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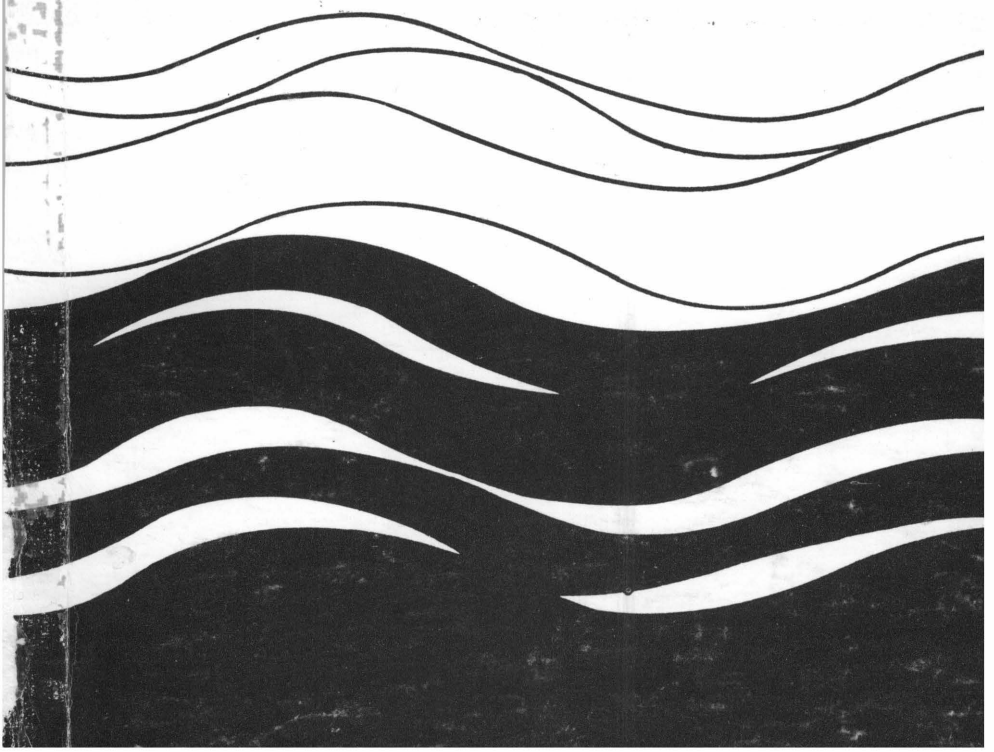

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Dynamics and Control of the Asiatic Clam in the New River, Virginia

Donald S. Cherry
John H. Rodgers, Jr.
Robert L. Graney
John Cairns, Jr.

Department of Biology and Center for Environmental Studies
Virginia Tech

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PREFACE

The Asiatic clam *(Corbicula fluminea)* has been rapidly invading most aquatic systems in the United States, adapting to new conditions, and possessing a potential to interact competitively with many of the endemic molluscan fauna. Besides having ecological significance, *Corbicula* has become a nuisance as a biofouling organism in energy production and other industries. Some natural predators upon *Corbicula* are known, and their resistance to conventional biocidal practices has been documented.

Using field and laboratory techniques, (1) rate of invasion, (2) population dynamics, and (3) resistance to heavy metals and chlorine residuals were investigated. The purpose of this research was to study the clam's population density in thermally influenced and unheated areas around the Glen Lyn Power Plant on the New River, and to determine sensitivity to several elemental pollutants using static bioassays and artificial streams.

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ABSTRACT

The Asiatic clam, *Corbicula fluminea,* has invaded the New River at the rate of nine miles a year from the Kanawha River, which enters downstream from the Glen Lyn coal-powered generating plant in Virginia. During the period of investigation, October 1976-September 1978, clams were more numerous in the vicinity of the thermal discharge of the plant than they were in unheated waters, and their population fell sharply during the winter months, when the water temperature dropped to approximately 2°C. The temperature (35°C) of the heated discharge water in late summer did not adversely affect the clam. High mortality occurred at temperatures $\geqslant$36°C in laboratory thermal tolerance studies.

The clam proved to be highly resistant to the conventional biocidal practice of intermittent chlorination and to exposure to heavy metals in both static and artificial stream bioassays. Copper was more toxic than either zinc or a combination of zinc and copper. Potassium was not an effective biocidal agent at low concentrations ($<$100 mg/l).

Measurements of 42 elements in water, sediment, clam shell, and visceral tissue revealed that *Corbicula* was an efficient accumulator of many elements. Concentrations in all tissue samples were greater than those measured in river water. Fifteen elements were more concentrated in tissue samples than in river sediment, but the converse was true for 25 elements. Elements released from discharges at the Glen Lyn Plant did not limit the clam's development or ability to propagate.

Although only minor incidents of *Corbicula* infestation have been observed in the cooling system of the power plant, such infestation could become a serious problem if winter water temperatures rise. No effective means of controlling the clam's population has been developed.

Key Words: *Corbicula,* Asiatic Clam, Toxicity, Bioconcentration, Population Density, Bioassays, New River

INTRODUCTION

In certain areas of the country, the Asiatic clam, *Corbicula fluminea,* has become a threat as a biofouling organism to power-generating companies and other industries requiring cooling water. The clam was first discovered in 1938 in Washington's Columbia River [Sinclair and Isom, 1963; McMahon 1977]. By the late 1940's, these clams were well established in most western states *(Figure 1),* and were becoming nuisance problems in the California irrigation systems [Ingram, 1959]. *Corbicula* invaded the Mississippi and Ohio River drainage systems by the late 1950's, subsequently spreading throughout both basins [Bickel, 1966]. In 1961, Thomas and Mackenthun [1964] collected *Corbicula* in the Kanawha River at Charleston, West Virginia, with propagules probably originating from the Ohio River. By 1975 the clam was reported to have colonized the New River in the thermal effluent of Appalachian Power Company's Glen Lyn plant, located in Southwest Virginia [Rodgers et al., 1977]. Potential propagules originated downstream in the Kanawha River *(Figure 2).*

The rapid spread of *Corbicula* and its ability to invade a variety of aquatic habitats have caused numerous economic and biological problems [Goss and Cain, 1977; McMahon, 1977]. Once established, they become a major component of the ecosystem, threatening the survival of other indigenous bivalves [Gardner et al., 1976]. Major economic problems generated by *Corbicula* include the biofouling of agricultural, industrial, gravel industries, and municipal water supplies. Standard biofouling procedures and molluscicide applications have been rendered ineffective by the behavioral ability of *Corbicula* to avoid environmental toxicants (i.e., cessation of siphoning activity, tight closing of valves) [Rodgers et al., in press (a)].

Studies on the rate of invasion, density, population dynamics, and control of the Asiatic clam have been carried out for a 15-month period in the vicinity of the Appalachian Power Company's Glen Lyn plant on the New River. Work was conducted in the field, in laboratory model (artificial) streams, and in static bioassays. The objectives, for which data will be presented in the study, included: (1) the rate at which the clams were invading the river upstream of the Glen Lyn plant; (2) the density and age classes of clams in substrates above, below, and within the thermally influenced regions of the river; (3) the effects of unusually cold winter conditions on population density and age structure of the clams; (4) the occurrence of clams relative to water quality and substrate characteris-

tics; (5) the concentrations of approximately 40 elements in the river's water and sediment and the potential uptake of these elements in clam valve and visceral tissue; (6) laboratory toxicity testing of clams exposed to several elements (copper, zinc, copper and zinc, potassium, chlorine) in static and artificial stream systems; and (7) comparisons of toxicant bioaccumulation to behavioral activities (filtering, foot immobilization, gaping, and closure of valves).

ECOLOGICAL CHARACTERISTICS AND METHODOLOGY

I. Ecology and Life History

Corbicula fluminea is a bivalve mollusk of the class *Pelecypoda,* order *Heterodonta,* superfamily *Sphaereacea,* and family *Corbiculidae.* The species is best identified by morphology of the hinged teeth, exhibiting a double pair of serrated lateral teeth on the right valves, with a single pair appearing on the left valves *(Figure 3)* [Sinclair and Isom, 1963]. In this country, the species has been found primarily in the more southern states, with northern range perhaps limited by a lower temperature tolerance of ~2°C [Mattice and Dye, 1976]. The distribution includes both lentic and lotic environments, with no established preference for either. *Corbicula* reportedly prefer a sandy substrate [Filice, 1958; Sinclair and Isom, 1963; Bickel, 1966], although the species also has been found inhabiting silt, gravel, rock rubble, and clay substrates [Parmalee, 1965; Aldridge, 1976; Gardner et al., 1976; Sinclair and Isom, 1963; Heinsohn, 1955; Rinne, 1974]. This mollusk is primarily considered to be a suspension feeder, filtering phytoplankton and detritus from the water column. Except for studies analyzing gut contents, little has been reported about their feeding behavior. Data concerning predator utilization of *Corbicula* have been reported for fish, ducks, and racoons. Gut analysis of various waterfowl and fish species, including channel catfish *(Ictalurus punctatus),* redear sunfish *(Lepomis microlophus),* and the freshwater drum *(Aplodinotus grunniens),* have indicated that they do feed on *Corbicula* [Sinclair and Isom, 1973; Thompson and Sparks, 1977], but the extent and importance of this utilization has yet to be documented.

According to Sinclair and Isom [1963], the Asiatic clam is both hermaphroditic and incubatory. Eggs are fertilized within the reproductive ducts and passed through the suprabranchial chambers into the inner gills, which become greatly distended and function as marsupia. The marsupial veligers undergo development in the inner gills, after which they are released as non-swimming planktotrophic veligers. A more detailed account of the life history is reported by Sinclair and Isom [1963]. The time spent as planktotrophic veligers is relatively short, possibly being influenced by the intensity of water movement and currents. Upon settling to the sediment for benthic existence, the species attaches to a suitable substrate by means of an adhesive patch located at the tip of the foot. At ~.9 mm, shell formation is completed with shell growth continuing until death. Sexual maturity is reached within the first year, normally at

a shell length averaging between 6.5 and 8.5 mm [Aldridge and McMahon, 1978; Sinclair and Isom, 1963]. Spawning, which is primarily temperature-dependent, generally occurs twice a year, in late spring and fall, depending upon the area.

II. Biofouling and Control

The high reproductive capacity, precocious development, and resistance to biocidal control by *Corbicula* ensure high population densities which increase its fouling capabilities. Many industries which utilize raw water supplies have been adversely affected by Asiatic clam invasion. The first incidents of this problem were reported on the West Coast by agricultural industries. Within two to three years after colonization of irrigation ditches, deposition from sedimentation (by clam biodeposition) and dead clam shells amounted to two to three feet on the canal floor of the Delta Mendota [Prokopovitch and Herbert, 1965; Prokopovitch, 1969]. Increased deposition drastically shortened the longevity of agricultural irrigation canals [Ingram, 1959; Fast, 1971; Prokopovitch and Herbert, 1965]. The most effective treatment was the mechanical removal of shells and sediments, although chemical treatment has been utilized with limited success. Problems encountered by the sand and gravel industry have included interference with production procedures by a large number of clams inhabiting sand and gravel deposits [Sinclair and Isom, 1963]. If clams are present in the concrete aggregate during the pouring process, clam movement may cause voids, resulting in structural weakness. Mechanical separation of clams from gravel has been a costly and time-consuming operation.

Biofouling in condenser and service water systems of steam electric power plants has been another major problem associated with *Corbicula.* Small clams, which pass through the water intake screens [McMahon, 1977], have been reported to wedge or clog within the condenser tubes (5/8-in. diameter). Depending upon the degree of fouling, the unit efficiency of the power plant may be reduced [Goss and Cain, 1977].

The potentially competitive nature and reproductive and growth potentials of *Corbicula* may also influence or limit the development of native bivalve populations. Gardner et al. [1976] found that following five years of *Corbicula* colonization of the Altamaha River (Georgia), indigenous bivalve populations had declined drastically. This may have alarming im-

plications when one examines the bivalve endangered species list for the southern United States.

Problems created by *Corbicula* are numerous, but successful control methods are scarce. No effective control procedure has been found for the agricultural and sand-gravel industries. Three weeks of continuous chlorination (1.0 parts per million [ppm] total residual chlorine) during the spawning season has been recommended as an effective control method for condenser biofouling [Sinclair and Isom, 1963]; however, the release of this level of chlorine into the environment is unacceptable [Brungs, 1976]. Bayer-73, a common molluscicide used in the tropics, also has been demonstrated to be an effective biofouling agent [Sinclair and Isom, 1963]. Backflushing of condenser system waters on a weekly basis has been a measure which has slowed the rate of biofouling but has not eliminated it. At the Brown's Ferry Nuclear Plant on the Tennessee River, the severity of biofouling resulted in dismantling and manual cleaning of the condenser system [Goss and Cain, 1977]. Controlled-release biofouling paint also has been suggested for protection against clam colonization of condenser systems [Goss and Cain, 1977], but it has a number of environmental disadvantages. At this time, more research needs to be carried out in order to determine effective control procedures.

III. Utilization

The utilization of *Corbicula* may be a viable alternative if the organism becomes a major component of certain drainage basins. Suggestions for potential utilization have included use as fish bait, biofilters for organically polluted areas, bioindicators of heavy metal pollution, and aquaculture for poultry and animal feed and fertilizer [Habel, 1970; Rodgers et al., 1977; Mattice and Dye, 1976]. Accumulation of heavy metals and radioactive wastes in bivalves has been reported [Nelson, 1962; Merlini, 1966; Clarke and Clarke, 1974]. The use of bivalves as indicators has many inherent problems, particularly in sampling methodology and analysis [Merlini, 1966]. *Corbicula,* however, may alleviate some of these problems in its inherent ability to colonize many habitats and because of its high population densities, small size, and penchant for accumulating metals.

For years, *Corbicula* has been cultivated in many Asian countries, being considered a delicacy for human consumption. Nutritional analysis has shown a high protein and carbohydrate content, superior to that of

oysters and other shellfish [Gonzales et al., 1975]. Though large-scale cultivation of *Corbicula* for American consumption does not seem likely, the use of its shell and tissue for poultry feed is promising.

IV. Description of Research Site and Sampling Procedures

Samples were collected from the New River at Glen Lyn, Giles County, Virginia (latitude 35°22'20"; longitude 80°51'45"; 454 m above mean sea level) in the vicinity of the Glen Lyn coal-fired generating plant *(Figure 4).* The Glen Lyn plant normally generates approximately 300 milliwatts (MW) with a maximum of about 340 MW. Water is withdrawn from the New River for condenser-cooling, and maximal plant-cooling flow rates of 15.15 m^3/sec (535 cubic feet/sec [cfs]) may represent up to 45 percent of the total river flow in low flow periods. The hot-water discharge is released in two areas. About half of the water is returned to the river just downstream from the intake and the rest is passed through a small canal into the East River. The heated effluent usually is chlorinated three times daily with in-house free residual chlorine (FRC) concentrations ranging from ~0.10 to 0.50 mg/l to control biofouling of the condenser pipes. FRC concentrations in the heated effluent have been measured as high as 0.62 mg/l [Cherry et al., 1977]. With an average width of 500 m, the New River at Glen Lyn (river mile 95) is relatively shallow with a mean depth of about 1.2 m and contains a series of pools and rapids. River flow ranges from about 1,000 cfs (28.3 m^3/sec) to an annual maximum of about 50,000 (1,416 m^3/sec) and an average of 5,023 cfs (142.3 m^3/sec).

Six sampling stations were established above and within the thermal effluent of the Glen Lyn plant *(Figure 4).* Stations 1 and 2 in the New River, which were not influenced by heated water, were located 140 and 45 m, respectively, above the water intake facility situated adjacent to the power plant. Stations 3 and 4 were thermally influenced. Station 3 was located approximately 50 m below the discharge pipe in the New River, while Station 4 was located at the confluence of a dredged canal in the East River. Station 5 was located approximately 260 m above Station 4 in the East River and received no heated discharge. Station 6 was established 2,450 m downstream from the power plant in the New River, where elevated temperatures from waste heat were reduced by approximately 50 percent. As river water passed through the plant, it was heated by a maximum of 8°C in Station 3 relative to ambient temperature in Stations 1 and 2 of the New River, while the ΔT was even higher (~12°C)

Stations 1 and 2 of the New River, while the ΔT was even higher ($\sim 12°C$) between ambient (Station 5) and thermal sampling sites (Station 4) in the East River. Sediment composition in all stations was primarily pebble, sand, and cobble with small amounts (<4 percent) of clay and silt.

Five samples were taken at each station using a 0.25 m^2 frame with a plankton net attachment of 0.05-mm mesh *(Figure 5)*. The substrate was shoveled to a depth of at least 15 cm with clams and river sediment carried directly into the net by river current. Water depth and flow rate during field sampling generally ranged from 0.5 to 1.0 m and 18 to 21 cm/sec, respectively. Samples were returned within two hours to the laboratory for further analyses. Additional information may be found in Rodgers et al. [1977].

