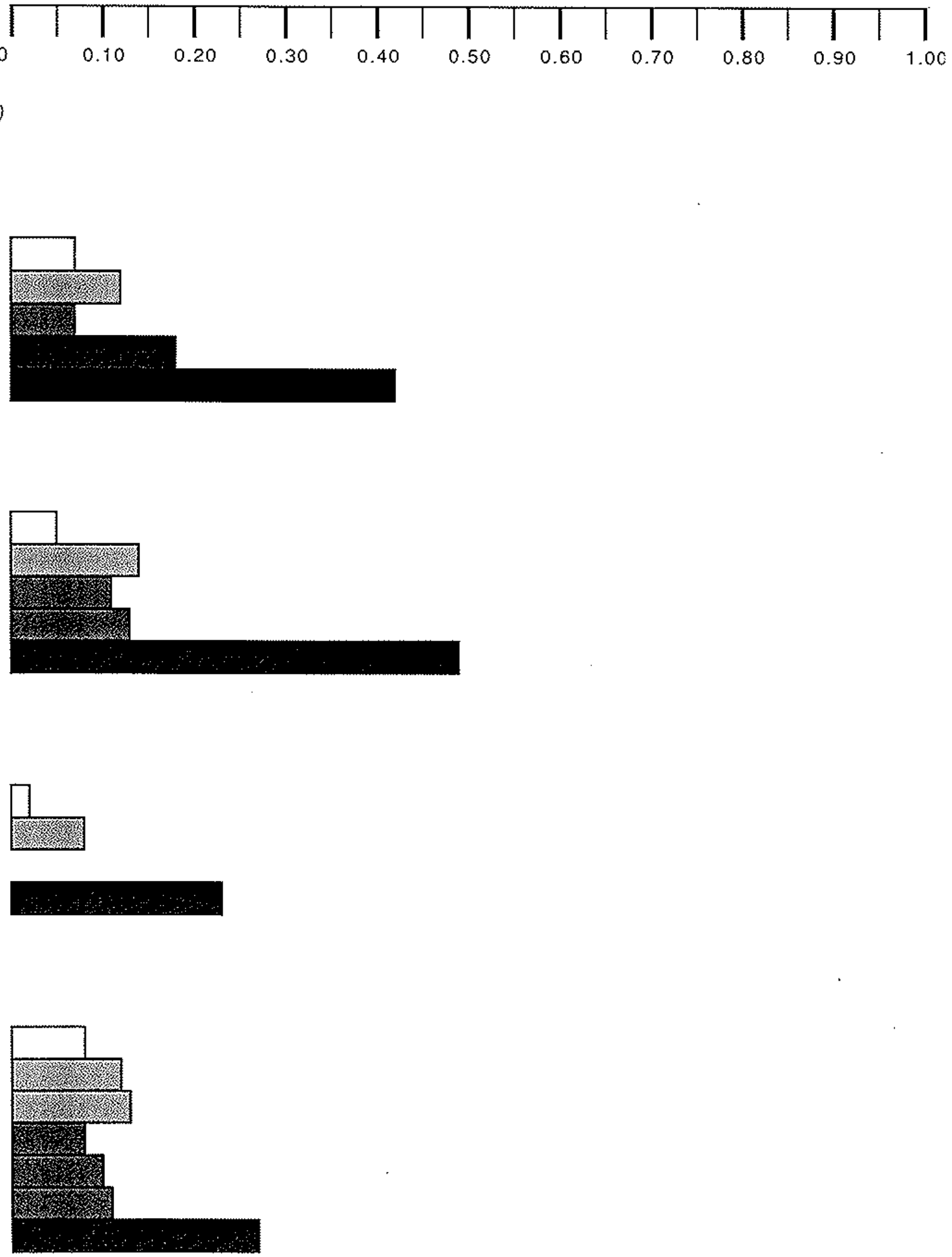


Table 4. (continued)

identification	trophic level	Hg (dry wt ppm)
16*. Lower Yuba River at UC field station. (11/16/95)***		
Hydropsychidae	drift feeder	**0.225**
Perlodidae-med/Lg	small predator	**0.155**
Perlidae-Hesperoperla-med/Lg	small predator	**0.218**
Perlidae-Hesperoperla-giant-2 yr	small predator	**0.169**
16**. Lower Yuba River at UC field station. (2/16/96)***		
Mixed Mayflies	herbivore	**0.080**
Hydropsychidae-med/lg	drift feeder	**0.211**
Perlodidae	small predator	**0.094**

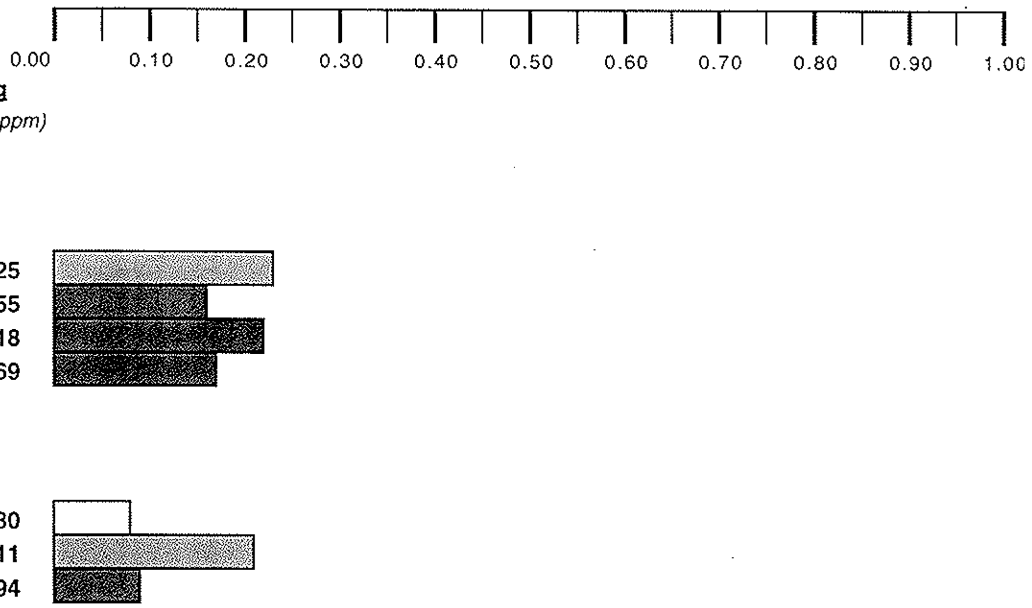


Table 4. (continued)

