AN ABSTRACT OF THE THESIS OF

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Title: THE ACCUMULATION OF CADMIUM, COPPER AND NICKEL IN FRESHWATER MUSSELS (*MARGARITIFERA MARGARITIFERA*), ALGAE (*CLADOPHORA* SP.), AND SEDIMENT FROM ELK CREEK, OREGON.

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Dr. Michael C. Mix

Concern about heavy metal pollution has increased during the past decade in which studies have shown that heavy metals are accumulating in the environment and that these metals, in excess, are toxic to organisms, including man. Because of this concern, scientists have suggested the use of indigenous organisms as monitors of environmental pollution levels. However, many factors, in addition to pollution, have recently been shown to affect metal levels in organisms and knowledge of how these factors operate is necessary before biota can be used efficiently as monitors.

This study examined how metal levels in three components of a relatively unpolluted freshwater ecosystem varied seasonally. Mussels, algae and sediment were collected during a ten-month period from Elk Creek in the Oregon Coastal Mountain Range. The samples, consisting of whole soft parts of mussels, whole algae and total sediments, were prepared by acid digestion and then analyzed for copper, cadmium and nickel using flame atomic absorption. The results of a Kruskal-Wallis statistical test indicated that metal levels in mussels and sediment varied significantly over the study period. The highest levels occurred in July after which there was an abrupt decrease to approxi-

mately one-half the July levels in August and September. The metal levels remained low throughout the winter and spring. In mussels, the order of metal levels was Cu > Ni > Cd. However, in sediment and algae, the order was Ni > Cu >> Cd. The concentrations of Cu and Ni in mussels were similar to those in sediments while Cd concentrations in mussels were ten times greater than in sediment.

The high metal levels in July followed by relatively constant levels thereafter may indicate that the variations seen in this study were due to an isolated, temporary point source such as a recent clear-cut and will not be seen in future years. If the observed variation was indicative of true seasonal variation, then growth, reproductive condition or changes in run-off may have been responsible.

Measurements of metal levels in *M. margaritifera* and sediments have potential value in an environmental monitoring program. *Cladophora* can not be recommended as an indicator organism because of sampling and analytical difficulties. The possibility of seasonal variation should be considered when using any of these components as indicators. Samples from different areas should be taken in the same season or during the same run-off conditions, relative to season, before any inferences as to relative contamination levels can be made.

THE ACCUMULATION OF CADMIUM, COPPER AND NICKEL IN FRESHWATER MUSSELS (*Margaritifera margaritifera*), ALGAE (*Cladophora* sp.), AND SEDIMENT FROM ELK CREEK, OREGON

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INTRODUCTION

Heavy metals are found in trace amounts in the earth's crust. They enter the aquatic environment naturally by geological weathering of rock and volcanic activity (Cunningham 1979). However, because of the current industrial demand for metals, they are being mined and released into the environment at rates several times greater than from natural weathering and these rates are likely to increase as demand increases (Phillips 1980). Many studies have shown that, in excess, heavy metals adversely affect aquatic organisms and ecosystems (Van Hassel et al. 1980, Cunningham 1979, Hodson et al. 1979, Stokes 1979, and many others). Heavy metals in the environment have caused disease and death in humans (Forstner and Wittman 1979, Friberg et al. 1971). Because of their abundance and toxicity, heavy metals are of interest to environmental scientists. Further research is required to determine efficient methods for monitoring their levels in the environment.

Experimental Methods

The metals chosen for this study were copper, cadmium, and nickel (Cu, Cd, Ni). These metals, along with arsenic, beryllium, chromium, lead, mercury, selenium, silver, thallium and zinc, are considered Priority Pollutants by the Environmental Protection Agency (Keith and Telliard 1979). All are very toxic, in excess, and relatively abundant in the environment (Forstner and Wittmann 1979). Copper, Cd and Ni were chosen as representative metal pollutants because they can be easily and accurately measured and because they were present in detectable quantities in organisms and sediments at the sample site selected for this study.

Copper

Copper is a transition element with an atomic number of 29 and an atomic weight of 63.5. It is found in group IB of the periodic table. It can exist in a variety of forms in the aquatic environment, including Cu^{2+}, $Cu_2CO_3(OH)_2$, $CuCO_3$, $Cu(OH)_2$, CuS and, less commonly, $CuSO_4$ (Forstner and Wittmann 1979). Copper is also found in chelates, colloids and associated with inorganic or organic particulates (Phillips 1980). Allen et al. (1980) found that, in freshwater, Cu is predominantly in the organic colloidal form.

Copper enters the aquatic environment in waste waters from multiple industrial and domestic sources. Effluents from metal mining and processing areas are contaminated with Cu. Processed Cu is used by various industries, including pulp and paper mills, fertilizer manufacturers, petroleum refineries, steel foundries, nonferrous metal works and motor vehicle/aircraft plating industries. Other businesses, such as laundries and bakeries, that use or deal with copper-containing products also have Cu in their waste waters. Domestic point sources of Cu include water supply networks (copper pipes) that are corroded and enzyme detergents. Non-point sources include storm runoff from surfaces on which atmospheric Cu is deposited and leaching from domestic refuse heaps (Forstner and Wittmann 1979).

Besides the addition of Cu to natural waters from industrial and domestic wastes, it is sometimes placed intentionally in the aquatic environment. Copper sulfate is used as a selective fish poison to reduce populations of coarse fish at a concentration of two ppm. It is also used in a standard method of reducing algal populations at concentrations of one ppm or less in soft water or at concentrations of 5 to 12 ppm in hard water (Bennett 1970).

Some concentrations of Cu that have been measured in the environment are summarized in Table 1. The lower end of the ranges represent "clean" environments while the higher values are from relatively polluted environments.

Copper has several sublethal effects on aquatic flora and

TABLE 1: Reported concentrations of heavy metals in the environment.

LOCATION	CONCENTRATION OF METAL (μG/L)		
	COPPER	CADMIUM	NICKEL
Open ocean	0.05-27.0[1]	0.01-0.41[1]	0.13-43.0[1]
Near-shore ocean	0.1 -22.4[1]	0.01-0.62[1]	0.16-22.9[1]
Estuarine	0.4 -160.0[1]	0.01-100.0[1]	0.2 -30.0[1]
Freshwater	3.0 -10.0[2,3]	0-36000[5]	1-7000[6,7]
Freshwater sediment	1000-82000[4]	20-121000[4,6]	200-124000[4,6]
Marine sediment	1000-2424000[1]	130-9900[1]	2000-219000[1]

[1]Phillips 1980
[2]Heit et al. 1980
[3]Stokes 1979
[4]Mathis and Cummings 1973
[5]Coombs 1979
[6]Van Hassel et al. 1980
[7]Forstner and Wittmann 1979

fauna. Various studies have reported reductions in growth, photosynthesis, respiration, nitrogen fixation and reproduction in algae (Hodson et al. 1979). In aquatic invertebrates, reproduction and growth were inhibited and chronic mortality was increased at Cu concentrations of 5-3000 μg/l, depending on the species. Decreased respiration and heart rate were also reported as well as behavioral changes such as the cessation of burrowing activity in clams, closing of valves and operculums in molluscs and a decreased attraction to food (Hodson et al. 1979). In fish, Cu can reduce growth, egg production, spawning and resistance to disease. Behavioral effects on activity, avoidance, coughing, appetite and migration have also been observed. These sublethal effects on fish occurred between 4-150 μg/l, depending on the species and the response (Hodson et al. 1979).

Copper's lethal effects on algae provide the basis for its use as an algacide in both fresh and marine waters. Copper lethality to algae has also been observed below outfalls of copper-processing plants (Hodson et al. 1979). In aquatic invertebrates, 96-hour LC-50 values range from 4-100,000 μg/l, depending on the species and various physiological and environmental conditions. Daphnids, euphasids, ctenophores and medusae are the most sensitive organisms. Early life stages are more sensitive than adults, yet eggs can be much more resistant than either the adults or larva. Organisms with hard outer coverings such as molluscs with shells or arthropods with exoskeletons are generally more resistant to Cu exposure than soft-bodied organisms (Hodson et al. 1979). In fish, lethal concentrations range from 11-10,000 μg/l, with salmonids and cyprinids (carp, goldfish, chubs, shiners, dace) being the most sensitive, and centrarchids (crappie, bluegill, bass, walleye, perch) and pericthyids (striped bass) being the least sensitive (Hodson et al. 1979).

Copper is also accumulated by aquatic organisms. In algae, concentration factors (ratio of metal concentration in tissues to that in water) range from 1000-80,000 (Stokes 1979). This potential for accumulation has led to the use of several algae species to remove metals from waste waters (Hassett et al. 1980, Filip et al. 1979). Macrophytes, zooplankton, benthic invertebrates and fish also accumulate Cu in varying degrees (Stokes 1979).

Though there have been no catastrophic cases of Cu poisoning, through ingestion of food, in man, the possibility should not be ignored. Ingestion of acidic foods or beverages that are stored for long periods (overnight) in copper-lined containers can lead to nausea, vomiting and diarrhea (National Research Council 1977).

Cadmium

Cadmium is a transition element that has an atomic number of 48 and an atomic weight of 112.40. It is in group IIB of the periodic table. Species in water include Cd^{2+}, $CdCO_3$, $Cd(OH)_2$, CdS and, less commonly, $CdSO_4$ and $CdCl^+$ (Forstner and Wittmann 1979). Chelates, colloids, and association with organic and inorganic particulates are also possible but in freshwater the free ion and $CdCO_3$ are the dominant forms (Coombs 1979, Phillips 1977).

Like Cu, Cd enters the environment from multiple sources. Cadmium is released during mining and processing of lead and sulfide ores (Fassett 1972). The electroplating industry consumes the largest percentage of mined Cd, mostly for automobile manufacture. Cadmium is also used in the manufacture of pigments, plasticizers, batteries, bearing alloys, silver solder, semi-conductors, photocells, and some pesticides and fertilizers (Yost 1979, Forstner and Wittmann 1979, Friberg et al. 1971). Since these processes are not 100% efficient, Cd is lost to waste waters. Cadmium is also released during the burning of coals and incineration of cadmium-containing products. Sewage resulting from the industrial and domestic use of these products also contains Cd (Yost 1979). Some concentrations of Cd from both polluted and unpolluted environments are listed in Table 1.

Cadmium exerts its effects on aquatic organisms by complexing directly at cell organelles or by irreversible substitution for functional metals in enzymes (Coombs 1979). Leland et al. (1979) stated that the growth of diatoms decreased in the presence of Cd.

Wong et al. (1979) found that Cd reduced growth rate and the rate of ^{14}C uptake, and increased generation times in algae. Some physiological and biochemical effects on aquatic animals include inhibition of byssal thread production in mussels, inhibition of molting in some arthropods, decreased swimming response, decreased respiration, inhibition of certain enzymes and activation of other enzymes (Coombs 1979).

Cadmium is accumulated by aquatic organisms above water concentrations. Some representative values, in mg/l, are 0.2-25.6 for algae, 0.04-174 for bivalves, 0.15-33 for crustaceans and 0.03-7.3 for fish (Coombs 1979).

The consumption of cadmium-contaminated food has caused documented, disastrous effects in humans. An infamous case of chronic Cd poisoning occurred in inhabitants along the Jintsu River, Japan. A Zn mine released effluent and sludge into the river and the sludge was deposited on rice fields. The disease that resulted from consuming contaminated rice is known as "itai-itai" or "ouch-ouch" disease. It began with a discoloration of the teeth and loss of smell followed by a decrease in the number of red blood cells. Later symptoms included pains in bones and joints, lumbar pains, severe kidney damage, softening of bones, multiple fractures from slight traumas such as coughing, and skeletal deformation (Forstner and Wittmann 1979, Friberg et al. 1971). In workers exposed to Cd, renal tubular dysfunction, changes in metabolism of calcium and phosphorus, osteomalacia (bone disease), anemia, liver dysfunction and testicular changes have been reported (Friberg et al. 1971).

Nickel

Nickel is a transitional element with an atomic number of 28 and an atomic weight of 58.71. It is in group VIII of the periodic table. It exists in water as Ni^{2+}, $Ni(OH)_2$, NiS and, less commonly, $NiSO_4$ (Forstner and Wittmann 1979). Colloids, chelates, and associations with organic and inorganic particulates are possible (Phillips 1980), although it is usually found in the colloidal state (Mathis and Cummings 1973).

Sources of Ni in the environment include nickel mining and processing, electroplating, battery manufacturing, manufacture of electronic equipment and computers, asbestos processing, and combustion of coal and petroleum (National Research Council 1975). It is also used in pulp and paper mills, fertilizers, petroleum refining, and basic steel foundries (Forstner and Wittmann 1979). Some concentrations of Ni in both polluted and unpolluted environments are listed in Table 1.

In the few studies conducted with Ni, toxic effects on aquatic biota have been reported. Nickel affected the larval growth in two species of marine bivalves; they were abnormal with tissues extruding from their shells (Calabrese et al. 1977). Decreased growth rates for algae and changes in species composition (a decrease in diatoms and an increase in green and blue-green algae) were described by Fezy et al. (1979). They also showed that growth rates of diatoms decreased as Ni concentrations increased. Nickel was also found to be very toxic to other plants, fungi and fish (Mathis and Cummings 1973).

Some representative concentrations (mg/l) of Ni in aquatic organisms are 0.03-1.07 in algae (Trollope and Evans 1976), 0.1-133 in mussels (Manly and George 1977, Segar 1971), 4-18 in tubificid worms and 0.05-0.28 in fish (Mathis and Cummings 1973).

Most of the Ni ingested by humans is excreted in the feces. Absorbed Ni becomes associated with proteins, amino acids and possibly nucleic acids. Responses to acute Ni exposure include hyperglycemia, gastrointestinal effects and central nervous system effects (National Research Council 1975). Industrial exposure to nickel was associated with an increased incidence of cancers in the respiratory tract (National Research Council 1975).

Measurement of Metal Pollution

Because certain heavy metals are toxic and accumulate in the environment, it is desirable to be able to monitor environmental levels of these contaminants. Knowledge of metal levels also allows for realistic planning for locating future industries in order to minimize the environmental impact (Phillips 1977). Metal levels in the environment can be monitored by analyzing water, sediment, or biota; each has its advantages and disadvantages.

Water

Analysis of water for heavy metals is possible, but has severe disadvantages. Heavy metal concentrations in water are often low and preconcentration methods are necessary before analysis. This is expensive, time-consuming and increases the chance for contamination or even the loss of metals. In addition, the presence of other compounds such as complexing or chelating agents in water makes metals unavailable to organisms. Thus, the total concentration of a metal in water or the concentrations in certain size fractions does not give a clear idea of levels in the biota. Finally, the greatest disadvantage is that the metal concentrations at any location are subject to large variations associated with differences in season, time of day, extent of freshwater run-off, depth of sampling, hydrological factors such as currents, and intermittant fluxes of industrial effluents. Thus a large number of samples would be necessary in order to obtain an average concentration (Phillips 1977).