V. Invasion Rate

Occurrence of the Asiatic clam was evaluated by obtaining grab samples in the New River drainage system from Glen Lyn, Virginia, downstream to the Kanawha River in Charleston, West Virginia, in order to establish the source of propagules. Upstream sampling in the New River also was carried out within and above Claytor Lake and in several tributaries above the power plant. A thorough literature review was undertaken to determine the time at which *Corbicula* was observed in the drainage system. The invasion rate was obtained by calculating the time and area of occurrence, which was related to the distance in river miles to Glen Lyn when the clams were found in 1975.

VI. Thermal Influence Upon Survivorship in Field and Laboratory Studies

Upper and lower lethal temperature limits were determined from field sampling evaluations during maximum summer temperatures in the thermal effluent ($\sim 36°C$) and from minimum winter conditions in unheated areas during 1976-1977 ($0°C$). Laboratory studies of lethal temperature limits were carried out to confirm the findings observed in the field. A 96-hour thermal tolerance test was carried out for clams acclimated at $25°C$. Test organisms were placed in heated aquatic chambers that were raised over a 24-hour period to 27, 29, 31, 33, 35, 36, and $37°C$, and then held at these respective temperatures for 96 hours. Heat was provided from infrared lamps positioned under each chamber. Chambers contained 19 clams with the control group maintained at $25°C$.

VII. Population Densities and Sediment Analysis

Shell dimensions and weight were determined as described by Joy and McCoy [1975]. Length was measured, to the nearest 0.1 mm, as the greatest linear distance perpendicular to a line at right angles to the hinge site; and width was the greatest shell dimension from right to left valve. Approximate size classes were determined from dimensions after Gardner et al. [1976]. In the laboratory, clams were sorted from the sediment by washing them through a series of five U.S. standard soil sieves (2.00, 4.75, 9.50, 12.50, and 19.00-mm openings).

Sediment from each station was partitioned by using a Rotap Testing Sieve Shaker (Tyler Industrial Products, Mentor, Ohio). Samples were separated (#10 sieve) into pebbles (2-64 mm) and cobble (64-256 mm) components. The smaller entities, sand (0.02-2.0 mm), silt (0.002-0.02 mm), and clay (<0.002 mm), were partitioned according to the hydrometer method [Bouyoucos, 1962]. In this procedure, soil characteristics were obtained by mechanical dispersion and hydrometer readout after the sedimentation process.

VIII. Water Quality

To provide supportive information, monthly water samples were taken for analysis at the six sampling sites for clam density in the New River. The physical and chemical parameters and the methods used in their determinations are shown in *Table 1.* Additional ambient New River water-quality data from the onset of *Corbicula* invasion in 1975 also are reported.

Water samples were collected in the recommended manner [American Public Health Association (APHA), 1976] and were either fixed in the field or stored on ice for return to the water chemistry laboratory at Virginia Polytechnic Institute and State University (VPI & SU). Some analyses (temperature, pH, dissolved oxygen, etc.) were performed at the sample collection sites. Environmental parameters *(Table 1)* were measured according to the standard protocols, and the analyses involved have been described in detail in the cited references [APHA, 1976].

IX. Static and Continous-Flow Bioassays

Static and continuous-flow (artificial streams) tests were used to deter-

mine the toxicity of copper sulfate and zinc sulfate separately, copper-zinc in combination, and separate tests using potassium sulfate and chlorine (calcium hypochlorite). Each static test usually was carried out for 24 and 96 hours [Sprague, 1973], while stream bioassays were conducted for 96 hours. Static tests with chlorine were extended to 10 days in order to obtain a lethal response. One week prior to testing, clams were collected from the New River, and held in a flow-through holding tank and fed daily with a finely ground mixture of trout chow and tropical fish food. Clams were tested in groups of 12 and 9 at several concentrations in static and continuous-flow tests, respectively, with clam sizes ranging from 10 to 21 mm in length (measured by the greatest distance perpendicular to a line forming a right angle with the hinge site).

Fourteen aquaria, each with a 5-l capacity, were filled with 4 l of river water and allowed to settle for two days in the static tests. Test aquaria were dosed from a standard solution of copper sulfate or zinc sulfate. Six toxicant concentrations for copper ranged from 0.005 to 10.0 mg/l and 0.005 to 1.0 mg/l, respectively, for 24 and 96-hour tests. Zinc concentrations for the same tests ranged from 0.10 to 40.0 mg/l and 0.05 to 10.0 mg/l. Copper-zinc tests had the same dose ranges as the copper trials (for example, at the 10.0 mg/l target dose, copper and zinc concentrations were each 10.0 mg/l). Potassium concentrations ranged from 1.6 to 140 mg/l in static and stream bioassays. Static assays for chlorine ranged from 0.15 to 10.0 mg/l total residual chlorine (TRC) with the free residual component (FRC) ranging from 0.05 to 4.5 mg/l. Chlorine residuals were measured by amperometric titration, and stock chlorine solutions were mixed from anhydrous calcium hypochlorite (HTH).

Temperature, dissolved oxygen, and pH were measured before each bioassay with copper, zinc, copper-zinc, or potassium concentrations measured by atomic absorption after each observation (1, 2, 6, 24, . . . 96 hours). If needed, additional toxicant was added to maintain a consistent target dose level. Toxicant samples were collected by pipette midway from the water surface where clams were suspended in screen (1-mm mesh) baskets (130 x 90 x 70 mm). Additional water-quality parameters recommended for toxicity testing were determined or analyzed [Sprague, 1973].

In the continuous-flow tests, four streams were utilized *(Figure 6).* Each stream was partitioned in half with one side covered with New River sediment and the other containing no substrate. This allowed for testing

clams in a natural versus an artificial situation. Six cages were placed in each stream, with 10 mm of sediment added to the three cages that were held in the substrate-filled side. Tests were carried out for four days with observations made at 5, 24, . . . 96-hour intervals.

Tap water was passed through two activated charcoal filtering systems prior to entering the streams. Toxicants from stock solution bottles were pumped into three streams using peristaltic pumps. Doses of heavy metals, potassium, and chlorine varied from 0.04 to ~140 mg/l and were regulated by stream flow rate, target dose level, and stock solution concentration. Flow rates varied from 0.50 to 0.80 l/min, while stream water depth was ~50 mm.

Effects of the toxicants were evaluated by five responses: death, gaping, foot immobilization, siphoning activity, and valve closure ("clamming up"). To determine mortality, the probe and gape technique was employed by gently opening clam valves with a micro-spatula. Lack of a closing response indicated mortality. Preliminary testing verified this testing procedure. Gaping of valves, followed by closing when probed with a spatula, and foot immobilization (extended foot and failure to retract upon stimulation), were considered to be a weakening response to stress. Observations of siphoning or filtering represented normal feeding activity. Dead clams were removed from their containers after each period of observation and analyzed for heavy metal uptake by atomic absorption. If no mortality occurred at sublethal exposures, elemental uptake was measured after the bioassay was completed.

Data were analyzed by a probit method, based on Finney's approximation [Finney, 1971], in a computerized procedure from the Statistical Analysis System [Barr et al., 1976]. Estimates of the LC50, 95-percent confidence limits, and the slope of the probit line through the percent killed were reported. In instances where no confidence limits were obtained, 100 percent mortality was not obtained (i.e., zinc and potassium bioassays).

X. Field Elemental Concentrations in Water, Sediment, and Clams

Water, sediment, and clams were collected at each station for analysis by a neutron activation procedure [Furr et al., 1975]. Using appropriate precautions to prevent contamination, samples were transferred to preweighed, sterile, flip-top polyethylene vials. For clam samples, the visceral

mass (soft body tissue) was removed from the shell. Sediment, shell, and visceral samples were dried in a drying oven (70 ± 2°C) for 48 hours. Samples were irradiated at the Nuclear Reactor Laboratory at VPI & SU. Advantages of this laboratory include simultaneous analysis of approximately 40 elements from each sample with a high degree of sensitivity. The technique is non-destructive in nature, and samples may be analyzed in any physical state without requiring lengthy laboratory preparation.

RESULTS AND DISCUSSION

I. Temperature and Substrate Influence Upon Population Densities

Densities of the Asiatic clam have increased rapidly in the New River at the Glen Lyn plant for the past three years *(Figure 7)*. Although *Corbicula* was not found before 1975 [Rodgers et al., 1977], densities increased in the East River discharge to approximately 1,020/m^2 by September 1977 and 11,522/m^2 by February 1978 *(Table 2)*. Thereafter, in the heated discharge that year, densities decreased to a level of 1,859/m^2 (Station 4), while densities in the unheated area increased from 94/m^2 in February to 2,286/m^2 (Station 1) by November 1978.

Population densities of *Corbicula* closely corresponded to water temperatures during 1976-1977 *(Figure 8)*. Densities declined drastically during the winter to the point that no specimens were detected in extensive surveys during January-April 1977. In the power plant thermal effluent, population levels in Stations 3 and 4 essentially remained constant. Apparently, the approximate 8°C increase above ambient temperature was sufficient to maintain the population in the effluent and to be a source of supply for upstream areas in warmer seasons. The heated wastewater maintained river water temperatures 5-6°C above freezing during the winter. Restoration of upstream population densities commenced in May 1977 and by September population densities had recovered to approximately 1,000 clams per m^2. A similar fluctuation in *Corbicula* population density attributed to cold temperatures of winter was previously reported from the Ohio River by Horning and Keup [1964]. These observations are further substantiation of the laboratory-determined lower incipient lethal temperature of about 2°C [Mattice and Dye, 1976]. In January-February 1978, a similar reduction in population densities occurred in unheated areas but was not as evident as in 1977 since ambient temperatures were slightly higher than in 1977. In the upper East River (Station 5), where ambient temperatures were $\leqslant$2°C during the winter, *Corbicula* were not found, nor did they re-invade this habitat during the summer of 1978 *(Table 2)*. Population densities in the New River generally have increased during the warmer months of 1978 to levels greater than those found from 1975 through 1977. By the fall of 1978, densities in unheated areas varied from 1,907 to 2,286/m^2, with densities in the heated stations being approximately twice as great. However, after densities peaked in the thermal discharges (Station 4 in February 1978), a population "crash" was noted during the spring (April).

The density composition of clams was predominantly in shell-length sizes of 7.5-13.5 mm, followed by <7.5 mm *(Table 3).* In the thermally influenced Station 4, clam sizes <7.5 mm comprised 57.6 percent of the samples during February 1978, with larger sizes (7.5-13.5 mm) representing 69-74.5 percent of the density in the other heated sites *(Table 4).* Clams in sieve sizes <7.5 mm represented 63.8 percent of the total sample in Station 3 during the summer, while no distinct high increase of first-year clams (>50 percent) was observed in unheated stations. Sizes ⩾18.5 mm were low to absent (4.2-0 percent) in unheated stations during 1978, while heated stations contained amounts ⩾19.7 percent of the total sample (Station 6).

Size-frequency analysis showed population restructuring after the particularly cold months of 1977 *(Figure 9).* An expected progression of size classes was found in samples from the thermally influenced area. At the ambient temperature stations, specimens were found in the first-year size class as recruitment restored population numbers. By October-December 1977, the population structure in the thermal discharge stations was comprised of I, II, and III-size classes of clams with only first-year sizes (approximately ⩽7.5 mm in shell length) in uninfluenced sites. Through the milder winter of 1978, the population structure in thermally influenced and unheated stations generally consisted of I, II, III, and IV-size classes with a greater percentage of clams ranging from 18.5 to 28.0 mm in shell length found in thermally influenced areas (Stations 3 and 6) *(Figure 9; Tables 3* and *4).* The greatest number of clams sampled in the late winter months consisted of those with shell lengths of 7.5-13.5 mm. By April 1978, the percentage of first-year clams more than tripled in Stations 1, 2, 3, and 6, when compared to February 1978. Although fluctuations in densities of I and II-size classes occurred between stations during the summer, the II-size class (7.5-13.5 mm in shell length) was more frequently sampled. By September 1978, all stations (except Station 5 where no clams were found) contained *Corbicula* from size classes of I-IV. General trends for 1978, where the Asiatic clam was sampled, indicated that the size class of 7.5-13.5 mm was most abundant (62.1-67.6 percent and 54.8-60.2 percent, in unheated and heated areas, respectively), followed by one-year classes, and then by clams 13.5-28.0 mm in length) *(Table 3).* It should be noted that the selection of size classes I-V in *Tables 3* and *4,* which were taken from Gardner et al. [1976], may not represent the same year classes of *Corbicula* aged 1-5. Differences in shell lengths relative to age classes will vary from the New River ambient and

thermally influenced areas when compared to the area of study reported by Gardner et al. [1976].

Upstream progression of *Corbicula* has been somewhat slower than would be expected. Rodgers et al. [1977] calculated an invasion rate of nine miles per year for *Corbicula* migration from the Kanawha River to the Glen Lyn Power Plant at the New River (~138 river miles). Outside of the thermally influenced areas, clam densities fluctuated in response to seasonal temperature or reproductive cycles. Low temperatures (0°C) caused severe clam die-offs in the winter of 1977, corresponding to similar population fluctuations observed in the Ohio River [Horning and Keup, 1964]. The inability of *Corbicula* to survive low temperatures may impede the invasion process in areas subjected to cold winter temperatures (<2°C). This hypothesis appears supported in the New River, as colonization beyond the thermal effluent at the Glen Lyn plant has been limited by the cold winter of 1977. In 3.5 years, *Corbicula* migrated approximately nine river miles upstream from the Glen Lyn colonization site *(Figure 2),* a substantially lower invasion rate than calculated by Rodgers et al. [in press]. Failure of this population to achieve substantial upstream migration supports the assumption of some physical or biological augmentation for dispersal of this species.

II. Upper 96-Hour Thermal Tolerance Studies

The highest temperature at which *Corbicula* would suffer no thermal mortality during a 96-hour observation period, when acclimated and tested at 25°C, was 35°C. At 36°C and higher, 100 percent mortality was observed in either 96 hours (at 36°C) or 48 hours (at 37°C). Field temperature in the thermal discharge canal (Stations 3 and 4) generally reached 35°C during late summer 1978, with some brief, partial exposures to 36°C for periods less than six hours for less than seven days. It is difficult to relate these data to field conditions since *Corbicula* in the field had the advantage of daily to weekly seasonal fluctuations and gradual acclimations to 36°C, which were not characteristic of the laboratory tests. Similar problems were discussed by Cherry et al. [1976], in comparing laboratory-controlled elevations in temperature for the mosquito fish *(Gambusia affinis)* to *in situ* conditions in thermally influenced sites.

III. Sediment Characteristics and Population Densities

Sediment characteristics of the New River in which the Asiatic clam was found included clay, silt, sand, pebble, and cobble, with the predominant substrate characteristic being pebble ($\geqslant$12.5 to $\leqslant$19.0 mm), followed by sand ($\geqslant$9.5 to $\leqslant$12.5 mm) in the six sampling stations *(Table 5).* Pebble was predominantly higher in unheated stations ($\bar{x}$ = 71.8 percent) than in thermally influenced ones ($\bar{x}$ = 59.0 percent). Sand formed a greater percentage in heated stations ($\bar{x}$ = 32.7 percent) than in uninfluenced ones ($\bar{x}$ = 23.7 percent). In descending order of occurrence, cobble, clay, and silt were found less often. On a seasonal basis, it was difficult to determine if specific trends in sediment composition were evident *(Table 6).* The incidence of cobble was highest in spring and summer. Higher water levels in the colder seasons influenced sampling efforts considerably. Substrate characteristics generally preferred by larval *Corbicula* in substrate preference studies have included fine sand, coarse sand, and mud, in decreasing order of preference [Sickel and Burbanck, 1974]. Gardner et al. [1976] reported that clams inhabited substrates of various composition, mainly sand with mud or detritus. Other studies have reported the Asiatic clam to inhabit shifting sand [Fuller and Powell, 1973], rock and rubble substrate [Rhinne, 1974], and silt-clay sediment [Diaz, 1974].

The Asiatic clam is apparently an opportunistic organism with characteristics of both *r* (population characteristic of a rapid rate of intrinsic increase) and *k* (populations of established numbers that tend to be regulated by environmental influences) selection. Part of their unique competitive ability is derived from the unusually high intrinsic rate of natural increase. Each sexually mature clam may produce several thousand offspring each year [Aldridge and McMahon, 1978]. At the latitude of Glen Lyn, Virginia, *Corbicula* would have two spawning periods during the warmer months. They probably have few competitors and may successfully compete with other molluscan fauna in invaded areas. Clam densities of several thousand per square meter have been reported in warmer climates of South Carolina and California with little to no diversity of other molluscan forms present [Harvey, 1977].

IV. New River Water Quality

The characteristics of New River water during the period of investigation are presented in *Table 7,* with no appreciable differences observed be-

tween 1975 and 1976 *(Figure 10).* On a yearly average, alkalinity was 61 mg/l as $CaCO_3$, while the pH was slightly alkaline (7.8). Dissolved oxygen over the entire period was adequate for aerobic organisms and apparently was strongly influenced by temperature and physical reaeration. Turbidity and suspended solids were relatively low for a large river which could be attributed to the influence of the hydroelectric dam at Claytor Lake. Examination of nutrient concentration showed that the river water was not impoverished concerning the abundance of plant-growth nutrients.