identification	trophic level	Hg (dry wt ppm)
17. N Fk / M Fk Yuba River below Colgate inflow. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	**0.040**
Mayflies	herbivore	**0.099**
Hydropsychidae	drift feeder	**0.163**
Perlodidae-sm	small predator	**0.130**
Perlidae-lg	small predator	**0.390**
Hellgrammites-lg	large predator	**0.970**
Hellgrammites-giant	large predator	**0.680**
17. N Fk / M Fk Yuba River below Colgate inflow. (6/30/95)*		
Mayflies	herbivore	**0.006**
Hydropsychidae	drift feeder	**0.094**
Perlidae-sm	small predator	**0.073**
Perlidae-lg	small predator	**0.031**
Perlidae-giant	small predator	**0.224**
Hellgrammites-sm	large predator	**0.314**
Hellgrammites-lg	large predator	**0.577**
*17**. N Fk / M Fk Yuba River below Colgate inflow. (8/15/95)*		
Hydropsychidae	drift feeder	**0.078**

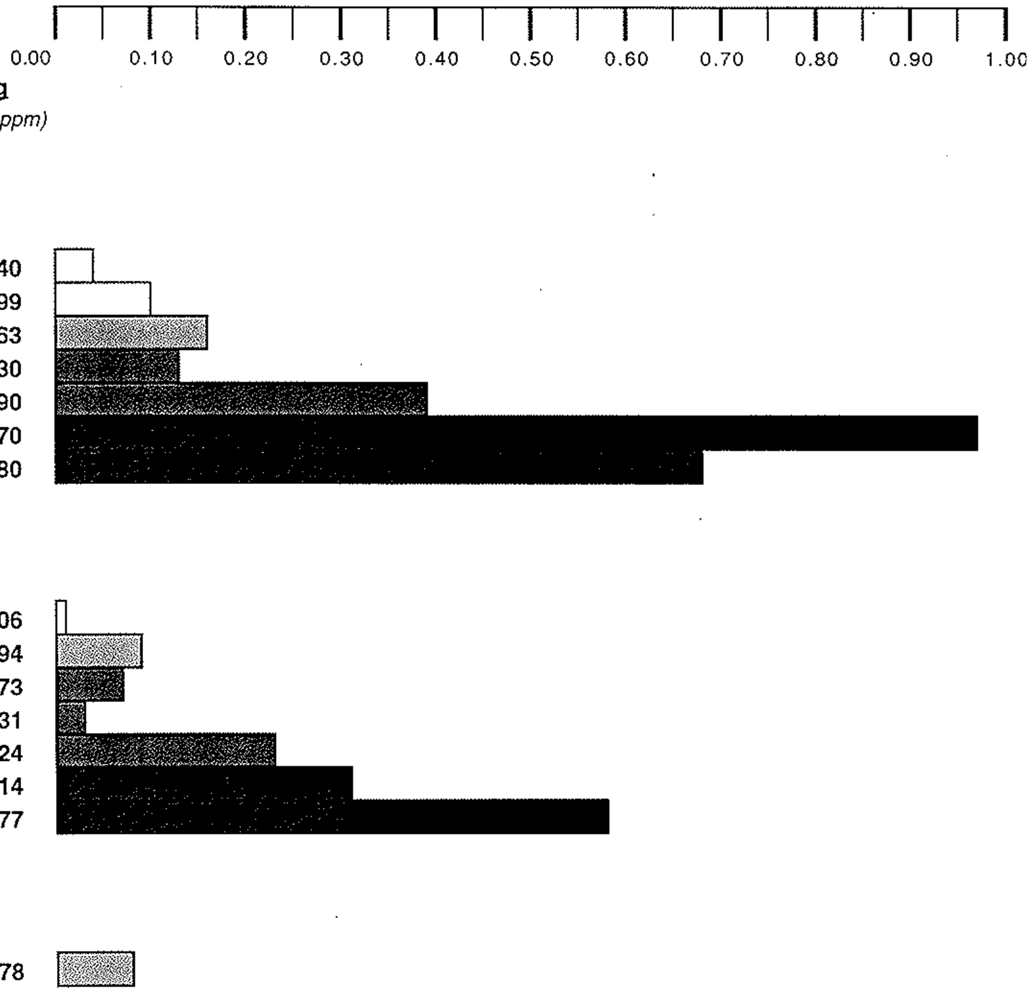


Table 4. (continued)

identification	trophic level	Hg *(dry wt ppm)*
28. South Fork Yuba River at Bridgeport. (4/24/95)		
Pteronarcyidae-sm	leaf shredder	**0.077**
Mayflies	herbivore	**0.267**
Ptilodactylidae	herbivore	**0.177**
Hydropsychidae	drift feeder	**0.296**
Perlidae	small predator	**0.495**
Hellgrammites-lg	large predator	**0.850**
28*. South Fork Yuba River at Bridgeport. (6/30/95)		
Pteronarcyidae	leaf shredder	**0.036**
Mayflies	herbivore	**0.161**
Ptilodactylidae	herbivore	**0.107**
Hydropsychidae	drift feeder	**0.170**
Perlodidae-sm	Sm. Stoneflies	***0.123***
Hellgrammites-lg	large predator	**1.306**
Hellgrammites-giant	large predator	**0.941**
28**. South Fork Yuba River at Bridgeport. (8/15/95)		
Mixed Grazers	herbivore	**0.194**
Perlidae-sm/med	small predator	**0.400**
Perlidae-Heperoperla-med/lg	small predator	**0.446**
Perlidae-Heperoperla-lg/giant	small predator	**0.501**
Hellgrammites-sm/med	large predator	**0.642**
Hellgrammites-med/lg	large predator	**0.600**
Hellgrammites-lg/giant	large predator	**0.649**