Sediments

Sediments, though more easily analyzed, present other difficulties. The metal concentrations in sediments depend not only on the amount of metal deposited but also on the amount and size of other particles deposited over time. Also, the metal contents of sediments are directly related to the organic matter content and not simply to pollution levels. That difficulty can be reduced by reporting sediment levels as grams metals per gram organic carbon. An additional problem is that even if the metals in sediments are accurately analyzed, they do not necessarily reflect the availability to biota, except, perhaps, for those living in the sediments. Often, high metal concentrations in the sediments indicate that metals are being removed from the water column and biota living in the water column are actually exposed to much smaller concentrations (Phillips 1977).

The above problems make it difficult to compare sediment metal levels between various areas as an index of relative pollution. However, sediment analyses should not be disregarded when studying metal dynamics in aquatic systems because they may be helpful in understanding seasonal cycles of metals in organisms. Therefore, sediments were analyzed in this study.

Indicator Organisms

A biological indicator is an organism used to quantify relative levels of metal pollution in the environment. This can be accomplished by measuring metal concentrations in their tissues (Phillips 1977). The value of using such monitors is that levels in their tissues represent, to some degree, the amount of metal available to the organism. Also, these levels represent integrations over time and this reduces the effects of temporary fluctuations. An ideal indicator organism satisfies the following criteria: (1) accumulates the pollutant without being killed at environmental levels; (2) is sedentary so it cannot migrate from the pollution source; (3) is long-lived; (4) is of reasonable size; (5) is easy to obtain and hardy enough to survive in the lab; (6) is abundant and wide-spread; (7) has the ability to concentrate metals to high levels; (8) exhibits a simple correlation between metal content of its tissues and that of water; and, (9) has the same correlation between metal content of its tissues and that of water for all locations studied (Phillips 1977).

In addition to having the above characteristics, an indicator organism should respond to the metal form of interest. For example, if one is interested in metals in solution, algae, which responds only to this form, should be used. However, if one is interested in metals obtained from food and from ingestion of particulate matter as well as from solution, a better choice is to use a bivalve mollusc which takes up metals by all three routes (Phillips 1980). Rates of uptake and excretion should also be considered in order to determine the necessary frequency of sampling (Phillips 1980).

The largest amount of research with indicator species has been done on algae and bivalves from the marine environment. Various species of marine algae concentrate different metals to different levels (Phillips 1977). Algae are responsive to soluble metals in water and not necessarily to the total metal load. Also, biological half-lives of metals within algae are extremely long. Thus, algae have a high degree of time integration which makes them good indicators for measuring metal pollutants. Also, some algae accumulate metals for only a short period of growth, usually less than one year; these species would be suitable indicators for localized, short-term pollution (Forstner and Wittmann 1979).

In contrast to the large amount of marine work, only a few studies have been done on freshwater algae. Laube et al. (1979) and Hassett et al. (1980) showed that freshwater algae accumulate certain metals in the laboratory. Klotz (1981), Hassett et al. (1980), Johnson et al. (1978) and Trollope and Evans (1976) measured concentrations of some metals in freshwater algae in the field. Johnson et al. (1978) reported that metal concentrations in algae had a positive correlation with water concentrations in a polluted lake. Hassett et al. (1980), Filip et al. (1979) and Jennett et al. (1977) used freshwater algae in waste-water treatment to efficiently remove excessive metals. Forstner and Wittmann (1979) and Keeny (1976) considered freshwater algae to be good biological indicators.

Bivalves are often used to monitor pollution in marine and estuarine waters since they satisfy many criteria for ideal indicators. They accumulate metals with concentration factors of 10^3-10^6 depending on the species and the metal involved. They are filter-feeders so they obtain metals from food, water, and particulates which pass their gills and thus, they are indicators of total metal pollution (Phillips 1977).

Again, work on freshwater bivalves lags behind studies on marine bivalves. Heit et al. (1980), Friant (1979), Jones and Walker (1979), Price and Knight (1978), Anderson (1977a, b), Manly and George (1977), Mathis and Cummings (1973), and Segar (1971) described the concentrations of some metals in indigenous freshwater bivalves. Most of these studies were on molluscs from polluted rivers though there are one or two reports for non-industrial streams (Friant 1979). Also, most of these studies, with the exception of Jones and Walker (1979), involved only a single sample or pooling of several samples and thus did not give a clear idea of what changes may have occurred over time. Foster and Bates (1978) and Mellinger (1972) showed that bivalves accumulated some metals in the laboratory.

A major problem with using indigenous organisms as indicators is that many variables, other than metal pollution levels, can affect metal concentrations in tissues. It has been reported that different species in the same area frequently show different metal concentrations (Frazier 1979). Within a species, instrinsic factors such as age, stage in life history, size, weight, sex, activity, growth, reproductive condition and current body burden of a metal can affect accumulation. Extrinsic factors such as temperature, salinity, season, alkalinity, pH, light, concentration and duration of exposure, depth in water column, distance from shoreline, chemical form of metal, diet, presence of chelating agents and reactions with other metals can also influence metal concentrations in the organism (Phillips 1980, Cunningham 1979, Forstner and Wittmann 1979, Hodson et al. 1979, Stokes 1979, and Phillips 1977).

Despite the above problems, the use of biological indicators in marine and estuarine systems is still of value as long as studies are done in a manner that minimizes variations. Cunningham (1979) listed five conditions that should be followed in a sampling program for bivalves: (1) all bivalves should be collected in the same season over a short time period, (2) the sampling period should be in winter when body residues are maximal, (3) all bivalves should be of similar size and at least ten individuals should be analyzed, (4) all bivalves should be collected from the same depth and (5) bivalves should be collected from areas of similar salinity. It is also advantageous to sample both bivalves and algae from a given area since they each reflect different sources of the trace element load and can give more information than if one species is studied (Phillips 1977).

The use of bivalves and algae as indicators should be extended to freshwater systems where pollution is also a problem. However, more information is needed on the effects of variables, other than pollution levels, on metal levels in freshwater organisms.

Definition of Problem and Objectives

Heavy metals are entering the aquatic environment at an ever increasing rate from industrial, urban, and agricultural sources. Excessive quantities of these metals are harmful to aquatic organisms and man. Therefore, it is desirable to monitor the levels of metals in aquatic environments and various indigenous organisms are suggested as potential monitors. However, before a species can be used for estimating levels of metal pollution, it is necessary to have data on baseline metal concentrations from organisms inhabiting a relatively unpolluted environment. Therefore, the objective of this research was to determine metal concentrations in three different components of a relatively pristine aquatic ecosystem during a ten-month period. Specifically, questions that were investigated included:

1. What are the concentrations of Cd, Cu and Ni in freshwater mussels, sediment and algae from Elk Creek?
2. Do these metal levels vary over time?
3. Are there any relationships between metal concentrations in mussels, sediment and algae?
4. What is the general sequence of metal concentrations in each of the three components analyzed?

MATERIALS AND METHODS

Experimental Organisms

Margaritifera margaritifera

Margaritifera margaritifera has the widest distribution of all pearly freshwater mussels. It is found in many parts of the northern hemisphere including northern Europe, northern Asia, Japan, Iceland and northern North America excluding the central region (Walker 1910).

The subspecies found west of the Rocky Mountains, and used in this research, was *Margaritifera margaritifera falcata* (Fig. 1). It has an elongated bivalve shell with a rounded anterior end and a pointed posterior end with two openings: a ventral inhalent aperture and a dorsal exhalent aperture (Smith 1980). The inside of the shell, or nacre, is purple to red which is the only difference between this subspecies and other subspecies of *M. margaritifera* (Roscoe and Redelings 1964).

The sexes in *M. margaritifera* are separate (Smith 1979). Individuals begin to breed when seven to eight years old (Simpson 1899) and continue to breed yearly throughout their life span of seventy to eighty years (Roscoe and Redelings 1964). Eggs develop in the ovaries of the female in late summer and continue to mature over the winter. In spring, the eggs move into the gill chambers which serve as brood pouches (Murphy 1942). Sperm released into the water are drawn into the inhalent opening of the female (Pennak 1978). In the gill chamber, the eggs develop into a tiny bivalved larvae called a glochidia in a period of 12-28 days depending on temperature (Murphy 1942). When the glochidia are mature, they are released from the female. They are parasitic and must attach to the gills of a fish, usually a rainbow or brown trout, to survive. After several weeks, they drop off the fish and become free-living on the river bottom (Ingram 1948). The breeding season for the western subspecies is from mid-May to late June (Murphy 1942). Roscoe and Redelings

Figure 1: Specimen of *Margaritifera margaritifera* taken from Elk Creek, Oregon

(1964) reported a breeding season of June to August for European and eastern North American subspecies. In contrast, Smith (1976) reported a breeding season from August to mid-October in eastern North America.

M. margaritifera are generally found in trout streams, in large stable areas containing gravel and sand (Murphy 1942). Often these areas have large rocks with sand in the crevices between rocks or in small scoured depressions. The mussels are found either lying on their sides or buried approximately two-thirds of their length with the anterior end downward and the foot serving as an anchor. The mussels are capable of some locomotion, usually in the late evening, night, or early morning hours (Roscoe and Redelings 1964).

M. margaritifera possesses characteristics that may make it a good indicator for heavy metal pollution. Its wide distribution would enable scientists to compare heavy metal levels in fresh waters throughout the northern hemisphere. Also, its long life span and sedentary life style would allow it to be indicative of heavy metals in a particular area over time. Finally, it has been shown to accumulate metals including cadmium, mercury, zinc (Mellinger 1972) and technetium (Hevland, personal communication), in the laboratory.

Cladophora sp.

Cladophora is a genus of filamentous green algae found in fresh, brackish and marine waters throughout the world (Smith 1950). It is often abundant in streams and standing waters (Whitton 1970). Whitton (1970) suggests that one species, *C. glomerata*, is ". . . the most abundant algae in streams throughout the world."

Cladophora consists of fairly long rhizoidal branches usually attached to a substratum, and elongated, multinucleate thallus cells which form long, branching filaments (Fig. 2) (Whitton 1970). Most species are perennial (Smith 1950). In the spring, the basal overwintering filaments send out upright branches. Peak growth occurs in early summer after which growth slows, possibly due to temperature or lighting conditions. In the fall, there is a second, usually

Figure 2: Specimen of *Cladophora* sp.

smaller, peak in growth then the upright part detaches leaving the thick-walled basal filaments to overwinter (Whitton 1970).

Cladophora is found on a wide range of substrates including rocks, macrophytes and shellfish. As a genus, *Cladophora* responds favorably to temperatures in the range of 6-30°C and high light intensities. Waters which are turbulent and have high nutrient levels (particularly phosphate and nitrate), high pH and high hardness levels are also favored (Whitton 1970).

Cladophora would seem to have good potential as an indicator species. It is a very hardy organism that is found in a wide range of environments. It possesses hold-fasts instead of roots so it would respond directly to soluble metals (Keeny et al. 1976). *Cladophora* is also sessile so the concentrations of metals in its tissues should be integrative over the time of its growth for that particular area. Whitton (1970) listed several lab studies which demonstrate that *Cladophora* accumulates various substances in its tissues and that accumulation depends on solution concentration. One major drawback to using *Cladophora* is that it is not present in a form that can be sampled from late fall through early spring. However, it may still be useful during the time it is present. In addition, if it is sampled during late spring/early summer, its metal concentration should reflect heavy metals accumulated over a fixed time interval which might be valuable in monitoring (Keeny et al. 1976).

Description of Sampling Site

Samples were collected from Elk Creek (also referred to as Big Elk Creek) which is a tributary of the Yaquina River in the western Oregon Coastal Mountain Range. The collecting site (latitude 44°36', longitude 123°51') was located 3.7 miles upstream from the junction of Elk Creek with the Yaquina River at Elk City, Oregon. At that point, Elk Creek is a 4th-order stream with numerous tributaries (Fig. 3), many of which drain unpopulated and undeveloped mountain valleys and peaks. Several of the larger tributaries are impacted by quarry and logging activities. A lightly traveled dirt road

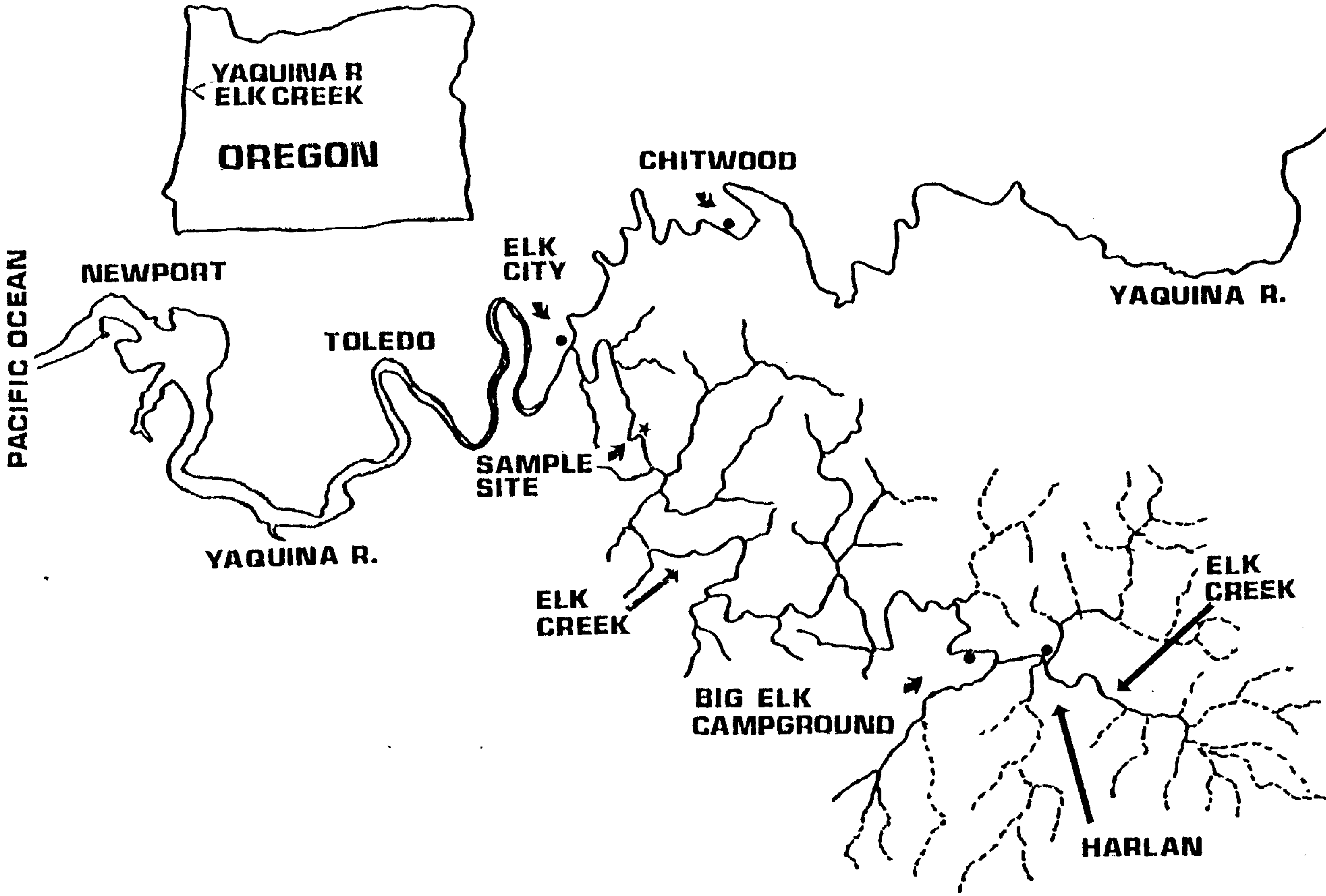

Figure 3: Map of Elk Creek drainage system. ——— indicates streams with year-round flows; - - - - indicates ephemeral streams.

parallels Elk Creek for most of its length. Along this road, some isolated houses are found at a density of approximately two to four per mile. Other potential impacts, upstream of the sample site, include fishing (steelhead, cutthroat trout, silver salmon and fall chinook salmon), livestock grazing, several gravel pits and clear-cuts, a campground and one very small town, Harlan.