The influence of such environmental factors as water temperature and chemical characteristics on the distribution and survival of *Corbicula* has been documented [Thompson and Sparks, 1977; Mattice and Dye, 1976; Rodgers et al., 1977]. Monitoring water quality in conjunction with field sampling and laboratory experiments was an essential part of this research. Changes in chemical and physical properties of aquatic systems have profound effects on the solubility and toxicity of a variety of elements [Stumm and Morgan, 1970; Sprague, 1973].

V. Static Bioassays

Copper was toxic to the Asiatic clam at lower concentrations than either the combined exposures of copper-zinc or zinc alone in both 24 and 96-hour tests *(Table 9).* No $LC50_{24hr}$ determinations were calculated for zinc even when exposed to 40 mg/l. Higher concentrations were not attempted as the toxicant precipitated out in the stock containers, and levels this high in most aquatic systems generally would be hazardous to aquatic biota. LC50 determinations for 96 hours were at least 10 times less for copper when compared to 24-hour results. Potential synergistic effects from the combined exposures of copper and zinc were not as toxic to *Corbicula* in comparison to bioassays of copper alone. Though the range of concentrations used was the same for both tests, zinc may have inhibited the toxicity of copper in the bioassays utilizing copper and zinc in combination.

The level at which the LC50 was determined by probit analysis for the three heavy metal exposure regimes (LC50 in mg/l for copper, zinc, and copper-zinc—0.04, 6.04, and 0.05, respectively) also appeared to be the effective concentration (EC50) at which gaping was observed by approximately 50 percent of the test organisms *(Figures 11-13).* At concentrations above the LC50, gaping generally decreased, most likely resulting

from the behavioral response of "clamming up" in the presence of higher concentrations. The EC50 determination in this study is not considered to be a precise calculation (as is the LC50) from the data generated, but rather is an observation approximating 50 percent of the clam test organisms that show a behavioral response (siphoning, gaping) to a toxic substance while subjected to a bioassay. Siphoning or feeding activity also declined to 10 percent or less at the $LC50_{96hr}$ determination. Gaping, unlike mortality, may occur at one period of observation for a clam but not at the next. Similar trends between gaping and siphoning were observed for copper and simultaneous copper-zinc exposures in the 24-hour tests.

No LC50 determinations were observed for potassium (K_2SO_4) exposures up to 300 mg/l for 96 hours, since only 20 percent mortality occurred *(Table 8).* For chlorine, mortality was 0 after 96 hours for concentrations as high as 20 mg/l TRC. When experiments were lengthened to 10 days under the same concentrations, however, $LC50_{240hr}$ determinations for TRC and FRC within the total residual (which were measured twice daily) were 0.69 and 0.54 mg/l, respectively. That the clams were exhibiting signs of stress was evident after 96 hours, as approximately half of the test organisms were gaping.

Elemental uptake of copper and zinc was more evident in the visceral tissue than in the clam valves *(Figures 11-13).* Copper concentrations in visceral tissue were greatest at sublethal concentrations (0.005-0.01 ppm) when filtering activity was high, followed by a decline as filtering ceased at the 0.05-ppm level *(Figure 13).* A similar trend was also observed for copper in the copper-zinc test *(Figure 12).*

Zinc, in the static, 96-hour test, was concentrated in both valves and visceral tissue to a greater extent than copper *(Figure 13).* Accumulations of zinc tended to increase with an increase in toxicant exposure. In the copper-zinc tests, zinc concentrations tended to follow a similar pattern of uptake as observed for copper. Following the highest visceral concentration at the calculated $LC50_{96hr}$, tissue concentrations declined as both filtering and gaping response decreased. Gaping and filtering responses were only reported for 24, 48, or 72-hour intervals, since in most cases, only a few live clams were available after 96 hours.

VI. Continuous-Flow Bioassays

Lethal concentrations in the artificial streams were 10 and 20 times greater for copper and combined copper-zinc exposures, respectively, than in the static tests *(Table 8).* Both the rate and actual mortality were nearly the same for clams in streams with and without river sediment. Apparently, the 10 mm of sediment in the streams was not sufficient to allow the clams to burrow to depths where toxicant exposure was lessened. Filtering activity decreased rapidly, and gaping was maximal after low copper exposures of $\geqslant$0.05 mg/l *(Figure 14).* The effective concentration (EC50) of copper that elicited a stressed response for 50 percent of the organisms occurred (0.05 mg/l) well below the LC50 (0.49 mg/l) and was more evident after 72 hours of exposure. During this period, clams may be more susceptible to predation or vulnerable to biocidal practices (e.g., intermittent chlorination). Copper uptake was highest in the visceral tissue, with concentrations increasing with an increase in the toxicant level. Tissue concentrations surpassed levels of 800-1200 ppm for copper and zinc at test concentrations of 10-20 ppm. These laboratory-induced levels of uptake greatly surpassed the naturally occurring visceral concentrations measured in clams and sediments from the New River, which are presented later in *Tables 14* and *16.*

No mortality was observed in potassium exposures up to 140 mg/l in the artificial streams during 96 hours, although a weakening or stressed condition was evident by more than 50 percent of the clams exhibiting gaping behavior *(Table 8).* Following cessation of dosing with potassium, but maintaining the test organisms in the streams for an additional 96 hours, 33-89 percent mortality occurred, depending upon the prior exposure. As in the static tests, no mortality in 96 hours was evident from chlorine exposures up to 10 mg/l TRC, although 40-50 percent of the organisms were gaping.

VII. Behavioral Responses

Siphoning activity by *Corbicula* in static, 24-hour copper bioassays was reduced from 95.8 percent in the controls to 33.0 percent at 0.05 mg/l after only four hours *(Table 9).* After 24 hours, siphoning was reduced to 50.0 percent at the 0.05 mg/l concentration, and at 0.50 mg/l copper and higher, siphoning was reduced to 0. The gaping response after 24 hours was $\geqslant$50.0 percent at concentrations from 0.50 to 10.0 mg/l copper. For zinc, a reduction in siphoning activity of more than 50 percent

after 24 hours occurred at 5.0 mg/l (4.2 percent siphoning) with a corresponding increase in gaping activity from 0 to 75 percent. The behavioral response in the copper-zinc bioassays was similar to the change occurring in the copper exposures in that the greatest reduction in siphoning activity (to 0 percent) occurred at 0.50 mg/l. However, the first reduction in siphoning activity (14.3 percent) after 24 hours occurred at 0.05 mg/l. Gaping activity was rarely observed. The reduction in siphoning activity in the three static bioassays generally occurred at or prior to the LC50 determination, while gaping (when evident) was observed near or after this concentration *(Table 8).*

In the 96-hour static bioassays for copper, siphoning activity after observations of 24, 48, 72, or 96 hours was reduced to approximately 8.3-0 percent at the 0.05 mg/l exposure *(Table 10).* At lower concentrations (0.01 and 0.005 mg/l), siphoning usually occurred in at least 50 percent of the clams. A corresponding increase in gaping was evident in 30-87.5 percent of the organisms at the 0.05 mg/l level which approximated the $LC50_{96hr}$ (0.04 mg/l) for copper. Gaping activity tended to increase at the higher exposure levels (0.10-1.0 mg/l), except at observations for 96 hours, in which most or all clams had already died.

Although no $LC50_{96hr}$ determinations were obtained for zinc in static tests, stress was evident from the behavioral responses observed at 1.0 mg/l (reduction in siphoning activity to 20.8 percent with gaping increasing to 52.5 percent in *Table 10).* Responses to copper and zinc combined generally were the same as those observed for copper alone *(Table 10).* The initial abrupt changes in behavioral responses (reduction in siphoning and increased incidence of gaping) occurred at 0.05 mg/l (0.05 mg/l each for copper and zinc), which was the 96-hour LC50 in the static tests *(Table 8).* Siphoning and gaping activity were relatively low at higher exposures (0.10-1.0 mg/l).

Siphoning activity was reduced to 0 at all observations (24, 48, 72, and 96 hours) from copper doses of 0.05 mg/l in the artificial stream bioassays *(Table 11).* Almost half (42.4-52.1 percent) of the clams were gaping after 48-96 hours of exposure at this same concentration. This stressed condition was about 10 times lower than the 96-hour LC50 (=0.49 mg/l) for copper in the stream bioassays *(Table 8).* Gaping at 96 hours was prevalent until exposures of 0.30 mg/l and higher were reached. Behavioral responses in the copper-zinc combined tests were difficult to assess since siphoning activity was only 42.6 percent after 24 hours and

declined to 23.1 percent by 96 hours *(Table 11).* No siphoning occurred at any exposure and gaping activity was minimal.

Gaping, which was the major response evaluated in the potassium exposures, was most prevalent at 100 mg/l in the stream and 135 mg/l in the static tests *(Table 12).* After 96 hours in the streams, 98.1 percent of the clams were gaping at 100 mg/l with 50 percent of the organisms gaping at 120 and 140 mg/l. In the static tests, where gaping was less prevalent at all concentrations compared to the stream tests, the incidence of gaping was almost non-existent at low exposures (0-8.3 percent at 2, 8, 45, and 75 mg/l), and declined rapidly in treatments $\geqslant$180 mg/l. At 300 mg/l, no gaping was evident at any time of observation. Anderson et al. [1976] also reported a decline in gaping (85 percent at 458 mg/l) at high potassium concentrations beyond the threshold gaping response (190 mg/l after 96 hours). However, no LC50 determination was possible in either stream or static tests in the present study, whereas Anderson et al. [1976] reported a 96-hour LC50 = 225 mg/l. The use of potassium as an effective biocidal agent alone is improbable, although the combination with other agents may be promising because of the ability of potassium to elicit a gaping response.

Gaping was consistently low (29.6-44.4 percent) in 96-hour chlorine bioassays *(Table 13).* Siphoning activity was reduced to 0 at all chlorine exposures (1.6-14.3 mg/l TRC consisting of 0.9-9.1 mg/l FRC). In the static tests, where 10 days were required to obtain an LC50 (0.69 mg/l TRC), siphoning activity was reduced from 87.5 percent in the control to 12.5 percent at the first exposure (0.10 mg/l TRC) after 24 hours, and reduced to 0 at all other times of observation ($>$0.10 mg/l). A stressed response was evident within 96 hours at 0.40 mg/l TRC when 79.2 percent of the clams were gaping. By 192 hours and thereafter at 0.40 mg/l, however, gaping diminished ($\leqslant$37.5 percent) as most clams maintained a tight closure of valves until death. Gaping by more than 70 percent of the clams (70.8-95.8) after 96 hours occurred at all chlorine exposures above 0.40 mg/l TRC. Little activity was evident at $\geqslant$1.20 mg/l TRC at 216 and 240 hours, since most clams were dead.

Because of its natural resistance and/or behavioral responses, the Asiatic clam was unexpectedly tolerant to heavy metal, potassium and chlorine exposures. Other mollusks appear to be more susceptible to lower heavy metal exposures. Extremely low toxic concentrations of copper ($\sim$0.02 ppm) have been reported for the clam, *Mya arenaria* [Pringle et al., 1968],

with a TLm_{96hr} = 1.9 ppm for the oyster, *Crassostrea gigas* [Fujiya, 1960]. Wurtz [1962] considered copper and zinc to be the most toxic metals for mollusks. *Corbicula,* when tested under normal temperatures (15-24°C) in our tests, appeared to be among the most resistant mollusk groups. Other mollusks appear to be more sensitive to potassium than *Corbicula* if data from long-term studies are considered. The bivalves, *Actinonaias carinata, Lampsilis radiata siliquoidea,* and *Fusconaia flava,* were reported to suffer 90 percent lethality from 11 mg/l potassium following 35-45 days of exposure with 7 mg/l being lethal to the latter two species in approximately eight months [Imlay, 1973]. Since data from long-term studies of exposure to selected elemental concentrations currently are not available for *Corbicula,* applicability of their tolerance to long-term studies for mollusks is difficult to assess.

The use of conventional, static bioassay procedures instead of artificial stream systems will alter the toxicity response of *Corbicula,* probably by creating a more unnatural, toxic situation than found in the natural environment. This was evident in the 96-hour LC50 determinations between static and artificial stream bioassays using copper and copper-zinc combined exposures where the tolerance of the Asiatic clam was one to two orders of magnitude greater in the artificial streams *(Table 8).* Instead of clams suffering from a combination of toxic substances and an unnatural, hostile environmental design in the static test, the artificial streams allowed the organisms to respond to the toxic substance in a lotic-type of environment similar to the habitat of the New River. Since the Asiatic clam is a filter-feeder residing on or within the river sediment, the bioassay utilizing an artificial stream system offers a more realistic approach to the vulnerability and subsequent control of the organism.

VIII. Field Elemental Concentrations

Concentrations of 42 elements, as measured by neutron activation, were usually lowest in New and East River water, intermediate in clam valves, and highest in either clam viscera or sediment, depending upon the element *(Tables 14-16).* Twenty-five elements were most highly concentrated in sediments with about half of the 25 being higher in stations upstream from the power plant influence. Some of the elements that were highly concentrated in sediment included some heavy and light metals and potentially toxic elements (aluminum, arsenic, cobalt, copper, mercury, magnesium, manganese, tin, and titanium). The most abundant elements in water were aluminum, calcium, chlorine (as chloride),

iron, magnesium, potassium, sodium, and zinc, with all concentrations being ⩾2 ppm. Fifteen of the 42 elements were most highly concentrated in clam viscera, with calcium being highest in the shells. Some of these tissue accumulations included the halogens (bromine and chlorine), and potentially toxic elements and heavy metals (cadmium, cesium, molybdenum, nickel, antimony, selenium, uranium, and zinc) that may be hazardous to aquatic biota. In comparison to bioaccumulation studies of mosquitofish stressed by coal ash and thermal discharge using neutron activation analysis [Cherry et al., 1976], *Corbicula* tended to accumulate more elements to a greater extent.

Zinc concentrations in field visceral tissue samples were similar to those measured by atomic absorption in the laboratory bioassays. Discrepancies in copper measurements were great between field and laboratory concentrations. Although some of the heavy metal concentrations in river water were high, it is doubtful that they were prevalent on a continuous basis as indicated by the variability between samples. From these field and laboratory data, *Corbicula* appears to be an efficient bioaccumulator of heavy metals and other potentially toxic elements without suffering adverse effects. From these data, river concentrations in the vicinity of the Glen Lyn plant do not appear to be a limiting factor in the population dynamics of *Corbicula* in the New River.

IX. Summary

To summarize the *Corbicula* research—the Asiatic clam has successfully invaded and colonized the New River at the Glen Lyn power plant. Although the unusually cold winters of 1975-76 and 1976-77 limited the increase in population densities in thermally uninfluenced regions around the power plant, the heated discharge thermally enriched and maintained the clam populations and served as an origin for invading the surrounding river habitat during the warmer seasons. These organisms were unexpectedly tolerant of heavy metal exposures in laboratory toxicity testing, which may be attributed to their natural resistance or to behavioral mechanisms of filtering cessation ("clamming up") during periods of high toxicant exposures. The clams tended to be efficient bioaccumulators or bioconcentrators of heavy metals in both field sampling and laboratory bioassays. The use of an EC50 (effective concentration to elicit a specific behavioral response to 50 percent of the test organisms), that caused a gaping response at certain low to intermediate bioassay exposures, may become a potential control mechanism within certain concentration

ranges for predicting when *Corbicula* would be more susceptible to treatment when utilizing a combination of test variables. The use of excessively high or low temperatures combined with heavy metal exposure, or the possible application of potassium (which promotes the gaping response), followed by chlorination, may become a more efficient control procedure. At a time when Asiatic clam densities are continuing to increase in the river sediments to the level of being lodged and residing in the condensers of the power plant (during the summer of 1978), the need for an effective control has been predicted to become an important issue to plant operation procedures during subsequent years.