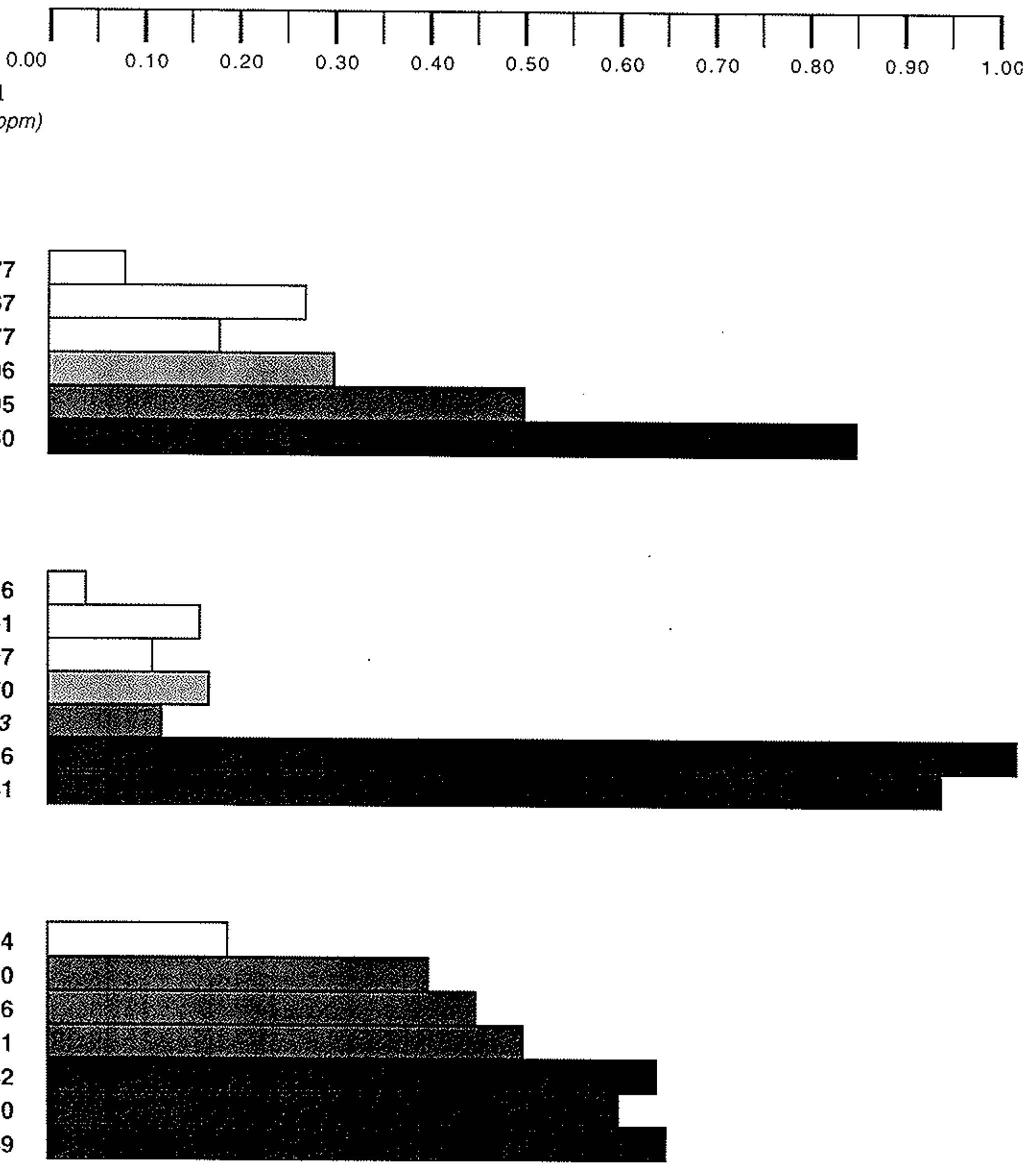
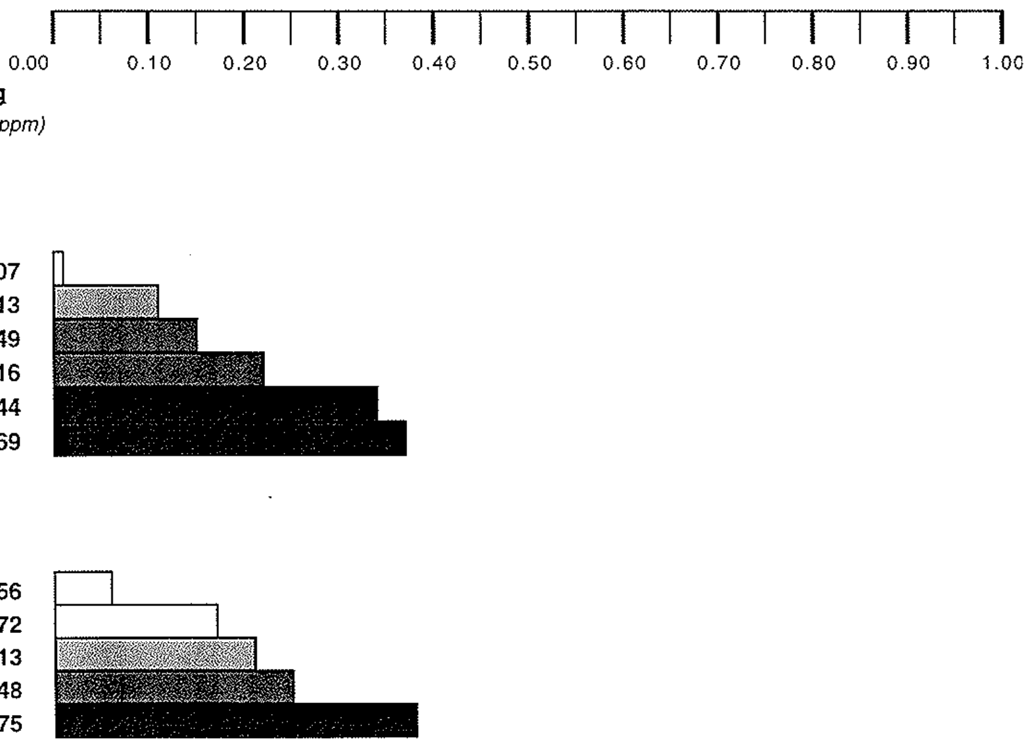