The sample site contained many large flat rocks with circular potholes (Fig. 4). A sediment of coarse sand and gravel collected in the potholes and in crevices between rocks. Mussels were found either lying on top of this sediment or, more commonly, buried vertically in the sediment. *Cladophora* was attached to rocks or to mussel shells.

The surrounding banks were covered by long grasses and brambles and a few deciduous trees, primarily maple and alder. Within the stream, obvious organisms, in addition to mussels, included snails, caddisfly larvae, crayfish and small fish, presumably dace or minnow.

General Procedures

Samples of sediment and mussels were obtained from Elk Creek in July, August, September and October of 1980 and January, March and May of 1981. Each sample consisted of 20 mussels and 10 vials of sediment. Algae samples were obtained, as available, in July, August and September of 1980.

Samples were prepared for analysis using a modification of the procedures developed by Dr. David LaTouche (personal communication) as discussed below.

In order to prevent metal contamination from the sample containers, all glassware used in the storage of sample material was soaked prior to use, in a bath of 50% conc HNO_3 and 50% redistilled water, for a minimum period of 16 h (overnight). All other glassware used to handle or transfer sample material was soaked in the acid bath for at least 1 h before use and rinsed with a 40% HNO_3 solution between handling different samples. Teflon caps were used on all vials and test tubes. To prevent the loss of metals to containers

Figure 4: Sampling site for mussels, sediment and algae on Elk Creek, Oregon Coastal Mountain Range

during storage, all samples and standards were prepared in acidic solutions.

Sediment

Sediment samples were obtained in 24 ml glass vials by scooping sediment from the river bottom. Each sample was transferred to a glass Petri dish and dried overnight at 65-75°C. For each July and August sample, approximately 1 g of dried sediment was placed in a screw-cap test tube and weighed. This amount was later increased to 3 g to improve detection during analysis. Approximately 4 ml of conc HNO_3 was then added to each test tube. Closed test tubes were heated in a Multi-Blok test tube heater (Lab Line Instruments No. 2093) for 3 h at 92-96°C. Samples were then quantitatively transferred through glass wool to volumetric flasks and diluted to 10 ml. Finally, each sample was transferred to a 16 ml vial for storage prior to analysis by atomic absorption.

Algae

Cladophora sp. was removed in clumps from rocks on the river bottom and placed in a 24 ml glass vial. Each sample was rinsed several times with redistilled water and then placed in a glass Petri dish. These samples were dried overnight at 65-75°C. Approximately 0.2-0.5 g of the dry algae was then placed in a screw-cap test tube and weighed. The remainder of the algae preparation was the same as for the sediment.

Mussels

Mussels were collected by hand from the river bottom. They were brought to the lab and allowed to depurate in river water for 24 hr in order to remove the stomach contents which may have contained unabsorbed metals. At the end of the depuration, mussels were either processed immediately or placed in a freezer and defrosted several hours prior to preparation.

The total weight and length of each mussel were recorded. Individual mussels were shucked (removed from the shell) and homogenized separately in a 50 ml blender. For each mussel in the July and August samples, approximately 3 g of the homogenate was transferred to a screw-cap test tube and weighed. An additional 1-3 g of homogenate was placed in a Petri dish, weighed, dried overnight at 65-75°C and reweighed to determine the ratio of wet to dry tissue weight. The remainder of the preparation was the same as for the sediment.

In order to improve detection, the September through May mussel samples were concentrated prior to analysis. Individual mussels were shucked and homogenized. Approximately 6-8 g of the homogenate were transferred to a screw-cap test tube and weighed. An addition 1-3 g were dried to determine the wet to dry weight ratio. Next, 4 ml conc HNO_3 were added to each test tube and closed test tubes were heated for 3 h in the test tube block at 92-96°C. Periodically, the caps were loosened to relieve any build-up or pressure.

After cooling, the samples were quantitatively transferred through glass wool to a 20 ml beaker and placed on a heating block to evaporate. A funnel hood was placed over the beakers so that as acid vapor rose from the beakers, it could be aspirated into running water and thus diluted. The samples were concentrated to approximately 2 ml, cooled, transferred through Whatmann #2 filter paper to an A-line graduate cylinder and diluted to 5 ml. The final sample solution was then transferred to a 16 ml vial for storage prior to analysis by atomic absorption spectrophotometry.

Atomic Absorption

All samples were analyzed for Cu, Cd and Ni by flame analysis on a Perkin-Elmer 403 atomic absorption spectrophotometer. The instrument was set for each metal as recommended in the instruction book (Appendix A). A series of standards was prepared for each metal in the linear absorption range. Standards and samples were then run consecutively and their absorbances were recorded. The concentration of the samples was then determined from a linear regression of standard absorbance versus concentration. The concentration of each metal in the original sample was backcalculated to μg metal per g sample dry weight:

$$\mu g/g = \mu g/ml \times ml \text{ in sample} \times 1/\text{sample dry weight}$$

The performance of the atomic absorption spectrophotometer was evaluated using National Bureau of Standards oyster tissue dried as specified and prepared in the same manner as the mussel tissue.

Statistics

Scatter graphs of the data on metal concentrations in mussels and sediments are shown in Figures 8-13. The data indicated the values were not normally distributed and that the variances were heterogeneous. This was confirmed using Bartlett's test for homogeneity of variance (Sokal and Rohlf 1969). Geisy and Wiener (1977) demonstrated that frequency distributions of trace metals in fish were often distributed in a log normal fashion and they cited several other authors who found a similar distribution of trace metals in other aquatic biota.

When samples are non-normal with heterogeneous variances, biological statistics books suggest a log transformation of the data (Zar 1974, Sokal and Rohlf 1969). Adams et al. (1980) used this procedure successfully. The log transformation was used on the data from this experiment, but it was not sufficient to reduce the heterogeneity of variances to a non-significant level. Thus, the nonparametric Kruskal-Wallis test for one-way layouts was used to compare metal levels over time for both mussels and sediment. For those samples where the levels were significantly different, a nonparametric multiple comparison test suggested in Daniel (1978) was used. Van Hassell et al. (1980), in their comparisons among seasons, stations and species, used a similar approach.

RESULTS

The mean metal concentrations in mussels, sediments and algae, for each month sampled, are listed in Table 2 and illustrated graphically for mussels in Figures 5, 9 and 13. Individual metal concentrations for each sample are listed in Appendix B and illustrated on scatter graphs for mussels and sediments in Figures 6-8 and 10-12.

Mussels

For mussels, the general pattern was for a relatively high metal concentration in July followed by an abrupt decrease in August to approximately 50% of the July level (Table 2, Fig. 5). The metal levels remained low throughout the fall, winter and spring samples with the exception of a peak for Ni in March. In all cases, a greater variability about the mean was associated with the high metal levels in the July samples than in the samples from other months (Figs. 6-8). A greater variability was also found in the March peak for Ni (Fig. 8). In most cases, the distribution of data points for a given metal in a given month was positively skewed with a large cluster of data points just below the mean and fewer, but more widely scattered, points at concentrations above the mean.

Copper was present in the highest concentration in mussels with levels ranging from 10.13-44.53 μg/g in July and 4.82-12.04 μg/g during the remainder of the study period. Nickel was next in abundance with concentrations ranging from 2.53-19.41 μg/g in July and March and 1.57-8.68 μg/g for the other samples. Cadmium exhibited the lowest concentration in mussels with values of 1.67-6.21 μg/g in July and 0.94-4.63 μg/g in the remaining months.

Sediments

In sediments, a pattern similar to mussels was found for Cd and Ni (Fig. 9). Concentrations in July were higher and more variable than those in other months with the exception of Cd in August which exhibited a mean concentration and variability similar to July.

TABLE 2: Metal concentrations (μg/g): Mean ± standard deviation

MUSSELS

DATE	COPPER	CADMIUM	NICKEL
7/8/80	21.07 ± 10.11	3.81 ± 1.31	10.49 ± 4.29
8/8/80	7.93 ± 1.54	2.56 ± 0.87	4.19 ± 1.01
9/11/80	7.35 ± 1.28	2.27 ± 0.66	3.77 ± 1.39
10/5/80	6.63 ± 1.44	1.98 ± 0.80	3.24 ± 0.83
1/10/81	7.53 ± 1.47	2.21 ± 0.88	4.32 ± 1.74
3/12/81	7.60 ± 1.75	2.16 ± 0.78	7.31 ± 3.46
5/7/81	7.63 ± 1.61	2.30 ± 0.74	3.97 ± 0.69

SEDIMENT

DATE	COPPER	CADMIUM	NICKEL
7/8/80	6.48 ± 3.53	0.37 ± 0.11	13.83 ± 3.47
8/8/80	6.44 ± 2.02	0.35 ± 0.10	9.76 ± 1.39
9/11/80	5.54 ± 0.85	0.24 ± 0.05	9.85 ± 1.38
10/5/80	6.54 ± 3.24	0.17 ± 0.04	8.94 ± 1.25
1/10/81	4.91 ± 1.59	0.16 ± 0.03	7.93 ± 0.92
3/12/81	5.63 ± 2.65	0.14 ± 0.02	7.98 ± 0.99
5/7/81	4.31 ± 1.21	0.21 ± 0.02	7.74 ± 1.26

ALGAE

DATE[1]	COPPER	CADMIUM	NICKEL
7/8/80	16.17 ± 8.47	3.47 ± 3.51	23.63 ± 6.00
8/8/80	8.34 ± 0.79	2.83 ± 2.87	17.13 ± 4.45
9/11/80	5.80	0.44	11.61

[1]Algae samples were collected only on the 3 dates included below.

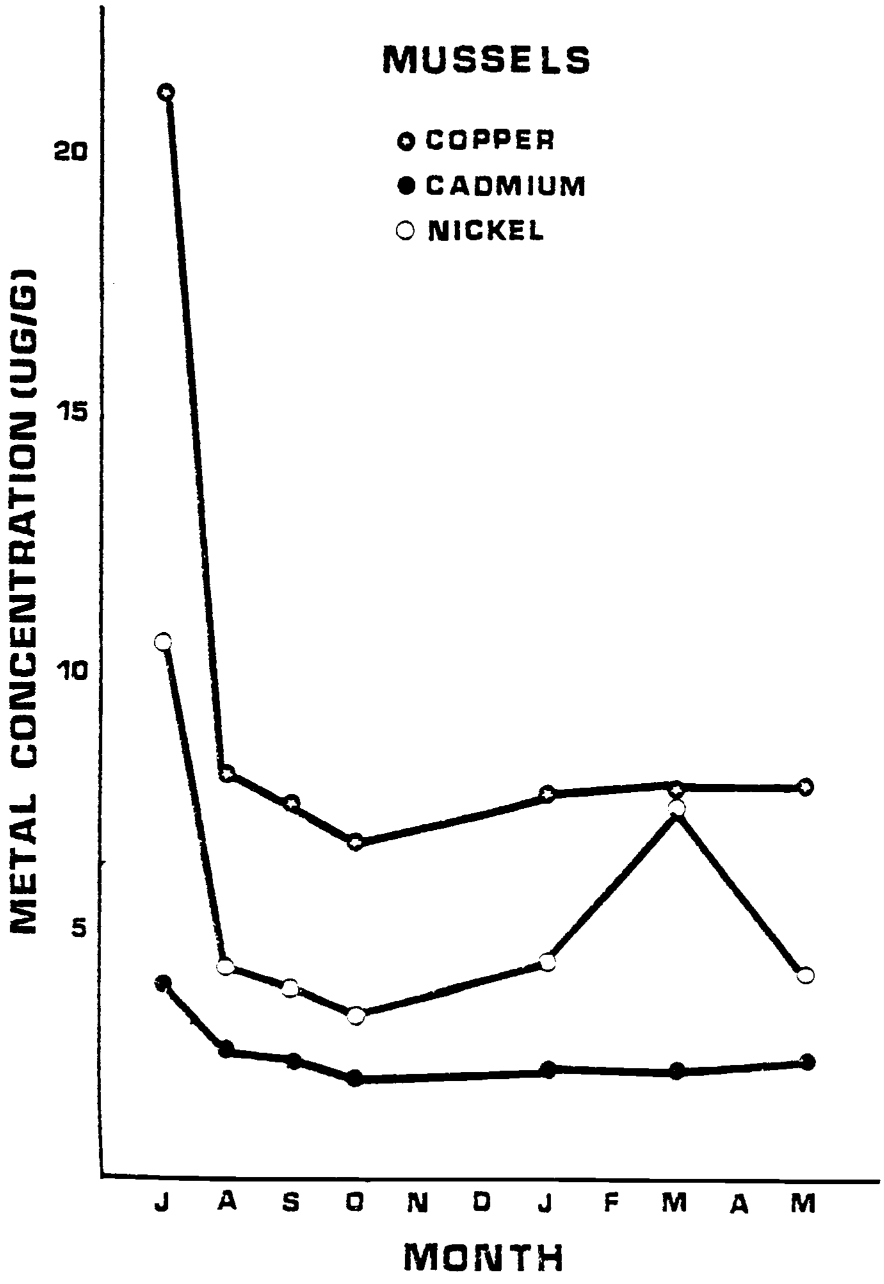

Figure 5: Mean metal concentrations in mussels from July 1980 through May 1981

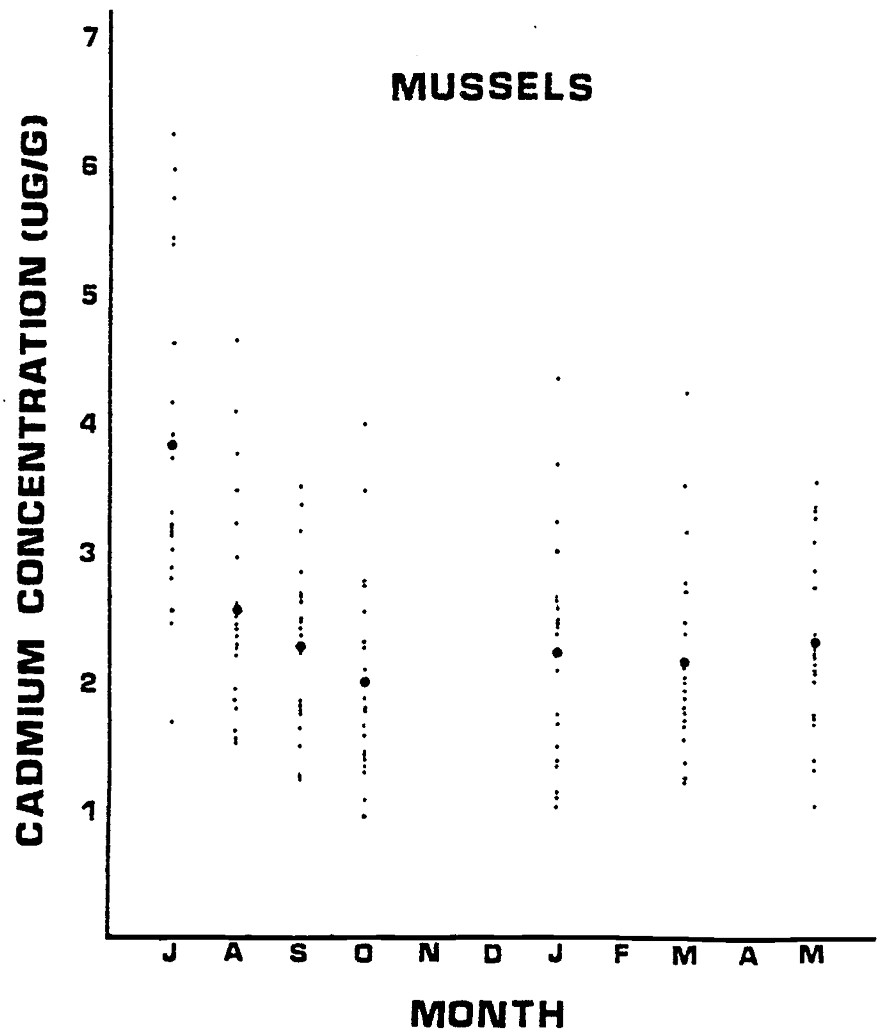

Figure 6: Mean (•) and individual (·) cadmium concentrations in mussels from July 1980 through May 1981