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FIGURES

FIGURE 1

Distribution of the Asiatic Clam (Corbicula fluminea) in the United States from Its Introduction on the West Coast in 1938 and Subsequent Invasion (to 1978)

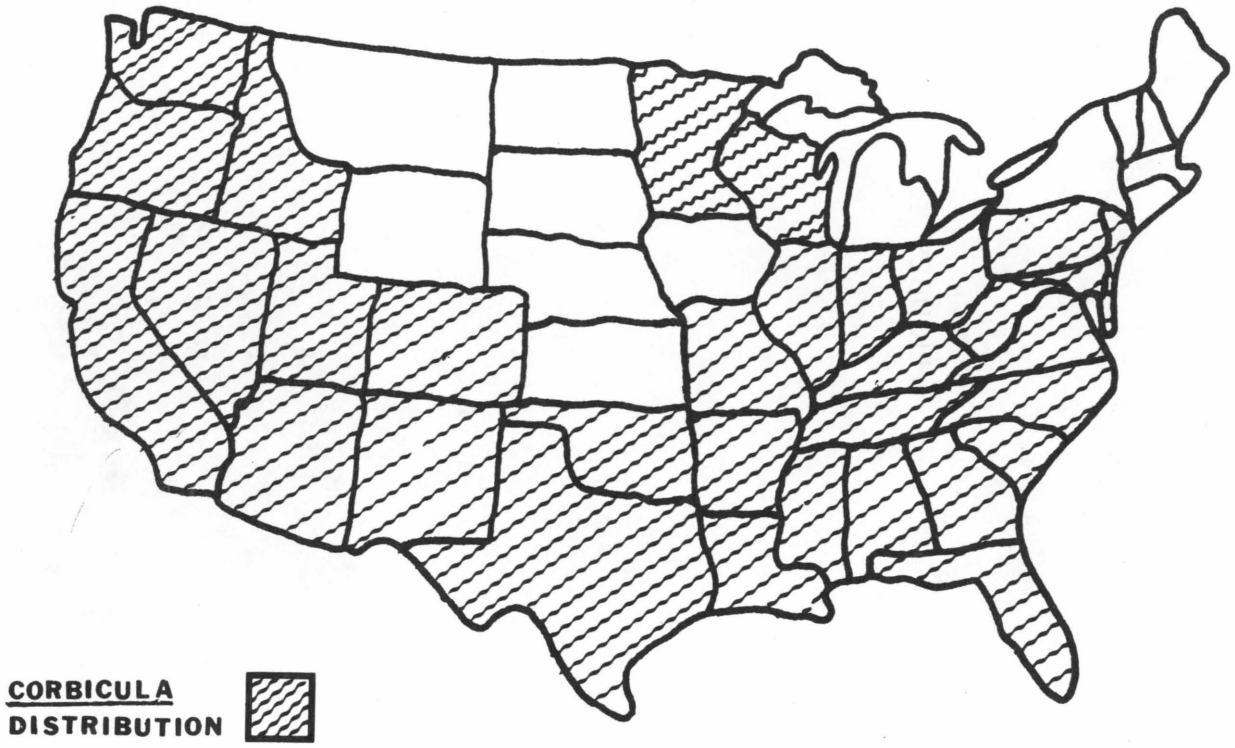


FIGURE 2

Kanawha and New River Basins and Glen Lyn Sampling Location for the Asiatic Clam in Virginia

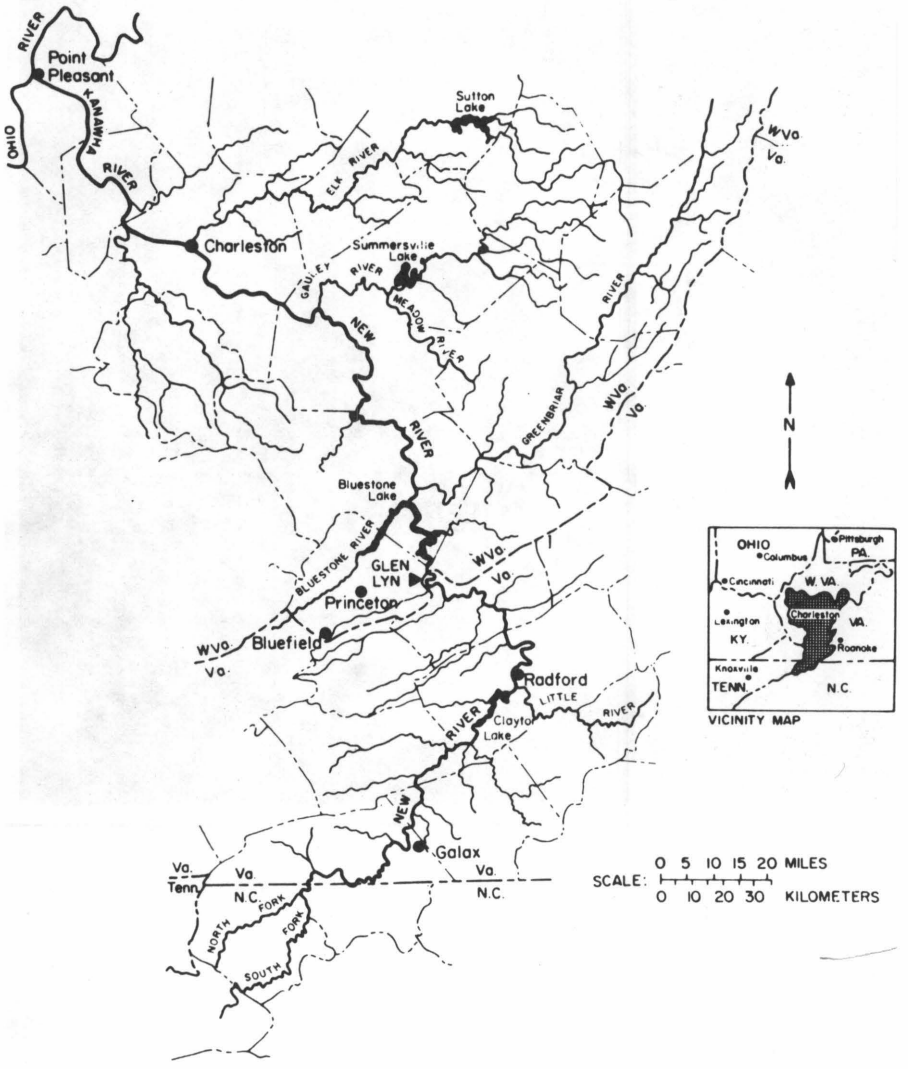


FIGURE 3

Identification of Corbicula by Serrated Lateral Teeth on Right Valve

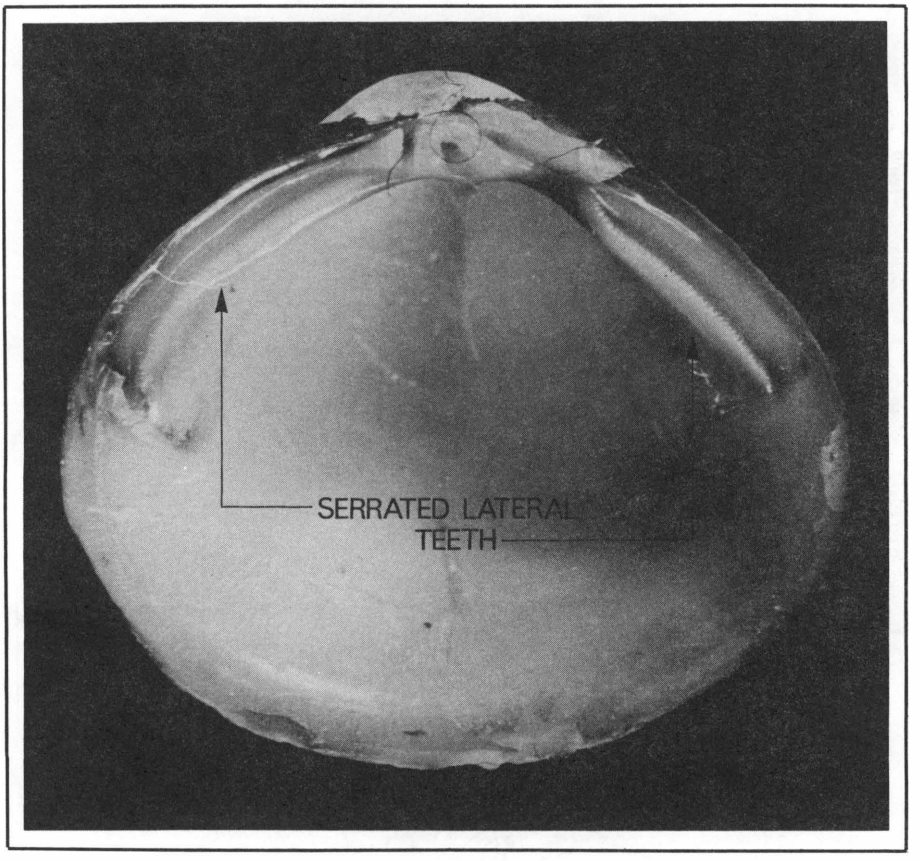


FIGURE 4

Six Sampling Stations for the Asiatic Clam in the New River from October 1976 to December 1978 at Glen Lyn, Virginia

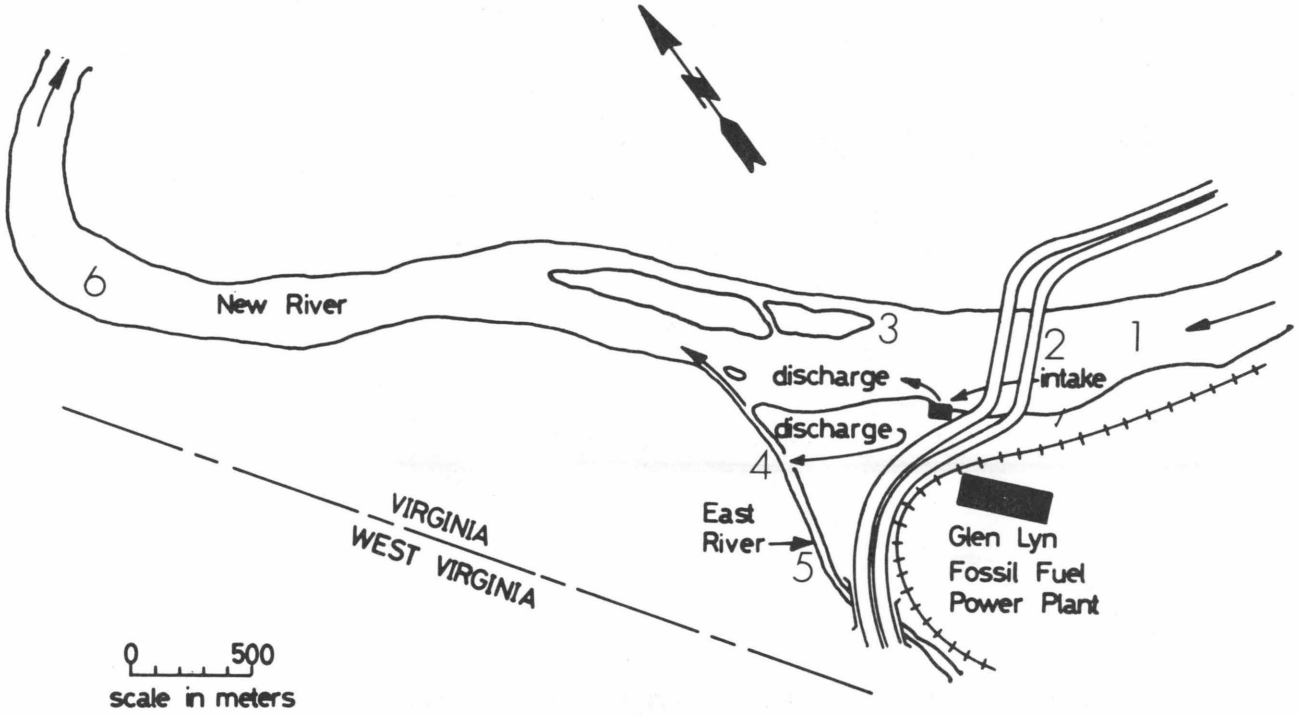


FIGURE 5
Diagram of Clam Sampler with a 0.05-mm Mesh Plankton Net Attached

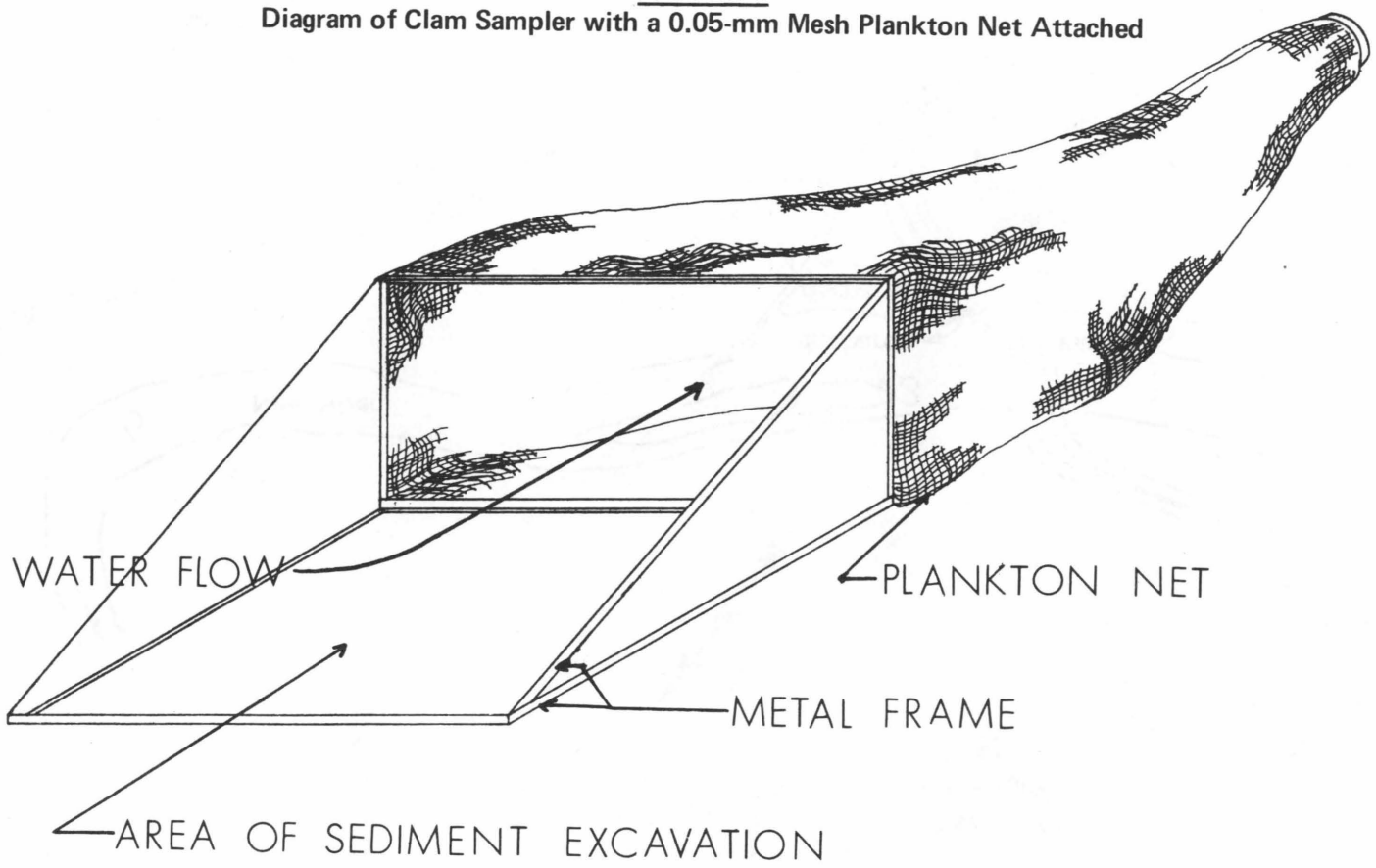


FIGURE 6
Artificial Streams Used in Continuous-Flow Bioassays

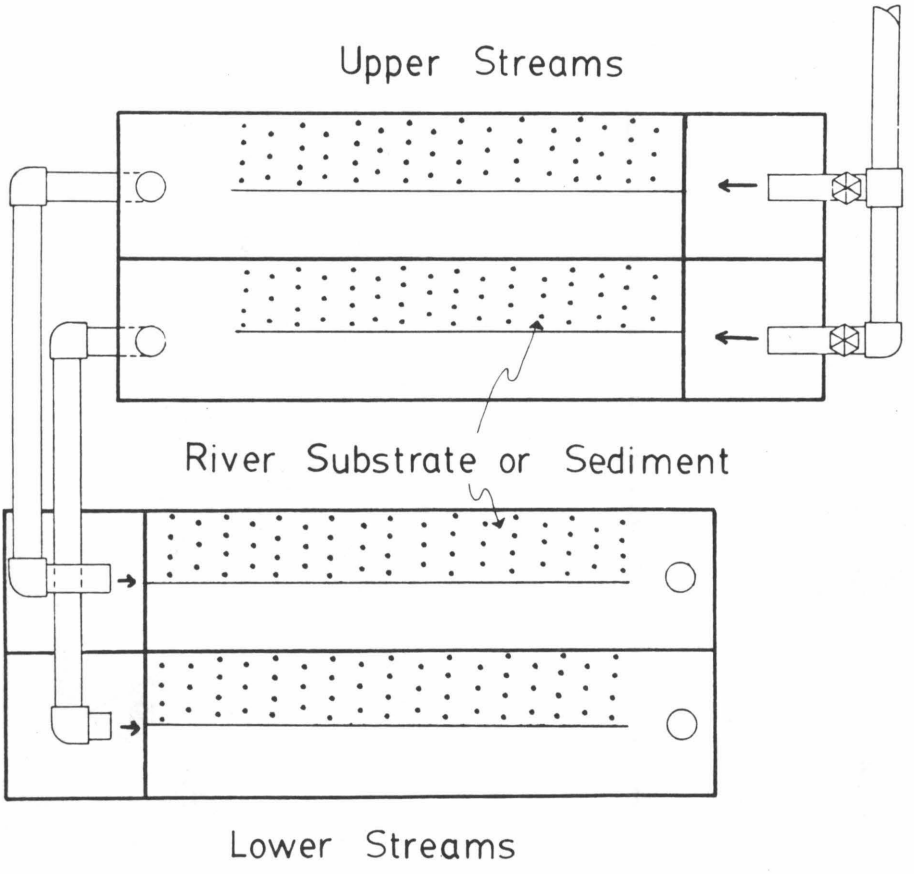


FIGURE 7

Comparison of Population Densities of Corbicula
in Heated and Unheated Areas from October 1976 to November 1978