Table 4. (continued)

identification	trophic level	Hg (dry wt ppm)
28. South Fork Yuba River at Bridgeport. (11/16/95)***		
Pteronarcyidae	leaf shredder	**0.007**
Hydropsychidae	drift feeder	**0.113**
Perlodidae-med/Lg	small predator	**0.149**
Perlidae-Lg	small predator	**0.216**
Hellgrammites-sm	large predator	**0.344**
Hellgrammites-sm	large predator	**0.369**
28*. South Fork Yuba River at Bridgeport. (2/16/96)***		
Pteronarcyidae-sm/med	leaf shredder	**0.056**
Mixed Mayflies	herbivore	**0.172**
Hydropsychidae-med/lg	drift feeder	**0.213**
Perlidae	small predator	**0.248**
Hellgrammite-giant	large predator	**0.375**



date and, on subsequent samplings, the site was essentially barren. We attributed this to the unnatural mid-summer releases of very cold North Fork Yuba water from the base of New Bullards Bar Reservoir and the erratic flow regime, which varied between zero and very high flows from this cold source. When the flows from New Bullards Bar Reservoir were high, the water beneath the Colgate powerhouse was very swift and cold; when that source was shut down, the flow returned to that of the relatively warm, low flow Middle Fork Yuba. Our unsuccessful collection attempts (despite considerable sampling effort) from mid-summer through the winter indicate that the conditions at this site were too erratic to maintain a diverse community of typical benthic invertebrate fauna.

Comparing the entire data sets for each site, it is apparent that the below-reservoir site on the Yuba River (Site 16) was consistent in demonstrating significantly lower levels of mercury accumulation, throughout the trophic levels, than the sites above the reservoir. Because of a shift in species present at this site over time, it is difficult to draw conclusions with regard to potential seasonal changes in mercury accumulation here. Hydropsychid caddisfly larvae, which were present in all Lower Yuba collections, suggest a possible increase in mercury accumulation at the Lower Yuba site in the fall and winter, as integrated by the November 1995 and February 1996 samples (0.21-0.23 ppm Hg Nov-Feb vs 0.08-0.14 ppm Hg Apr-Aug). However, other sampled species did not follow any particular trend. Except for a single somewhat anomalous data point for Tipulid dipteran larvae in June 1995 (0.49 ppm), all Lower Yuba benthic invertebrate indicator samples contained ≤ 0.27 ppm mercury.

In contrast, composite samples of benthic invertebrates from the inflowing tributaries to the reservoir consistently demonstrated significantly elevated levels of mercury accumulation in most trophic levels. All samples of second order predatory invertebrates from these sites were found to contain more than 0.30 ppm mercury, with individual composites ranging to over 1.30 ppm. Comparative trout were not present at the reservoir inflow sites, though trout collected below the reservoir were far lower in mercury than were trout taken at sites where they were present further up the Forks of the Yuba within the historic gold mining region.

After seeing firsthand the large variation in flow conditions, we hesitate to form conclusions on potential temporal trends for the North Fork/Middle Fork Yuba reservoir inflow site below the Colgate powerhouse (17). Diverse samples were only available for the first two collections (April and June), during which time mercury levels appeared to drop fairly uniformly. However, because of the unique conditions at this site brought on by flow manipulations, it is unclear whether this apparent trend might be a function of different proportions of Middle Fork Yuba water being present at different times or if the invertebrates taken below the powerhouse on one or both of the significant collections might actually represent drift from the Middle Fork.

The samples from the South Fork inflow, however, indicate an interesting trend of apparent reduced mercury accumulation in fall and winter as compared to earlier collections. This was particularly the case for the predatory trophic levels. Corydalid hellgrammite composites from April through August averaged a very high 0.83 ppm mercury, as compared to 0.36 ppm in November and February. Perlid stoneflies averaged 0.46 ppm in April-August collections, as compared to 0.23 ppm in November and February. This indicates that, at this representative site and this sampling year, less bioavailable mercury moved into the food web later in the year as compared to earlier. This could be a function of changes in bulk mercury presence, changes in mercury methylation within the stream, or a combination of the two.

One conclusion to be drawn from the temporal collections is that comparative sampling of benthic invertebrate indicator samples between sites should be done within a relatively similar time frame, as levels can change fairly significantly across periods on the order of 6 months. Fortunately, the great majority of collections made for the survey work occurred between the months of September and December in each of the years.