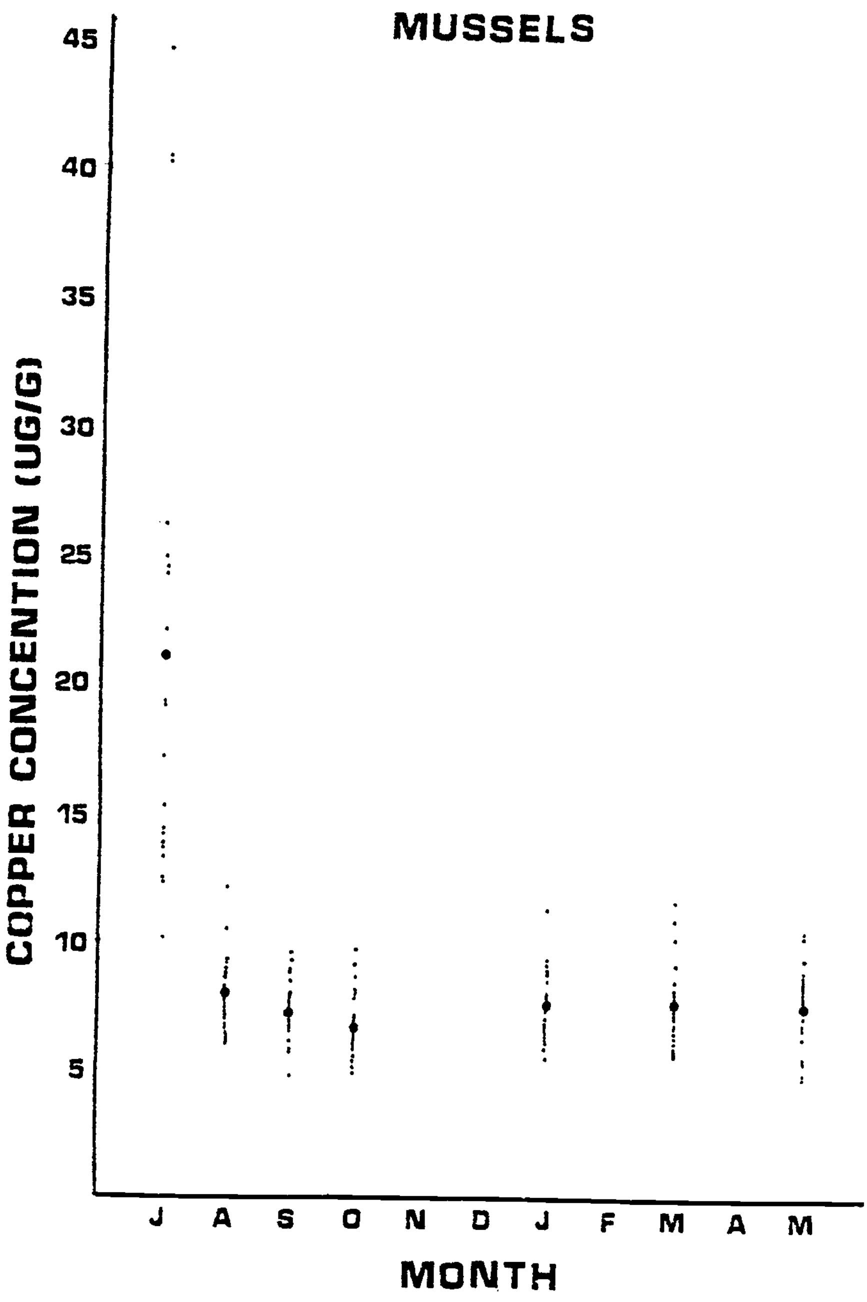

Figure 7: Mean (•) and individual (·) copper concentrations in mussels from July 1980 through May 1981

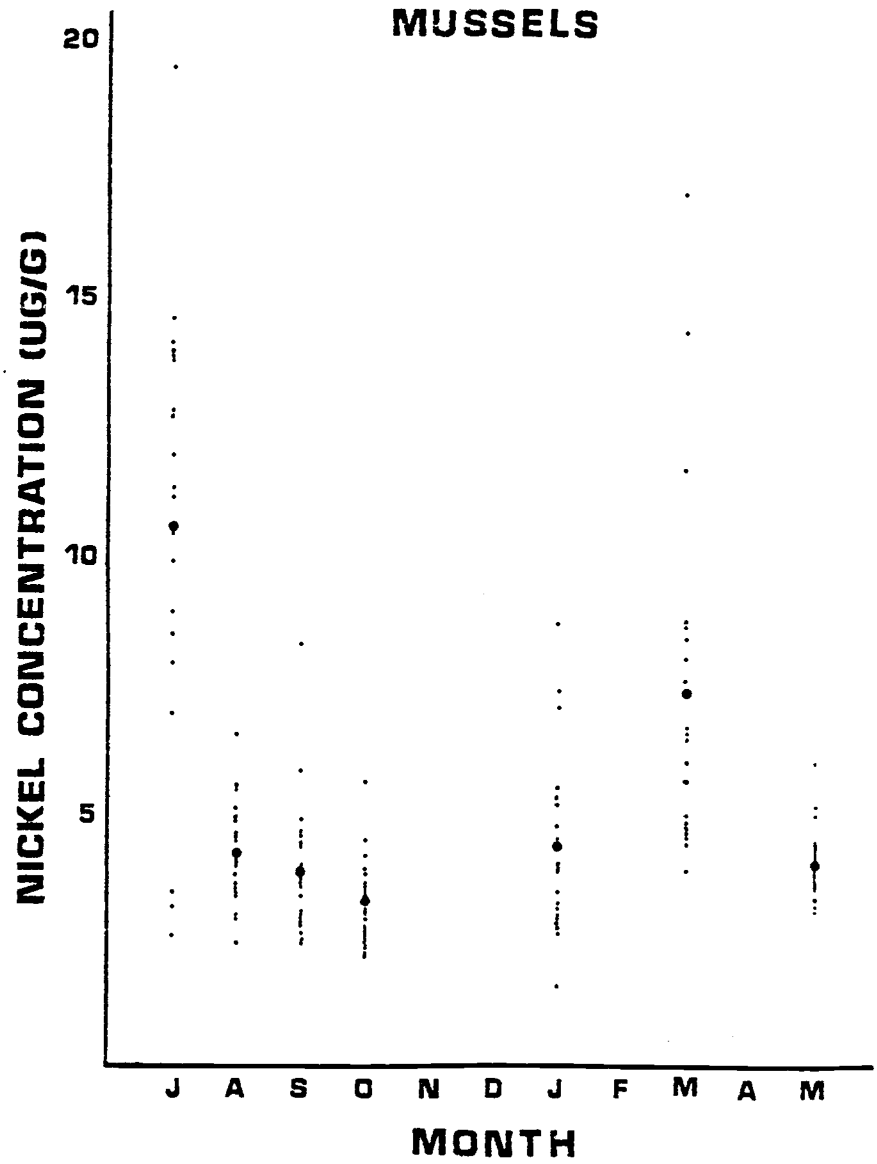

Figure 8: Mean (•) and individual (·) nickel concentrations in mussels from July 1980 through May 1981

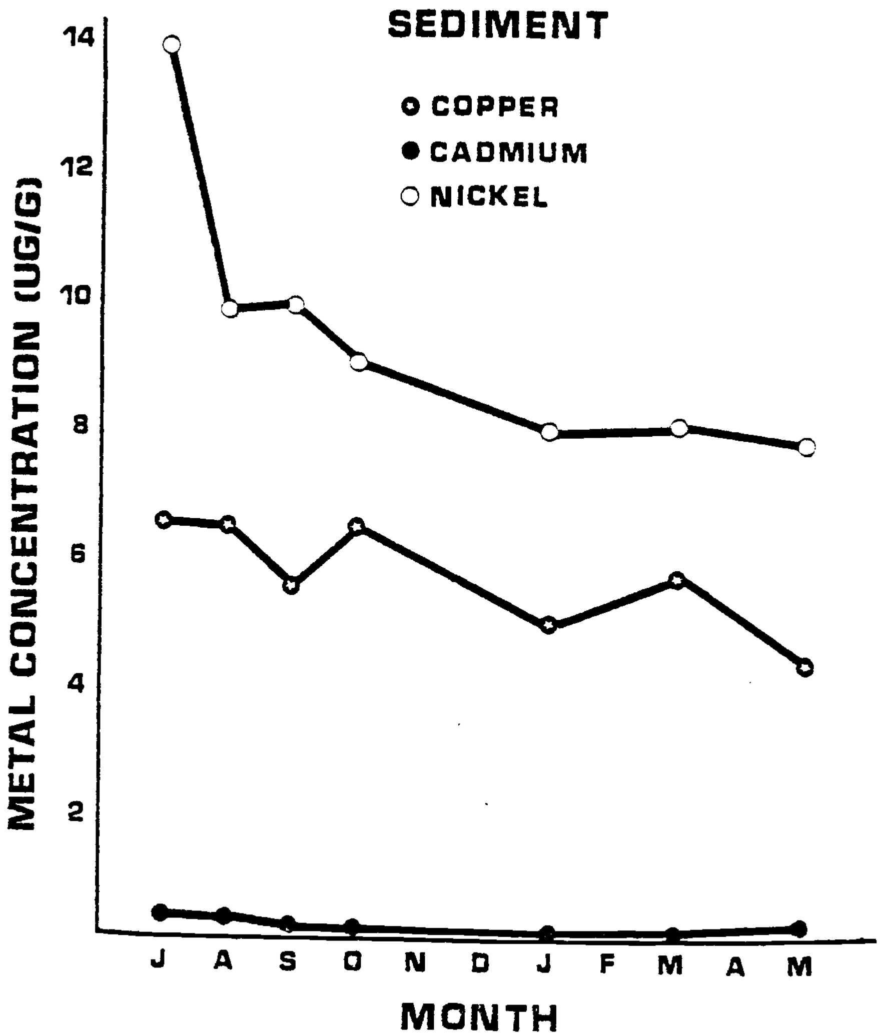

Figure 9: Mean metal concentrations in sediment from July 1980 through May 1981

Many of the distributions were positively skewed (Figs. 10-12). Copper in sediments did not vary over time though some months showed higher variabilities than others, with no general pattern (Fig. 10). Nearly all months exhibited a positively skewed distribution.

Nickel concentrations in sediments were highest in July, ranging from 10.60-21.17 μg/g, followed by a decrease to 6.01-13.10 μg/g in the remainder of the months sampled. Copper was next in abundance with concentrations ranging from 2.90-14.43 μg/g. Cadmium was present in concentrations an order of magnitude lower than Cu or Ni with levels ranging from 0.21-0.62 μg/g in July and August and 0.11-0.35 μg/g in the remaining months.

The six Kruskal-Wallis nonparametric statistical tests performed on mussel and sediment metal levels over time yielded results that confirm the above observations (Table 3). Significant differences in metal concentrations over time were found for all metals except Cu in sediment. For mussels, the result of multiple comparison tests showed that July was significantly different than all other months with the exception of Ni in March. For sediments, Cd and Ni multiple comparison tests did not yield an exact pattern. For Cd, July, August, and September levels were generally different than October, January, and March but similar to May. For Ni, July levels were significantly different than all other months but other significant differences had no general pattern. The validity of these multiple comparison statistics on the sediment metal levels is considered questionable since levels varied by only 0.1-0.2 μg/g for Cd and 1-2 μg/g for Ni.