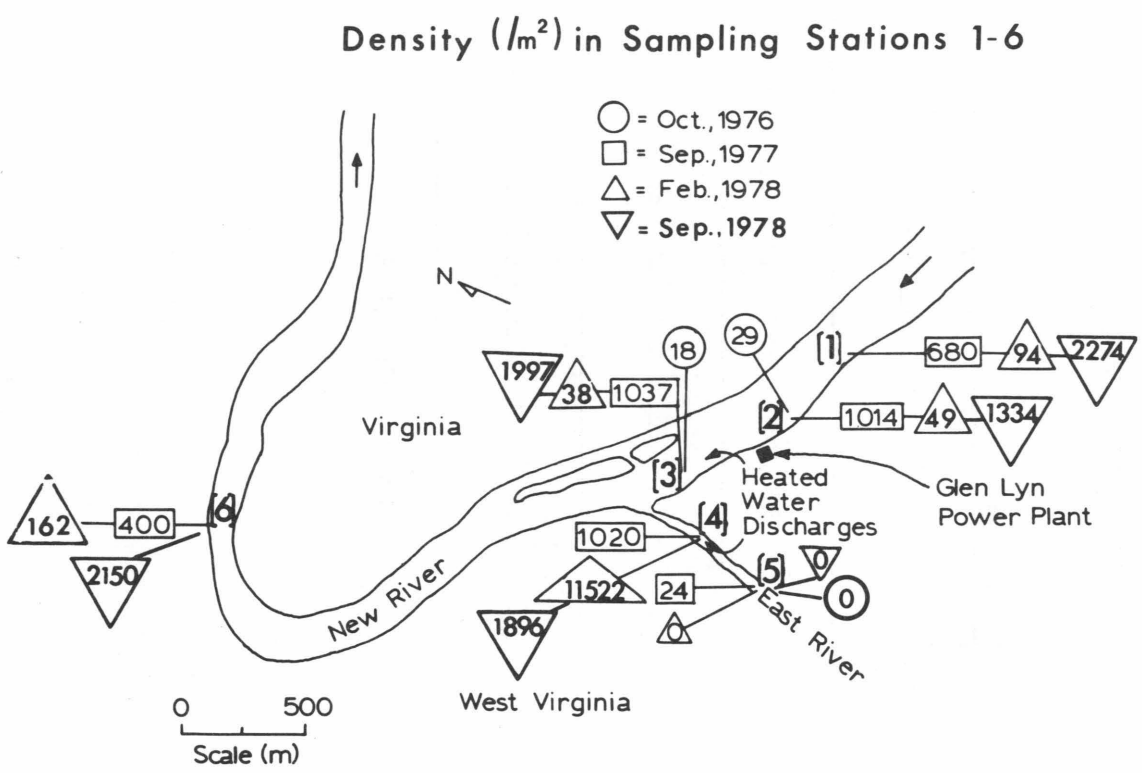
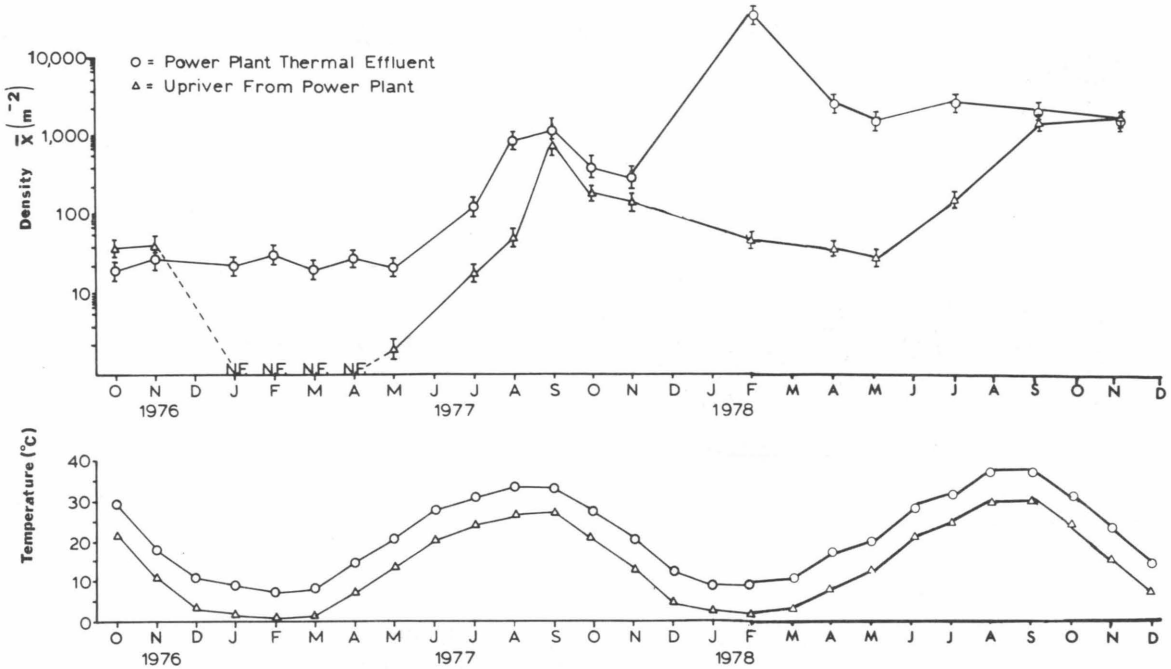


FIGURE 8

Maximum Density of Asiatic Clams Sampled in Ambient (Station 1) and Thermally Influenced (Station 4) Locations of the New River from October 1976 through February 1978*



*Absence of clams from January to April 1976 is indicated by "NF" (not found).

FIGURE 9

Comparison of Size Classes of the Asiatic Clam Sampled in Thermally Influenced and Unheated Regions of the New River

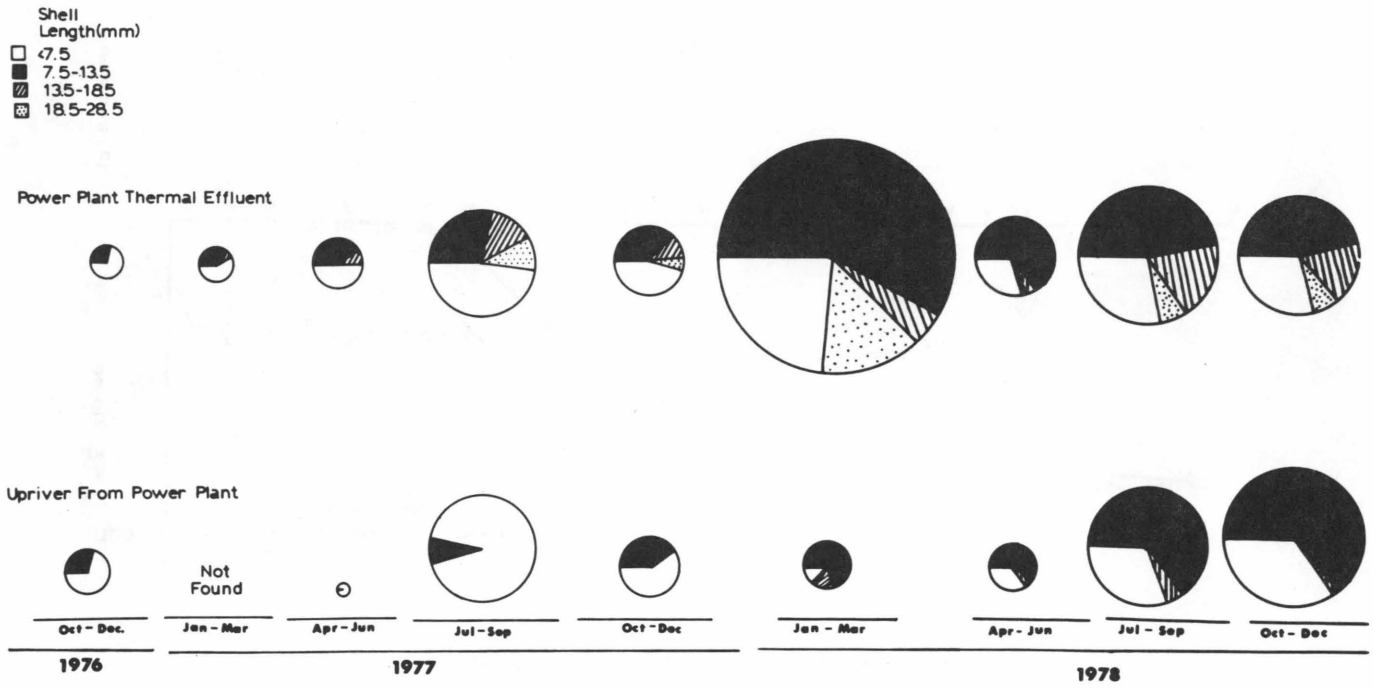


FIGURE 10

Monthly Changes of 15 Water Quality Parameters in the New River Not Influenced by Power Plant Effluent (Station 1) During 1975 and 1976

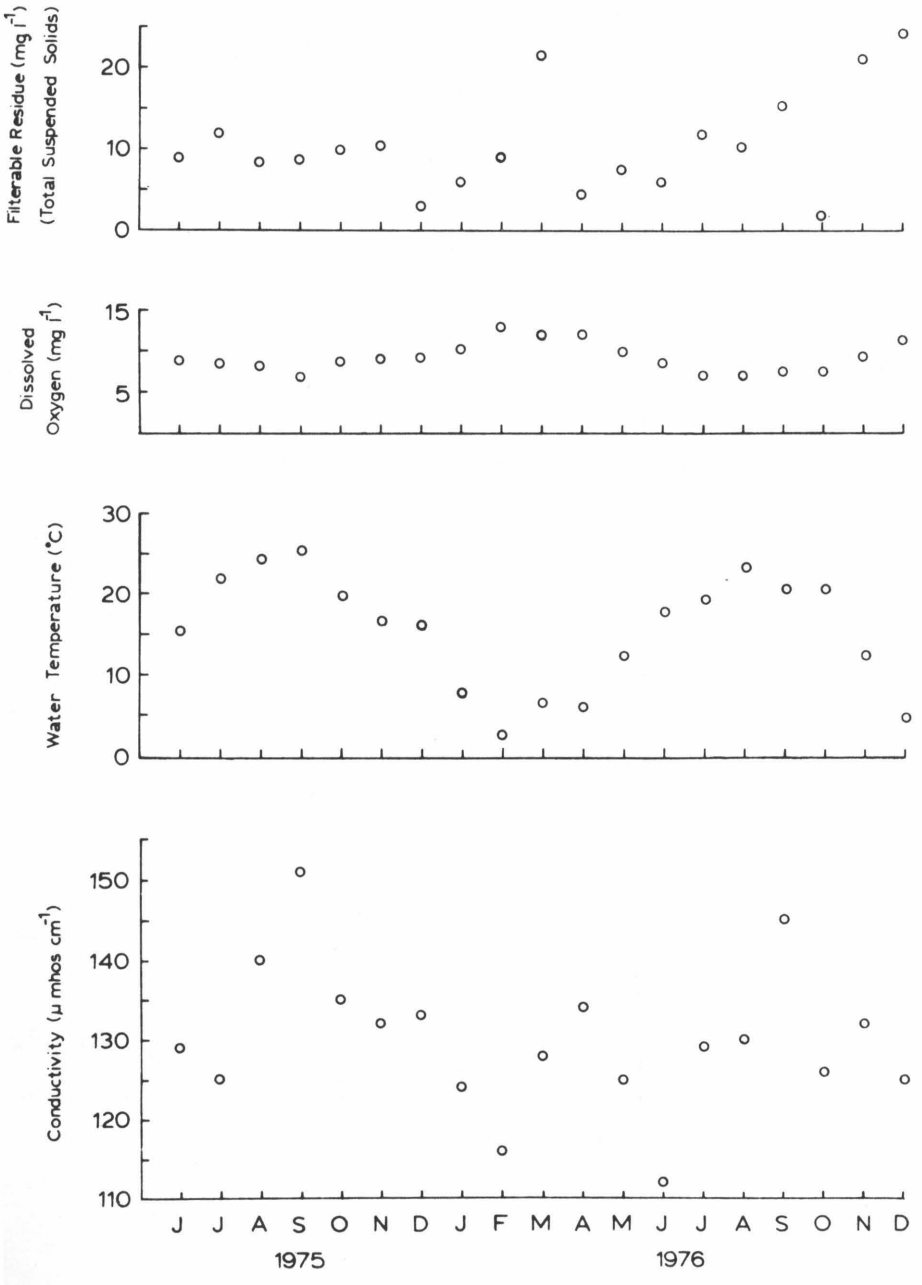


FIGURE 10 (continued)

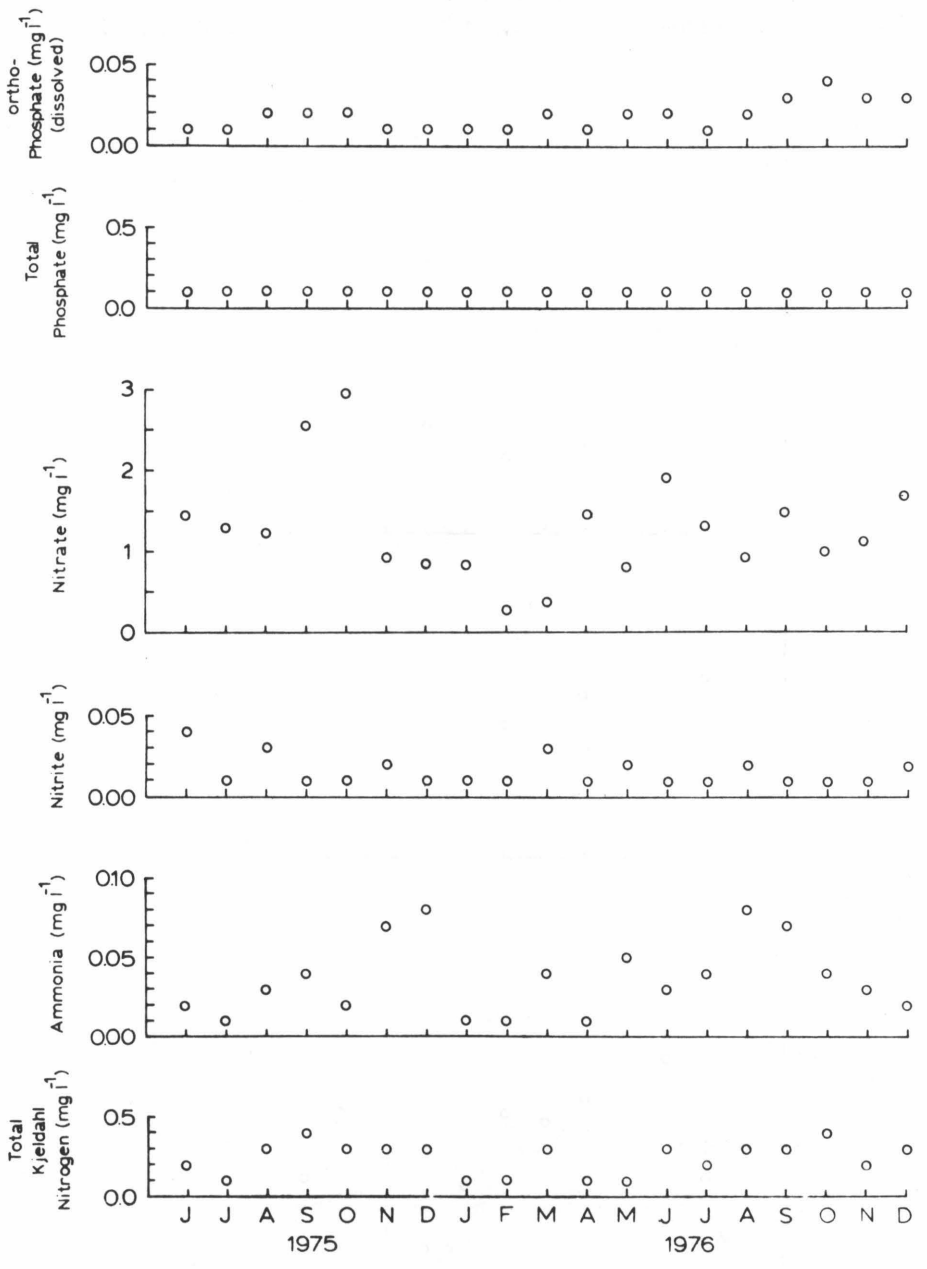


FIGURE 10 (continued)