Methyl mercury split data

Splits of a subset of the total samples were sent to Frontier Geosciences Laboratory in Washington state for analysis of methyl mercury. Results from split and duplicate samples indicated that this particular assay was limited in accuracy to a range of approximately ± 25%, as compared to the total mercury analysis which has a variability closer to ± 10%. Because of the fairly high level of analytical variation, temporal trends in methyl mercury content cannot be ascertained. Methyl fractions varied fairly erratically and within a range generally less than or equal to the analytical range of variation. However, the general methyl mercury results provide some useful information.

Reduced methyl mercury data are presented in Table 5, together with corresponding total mercury results and the calculated methyl mercury percentage for each sample. Except for a single lower point, all of the data that passed QA/QC controls varied somewhat erratically in the general range of 55-100% methyl mercury. In approximately 10% of the samples that were near the respective limits of detection, impossible results of 110-500+% methyl mercury were obtained, presumably through analytical error at the bottom end of the scale. These data are not shown in the table.

Pteronarcyid stoneflies, which are shredders of primarily terrestrial leaf fall, had methyl mercury percentages which varied between 64% and 100%, with a mean of 76.2% ± 14.5%. Herbivorous mayflies ranged from 60% to 79% methyl mercury, with a mean of 69.4% ± 12.8%. Hydropsychid caddisfly larvae ranged between 36% and 94%, with a mean value of 68.8% ±

Table 5. Methyl Mercury / Total Mercury Split Data (dry weight ppm Hg)

ENGLEBRIGHT SERIES

	Mayflies			Pteronarcyids			Hydropsyche			Perlodids			Perlids			Hellgrammites		
	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%
4/24/95																		
Lower Yuba	.032	.054	60.3%				.050	.141	35.5%	.085	.113	75.4%						
Colgate							.106	.163	65.0%							0.821	0.971	84.6%
S Fk Yuba				.051	.077	66.0%	.172	.296	58.0%				.442	.495	89.2%	0.611	0.848	72.0%
6/30/95																		
Lower Yuba							.077	.082	94.2%									
Colgate							.070	.094	74.5%									
S Fk Yuba																1.096	1.306	83.9%
8/15/95																		
Lower Yuba	.063	.080	78.5%				.118	.129	91.9%							0.190	0.273	69.6%
Colgate							.052	.078	66.4%									
S Fk Yuba																0.346	0.600	57.6%
11/16/95																		
Lower Yuba							.144	.225	63.8%	.154	.155	99.2%	.189	.218	86.6%			
Colgate																		
S Fk Yuba										.110	.149	73.9%	.192	.216	88.5%	0.336	0.369	91.1%
M Fk Yuba				.114	.115	99.6%	.128	.204	62.8%	.177	.177	100.4%	.239	.246	97.4%	0.311	0.411	75.6%

Table 5. (continued)

INTER-ANNUAL SERIES (Middle Fk Yuba at Tyler Foote Crossing)

	Mayflies			Pteronarcyids			Hydropsyche			Perlodids			Perlids			Hellgrammites		
	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%
Oct-93				.066	.103	63.6%							.270	.325	82.9%			
Oct-94				.177	.220	80.3%	.308	.543	56.7%				.806	.797	101.2%	0.415	0.593	69.9%
Oct-95				.043	.060	71.7%	.125	.222	56.4%				.241	.244	99.0%	0.187	0.215	87.1%

ABOVE/BELOW CAMP FAR WEST RESERVOIR

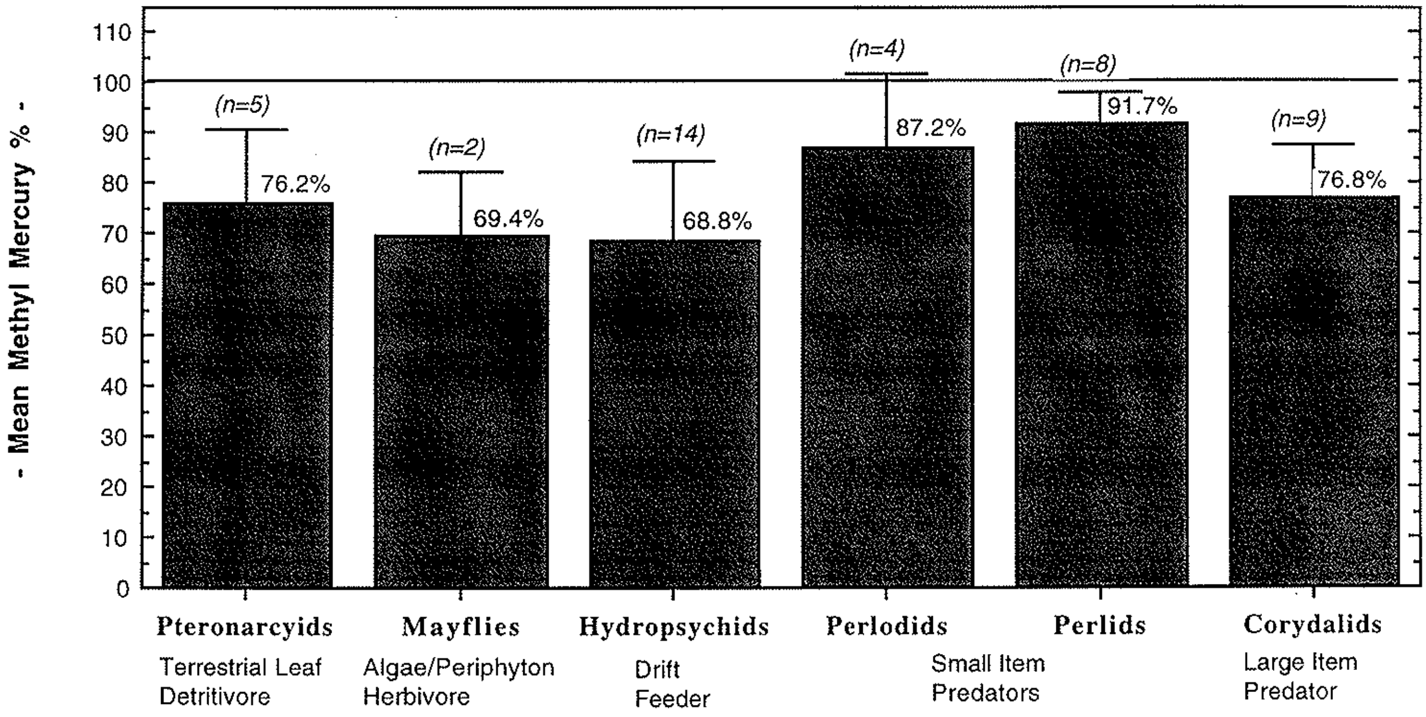
	Mayflies			Pteronarcyids			Hydropsyche			Perlodids			Perlids			Hellgrammites		
	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%
Bear R, Hwy 49							.216	.286	75.5%									
Below Camp FW							.138	.162	85.2%									