Algae

Algae was available for analysis only in July, August and September because of its growth cycle. All three metals in algae exhibited a decrease over time with the most abrupt decrease in Cu (Fig. 13). Because it was difficult to get samples with enough dry biomass to accurately analyze, only one to four samples were collected each month. Thus, there was not enough information to determine

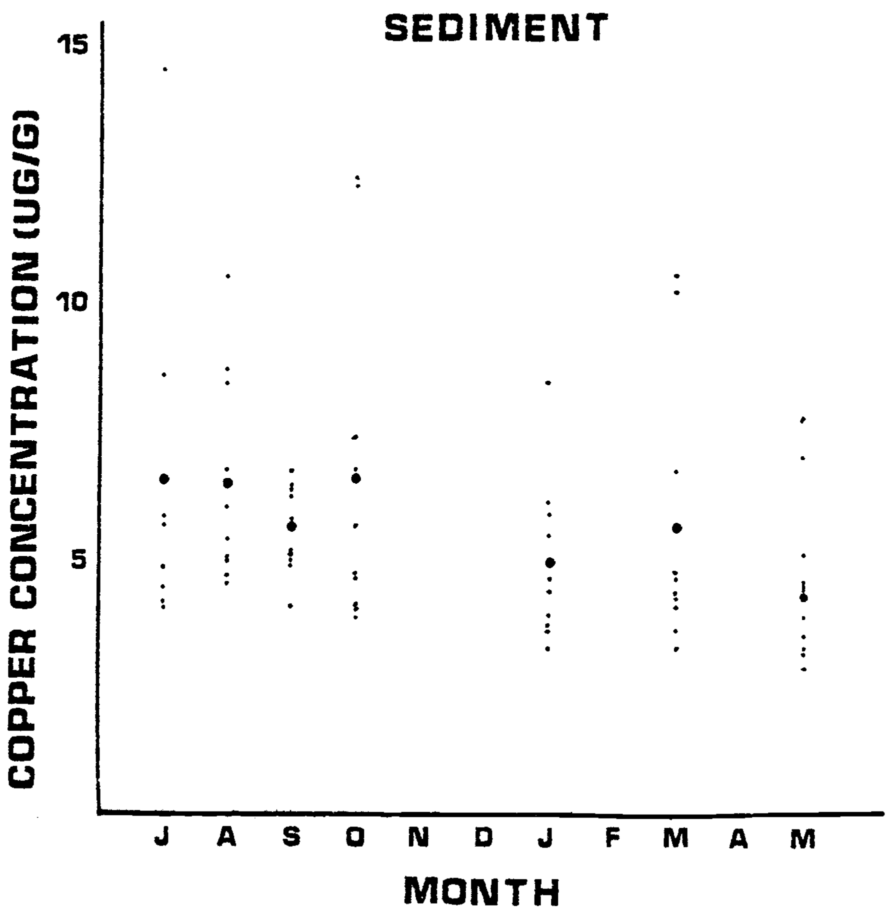

Figure 10: Mean (•) and individual (·) copper concentrations in sediments from July 1980 through May 1981

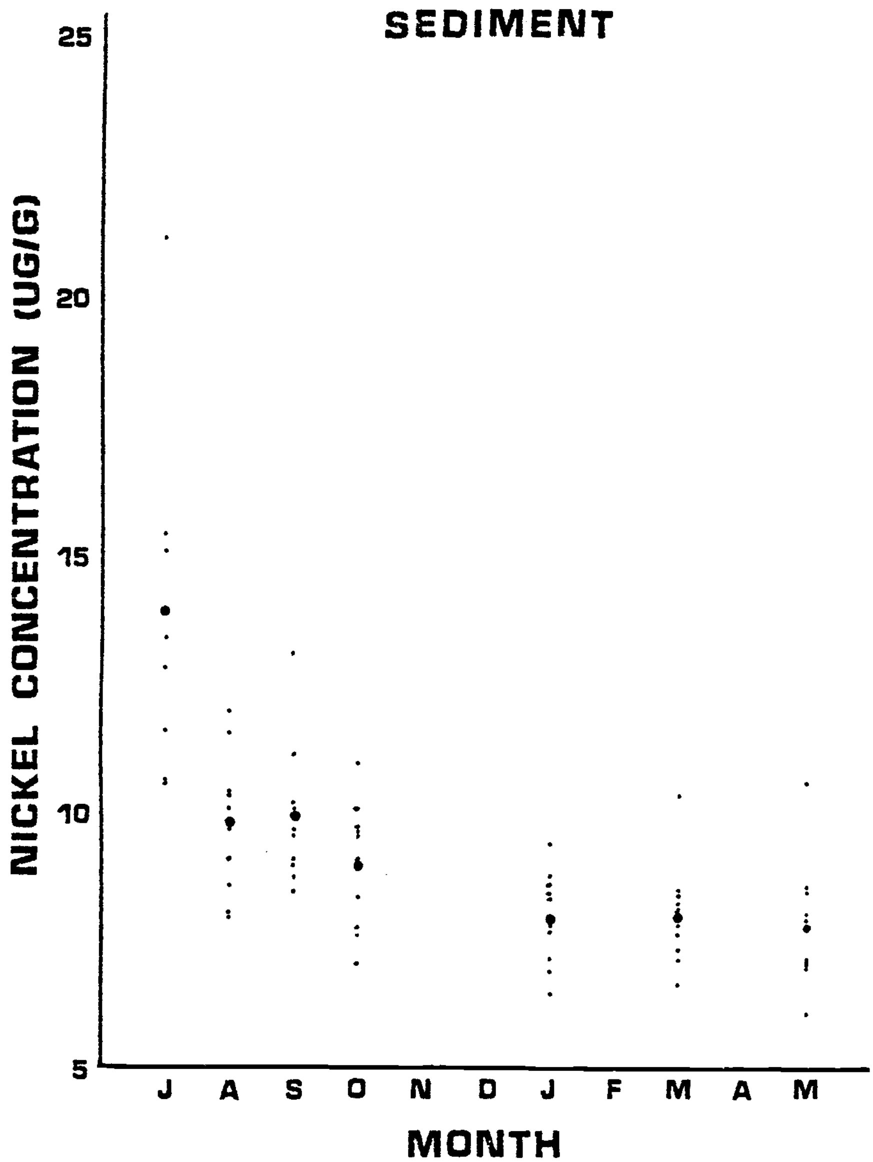

Figure 11: Mean (•) and individual (·) nickel concentrations in sediments from July 1980 through May 1981

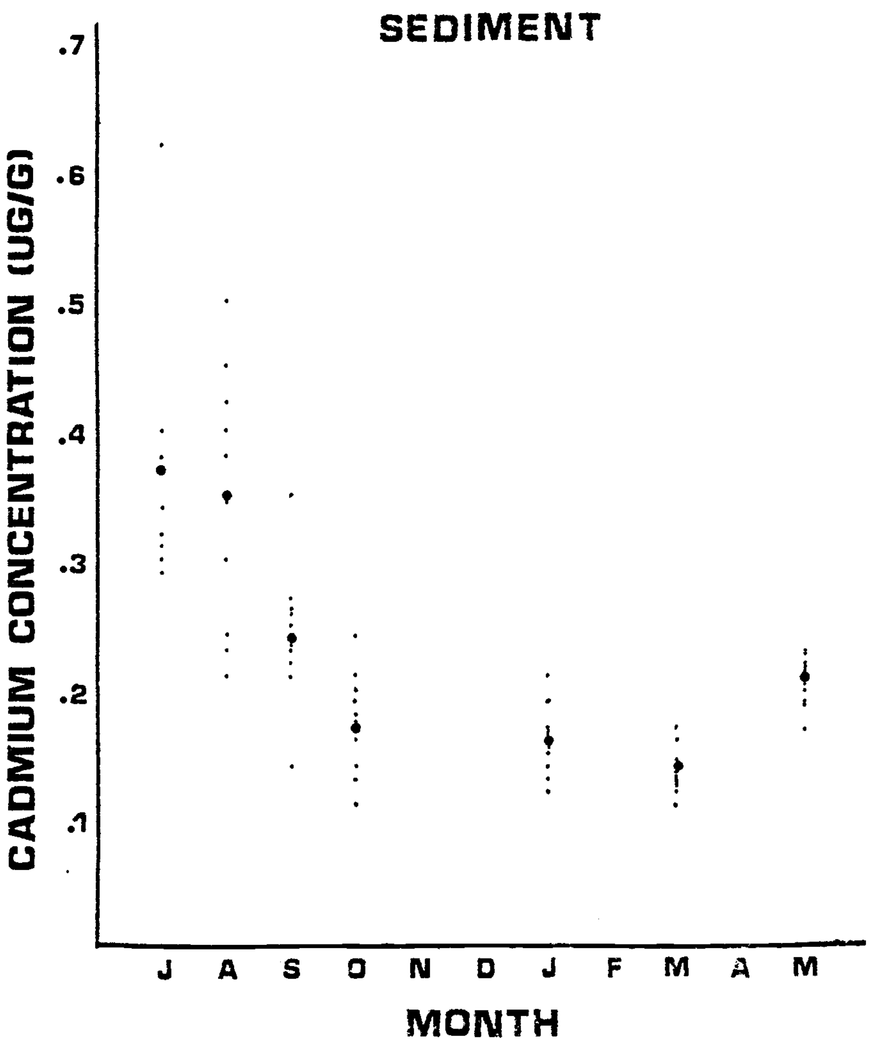

Figure 12: Mean (•) and individual (·) cadmium concentrations in sediments from July 1980 through May 1981

TABLE 3: Statistical results using Kruskal-Wallis test and multiple comparisons

METAL LEVELS (μG/G) IN MUSSELS

Copper	* July was significantly different than all other months.
Cadmium	* July was significantly different than all other months.
Nickel	* July and March were significantly different than other months but were not different from each other.

METAL LEVELS (μG/G) IN SEDIMENT

Copper	N. S.
Cadmium	* Generally, July, August and September were significantly different than October, January, and March but similar to May.
Nickel	* Variable. July was significantly different than October through May. Others were significantly different from one or two other months with no general pattern.

N. S. indicates that there was no significant difference between samples from different months.

* indicates that not all samples taken from different months were identical.

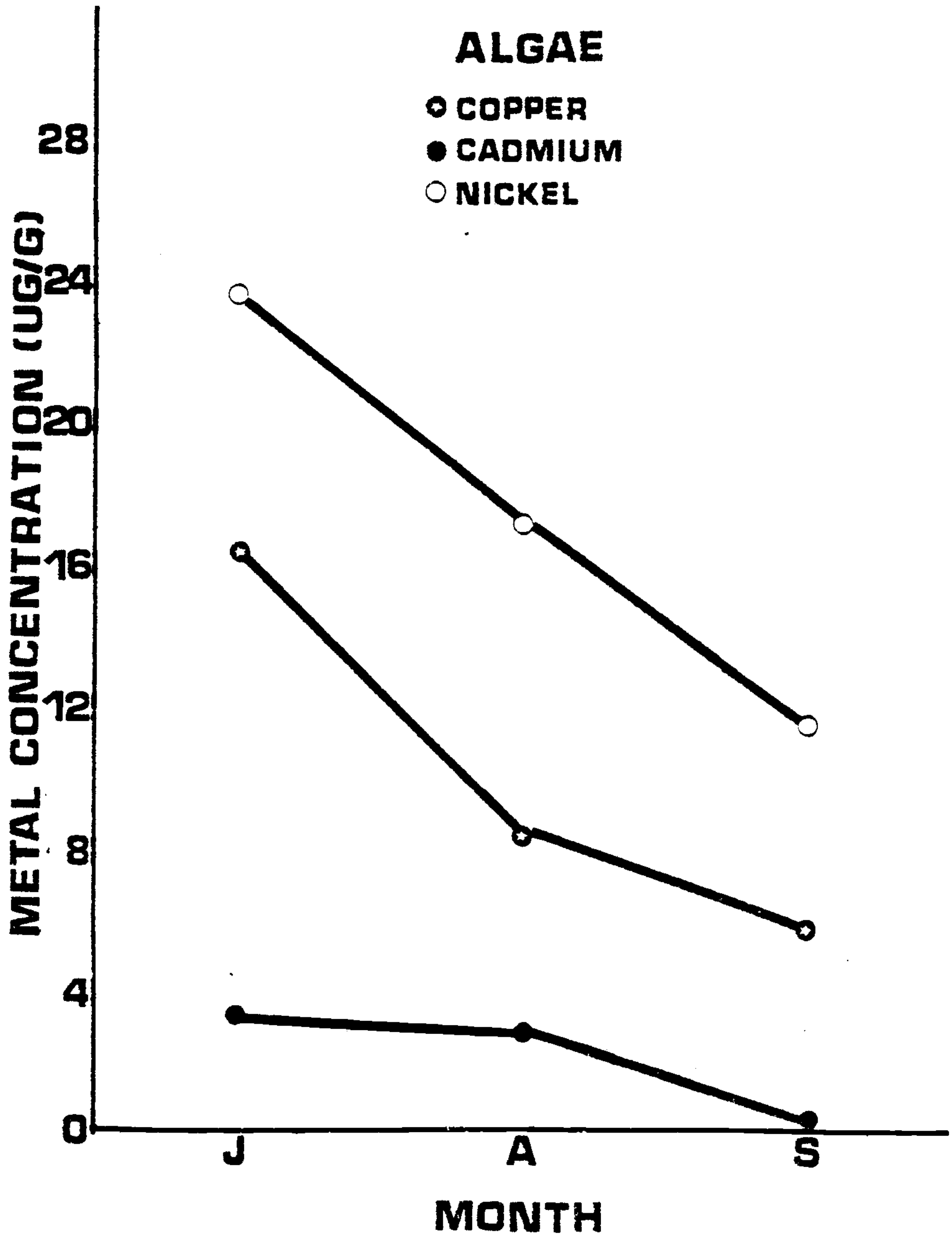

Figure 13: Mean metal concentrations in algae from July through September 1980

differences in variability or sample distribution or to conduct statistical analyses.

Comparisons

Copper was slightly higher in mussels than in algae. In turn, both mussel and algae Cu levels were slightly higher than sediment levels. It is probable that these slight differences of only 1-2 μg/g (with the exception of July) were not significant. Cadmium concentrations in mussels and algae were similar in July and August but in September the mussels exhibited higher concentrations. In turn, the concentrations of Cd in mussels and algae, with the exception of the September algae sample, were ten times greater than in sediments. Nickel levels were somewhat different than the other metals in that the highest concentrations were found in algae followed by sediment and then mussels.

Figures 14-16 show graphically the relationship between metal levels in mussels and sediment. For Cd and Ni, as sediment concentrations increased, mussel concentrations increased (Figs. 14, 15). However, no cause and effect relationship is implied. For copper, there was no apparent relationship.

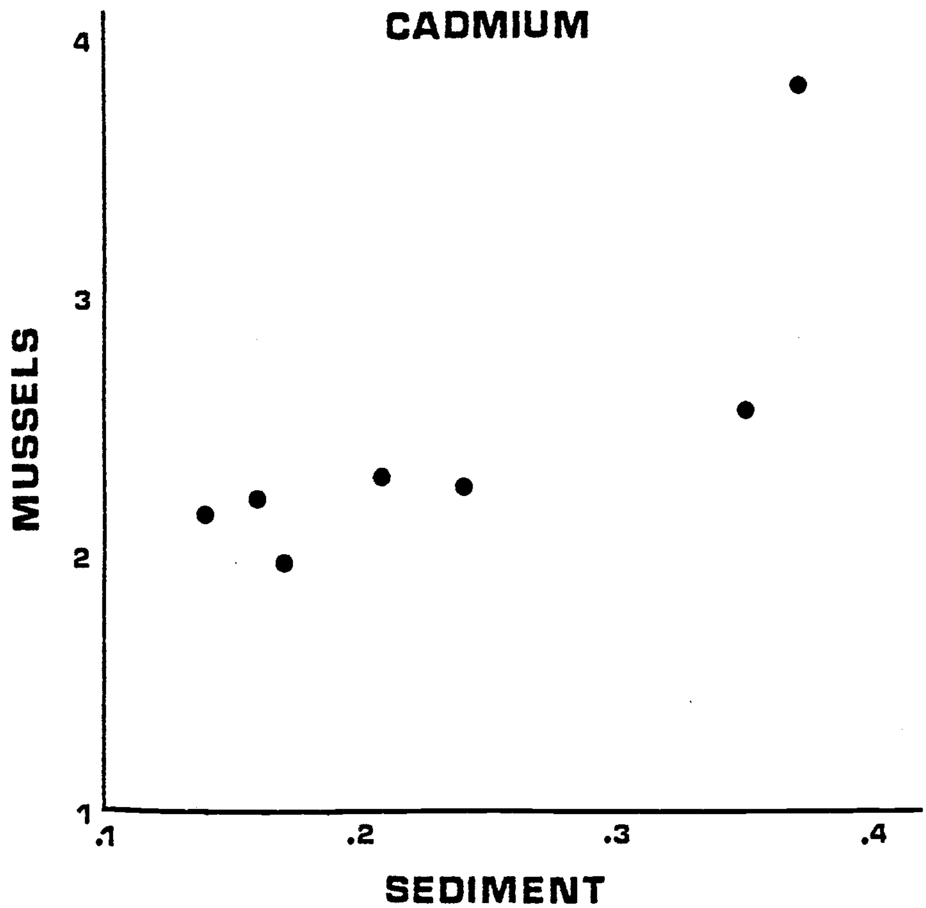

Figure 14: Mean cadmium concentrations in mussels versus mean cadmium concentrations in sediment (μg/g).