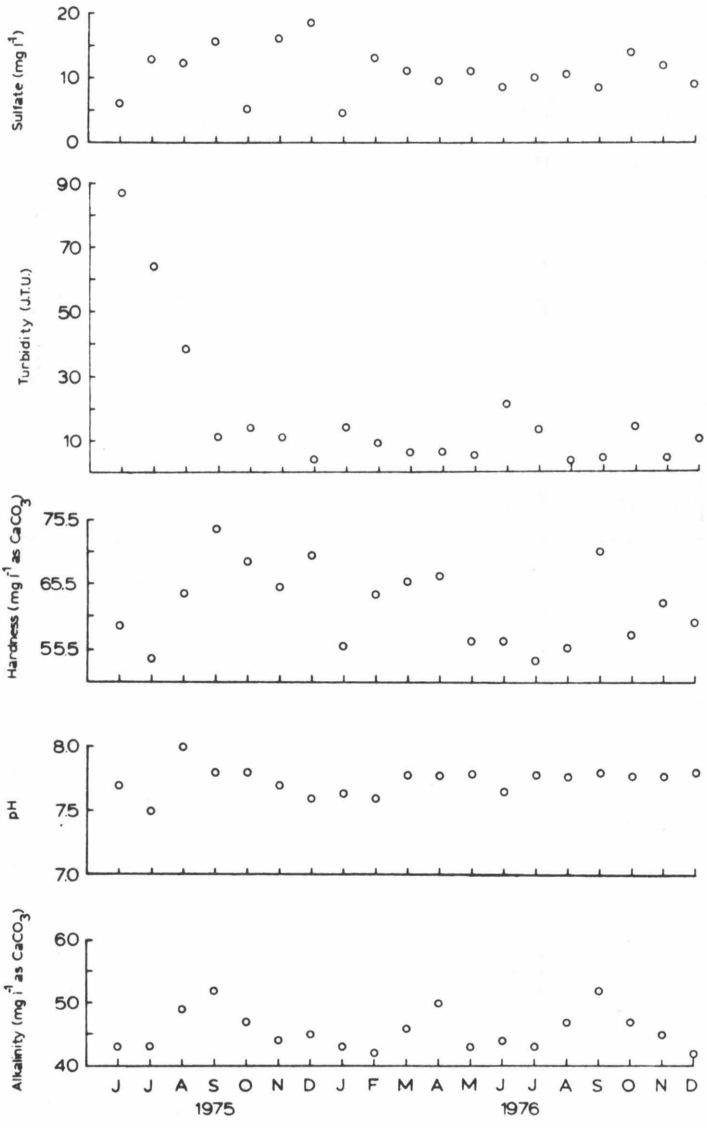
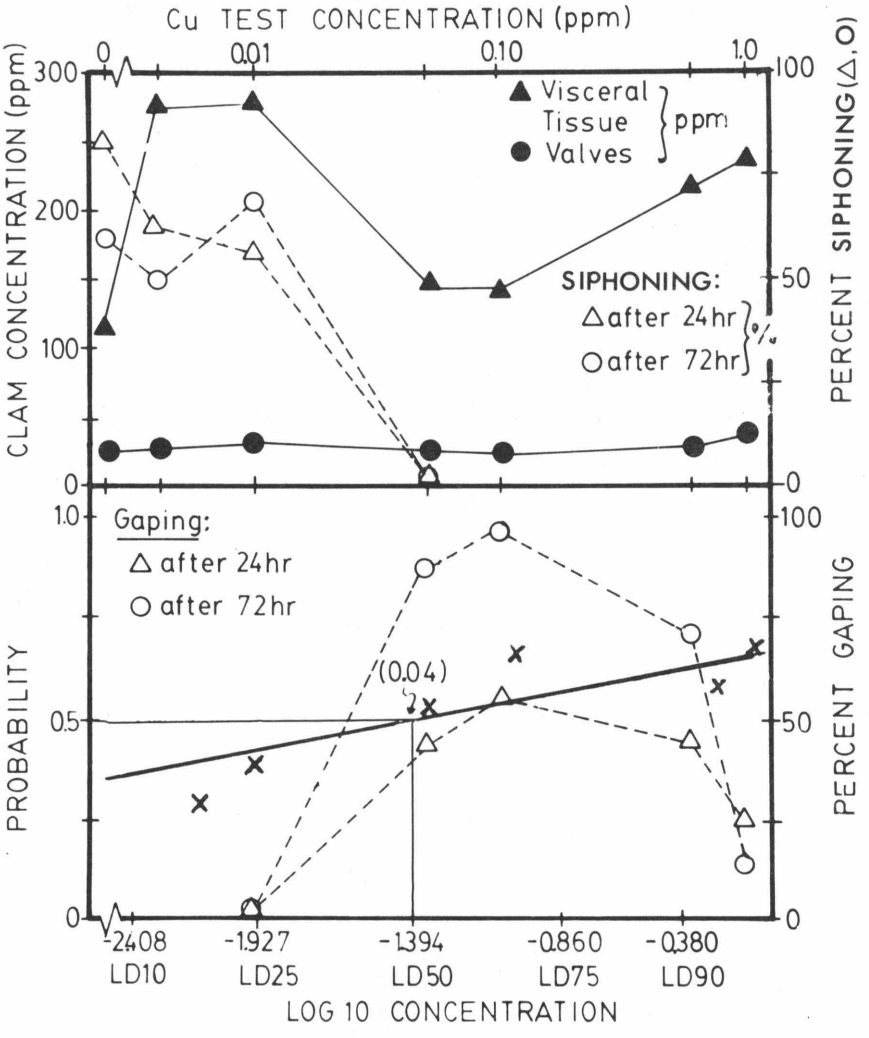


FIGURE 11

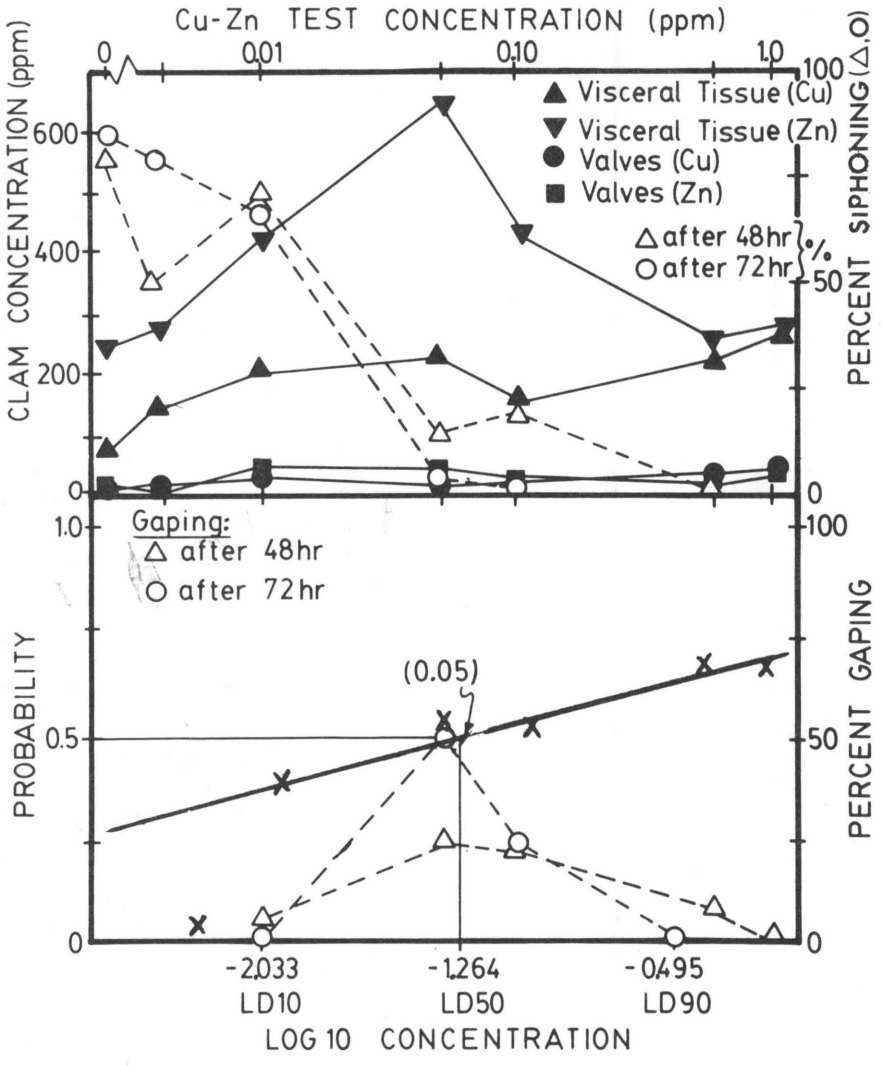
Acute Toxicity of Copper for a 96-Hour Period ($LC50_{96hr}$) Determined by the Probit Procedure (Heavy Solid Line)*



*The percentage of clams gaping and siphoning is plotted with the LC50 to ascertain an effective concentration (EC50) to the toxicant along with biological uptake during the exposure period.

FIGURE 12

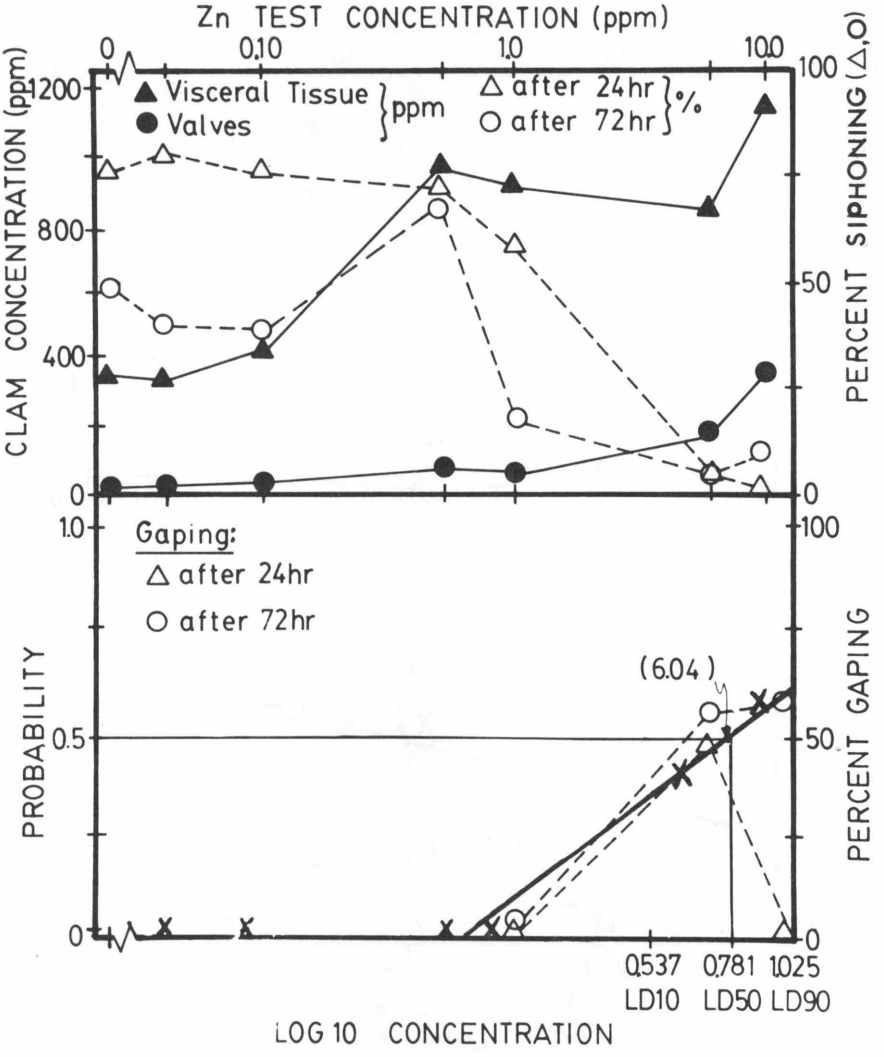
Acute Toxicity of Copper and Zinc for a 96-Hour Period ($LC50_{96hr}$) Determined by the Probit Procedure (Heavy Solid Line)*



*The percentage of clams gaping and siphoning is plotted with the LC50 to ascertain an effective concentration (EC50) to the toxicant along with biological uptake during the exposure period.

FIGURE 13

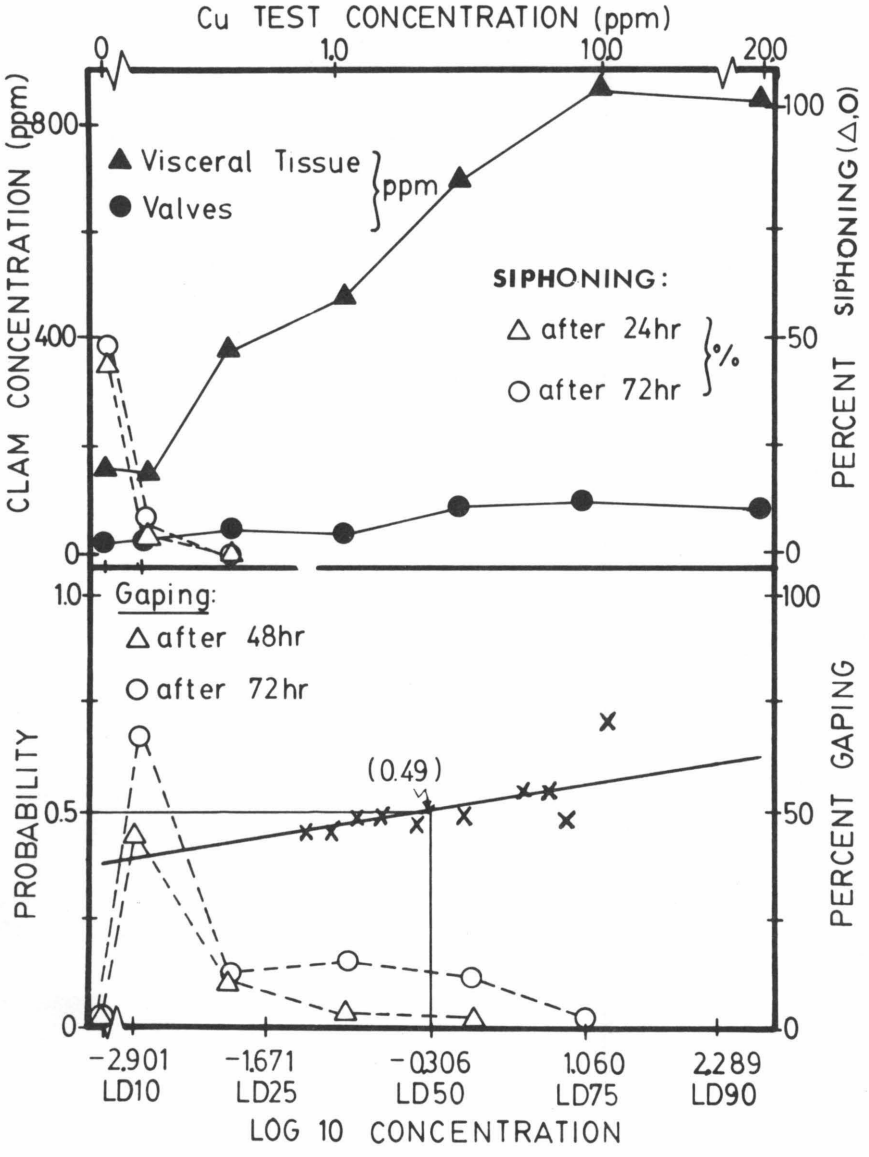
Acute Toxicity of Zinc for a 96-Hour Period ($LC50_{96hr}$) Determined by the Probit Procedure (Heavy Solid Line)*



*The percentage of clams gaping and siphoning is plotted with the LC50 to ascertain an effective concentration (EC50) to the toxicant along with biological uptake during the exposure period.

FIGURE 14

Toxicity of Copper for a 96-Hour Period ($LC50_{96hr}$) in Artificial Streams Determined by the Probit Procedure (Heavy Solid Line)*



*The percentage of clams gaping and filtering is plotted with the LC50 to ascertain an effective concentration (EC50) to the toxicant along with biological uptake during the exposure period.