LARGE VALLEY RIVER

	Mayflies			Pteronarcyids			Hydropsyche			Perlodids			Perlids			Hellgrammites		
	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%	MeHg	THg	%
Lower Feather							.060	.078	77.1%									

Fig. 32. **Mean Methyl Mercury Percentages (Of Total Mercury) In Major Sierra Nevada Stream Macro-Invertebrates**

(multi-individual composite samples x n composite collections with 95% confidence intervals)



15.7%. Of the 14 Hydropsychid samples, 13 contained ≥ 56% methyl mercury. Small Perlodid stoneflies had methyl mercury percentages of 74-100% (mean = 87.2% ± 14.6%). Perlid stoneflies varied over a relatively narrow range of 83-101% methyl mercury (mean = 91.7% ± 6.6%) and Corydalid hellgrammites varied in methyl mercury fraction between 58% and 91% (mean = 76.8% ± 10.7%). These mean methyl mercury fractions are displayed graphically in Figure 32.

All of the benthic invertebrate trophic levels demonstrated relatively similar methyl mercury fractions of 69% to 92% on average. Methyl mercury accounted for more than 2/3 of the total mercury accumulated by each of these organisms. It is notable that there was no clear pattern of increasing methyl fraction with trophic level, as might be theoretically expected. However, the data clearly indicates the importance of the methyl species of mercury for biotic accumulation, consistent with many other studies in other aquatic habitats.

Mercury in Englebright Reservoir fish

In July 1996, we used an experimental gillnet from a boat to collect a sample of fish from the midsection of Englebright Reservoir, which receives the inflows from all three forks of the Yuba River. We had difficulty obtaining a large sample, but were able to collect at least a single representative of each of five reservoir fish species. Five Sacramento suckers were taken, together with one each hardhead, carp, smallmouth bass, and largemouth bass. The bass were small (11-12 inches, < 1 pound), while individuals of the other sampled species were mid to large sized adults. Data are presented below in Table 6.

This collection was notable for the relatively quite high mercury levels that were found throughout. Mercury in fresh (wet weight) edible filet muscle ranged from 0.41 to 0.89 ppm, with all values being near, at, or above the 0.50 ppm health advisory level. This was particularly significant in that the majority of the sampled fish were of species that are low in the trophic food web and typically demonstrate relatively very low levels of mercury accumulation. Hardhead is a native species that is herbivorous, while carp is an introduced species that feeds primarily on small invertebrates in the bottom sediment (Moyle 1976). The Sacramento sucker is a native species with feeding habits similar to carp. Comparative data from Clear Lake in the Coast Range, which is known to contain extremely elevated concentrations of sediment inorganic mercury, have consistently demonstrated carp muscle mercury to be in the ≤ 0.25 ppm range, even in very large and old individuals (TSMP 1990, 1991, 1992). The finding of significantly higher mercury concentrations accumulating in carp and other low trophic level fish within Englebright Reservoir indicates that the mercury in this Sierra Nevada foothill reservoir is more readily bioavailable to resident fish.

Table 6. Englebright Reservoir Fish Muscle (Filet) Mercury Concentrations
(fresh/wet weight ppm Hg, July 1996)

Identification	Weight *(g)*	Length *(mm)*	Weight *(lbs)*	Length *(inches)*	Muscle Hg *(wet wt ppm)*
Hardhead	1,160	440	2.55	17.3	0.47
Carp	2,350	540	5.17	21.3	0.88
Sacramento Sucker	870	410	1.91	16.1	0.57
Sacramento Sucker	1,020	450	2.24	17.7	0.68
Sacramento Sucker	1,110	470	2.44	18.5	0.50
Sacramento Sucker	1,150	460	2.53	18.1	0.41
Sacramento Sucker	1,460	523	3.21	20.6	0.89
Smallmouth Bass	330	280	0.73	11.0	0.52
Largemouth Bass	390	315	0.86	12.4	0.64

Only the bass in the collection were upper level predators. However, the two individuals sampled in this collection were quite small and young. Comparably sized bass from other systems characteristically contain lower mercury accumulations than co-occurring larger adults (TSMP 1990, Slotton 1991, Slotton *et al.* 1996). The relatively elevated levels in the young smallmouth (0.52 ppm) and largemouth (0.64 ppm) bass taken in this collection are consistent with the other Englebright data in suggesting that there is a considerable amount of fish uptake of mercury in this system. However, a more comprehensive sampling should be undertaken before drawing any firm conclusion on this matter, particularly from a regulatory standpoint.