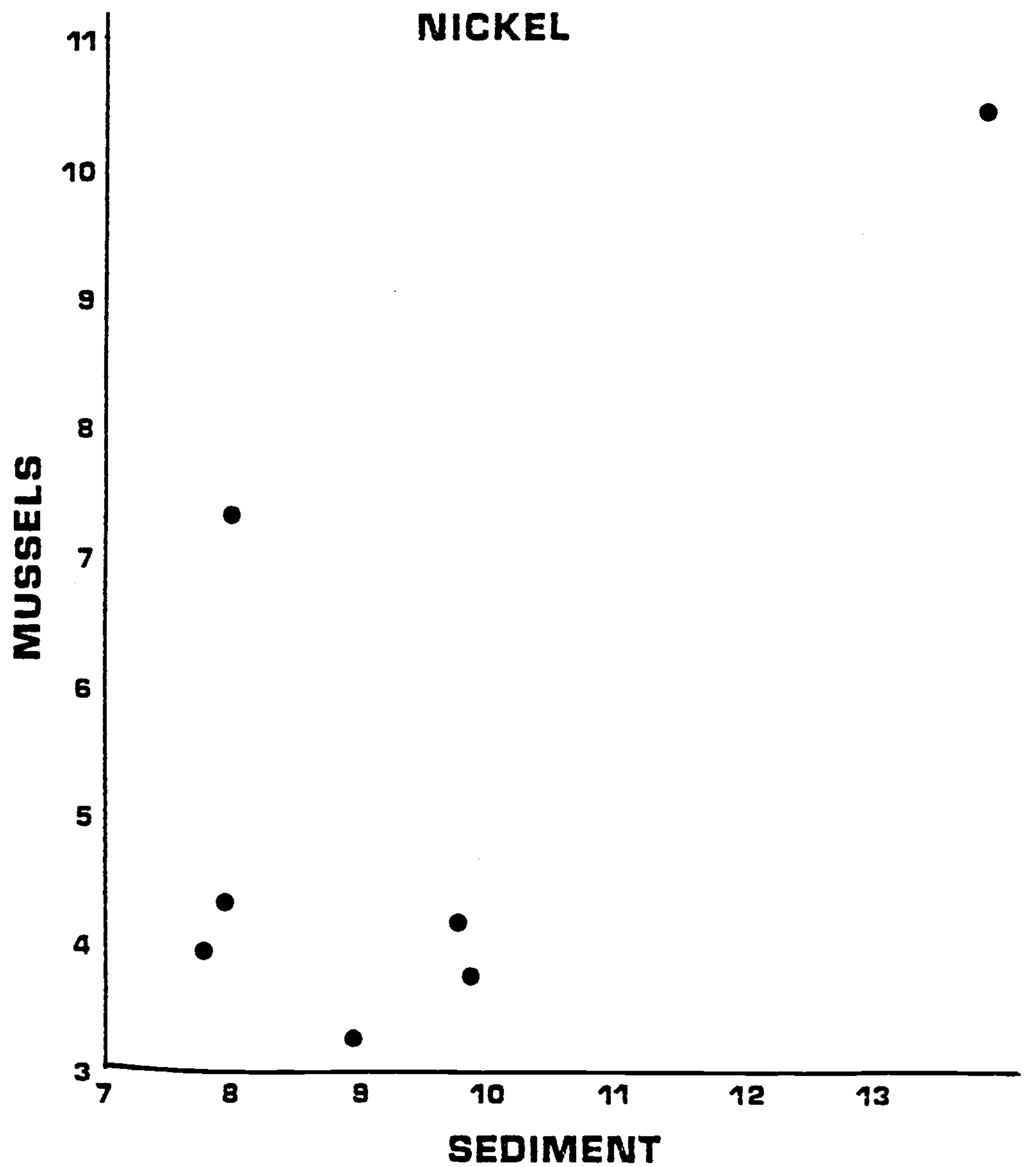

Figure 15: Mean nickel concentrations in mussels versus mean nickel concentrations in sediments (µg/g).

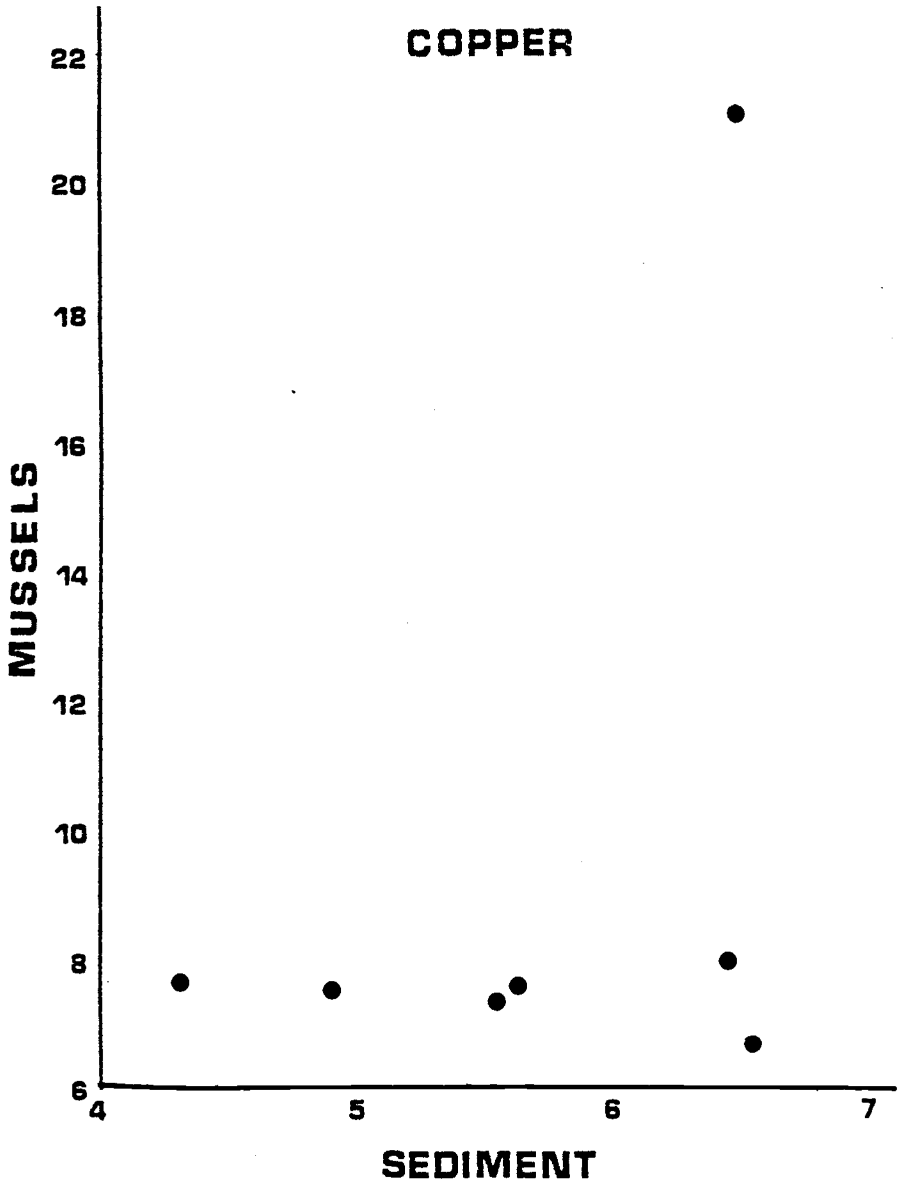

Figure 16: Mean copper concentrations in mussels versus mean copper concentrations in sediments (μg/g).

DISCUSSION

Comparison of Elk Creek Data to Other Studies

Bivalve Molluscs

The majority of studies concerning metal levels in bivalves have been conducted for marine and estuarine species and have often involved *Mytilus* and *Crassostrea* spp. Table 4 compares the metal concentrations reported in certain of those studies with concentrations in *Margaritifera* from Elk Creek. In general, Cu and Cd concentrations in Elk Creek mussels fall in the lower end of the ranges reported in marine and estuarine bivalves while Ni concentrations were similar in shellfish from the two environments.

Table 4 also lists the concentrations of metals in *Mytilus edulis* from Yaquina Bay, the estuary draining the Yaquina River and Elk Creek. If the July Elk Creek sample is excluded, the ranges for Cu and Ni concentrations are quite similar in the two species. The July levels in Elk Creek were much higher than those from Yaquina Bay. A July 1980 sample was taken in Yaquina Bay (LaTouche, personal communication) but an increase was not seen. The Cd levels in *Margaritifera* were lower than in *Mytilus* from Yaquina Bay, for all months.

Few studies have been published on metal levels in freshwater bivalves. Copper, Cd and Ni concentrations measured in bivalves from a variety of freshwater systems are summarized in Table 5. The first two studies listed, the Elk Creek study and Friant (1979), reported metal levels in bivalves from non-industrial rivers. The Cu concentration ranges are quite similar. The next seven studies involved bivalves from industrial rivers. In general, the concentration ranges of metals in Elk Creek mussels correspond to the lower end of the ranges for metals in those bivalves. This would be expected since bivalves from the industrial rivers would be exposed from more sources of metal pollution and therefore, would obtain higher body concen-

TABLE 4: Comparison between whole body metal concentrations (μg/g) in marine bivalves and mussels from Elk Creek

Environment, species	Metal levels (μg/g, dry wt.)		
	Cadmium	Copper	Nickel
Marine, cosmopolitan *Mytilus, Crassostrea*[1]	0.4-140.0	2.4-6480.0	0.9-14.0
Yaquina Bay, OR *M. edulis*[2]	7.0- 12.5	6.9- 13.6	0.9- 6.8
Elk Creek *M. margaritifera*[3]	1.67- 6.21	10.13-44.53	2.53-19.41
Elk Creek *M. margaritifera*[4]	0.94- 4.63	4.82- 12.04	1.57- 8.68*

[1]Phillips 1977

[2]LaTouche 1981

[3]Present study, 7/80

[4]Present study, 8/80-5/81

*March sample not included

TABLE 5: Comparison of metal levels in freshwater bivalve molluscs

SOURCE	LOCATION	BIVALVES ANALYZED	SAMPLING PERIOD	METAL CONCENTRATION RANGES (μG/G DRY WT.) COPPER	CADMIUM	NICKEL
Present Study	Elk Creek Oregon Non-industrial	*Margaritifera*	7/80	10.13-44.53 (21.07)	1.67-6.21 (3.31)	2.53-19.4 (10.49)
			8/80-5/81	4.82-12.04 (6.63-7.93)	0.94-4.63 (1.98-2.56)	1.57-8.68 ** (3.24-4.32)
Friant (1979)	Kennebec R. Maine Non-industrial	*Elliptio* *Lampsilis* *Anodonta*	1976	2.3-34.2	-	-
Mathis and Cummings (1973)	Illinois R. Illinois Industrial	*Fusconaia* *Amblema* *Quadrula*	Summer 1969	2-24 *	1-9.4 *	2.6-20 *
Manly and George (1977)	Thames R. Great Britain Industrial	*Anodonta*	12/74-5/75	8.2-250.0	0.1-21.1	0.1-45.9
Anderson (1977a,b)	Fox R. Illinois Industrial	*Anodonta* *Lampsilis* *Lasmigona* *Strophitus* *Sphaerium*	Summer 1973	(5.15-22.35)	(1.43-5.89)	-
Foster and Bates (1978)	Muskingum R. Michigan Electroplating	*Quadrula* (in cages)		76-173.3 * (5 km) 15.3-62.0 * (69 km)	-	-
Jones and Walker (1979)	Murray R. Australia Industrial	*Velesunio*	8/77-9/77	-	(0.67-0.69)	-
Adams et al. (1980)	Streams to and from Palestine Lake Indiana Electroplating	*Amblema*	Summer 1977	-	(1.61-12.5)	-
Mellinger (1972)	Willamette R. Oregon Industrial	*Margaritifera*	Summer 1971	-	(4*)	-
Segar (1971)	Lake at Aberffraw, Wales	*Anodonta*		(3)	(1.2)	(0.35)
Heit et al. (1980)	Lake George New York Non-industrial	*Lampsilis* *Elliptio* *Anodonta*	10/77	(9-18)	(9-10)	(3-5)
Price and Knight (1978)	Lake Washington Sardis Reservoir Mississippi Industrial	8 species	Winter 1975-76	-	(1.415*)	-

* indicates that values were converted from wet weight to dry weight by dividing by 0.15
() indicates mean ranges instead of individual ranges
** indicates that March sample was not included

trations. Exceptions to this generalization are found in the study by Mathis and Cummings (1973) on the Illinois River which showed concentration ranges similar to Elk Creek and the study by Jones and Walker (1979) on the Murray River in Australia in which shellfish had much lower Cd concentrations than those in Elk Creek. These discrepancies could have been due to species of geological differences. The remaining studies listed in Table 5 dealt with bivalves from freshwater lakes. The values for non-industrialized Lake George (Heit et al. 1980), with the exception of Ni, are slightly higher than the values for Elk Creek. The Cd levels in the industrial lakes in Mississippi (Price and Knight 1978) and Wales (Segar 1971) are lower than those for Elk Creek but similar to each other. This could be due to differences in hydrological and other patterns between rivers and lakes.

Sediment

Sediments have been analyzed often in both marine and freshwater environments. As with bivalves, the ranges of metal concentrations found in Elk Creek sediments fall in the lower end of the range for marine and estuarine sediments (Table 6).