TABLES

TABLE 1
Methods for Analyses of Physical and Chemical Parameters of Water Quality

Parameter	Units	Method or Instrument	Reference
Alkalinity, Total	mg/l^{-1} as $CaCO_3$	titration, mixed indicator	*APHA 1976
Ammonia	mg/l^{-1}	distillation, phenate finish	APHA 1976
Chlorine	mg/l^{-1}	amperometric titration, Fisher-Porter	APHA 1976
Chloride	mg/l^{-1}	$AgNO_3$ titration	APHA 1976
Conductivity, Specific	$\mu mhos\ cm^{-1}$	Wheatston bridge, Thomas Model 275	APHA 1976
Hardness (EDTA)	mg/l^{-1} as $CaCO_3$	titration	APHA 1976
Metals and Elements (Cu, Ca, Cr, K, Na, Mg, Zn, etc.)	mg/l^{-1}	atomic absorption, Perkin Elmer-Model 460 neutron activation analysis	APHA 1976
Nitrate	mg/l^{-1}	cadmium reduction	APHA 1976
Oxygen, Dissolved	mg/l^{-1}	membrane electrode (Yellow Springs Instrument Co. Model 54) standardized by the Azide Modification of the Winkler Method	APHA 1976
pH		glass electrode (Corning portable meter)	APHA 1976
Phosphate			
Total	mg/l^{-1}	ascorbic acid	APHA 1976
Ortho (dissolved)	mg/l^{-1}	ascorbic acid, glass fiber filter	APHA 1976
Sulfate	mg/l^{-1}	turbidimetric	APHA 1976
Temperature	°C	mercury-filled thermometer (0.1 C divisions) or thermister	APHA 1976

*American Public Health Association.

TABLE 2

Density (per m^2) of *Corbicula* in Heated (3, 4, and 6) and Unheated (1, 2, and 5) Stations During 1978

Month of Sample	Density (per m^2) in Sampling Stations					
	3 (max ΔT)	4 (max ΔT)	6 (min ΔT)	1	2	5
February	37.6	11,521.6	162.4	94.4	38.4	0
April	44.0	2,060.8	20.0	48.4	35.2	0
May	27.2	1,149.6	65.6	53.6	27.2	0
July	41.6	2,208.0	1,358.4	84.8	147.2	0
September	1,996.8	1,896.0	2,149.6	2,273.6	1,334.4	0
November	3,786.4	1,859.2	868.0	2,285.6	1,907.2	0
$\bar{X}$–1978	988.9	3,449.2	770.7	806.8	581.6	0

TABLE 3

Percent of Size Classes (I-V) Representing Selected Shell Length Intervals on an Annual Basis for *Corbicula* Sampled During 1978 in Heated (3, 4, and 5) and Unheated (1, 2, and 5) Stations*

		Percent of Clams in Sieve Sizes				
Station	Density (per m^2)	I (<7.5)	II (7.5-13.5)	III (13.5-18.5)	IV (18.5-28.0)	V (>28.0)mm (shell length)
3	988.9	38.2	55.0	2.9	3.9	0
4	3,449.2	31.8	54.8	12.2	1.2	0
6	770.7	10.0	60.2	18.0	11.7	0.1
1	806.8	26.6	67.6	5.6	0.2	0
2	581.6	31.9	62.1	4.7	1.3	0
5	0	0	0	0	0	0
$\bar{X}$ (excluding station 5)	1,319.4	27.7	59.9	8.7	3.7	<0.1

*Size classes I-V were partitioned from sieve size procedures reported by Gardner et al. [1976].

TABLE 4

Density and Percentage of Size Classes (I-V) Representing Selected Shell Length Intervals on a Seasonal Basis for *Corbicula* from Heated (3, 4, and 6) and Unheated (1, 2, and 5) Stations During 1978*

			Percent of Clams in Sieve Sizes				
Season	Station	Density (per m^2)	I (<7.5)	II (7.5-13.5)	III (13.5-18.5)	IV (18.5-28.0)	V (>28.0)mm (shell length)
Winter	3	37.6	8.5	74.5	4.3	12.7	0
	4	11,521.6	57.6	42.3	0.1	0.1	0
	6	162.4	3.9	69.0	6.9	19.7	0.5
	1	94.4	16.1	72.9	11.0	0	0
	2	38.4	14.6	70.8	10.4	4.2	0
	5	0	0	0	0	0	0
Spring	3	35.6	25.9	70.4	2.8	0.9	0
	4	1,605.2	46.5	52.0	1.0	0.5	0
	6	42.8	12.4	87.6	0	0	0
	1	51.2	34.1	61.9	4.0	0	0
	2	31.2	40.1	57.0	2.9	0	0
	5	0	0	0	0	0	0
Summer	3	1,019.2	63.8	30.3	4.0	1.9	0
	4	2,052.0	6.2	70.6	21.0	2.2	0
	6	3,508.0	13.2	41.0	33.8	12.0	0
	1	1,179.2	30.2	64.0	5.6	0.2	0
	2	740.8	28.0	68.6	3.3	0.1	0
	5	0	0	0	0	0	0

(continued)

TABLE 4 (continued)

Season	Station	Density (per m^2)	Percent of Clams in Sieve Sizes				
			I (<7.5)	II (7.5-13.5)	III (13.5-18.5)	IV (18.5-28.0)	V (>28.0)mm (shell length)
Fall	3	3,786.4	54.4	44.8	0.6	0.2	0
	4	1,859.2	17.0	54.4	26.5	2.1	0
	6	868.0	10.6	43.0	31.2	15.2	0
	1	2,285.6	26.2	71.4	1.6	0.8	0
	2	1,907.2	45.0	51.8	1.8	0.8	0
	5	0	0	0	0	0	0

*Size classes I-V were partitioned after the procedure reported by Gardner et al. [1976].

TABLE 5

Percent Composition by Weight of Sediment Samples for 1978 in Thermally Influenced (3, 4, and 6) and Unheated (1, 2, and 5) Stations in the New River

Station	Percent Sediment Composition				
	Clay	Silt	Sand	Pebble	Cobble
3	2.2	1.1	36.7	51.2	8.8
4	1.8	0.8	37.4	55.0	5.0
6	1.7	0.6	24.0	70.6	3.1
$\bar{x}$	1.9	0.8	32.7	59.0	5.6
1	1.5	0.9	28.6	63.8	5.2
2	1.3	0.5	23.3	73.3	1.6
5	1.1	0.6	19.2	78.2	0.9
$\bar{x}$	1.3	0.7	23.7	71.8	2.5

TABLE 6

Percent Composition by Weight of Sediment Samples for 1978 on a Seasonal Basis in Thermally Influenced (3, 4, and 6) and Unheated (1, 2, and 5) Stations in the New River

		Percent Sediment Composition				
Season	**Station**	**Clay**	**Silt**	**Sand**	**Pebble**	**Cobble**
Winter	3	4.3	4.2	27.7	63.7	0
	4	–	–	–	–	–
	6	–	–	–	–	–
	1	2.5	2.6	78.9	15.9	0
	2	0.8	0.7	26.8	71.7	0
	5	1.8	1.2	22.8	74.1	0
Spring	3	1.5	0.7	38.7	32.7	26.4
	4	1.6	1.0	34.0	62.0	1.4
	6	1.4	0.7	14.1	81.0	2.8
	1	1.2	0.7	16.4	75.0	6.7
	2	1.2	0.5	14.3	79.0	5.0
	5	1.1	0.5	17.6	80.8	0
Summer	3	1.6	0.3	30.7	67.4	0
	4	1.9	0.9	37.6	48.6	11.0
	6	1.5	0.6	25.7	67.4	4.8
	1	1.1	0.4	16.3	73.2	9.0
	2	1.4	0.7	26.1	71.8	0
	5	0.6	0.3	8.8	88.0	2.3
Fall	3	2.6	0.5	53.6	43.2	0
	4	2.2	0.4	43.9	53.5	0
	6	2.4	0.7	40.2	56.6	0
	1	2.0	0.4	27.3	70.2	0
	2	1.7	0.1	31.5	66.6	0
	5	1.6	1.1	39.6	57.7	0

TABLE 7

Mean Water-Quality Measurements Per Heated and Uninfluenced Stations of the New River During 1978

	Thermally Influenced Stations				Uninfluenced Stations				
Parameter	**3**	**4**	**6**	$\bar{x}$	**1**	**2**	**5**	$\bar{x}$	**Ranges**
Temperature (C)	16.9	18.6	14.5	16.7	12.6	12.9	10.5	12.0	0.0-36.0
pH	7.8	7.8	7.9	7.8	7.6	7.8	7.8	7.7	7.1-8.0
Alkalinity (mg/l as $CaCO_3$)	52.1	52.9	55.3	53.4	52.0	52.5	103.9	69.5	39-54
Hardness (mg/l as $CaCO_3$)	65.0	68.3	73.0	68.8	66.6	67.0	134.5	89.4	51-76
Conductivity (μmhos/cm)	112.0	119.4	125.4	118.9	116.1	112.4	278.2	168.9	90-155
Nitrate–N (mg/l)	5.06	5.77	5.6	5.5	3.7	4.5	5.4	4.5	2.04-6.10
Ammonia–N (mg/l)	0.08	0.08	0.09	0.08	0.08	0.08	0.07	0.08	0.005-0.09
Total Phosphate (mg/l)	0.07	0.07	0.07	0.07	0.07	0.06	0.04	0.06	0.05-0.20
Dissolved Ortho-Phosphate (mg/l)	0.03	0.03	0.03	0.03	0.04	0.03	0.02	0.02	0.005-0.04
Sulfate–S (mg/l)	13.8	13.8	15.8	14.5	13.8	14.1	30.8	19.6	10.0-34.6

TABLE 8

Static (24-, 96-, and 240-Hour) and Artificial Stream (96-Hour) Bioassays of the Asiatic Clam to Several Toxicant Concentrations (mg/l) with 95 Percent Confidence Limits

	Static Test						Artificial Stream Test	
	24-hour	Confidence Limits	96-hour	Confidence Limits	240-hour	Confidence Limits	96-hour	Confidence Limits
Copper	0.59	0.01-3.74	0.04	0.01-0.14			0.49	0.13-1.75
Zinc	*	–	6.04	4.72-7.26	–	–	–	–
Copper-Zinc	2.41	1.14-7.35	0.05	0.04-0.08	–	–	3.06	0.29-10.64
Potassium	–	–	†	–	–	–	‡	–
Chlorine								
TRC	–	–	§	–	0.69	0.53-0.82	§	–
FRC	–	–	§	–	0.54	0.46-0.66	§	–

*No LC50 obtained in exposures ranging from 0.10 to 40 mg/l Zn.

†Only 0-20 percent mortality obtained in exposures from 2.0 to 300 mg/l K.

‡No mortality obtained in exposures from 1.5 to 140 mg/l K, but 33-89 percent mortality determined in 96 additional hours after cessation of K.

§No significant mortality obtained in exposures from 1.0 to 14.3 mg/l TRC (0-9.1 mg/l FRC) in artificial streams or 0.40 mg/l TRC (0-2.2 mg/l FRC) in static bioassays, except for ≈30-95 percent gaping after 96 hours.

TABLE 9

Percent of Corbicula Siphoning and Gaping in Static, 24-Hour Bioassays with Concentrations Ranging from 1 to 10 mg/l Copper, 0 to 40 mg/l Zinc, and 0 to 10 mg/l Copper and Zinc Combined*

Element	Time of Observation (hour)	Type of Response	Exposures to Copper						
			0	0.005	0.05	0.50	1.0	5.0	10.0 (mg/l)
Copper	4	Siphoning	95.8	95.8	33.0	4.2	0	0	0
		Gaping	0	0	0	0	0	0	0
	6	Siphoning	95.8	95.8	33.0	4.2	0	0	0
		Gaping	0	0	0	0	0	0	0
	24	Siphoning	79.2	50.0	29.2	0	0	0	0
		Gaping	0	0	0	52.5	58.3	48.8	62.5
			Exposures to Zinc						
			0	0.10	1.0	5.0	10.0	20.0	40.0 (mg/l)
Zinc	4	Siphoning	87.5	100.0	62.5	0	4.2	0	0
		Gaping	0	0	0	0	0	0	0
	6	Siphoning	58.3	41.7	62.5	16.7	4.2	0	0
		Gaping	0	0	0	0	0	0	0
	24	Siphoning	100.0	87.5	70.8	4.2	0	0	0
		Gaping	0	0	0	75.0	79.2	91.7	75.0

(continued)

TABLE 9 (continued)

			Exposures to Copper and Zinc Combined						
			0	0.05	0.10	0.50	1.0	5.0	10.0 (mg/l)
Copper-Zinc	4	Siphoning	95.8	0	0	0	0	0	0
		Gaping	0	0	0	0	0	0	0
	6	Siphoning	100.0	16.7	33.3	0	0	0	0
		Gaping	0	0	0	0	0	0	0
	24	Siphoning	95.8	14.3	11.1	0	0	0	0
		Gaping	0	0	16.7	11.8	5.3	0	0

*Copper-zinc assays contained equal amounts of copper and zinc at each exposure.

TABLE 10

Percent of Corbicula Siphoning and Gaping in Static, 96-Hour Bioassays for Concentrations of 0 to 1.0 mg/l Copper, 0 to 10 mg/l Zinc, and 0 to 1.0 mg/l Copper and Zinc Combined*

Element	Time of Observation (hour)	Type of Response	Exposures to Copper						
			0	0.005	0.01	0.05	0.10	0.50	1.0 (mg/l)
Copper	24	Siphoning	83.3	62.5	54.2	0	0	0	0
		Gaping	0	0	0	41.7	54.2	41.7	34.8
	48	Siphoning	37.5	12.5	33.3	8.3	12.5	0	0
		Gaping	0	0	29.2	54.2	75.0	40.0	26.1
	72	Siphoning	58.3	45.8	75.0	0	0	0	0
		Gaping	0	0	0	87.5	100.0	66.7	18.2
	96	Siphoning	58.3	77.3	60.0	8.3	0†	0†	0†
		Gaping	0	0	0	30.0	0	0	0
			Exposures to Zinc						
			0	0.05	0.10	0.50	1.0	5.0	10.0 (mg/l)
Zinc	24	Siphoning	75.0	83.3	75.0	70.8	58.3	4.2	0
		Gaping	0	0	0	0	0	50.0	40.0
	48	Siphoning	29.2	29.2	25.0	50.0	41.7	8.3	0
		Gaping	0	0	0	0	0	52.5	50.0
	72	Siphoning	45.8	37.5	29.2	70.8	16.7	4.3	6.2
		Gaping	0	0	0	0	8.3	54.5	58.8
	96	Siphoning	83.3	45.8	62.5	70.8	20.8	0	0
		Gaping	0	0	0	4.3	52.5	60.4	8.3

(continued)

TABLE 10 (continued)

			Exposures to Copper and Zinc Combined						
			0	0.005	0.01	0.05	0.10	0.50	1.0 (mg/l)
Copper-Zinc	24	Siphoning	62.5	50.0	66.7	20.8	12.5	0	0
		Gaping	0	0	0	0	0	0	9.1
	48	Siphoning	79.2	50.0	69.5	15.0	27.8	0	0
		Gaping	0	0	0	25.0	27.8	14.3	0
	72	Siphoning	83.3	79.2	62.5	4.3	0	0	0
		Gaping	0	0	0	43.5	21.4	0	0
	96	Siphoning	58.3	33.3	58.3	0	0	0	0
		Gaping	0	0	0	33.3	0	0†	0†

*Copper-zinc assays contained equal amounts of copper and zinc at each exposure.
†Approximately 100 percent mortality at these exposure levels.