While similar fish could not be collected at both the reservoir and river sites upstream or downstream, the data indicate a significant general increase in mercury bioavailability to fish within the reservoir, even as compared to the most highly elevated upstream stretches of the Yuba River tributaries. What is most interesting is the consistently low levels of mercury accumulation, across a wide range of sizes and ages, in rainbow trout taken below Englebright Reservoir (Site 16).

DISCUSSION AND CONCLUSIONS

Biotic mercury presence and distribution in the Sierra gold region

A clear signature of anthropogenic mercury was present in the aquatic biota sampled throughout the historic Sierra Nevada gold region in this research. Concentrations ≥ 0.01 mg kg^{-1} (dry weight) were found in virtually all invertebrates sampled. On a wet weight basis, fish filet muscle mercury was ≥ 0.03 mg kg^{-1} at all sites (≥ 0.14 mg kg^{-1}, dry weight). Both invertebrates and fish demonstrated significantly higher mercury concentrations in regions that have sustained greatest intensities of gold mining pressure, both historically and at present.

Trout and invertebrate samples indicate relatively low current levels of mercury bioavailability in the majority of the Feather and American River watersheds. In contrast, significantly greater bioavailability was indicated by higher bioaccumulation of mercury in a number of areas. Notably higher mercury regions included the upper forks of the Yuba River, with the mid-reaches of the Middle and South Forks having the highest biotic mercury concentrations in that drainage. Other notably elevated mercury streams within the Sacramento river watershed included the mid-section of the Middle Fork of the Feather River, Deer Creek, particularly below Lake Wildwood, and tributaries throughout the gold mining region of the Bear River drainage. The North Fork of the Cosumnes River, in the San Joaquin watershed, demonstrated the highest concentrations of biotic mercury among all of the 57 study sites. Elevated to a lesser extent, but on a relative basis as compared to adjacent sites were the North Fork of the Middle Fork of the American River (49), and Spanish Creek (7, tributary to the North Fork Feather River). The above noted streams with elevated biotic mercury included the highest densities of active dredging operations, which also corresponded generally to the greatest historical mining intensities. At sites located upstream of heavily mined stretches, e.g. the Plumbago site (27) on the Middle Fork Yuba River and the headwaters collections on the Bear River (Site 44), significantly lower mercury concentrations were found throughout the food web, as compared to levels within and downstream of intensively mined reaches.

The relative biotic mercury concentrations found in this study can presumably be linked to relative concentrations of aqueous, bioavailable mercury moving down each of these streams. It is important to distinguish between *concentration* and *mass load.* Sites with the highest concentrations of mercury may not necessarily be the most important overall contributors of mercury to the downstream Delta/Bay system. However, with regard to potential mercury remediation projects in the Sacramento River watershed, it is precisely those regions identified as having the greatest mercury concentrations that offer the most realistic options for effective mitigation work.

One important conclusion of the survey work is that the elevated mercury regions did not demonstrate a point source signature. Where biotic accumulations of mercury were elevated, this elevation was generally distributed across many miles of stream or river. The elevated bioavailable mercury regions could thus be localized to specific tributaries or series of river miles, but not to highly localized "hot spot" point sources. This is consistent with the historic widespread use of mercury throughout the gold mining region and its subsequent redistribution downstream.

Fish mercury concentrations in relation to environmental and health concerns

While these data clearly indicate the differences in relative mercury bioavailability among the various streams of the region, the absolute concentrations in rainbow trout were all well below existing health criteria. Even at the highest mercury sites, the normalized 250 g rainbow trout, fresh weight, filet muscle mercury levels were less than 50% of the 0.5 ppm guidelines suggested by the California Department of Health Services and the Academy of Sciences, and $\leq 21\%$ of the existing U.S. FDA fish criterion of 1.0 ppm. The entire data set for 250 g normalized rainbow trout ranged between 0.03 and 0.21 mg kg^{-1} (ppm). Larger fish ranged higher but were still all within the 0.5 ppm guidelines. We conclude that there is relatively little direct health hazard associated with the consumption of rainbow trout from these Sierra Nevada streams and rivers. The notably elevated levels of mercury in edible muscle of fish from within Englebright Reservoir suggests that a problem may exist in some of the foothill reservoirs--one that may warrant additional study. The fact that this elevated mercury phenomenon was not additionally found downstream of the reservoir indicates that the foothill reservoir habitat may be trapping bioavailable mercury in addition to the bulk, inorganic mercury which deposits there with sediment.

Influence of reservoirs on downstream biotic mercury

It was expected that mercury bioavailability might be relatively low in the rivers and streams of this region, despite the presence of still considerable amounts of inorganic mercury from the gold mining era. This is because methyl mercury, the predominant form of mercury that enters and moves through the food web, requires a biological process, bacterial methylation, for the bulk of its production (Gilmour *et al.* 1992). The opportunity for bacterial mercury methylation or even the presence of significant bacterial populations is minimized in the fast moving, cold, clear water habitat typical of many of these Sierra Nevada foothill streams. However, once transported to calmer waters such as downstream reservoirs, turbid valley rivers, the Sacramento/San Joaquin Delta, and San Francisco Bay, the potential for bacterial methylation of mercury derived from the

Sierra gold mining region increases dramatically. The foothill reservoirs, in particular, are likely sites of enhanced mercury methylation. Limited prior analyses of fish from some of these reservoirs have indeed found markedly higher mercury concentrations than those found in this study of the upstream rivers (TSMP 1990, 1991, 1992). Our sampling in Englebright Reservoir also detected quite elevated levels of mercury in edible filet muscle from a variety of species.