Some metal levels in freshwater sediments are summarized in Table 7. The first five studies were on non-industrial streams. Generally, the metal concentration ranges reported were similar to those in Elk Creek. Cadmium and Ni ranges in Back Creek, Virginia (Van Hassel et al. 1980) and Cd in Jubilee Creek, Illinois (Enk and Mathis 1977) extend to lower values than in Elk Creek but the ranges still overlap. The next five studies were on sediments from industrialized rivers. As expected, the metal levels in Elk Creek sediments are less than, or in the lower end of, the ranges of those from industrialized streams. The one exception is Skeleton Creek, Oklahoma (Namminga and Wihlm 1977). The authors attributed their lower values to higher stream discharges and scouring. The remaining three studies were on lake sediments. For the non-industrial basin of Palestine Lake (Wentzel et al. 1977) and Lake George (Heit et al. 1980), metal

TABLE 6: Comparison between metal concentrations (μg/g) in marine sediments and sediments from Elk Creek

Environment	Metal levels (μg/g, dry wt.)		
	Copper	Cadmium	Nickel
Marine and estuarine[1]	1.0-2424.0	0.13-9.9	2.0-219.0
Elk Creek, 7/80	4.07-14.43	0.29-0.62	10.63-21.17
Elk Creek, 8/80-5/81	2.9-12.31	0.11-0.50	6.01-13.10

[1]From Phillips 1977

TABLE 7: Comparison between metal concentrations in freshwater sediments

SOURCE	LOCATION	SAMPLING PERIOD	METAL CONCENTRATION RANGES (uG/G DRY WT.) COPPER	CADMIUM	NICKEL
Present Study	Elk Creek Oregon Non-industrial	7/80	4.07-14.43 (6.48)	0.29-0.62 (0.37)	10.63-21.17 (13.83)
		8/80-5/81	2.9-12.31 (4.31-6.54)	0.11-0.50 (0.14-0.35)	6.01-13.10 (7.74-9.85)
Enk and Mathis (1977)	Jubilee Creek Illinois Non-industrial	Fall 1974	-	0.08-0.23	-
Van Hassel et al. (1980)	Back Creek Virginia Non-industrial	4/78-2/79	-	0.02-0.24	0.2-4.4
Friant (1979)	Kennebec R. Maine Non-industrial	1976	3.6-10.6	-	-
Mathis and Cummings (1973)	Streams Illinois Non-industrial	Summer 1969	3.5-11.2	0.3-0.5	10-22
	Illinois R. Illinois Industrial		1-82	0.2-12.1	3-124
Oliver (1973)	Ottawa R.	7/71	(28)	-	(22)
	Rideau R. Canada Industrial		(24)	-	(23)
Namminga and Wilhm (1977)	Skeleton Creek Oklahoma Industrial	2/73	0.3-1.9	-	-
		8/73	1.3-6.4	-	-
Anderson (1977a)	Fox R. Illinois Industrial	Summer 1973	13.8-51.5	1.0-10.7	-
Adams et al. (1980)	Streams to and from Palestine Lake Indiana Industrial	Summer 1977	-	2.45-119	-
Wentzel et al. (1977)	Palestine Lake Indiana Industrial	1 Year Period	-	(282-969)	-
Nriagu and Coker (1980)	Lake Ontario Industrial		(53-68)	(2.1-3.1)	(53-60)
Heit et al. (1980)	Lake George New York	10/77	(4±1)	(0.3±0.3)	(4±1)

() indicates mean ranges instead of individual ranges

ranges are comparable to those from Elk Creek. For the industrial basin of Palestine Lake and for Lake Ontario (Nriagu and Coker 1980), the metal levels are much higher.

Algae

As with bivalves, the majority of reports on metal accumulation in algae have been on marine species. The concentrations of metals in algae from Elk Creek were in the middle of the ranges for algae in marine and estuarine environments (Table 8).

The small number of studies available on freshwater algae under field conditions are summarized in Table 9. In Elk Creek and Upper Bee Fork, Missouri (Hassett et al. 1980) which have no industrial activities, the ranges of Cu overlapped, though levels were slightly higher in Elk Creek algae during July and August. Strother Creek (Hassett et al. 1980) which received effluent from lead mines had rather high values of Cu, though the value for *Cladophora*, 26 μg/g, is only slightly higher than the July Elk Creek sample. The remainder of the studies were on algae from relatively industrialized lakes. Except for Lake Ontario (Keeny et al. 1976), the algal metal levels in these lakes are much higher than in algae from Elk Creek. Lake Ontario levels are in the middle of the range for Elk Creek algae possibly due to its large area available for metal dilution.

In summary, with a few exceptions, metal concentrations in the Elk Creek sediments and organisms were similar to those reported for inhabitants and sediments from non-industrial streams and less than or in the lower range of levels from industrial areas. Thus, the metal concentrations in the Elk Creek system were relatively normal and reflect expected background levels associated with the geology and geography of the region.

Seasonality

The results of this study indicated that there were significant variations in metal concentrations between July 1980 and May 1981 in organisms and sediments from Elk Creek. However, because the high metal concentrations occurred in a single sample, July 1980, and

TABLE 8: Comparison between metal concentrations in marine algae and algae from Elk Creek

Species, Environment	Metal levels (μg/g, dry wt.)		
	Copper	Cadmium	Nickel
Algae, marine & estuarine[1]	0.9-301.0	0.05-25.6	0.11-33.0
Cladophora sp., Elk Creek	5.8-22.16	0.44-7.04	11.61-27.87

[1] From Phillips 1977

TABLE 9: Comparison of metal concentrations in freshwater algae

SOURCE	LOCATION	SPECIES	SAMPLING PERIOD	METAL CONCENTRATIONS (μG/G DRY WT.) COPPER	CADMIUM	NICKEL
Present Study	Elk Creek Oregon Non-industrial	*Cladophora*	7/80-9/80	5.8-22.16	0.44-7.04	11.61-27.87
Hassett et al. (1980)	Upper Bee Fork SE Missouri Non-industrial	*Spirogyra* and Sedge		1-7	-	-
	Strother Creek SE Missouri Lead Mine	6 species including *Cladophora*		26-299	-	-
Johnson et al. (1978)	Little Center Lk., Indiana Industrial	several species	Summer 1975	-	27.56	-
	Palestine Lake Indiana Industrial	several species	Summer 1975	-	5.6-430.0	-
Trollope and Evans (1976)	Lower Swansea Valley, Wales Industrial	4 species	9/69	380-1330	-	150-700
	Outside Valley Wales Industrial	*Cladophora* + 2 species	9/69	50-290	-	30-130
Keeny et al. (1976)	Lake Ontario Industrial	*Cladophora*	10/73 & 8/74	6.4-7.2	1.4-3.9	-

because concentrations were lower and fairly constant during the remainder of the study period, it is possible that the high July level was an aberration and not the result of seasonal variation. The unusual level may have been caused by a temporary source of metals such as a recent clear-cut, followed by comparatively heavy rains in June (Appendix C), a large septic tank leak, or other, unknown, factors. If the high July concentrations were aberrations, the July peak would not be expected to occur in future years. Though time limitations prevented taking another sample for this report, July 1981 data will be included in a future paper.

If the temporal variations seen in this study represent true seasonal variation, a number of factors may have contributed to the observed changes. Phillips (1980) described three general factors associated with seasonality: weight changes in the organism (growth and sexual cycle); extent of pollutant delivery (pollution discharges and runoff); and direct effects of salinity, temperature and other water quality factors which vary seasonally. The manner in which each of these factors might have affected metal concentrations during the present study will be discussed below.

Weight Changes

One of the major factors causing seasonal variation in metals in marine bivalves is the sexual cycle. In most marine species, the gonads make up a large percentage (30-40%) of the body weight just prior to spawning. However, studies have shown that the gametes contain much smaller concentrations of metals than the whole body concentrations of the adult (Phillips 1980, LaTouche 1981). Thus, when the shellfish spawn, there is a significant decrease in body weight but a small decrease in total metal contents. Consequently, the body concentrations of metals increases.

In *M. margaritifera,* the spawning period occurs from mid-May to late June for the western subspecies (Murphy 1942). Thus body weights may have been lowest in July which corresponded to the period of highest metal concentrations in Elk Creek mussels. However, the majority of the body weight in *Margaritifera* consists of gills and the large muscular foot. Thus, the spawning weight loss may be less than that for marine bivalves; if so, great increases in metal concentrations would not be expected to occur. Further research to evaluate gonad weights and their metal contents is necessary to determine how much of an effect, if any, reproductive condition has on metal contents. The fact that *Margaritifera* broods their young also needs to be considered along with larval weights and metal contents.

Growth also results in weight changes and affects metal concentrations in shellfish. If growth occurs during a period when there is a constant metal uptake rate, then the metal concentrations would become diluted. Thus, during the spring-summer period of rapid growth, metal concentrations would be expected to decrease and during the winter period, as glycogen stores are used up, to increase (Phillips 1980). Frazier (1979) attributed changes in metal concentrations recorded in oysters from Chesapeake Bay to growth. However, rates of uptake may also change during these periods since metabolic rates often decrease at lower temperatures. Also, the sexual cycle is superimposed on this pattern.

Possible growth effects seem possible for the algae in Elk Creek. As the algae grew during the summer, the concentrations of metals decreased. Phillips (1977) cited several studies on marine algae where maximum concentrations in spring and minima in autumn were attributed to growth.

The growth effect is not as applicable to the mussels in Elk Creek since the metal levels remained fairly constant from August through May even though differences in growth would have been expected. Growth also cannot explain the concentration changes in the sediment.

Extent of Pollutant Delivery

In areas where industries discharge metals to streams, concentrations in the system are expected to be highest when discharges are highest and discharge rates may vary seasonally. In areas with no apparent point sources of pollution, the degree of runoff determines the extent of pollutant delivery. At times of high rainfall, runoff is greatest and a large quantity of inorganic and organic particulates are delivered to stream systems (Phillips 1980). Since 99% of the Ni and probably large percentages of other metals are transported in association with suspended particulates (Snodgrass 1980), the exposure concentration to the organisms and sediment should increase during periods of high runoff. Cunningham (1979) reviewed several studies on marine bivalves where high metal concentrations corresponded to peak runoffs. Such a pattern would be predictable for estuarine conditions where high freshwater flows reduce mixing with less polluted ocean water. However, in a flowing freshwater system, high runoff also means high water flows which serve to dilute the concentrations of metals and scour the river bottom (Phillips 1980).

In late summer and early fall, there was little precipitation and runoff to bring metals into the system. In winter and spring, there was considerable runoff but the river flow is then rapid and metals are carried quickly downstream. In late spring/early summer, rainfall decreased and reduced river flows result in deposition of the sediment load with associated trace metals. This may cause metal concentrations in the sediment to increase. Since bivalves live in sediment and filter particulate matter, their exposure and accumulation of metals might also increase at this time. This explanation may well apply to the trend in metal concentrations seen in mussels and sediment from Elk Creek. River flow and precipitation data for western Oregon during the study period are listed in Appendix C. Van Hassel et al. (1980) found high metal levels in April and relatively equal low levels in July through November which they attributed to changes in runoff. The earlier maximum in this study may be due to differences in climate between Virginia and the present study in Oregon.

Water Quality Factors

One final factor that may have partially accounted for the seasonal variation in trace metal levels is a temporal difference in water quality. Temperature increases increase metabolic rate and metal uptake by organisms (Phillips 1980), but these changes are also associated with growth and the sexual cycle; thus, the temperature effect is difficult to evaluate.

It seems likely that all of the above factors contribute, to some degree, to the seasonal variations in metal concentrations observed in the data.

Comparisons between Metal Concentrations in Mussels, Algae and Sediments

Studies comparing metal concentrations in mussels and sediment are summarized in Table 10. Algae is not included because the available studies on algae did not include data on sediments or mussels from the same site and time period. The first three studies, including the Elk Creek study, involved mussels and sediments from non-industrial rivers and lakes. For Cu and Ni, the ranges for mussels and sediments overlapped. Copper was slightly higher in mussels and Ni was slightly higher in sediments though the differences are probably not significant. For Cd, however, levels in mussels were ten times higher than for sediments. In the remaining studies from industrial rivers, metals levels in mussels and sediments overlapped in all cases though the range of metal concentrations in sediments, with the exception of Cd, are much higher than for mussels.

Sediments serve as a sink for metals in the aquatic environment (Van Hassel et al. 1980). Metals also tend to become associated with suspended and colloidal materials within the water column (Namminga and Wilhm 1977). Since freshwater bivalves live in contact with the sediment and filter particulate matter, it is not surprising that concentrations of Cu and Ni in shellfish and sediments are similar. The higher levels of Cd in mussels compared to sediments from non-industrial streams may be explained by the observation that Cd

TABLE 10: Comparison between mussels and sediments

SOURCE	LOCATION	METAL CONCENTRATION RANGES (μG/G DRY WEIGHT)					
		COPPER		CADMIUM		NICKEL	
		MUSSELS	SEDIMENT	MUSSELS	SEDIMENT	MUSSELS	SEDIMENT
Present Study	Elk Creek Oregon Non-industrial	4.82-44.53 (6.63-21.07)	2.9-14.43 (4.31-6.54)	0.94-6.21 (1.98-3.81)	0.11-0.62 (0.14-0.37)	1.57-19.4 (3.24-10.49)	6.01-21.17 (7.74-13.83)
Friant (1979)	Kennebec R. Maine Non-industrial	2.3-34.2	3.6-10.6	-	-	-	-
Heit et al. (1980)	Lake George New York Non-industrial	(9-18)	(4±1)	(9-10)	(0.3±0.3)	(3-5)	(4±1)
Anderson (1977a)	Fox R. Illinois Industrial	(7.41-22.35)	13.8-51.5	(2.49-5.89)	1-10.7	-	-
Adams et al. (1980)	Streams to and from Palestine Lake Indiana Electroplating	-	-	(1.61-12.5)	(2.45-119)	-	-
Mathis & Cummings (1973)	Illinois R. Illinois Industrial	2-24	1-82	1-9.4	0.2-12.1	2.6-20	3-124

() indicates mean values instead of individual values has an extremely long half-life in *Margaritifera* (835 days; Mellinger 1971) which allows them to reach much higher levels than sediments which are subjected to continuous scouring and dilution. Sediments in industrial areas may have higher metal levels than in non-industrial areas because large inputs constantly replace those metals lost by scouring. The bivalves in industrial streams may not be able to accumulate metals as quickly as sediment deposition of metals and their tissue concentrations are thus less. Also, bivalves cannot tolerate extremely high metal levels and may be lost from the population if concentrations reached those measured in some sediments.

Algae respond mainly to soluble metals (Phillips 1980). Therefore, any relationships with sediments or mussels which, under field conditions, respond mainly to metals in particulate matter (Phillips 1980) are difficult to determine. This is especially true for the Elk Creek data which revealed no consistent pattern between mussels-sediment and algae from one month to the next.

Comparisons between Metals

The general trend for metal levels in both stream and lake sediments, including those from Elk Creek, is Ni $\geq$ Cu $\gg$ Cd (Table 7). This likely reflects differences in availability of these metals since Ni and Cu are present in much larger amounts in the earth's crust than Cd (Phillips 1980). In all of the river studies on bivalves (Table 5), the order of concentration was Cu $\geq$ Ni > Cd. In the lake studies, the pattern was slightly different with Cu $\geq$ Cd > Ni. The differences are likely due to variations in metal availability in the environment and differences in rates of uptake and excretion for the different metals. The order for algae was Cu $\approx$ Ni > Cd (Table 9), possibly for reasons similar to those for bivalves.

CONCLUSIONS

General

The following conclusions are supported by the results of this study:

1. During the ten-month study period, the concentration ranges of metals (μg/g) in mussels from Elk Creek were: Cu, 4.82-44.53; Cd, 0.94-6.21; and Ni, 1.57-19.41. Sediment concentrations were: Cu, 2.90-14.43; Cd, 0.11-0.69; and Ni, 6.01-21.17. Algae levels were: Cu, 5.80-22.16; Cd, 0.44-7.04; and Ni, 11.61-27.87. These levels were similar to those reported in organisms and sediments from non-industrial streams and less than, or in the lower range of, those from industrial streams.

2. Metal levels varied between July 1980 and May 1981 in mussels, sediment and algae from Elk Creek, Oregon with the exception of Cu in sediments. However, the main variation occurred in a single sample and may have been caused by a temporary high input such as a clear-cut or some unknown event or source. The high levels in July had decreased about 50% by September and remained constant during the remainder of the study. If the high July concentrations were not due to an aberration, the seasonal variation may be due to differences in organism physiology, pollutant delivery, or a combination of causes.