We hypothesized that, as a result of enhanced mercury methylation within Sierra foothill reservoirs, there might be a detectable net export of bioavailable mercury from them to their downstream rivers. In contrast, the data collected in this study indicate the reverse. Not only do the reservoirs not appear to be net exporters of bioavailable mercury, but they seem to be acting as sinks for bioavailable as well as inorganic mercury. In most instances where we sampled upstream and downstream of Sierra foothill reservoirs, significantly *lower* mercury was found in the downstream biota, throughout the entire aquatic food web (e.g. upstream/downstream of Englebright, New Bullards Bar, and Camp Far West Reservoirs). We conclude that, despite the likely enhancement of mercury methylation within these reservoirs, the bioavailable mercury must be quickly taken up within the reservoir ecosystem itself, becoming largely unavailable for downstream transport. It was understood that these reservoirs must act as giant sinks for the inorganic mercury moving into them from upstream. The finding that they are also apparently not net exporters of bioavailable mercury is a particularly interesting and relevant result of this study. Production and consumption of methyl mercury in the reservoir water column appears to be in equilibrium.

In any case, collections of biotic indicator species from below the final dams and reservoirs of the main stems of the Feather, Yuba, Bear, and American Rivers demonstrated uniformly low levels of time-integrated mercury bioavailability as compared to the elevated mercury stretches identified in the gold mining region. The Cosumnes River in the San Joaquin watershed, which was extremely elevated in bioavailable mercury and is a rare un-dammed system, may represent a more direct source of bioavailable mercury to the Delta than any of the rivers in the Sierra Nevada portion of the Sacramento River watershed.

Trophic feeding level relationship to mercury accumulation

Within each site, mercury concentrations in biota generally corresponded to trophic feeding level, with higher trophic levels of invertebrates containing greater concentrations of mercury. Corresponding rainbow trout, which prey on all of these invertebrates to varying extents, had still higher mercury accumulations, while piscivorous fish such as native squawfish and the larger brown trout had the highest mercury concentrations of all. Trophic bioconcentration of mercury is thus indicated to be a dominant mode of mercury accumulation by biota in this region. For basic ecological research, an interesting aspect of this work is the finding that relative mercury concentrations in aquatic species may offer a useful tool for determining the relative, time-integrated trophic feeding habits of specific aquatic species.

Correlations between the mercury contents of biota of different trophic levels were similar, whether identical types of organism were used for the comparison or a variety of representatives of each trophic guild. This suggests that when identical invertebrate species are not available between sites, a variety of species within the same trophic feeding guild may be utilized as comparative general indicators of relative mercury bioavailability.

Inter-trophic mercury correlations between various groups of co-existing invertebrates were found to be uniformly stronger than mercury concentration correlations between invertebrates and corresponding trout. This is likely due to the relative site fidelity of stream invertebrates, as compared to trout, which can wander extensively throughout their lifetime accumulation of mercury.

Correlations between mercury in stream invertebrates and mercury in co-occurring trout were stronger with increasing invertebrate trophic level. Predatory invertebrate species such as Perlid stoneflies and Corydalid hellgrammites were found to be the best indicators of corresponding trout mercury levels. The excellent correspondence between larger, predaceous invertebrates and co-occurring trout may be a function of similar diet and, particularly in the case of the large hellgrammites, similar ages and thus similar periods of mercury integration. Mercury in smaller, younger organisms such as most mayflies, Hydropsychid caddis nymphs, and young predators may not correlate as well with trout mercury, but may instead be a better indicator of shorter term conditions of mercury bioavailability. Under potentially dramatic seasonally or annually changing conditions of mercury bioavailability, changes will be far less pronounced in older organisms as compared to more ephemeral species, for which the most recent time period represents a larger proportion of the entire lifetime accumulation (Slotton *et al.* 1995b). Thus, different organisms may be utilized for different types of information. Trout mercury is of direct interest for health reasons and provides a general indicator of regional, long-term mercury availability. Larger predaceous species may be utilized as surrogates for trout. The larger/older invertebrates of all types provide localized, long-term integration of relative mercury availability, when same types are compared. Finally, smaller/younger invertebrates can potentially be used as integrators of mercury conditions over shorter time scales. Ongoing research by our U.C. Davis Heavy Metals Limnology Group is investigating all of these areas.

Future Considerations

Stream invertebrates appear to be appropriate indicators for determining relative, time-integrated mercury bioavailability between sites throughout the Sierra Nevada gold region.

However, the nature of the trophic structure of the invertebrate community must be considered and potentially significant temporal changes should be taken into account. Invertebrates are more widely available than trout and, because they do not have the mobility of fish, their mercury accumulations can be linked with greater confidence to conditions directly at and upstream of a given locale. Certain invertebrate species can also function as surrogates for trout, with larger predatory types showing the strongest relationship. Other species may be useful in determining short-term mercury conditions. The great advantage of using native biota as indicators, as compared to standard water grab sampling protocol, is their natural and continuous integration of conditions over time and their accumulation of, by definition, the bioavailable fraction of mercury.

As this comprehensive survey indicates that the elevated mercury regions of the gold country watersheds are not of a point source nature, potential future mercury remediation efforts would probably be best directed toward regional approaches such as an improved mercury buy-back program through ongoing small-scale miners. Costly point-source engineering solutions are not supported by the data.

Future research projects include similar survey work in the Sierra Nevada gold region to the south, particularly the Cosumnes and Mokelumne Rivers, survey work throughout the California Coast Range mercury mining district and into the Delta, together with simultaneous investigation of the research questions highlighted above. Another major area of research will involve the study of how the various mercury loads to the Delta/Bay system behave once in that system, with a particular emphasis on the long-term potential bioavailability of different mercury compounds from a variety of sources.

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