3. Generally, the concentrations of Cu and Ni in *Margaritifera* were similar to those in the sediments. Cadmium concentrations in mussels were ten times greater than those of sediments. Algae showed no consistent pattern.

4. In mussels, the general concentration order was Cu > Ni > Cd though the differences were not very great. In sediment, Ni > Cu >> Cd, with Ni and Cu ten times greater than Cd. In algae, Ni > Cu > Cd. Although Ni and Cu concentrations were not very different from each other, they were three to ten times greater than cadmium concentrations.

Indicator Potential of Components Analyzed

Margaritifera

M. margaritifera has significant potential as an indicator organism. Its general characteristics of wide distribution, large size and sedentary life style satisfy important criteria for selecting biological monitors. This study indicated that *Margaritifera* from a relatively unpolluted environment contained detectable levels of important metals although some preconcentration procedures were necessary. The present technique for measuring metal concentrations in mussels required four to five days for one person but the time could be reduced considerably if pooled, rather than individual, samples were used.

Cladophora

Cladophora sp. has several characteristics that may limit its effectiveness as a biological monitor. It was difficult to obtain large enough quantities to analyze accurately. Also, it was practically impossible to separate the algae from sediments, and extraneous organisms caught in the filaments, even with repeated rinsing. Finally, it was only available for a few months of the year so it could not be analyzed as frequently as mussels. Therefore, its use as an indicator in river systems cannot be highly recommended.

Sediment

Despite the limitations discussed previously, sediment analyses have some value for evaluating metal concentrations and movement in a river system and should be used, along with bivalve molluscs, for making predictions about the relative pollution of a system. However, differences in carbon content and sediment deposition rates should be accounted for before comparisons are made.

Consideration of Seasonality

This study indicated that seasonal variations in metal contents may occur in freshwater organisms and sediments. It is emphasized that additional data are required to confirm or disprove this possibility. Nevertheless, the possible existence of seasonal variations should not be ignored when using organisms as indicators of metal pollution. Organisms and sediments collected from different locations for the purpose of making comparisons should be collected over a short period of time and at approximately the same time from all locations. Water flow and precipitation records, as well as temperature differences between areas, should also be considered. When additional research indicates how these factors affect metal levels, the most suitable time(s) for sampling can be determined. At present, if only a yearly sample is to be taken, I recommend using fall samples since organism spawning will have occurred but water discharges will not be too high to prevent sampling. As with marine studies, other factors such as age should be held constant in order to reduce variations.

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APPENDICES

APPENDIX A

ATOMIC ABSORPTION SETTINGS FOR PERKIN-ELMER 403 SPECTROPHOTOMETER AND 56 RECORDER

SETTING	COPPER	CADMIUM	NICKEL
Wavelength	323.8 nm	228.1 nm	231.2 nm
Slit	4	4	3
Lamp milliamps	17	6	26
Speed	1	1	1
Recorder			
average reading	10	10	10
response	1	1	1
full scale	.25A	.25A	.25A
range	10mV	10mV	10mV
speed	20mm/min	20mm/min	20mm/min

APPENDIX B

Concentrations of copper, cadmium and nickel in individual mussel, sediment and algae samples for each month sampled

METAL LEVELS IN MUSSELS, SEDIMENT, AND ALGAE COLLECTED 7/8/80

SAMPLE NUMBER	LENGTH(CM)	METAL CONCENTRATION (μG/G DRY WEIGHT) COPPER	CADMIUM	NICKEL
		MUSSELS		
1	8.4	40.21	2.79	9.80
2	7.9	15.23	6.21	13.72
3	7.7	19.12	4.13	14.50
4	8.6	13.60	2.53	8.81
5	8.2	10.13	3.20	11.24
6	8.8	22.16	3.12	11.81
7	8.0	19.20	3.15	11.05
8	7.8	12.12	4.60	7.85
9	7.0	44.53	5.94	19.41
10	8.1	13.63	3.00	2.53
11	8.2	40.28	5.38	13.79
12	8.9	24.93	2.43	12.60
13	7.7	12.33	3.89	12.70
14	7.8	26.16	3.27	8.46
15	7.5	24.11	5.41	13.88
16	7.5	24.39	3.71	14.04
17	7.8	14.41	3.11	6.87
18	8.1	17.15	5.73	10.36
19	8.7	14.29	2.86	3.32
20	7.1	13.37	1.67	3.11
		SEDIMENT		
1		4.15	0.32	10.63
2		5.78	0.34	15.04
3		5.65	0.38	15.37
4		4.40	0.30	12.80
5		4.07	0.29	10.60
6		8.55	0.62	21.17
7		14.43	0.40	13.38
8		4.81	0.31	11.64
		ALGAE		
1		22.16	5.95	27.87
2		10.18	0.99	19.38

METAL LEVELS IN MUSSELS, SEDIMENT, AND ALGAE COLLECTED 8/8/80

SAMPLE NUMBER	LENGTH(CM)	METAL CONCENTRATION (μG/G DRY WEIGHT) COPPER	CADMIUM	NICKEL
		MUSSELS		
1	8.5	9.22	2.49	6.50
2	7.9	7.61	2.94	5.05
3	6.9	6.77	1.76	4.49
4	6.9	7.33	3.75	5.53
5	7.6	7.35	4.08	4.88
6	8.0	9.17	2.32	4.48
7	7.5	12.04	2.28	4.05
8	7.7	6.45	1.60	4.86
9	8.0	8.71	1.53	3.61
10	7.2	6.76	3.47	4.49
11	7.0	10.55	1.53	4.17
12	7.7	7.11	2.45	5.37
13	7.0	6.12	3.20	4.01
14	7.8	7.60	1.91	3.60
15	6.4	8.01	2.23	3.48
16	7.3	6.30	2.17	2.95
17	7.8	8.93	1.81	2.30
18	7.9	8.70	4.63	3.44
19	7.8	7.82	2.55	2.88
20	7.0	6.12	2.40	3.74
		SEDIMENT		
1		5.36	0.35	10.27
2		4.93	0.40	9.72
3		8.35	0.45	10.02
4		10.40	0.50	11.52
5		8.58	0.42	11.95
6		6.72	0.23	7.88
7		4.50	0.38	9.10
8		5.96	0.21	8.56
9		4.66	0.30	7.98
10		4.97	0.24	10.59
		ALGAE		
1		9.42	2.19	20.71
2		8.37	7.04	15.19
3		7.57	0.69	11.76
4		7.98	1.41	20.86

METAL LEVELS IN MUSSELS, SEDIMENT AND ALGAE COLLECTED 9/11/80

SAMPLE NUMBER	LENGTH(CM)	METAL CONCENTRATION (μG/G DRY WEIGHT) COPPER	CADMIUM	NICKEL
		MUSSELS		
1	8.1	8.80	2.63	3.80
2	8.2	4.82	2.66	4.82
3	7.9	7.22	1.28	8.23
4	7.4	8.48	2.47	2.92
5	7.0	8.16	1.48	2.54
6	7.0	7.33	2.63	3.37
7	7.1	9.62	2.26	3.74
8	7.4	9.27	1.77	5.79
9	7.3	7.52	2.40	4.33
10	7.5	6.03	2.33	2.95
11	8.0	7.36	1.80	3.60
12	8.0	7.40	1.60	3.85
13	7.5	6.83	3.16	4.54
14	7.3	7.28	1.26	2.75
15	7.0	7.06	3.50	3.05
16	7.8	5.31	1.76	4.50
17	7.6	6.96	3.36	2.84
18	8.0	6.87	2.83	2.97
19	7.7	5.72	2.45	2.37
20	8.7	8.99	1.78	2.41
		SEDIMENT		
1		4.95	0.21	9.51
2		5.14	0.23	9.62
3		4.94	0.24	10.21
4		6.74	0.26	9.86
5		6.23	0.27	8.72
6		6.27	0.35	13.10
7		4.03	0.14	8.44
8		6.35	0.22	8.92
9		5.04	0.25	9.02
10		5.67	0.26	11.09
		ALGAE		
1		5.80	0.44	11.61

METAL LEVELS IN MUSSELS AND SEDIMENT COLLECTED 10/5/80

SAMPLE NUMBER	LENGTH(CM)	METAL CONCENTRATION (μG/G DRY WEIGHT) COPPER	CADMIUM	NICKEL
		MUSSELS		
1	7.2	4.99	0.94	2.66
2	7.3	5.84	2.26	2.71
3	7.4	5.81	1.38	2.45
4	7.5	5.71	1.76	3.13
5	7.5	5.94	1.78	3.44
6	7.9	5.80	1.85	3.02
7	7.5	8.00	1.32	3.02
8	7.8	6.62	1.28	2.66
9	7.5	6.12	1.06	2.19
10	7.7	5.83	3.47	3.56
11	7.4	7.15	1.57	3.88
12	7.7	5.05	2.30	2.40
13	8.8	8.12	1.42	2.48
14	7.3	7.84	2.74	3.56
15	7.9	8.57	3.99	4.41
16	7.6	9.12	2.09	4.11
17	7.2	5.54	2.53	3.87
18	8.0	9.76	1.41	2.70
19	7.6	5.58	1.64	5.60
20	7.5	5.24	2.74	2.97
		SEDIMENT		
1		3.85	0.13	7.75
2		4.01	0.14	7.04
3		12.22	0.24	10.10
4		4.65	0.19	9.64
5		4.00	0.16	8.29
6		7.35	0.11	7.55
7		6.72	0.20	9.50
8		12.31	0.21	10.99
9		4.64	0.18	9.60
10		5.69	0.17	8.95

METAL LEVELS IN MUSSELS AND SEDIMENT COLLECTED 1/10/81

SAMPLE NUMBER	LENGTH(CM)	METAL CONCENTRATION (μG/G DRY WEIGHT) COPPER	CADMIUM	NICKEL
		MUSSELS		
1	7.9	8.90	2.59	2.98
2	8.4	7.64	2.07	3.45
3	7.5	6.05	2.41	5.48
4	7.3	7.77	2.54	4.70
5	8.0	7.23	1.48	5.13
6	8.1	6.33	2.35	4.07
7	8.2	5.85	1.03	1.57
8	7.5	6.56	1.32	4.36
9	8.2	5.44	1.10	3.14
10	7.7	6.16	1.67	8.68
11	7.1	11.30	1.38	7.04
12	6.7	8.93	3.24	7.37
13	6.8	8.55	1.13	3.92
14	6.8	9.37	2.45	5.30
15	7.3	9.16	2.63	2.76
16	7.6	6.67	4.32	3.84
17	6.8	6.83	2.41	2.72
18	7.4	7.94	3.66	3.37
19	7.4	7.06	2.61	2.83
20	7.0	6.81	1.71	2.62
		SEDIMENT		
1		3.86	0.17	7.67
2		4.34	0.19	7.85
3		3.57	0.13	6.81
4		8.48	0.16	8.74
5		6.08	0.14	8.57
6		5.77	0.16	8.42
7		5.43	0.21	9.33
8		3.68	0.16	7.18
9		4.66	0.16	8.32
10		3.23	0.12	6.39

METAL LEVELS IN MUSSELS AND SEDIMENT COLLECTED 3/12/81

SAMPLE NUMBER	LENGTH(CM)	METAL CONCENTRATION (μG/G DRY WEIGHT) COPPER	CADMIUM	NICKEL
		MUSSELS		
1	6.9	9.10	2.75	11.64
2	7.0	5.59	1.75	4.39
3	7.0	10.94	1.99	5.61
4	6.2	11.64	1.20	16.89
5	7.1	6.85	1.69	5.96
6	7.0	6.76	2.68	4.42
7	6.6	7.38	1.34	4.89
8	6.5	7.26	1.22	4.62
9	7.0	7.47	1.93	4.70
10	6.5	10.22	2.11	4.45
11	7.1	7.62	2.37	6.61
12	7.5	6.29	1.67	6.51
13	8.0	8.55	1.53	3.85
14	8.0	5.97	1.79	7.98
15	8.0	7.92	3.51	6.38
16	7.9	6.20	4.23	8.37
17	7.4	8.12	1.85	7.50
18	7.4	5.64	2.44	14.25
19	7.3	5.76	2.03	8.54
20	8.3	6.63	3.13	8.57
		SEDIMENT		
1		4.36	0.12	7.62
2		3.23	0.11	6.67
3		4.65	0.16	8.23
4		3.63	0.13	7.26
5		10.20	0.17	10.27
6		4.73	0.13	8.33
7		6.73	0.14	8.41
8		4.09	0.13	7.78
9		10.48	0.14	8.12
10		4.24	0.13	7.12

METAL LEVELS IN MUSSELS AND SEDIMENT COLLECTED 5/7/81

SAMPLE NUMBER	LENGTH(CM)	METAL CONCENTRATION (μG/G DRY WEIGHT) COPPER	CADMIUM	NICKEL
		MUSSELS		
1	7.2	7.82	3.08	4.79
2	7.0	9.06	2.71	5.89
3	7.0	6.45	2.37	4.16
4	7.0	7.75	1.37	3.61
5	7.1	7.72	2.12	4.08
6	7.5	6.81	1.99	3.52
7	7.5	10.43	2.20	3.00
8	7.1	10.52	2.09	5.05
9	7.6	5.62	2.86	3.59
10	7.2	8.70	1.66	3.61
11	8.6	8.18	3.35	4.22
12	8.1	8.11	3.54	4.00
13	8.5	8.29	3.26	4.10
14	8.1	4.82	2.28	3.67
15	7.7	7.30	1.70	3.52
16	8.3	5.51	1.30	3.16
17	7.5	5.14	1.71	3.68
18	8.1	6.96	3.33	4.35
19	7.7	9.54	1.04	4.21
20	8.0	7.89	2.06	3.25
		SEDIMENT		
1		3.94	0.17	7.05
2		5.15	0.22	10.56
3		3.30	0.21	7.03
4		4.55	0.20	7.09
5		3.25	0.21	6.88
6		2.90	0.22	6.01
7		4.56	0.23	8.41
8		7.07	0.23	8.54
9		3.77	0.19	7.83
10		4.59	0.19	8.03

APPENDIX C

PRECIPITATION AND DISCHARGE DATA

DATE	* MEAN AIR TEMPERATURE (Departure from normal)	* TOTAL PRECIPITATION (Departure from normal)	** MEAN GUAGE HEIGHT	** MEAN DISCHARGE Cubic Ft/ Second
6/80	57.1 (-2.0)	3.31 (0.91)	2.68	51.4
7/80	63.4 (0.6)	0.36 (-0.46)	2.66	24.3
8/80	61.6 (-1.7)	0.41 (-0.71)	2.54	11.4
9/80	62.9 (1.5)	2.14 (-0.89)	2.55	11.9
10/80	57.0 (1.6)	2.80 (-5.22)	2.57	12.3
11/80	50.4 (2.2)	12.40 (-0.98)	3.01	89.5
12/80	46.3 (2.5)	21.36 (5.65)	5.11	831.0
1/81	46.9 (4.9)	4.82 (-10.99)	3.44	200.0
2/81	48.4 (2.7)	8.60 (-3.48)	3.97	387.0
3/81			3.43	205.0
4/81			4.12	407.0

* At Tidewater, Oregon. From Oregon Climatological data

** At Chitwood, Oregon on the Yaquina R. From U.S.G.S.