TABLE 11

Percent of Corbicula Siphoning and Gaping in 96-Hour Artificial Stream Bioassays with Concentrations Ranging from 0 to 8.5 mg/l Copper and 0 to 20 mg/l Copper and Zinc Combined

Element	Time of Observation (hour)	Type of Response	Exposures to Copper								
			0	0.05	0.10	0.20	0.30	0.60	1.2	2.5	4.0	8.5 (mg/l)
Copper	24	Siphoning	31.5	0	2.1	0	0	0	0	0	0	0
		Gaping	0	20.8	37.5	4.2	0	0	0	0	0	0
	48	Siphoning	29.6	0	0	0	0	0	0	0	0	0
		Gaping	0	52.1	48.9	0	9.4	8.2	0	0	0	2.0
	72	Siphoning	37.0	0	0	0	0	0	0	0	0	0
		Gaping	0	48.8	78.4	37.0	45.2	9.1	16.2	15.8	13.9	2.3
	96	Siphoning	39.5	0	0	0	0	0	0	0	0	0
		Gaping	0	42.4	46.7	41.0	20.5	15.2	22.2	7.1	15.4	0

Element	Time of Observation (hour)	Type of Response	Exposures to Copper and Zinc Combined				
			0	0.40	4.0	8.0	20.0 (mg/l)
Copper-Zinc	24	Siphoning	42.6	0	0	0	0
		Gaping	0	0	0	0	0
	48	Siphoning	18.5	0	0	0	0
		Gaping	0	3.7	3.7	0	0
	72	Siphoning	21.3	0	0	0	0
		Gaping	0	14.8	0	0	0
	96	Siphoning	23.1	0	0	0	0
		Gaping	0	25.5	6.2	0	0

TABLE 12

Percent of *Corbicula* Gaping in Artificial and Static Bioassays with Potassium Concentrations from 1.6 to 140 and 2.8 to 300 mg/l, Respectively

Time of Observation (hour)	(Control)	Exposures (mg/l) in Artificial Streams					
	1.6	40	55	80	100	120	140
24	0	7.4	11.1	11.1	16.7	31.5	35.2
48	0	13.0	33.3	3.7	50.0	38.9	51.8
72	0	16.7	33.3	14.8	94.3	48.1	51.8
96	0	24.1	40.7	14.8	98.1	50.0	51.8
	(Control)	Exposures (mg/l) in Static Bioassays					
	2.8	45	75	135	180	200	300
24	0	0	8.3	45.8	25.0	4.2	0
48	0	0	8.3	47.8	20.8	4.2	0
72	0	0	4.8	55.6	21.7	4.2	0
96	0	0	5.3	46.7	23.8	0	0

TABLE 13

Percent of *Corbicula* Siphoning and Gaping in Artificial Stream and Static Bioassays with Chlorine Concentrations from 0 to 14.3 and 0 to 4.0 mg/l TRC (0 to 9.1 and 0 to 2.2 mg/l FRC), Respectively

Chlorine TRC (FRC)	Time of Observation (hour)	Type of Response	Exposures (mg/l) in Artificial Streams			
			0 (0)	(0.90)	(7.1)	(9.1)
	24	Siphoning	44.4	0	0	0
		Gaping	0	0	0	0
	48	Siphoning	37.3	0	0	0
		Gaping	0	0	0	0
	72	Siphoning	24.1	0	0	0
		Gaping	0	37.0	42.5	42.5
	96	Siphoning	35.2	0	0	0
		Gaping	0	44.4	33.3	29.6

			Exposures (mg/l) in Static Bioassays						
			0 (0)	0.10 (0.08)	0.40 (0.20)	0.70 (0.35)	1.20 (0.65)	1.50 (0.80)	4.0 (2.2)
	24	Siphoning	87.5	12.5	0	0	0	0	0
		Gaping	0	0	0	0	0	0	0
	48	Siphoning	29.2	4.2	0	0	0	0	0
		Gaping	0	0	12.5	41.7	52.2	70.8	62.5

(continued)

TABLE 13 (continued)

Chlorine TRC (FRC)	Time of Observation (hour)	Type of Response	Exposures (mg/l) in Static Bioassays						
			0 (0)	0.10 (0.08)	0.40 (0.20)	0.70 (0.35)	1.20 (0.65)	1.50 (0.80)	4.0 (2.2)
	72	Siphoning	20.8	0	0	0	0	0	0
		Gaping	0	0	29.2	54.2	86.9	79.2	100.0
	96	Siphoning	4.2	0	0	0	0	0	0
		Gaping	0	12.5	79.2	70.8	91.3	95.8	79.2
	120	Siphoning	0	0	0	0	0	0	0
		Gaping	0	16.7	58.3	66.7	82.6	83.3	87.5
	144	Siphoning	4.2	0	0	0	0	0	0
		Gaping	0	12.5	50.0	62.5	82.6	41.7	70.8
	168	Siphoning	29.2	0	0	0	0	0	0
		Gaping	0	12.5	54.2	61.9	53.8	37.5	50.0
	192	Siphoning	16.7	0	0	0	0	0	0
		Gaping	0	20.8	37.5	50.0	20.0	66.7	0
	216	Siphoning	8.3	12.5	0	0	0	0	0
		Gaping	0	0	30.4	12.5	0	0	0
	240	Siphoning	20.8	4.2	0	0	0	0	0
		Gaping	0	0	17.4	57.1	0	0	0

TABLE 14

Summary of Mean Elemental Concentrations in Water and (On a Dry-Weight Basis) of Sediment, Clam Valve, and Tissue in Thermally Influenced and Unheated Areas of the New and East Rivers Near the Glen Lyn Plant, from Quarterly Sampling Intervals (October 1977-August 1978)

	Mean Concentration (ppm)							
	Power Plant Influence				No Influence			
Element	Water	Sediment	Valve	Viscera	Water	Sediment	Valve	Viscera
Al	2.03	22,408	74.1	3,575	2.03	25,775	63.6	3,167
Ag	0.41	3.5	1.96	15.3	0.49	2.6	0.76	12.4
As	0.01	7.3	0.31	5.07	0.01	11.23	0.2	4.8
Au	<0.001	0.007	0.01	0.07	<0.001	0.01	0.01	0.07
Ba	0.42	437	54.5	79.3	0.22	559	22.4	87.2
Br	0.16	2.6	1.0	23.1	0.28	2.2	0.8	19.0
Ca	16.0	92,044	168,769	8,418	28.4	50,444	138,042	3,526
Cd	0.20	–	1.7	7.4	0.26	–	1.0	10.3
Ce	0.08	46.7	0.67	17.7	0.19	43.1	0.56	10.7
Cl	6.7	305	82.2	2,365	11.0	595	91.2	2,135
Cr	0.33	28.3	0.78	28.3	0.17	32.2	0.43	14.7
Co	0.15	9.7	0.57	7.8	0.13	8.4	0.38	4.0
Cs	0.02	1.5	0.13	2.0	0.02	1.9	0.09	1.4
Cu	0.40	110	14.5	75.4	0.59	215	5.2	43.0
Dy	<0.001	5.7	0.07	1.2	<0.001	5.0	0.04	1.5
Fe	37.2	23,483	185	4,904	22.3	30,483	113	3,332
Hf	0.02	4.3	0.07	1.2	0.04	3.0	0.06	0.7
Hg	0.01	1.01	0.06	0.39	0.04	0.53	0.05	0.92

(continued)

TABLE 14 (continued)

Mean Concentration (ppm)

Element	Power Plant Influence				No Influence			
	Water	Sediment	Valve	Viscera	Water	Sediment	Valve	Viscera
I	0.07	9.9	0.8	6.6	0.08	6.3	0.4	9.2
K	2.6	9,514	149	2,843	5.2	8,899	136	5,128
La	0.01	11.7	0.25	3.2	0.01	14.0	0.12	3.6
Lu	0.001	0.13	0.02	0.09	0.002	0.11	0.02	0.08
Mg	7.2	32,712	137	1,473	9.0	33,344	503	1,982
Mn	0.05	980	38.8	239	0.04	661	26.4	116
Mo	0.05	0.81	0.33	2.0	0.06	0.80	0.30	3.6
Na	4.3	1,403	1,886	2,018	9.0	2,108	2,315	2,696
Ni	–	190	–	530	–	99	18	290
Rb	0.26	38.3	3.2	32.9	1.19	56.3	2.0	16.8
Sb	0.02	0.69	0.18	1.06	0.04	0.51	0.11	0.93
Sc	<0.001	3.1	0.02	0.7	0.001	3.6	0.03	0.5
Se	0.11	0.77	0.60	6.6	0.11	1.30	0.28	4.0
Sm	0.01	11.2	0.09	3.9	0.01	11.3	0.06	2.8
Sn	0.18	332	18.5	37.5	0.76	368	10.6	43.4
Sr	0.61	670	228	126	0.79	469	227	153
Ta	0.01	0.40	0.03	0.48	0.007	0.40	–	0.19
Th	0.06	12.3	0.22	5.9	0.06	11.5	0.52	3.3
Ti	0.77	1,711	16.4	239	0.87	1,730	15.6	316
U	0.004	0.64	0.07	0.84	0.005	0.78	0.07	0.66
V	0.01	23.7	0.18	4.4	0.01	51.7	0.17	4.7
W	0.01	0.77	0.18	0.66	0.01	0.66	0.44	0.86
Yb	0.01	1.35	0.16	0.84	0.01	1.19	0.06	1.08
Zn	5.5	152	20.3	437	6.2	139	10.8	386

TABLE 15

Mean Elemental Concentrations in Unheated (Stations 1, 2, and 5) and Thermally Influenced (Stations 3, 4, and 6) Regions of the New River at Glen Lyn, Virginia, in Quarterly Sampling Intervals (October 1977-December 1978)

	Abiotic Concentrations (ppm)											
	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Element	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment
Al	1.75	20,750	1.95	17,575	1.80	12,975	2.60	16,250	2.41	39,000	1.70	38,000
Ag	0.48	1.7	0.41	2.90	0.39	2.5	0.45	2.2	0.58	3.2	0.38	5.8
As	0.01	10.8	0.03	5.51	0.01	4.1	0.01	4.5	0.003	17.4	0.006	13.2
Au	<0.001	0.002	0.001	0.007	<0.001	0.005	0.001	0.003	<0.001	0.006	0.001	0.006
Ba	0.16	720	0.27	406	–	856	0.74	143	–	550	0.09	313
Br	0.14	2.3	0.51	2.7	0.18	2.5	0.17	3.9	0.20	1.7	0.13	1.3
Ca	25.0	62,500	24.3	56,333	22.0	88,133	10.8	94,000	36.0	32,500	15.3	94,000
Cd	0.25	–	0.45	–	0.30	–	0.18	–	0.07	–	0.11	–
Ce	0.10	30.2	0.27	30.2	0.08	27.0	0.10	27.5	–	69.0	0.07	85.8
Cl	6.93	–	8.10	760	5.47	120	6.27	–	18.0	430	8.33	490
Cr	0.29	17.6	0.04	18.2	0.26	12.0	0.39	17.6	–	60.8	0.34	55.2
Co	0.12	3.8	0.19	5.2	0.13	9.6	0.20	3.5	0.07	16.2	0.12	16.0
Cs	0.03	1.1	<0.01	1.3	0.03	0.70	0.01	2.2	–	3.3	<0.01	1.5
Cu	0.96	165	0.29	150	0.60	–	0.37	81	0.53	330	0.22	140.0
Dy	0.001	2.6	<0.001	2.4	<0.001	2.5	0.001	1.8	0.003	9.9	<0.001	12.8
Fe	14.0	16,475	38.0	14,475	15.0	12,275	72.0	7,925	15.0	60,500	24.7	50,250
Hf	0.05	2.3	0.03	1.8	0.02	4.5	–	1.4	–	4.8	0.01	7.1
Hg	0.015	–	0.02	0.53	0.004	0.24	0.009	1.2	0.09	–	0.007	1.60

(continued)

TABLE 15 (continued)

Abiotic Concentrations (ppm)

	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Element	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment	Water	Sediment
I	0.08	10.1	0.08	6.2	0.08	6.5	0.07	13.4	0.07	2.6	0.07	–
K	3.5	6,342	8.6	9,631	2.3	11,622	1.9	6,250	3.4	10,725	3.6	10,670
La	0.007	11.9	–	8.0	0.008	80	0.004	7.9	0.008	22.0	0.004	19.05
Lu	0.002	0.06	0.002	0.02	0.001	0.05	0.001	0.08	0.002	0.26	0.001	0.26
Mg	9.1	49,250	6.9	45,250	8.2	47,502	7.0	38,633	11.0	5,533	6.4	12,000
Mn	0.04	748	0.05	456	0.06	428	0.04	1,518	0.04	780	0.05	995
Mo	0.04	0.42	0.10	0.56	0.09	0.36	0.02	0.36	0.03	1.43	0.03	1.70
Na	6.0	2,992	14.2	1,110	3.0	1,190	3.7	653	6.9	2,222	6.2	2,366
Ni	–	–	–	117	–	–	–	190	–	82	–	–
Rb	1.7	41	1.5	37	0.26	28	–	15	0.37	91	–	72
Sb	0.02	0.27	0.08	0.35	0.03	0.54	0.02	0.78	0.01	0.90	0.02	0.76
Sc	0.001	2.4	0.001	2.2	0.003	1.3	–	2.2	0.001	6.0	<0.001	5.8
Se	0.14	0.68	0.10	0.88	0.09	0.71	0.12	0.73	0.10	2.4	–	0.86
Sm	0.01	6.2	0.01	5.9	0.01	6.9	0.01	8.4	0.01	21.8	–	18.3
Sn	1.55	284	0.44	230	0.13	204	0.22	376	0.29	590	–	415
Sr	0.56	1,070	0.59	216	0.54	470	0.67	830	1.205	121	0.61	710
Ta	–	0.31	–	0.33	0.01	0.15	–	0.31	0.007	0.56	–	0.73
Th	–	9.1	0.07	5.1	0.08	4.1	0.06	9.7	0.04	20.2	0.05	23.2
Ti	1.20	1,327	0.67	1,387	0.56	482	0.94	702	0.74	2,475	0.81	3,950
U	0.006	0.93	0.005	0.63	0.006	0.53	0.002	0.79	0.004	–	0.004	0.60
V	0.01	38	0.005	33	0.01	16	0.005	19	0.005	84	0.01	36
W	0.01	0.25	0.01	0.37	0.01	0.34	0.01	0.51	0.01	1.35	0.01	1.45
Yb	0.01	0.74	0.01	0.98	0.01	0.40	0.008	2.17	0.01	1.85	–	1.49
Zn	5.0	166	8.1	120	7.1	53	5.4	54	5.6	132	3.9	348

TABLE 16

Mean Elemental Concentrations in Right Valve and Visceral Tissue of Clams Taken in Unheated (Stations 1 and 2) and Thermally Influenced (Stations 3, 4, and 6) Regions of the New River at Glen Lyn, Virginia, in Quarterly Sampling Intervals (October 1977-December 1978)

Biotic Concentrations (ppm)

	Station 1		Station 2		Station 3		Station 4		Station 6	
Element	Valve	Tissue	Valve	Tissue	Valve	Tissue	Valve	Tissue	Valve	Tissue
Al	59.9	2,643	67.3	3,691	80.4	2,291	48.4	2,843	93.4	5,591
Ag	0.63	8.1	0.89	16.8	1.77	17.2	3.09	18.0	1.03	10.6
As	0.24	4.9	0.15	4.7	0.22	5.0	0.37	5.8	0.34	4.4
Au	0.01	0.07	0.01	0.06	0.01	0.05	0.01	0.07	0.01	0.09
Ba	23.2	67.0	21.6	107.3	36.2	39.8	47.2	81.0	80.2	117.1
Br	0.77	21.2	0.83	16.8	1.10	32.8	1.11	24.4	0.78	12.0
Ca	173,575	2,783	102,509	4,269	162,152	3,833	195,156	6,593	149,000	14,829
Cd	1.12	12.7	0.87	7.9	0.64	6.6	2.95	13.9	1.40	1.8
Ce	0.40	13.0	0.71	8.3	1.18	16.3	0.41	14.3	0.43	22.6
Cl	55.3	1,375	127	2,895	73.7	1,378	90.3	2,301	82.6	3,416
Cr	0.36	17.5	0.49	11.9	0.73	55.7	0.98	15.7	0.64	13.6
Co	0.34	2.9	0.41	5.2	0.51	10.3	0.75	6.4	0.45	6.8
Cs	0.10	1.06	0.07	1.79	0.02	2.85	0.20	1.41	0.17	1.65
Cu	7.9	43.5	2.6	42.4	7.1	108.2	27.4	84.6	8.9	33.5
Dy	0.03	1.79	0.04	1.25	0.03	1.26	0.09	1.04	0.09	1.43
Fe	133	2,582	93	4,083	219	2,606	96	3,035	240	9,072
Hf	0.08	0.44	0.04	0.87	0.04	1.00	0.07	0.96	0.06	1.49
Hg	0.07	0.66	0.03	1.17	0.02	0.28	0.08	0.50	0.07	–
I	0.03	14.8	0.73	3.7	0.82	10.4	0.63	5.61	1.11	3.8
K	135	6,571	137	3,685	85	2,914	220	2,607	142	3,007
La	0.10	3.9	0.14	3.2	0.30	2.6	0.25	3.3	0.21	3.6

(continued)

TABLE 16 (continued)

Biotic Concentrations (ppm)

Element	Station 1		Station 2		Station 3		Station 4		Station 6	
	Valve	Tissue	Valve	Tissue	Valve	Tissue	Valve	Tissue	Valve	Tissue
Lu	0.02	0.10	0.01	0.06	0.01	0.05	0.02	0.15	0.02	0.08
Mg	746	1,629	261	2,336	148	1,124	74	1,822	190	1,472
Mn	30.5	114	22.3	117	27.4	123	264	200	62.6	394
Mo	0.25	3.5	0.35	3.7	0.30	2.0	0.44	2.8	0.24	1.3
Na	2,371	2,293	2,260	3,098	2,000	1,991	1,839	2,190	1,820	1,872
Ni	18	300	–	280	–	350	–	710	–	–
Rb	1.4	18.6	2.6	15.0	2.9	28.0	5.3	–	1.4	37.8
Sb	0.10	0.97	0.12	0.88	0.29	1.06	0.23	1.35	0.03	0.78
Sc	0.04	0.44	0.01	0.55	0.02	0.41	0.01	0.48	0.02	1.14
Se	0.27	4.06	0.28	3.83	0.42	6.42	0.81	6.83	0.56	6.57
Sm	0.07	2.52	0.04	3.08	0.05	2.35	0.12	3.89	0.11	5.49
Sn	9.4	37.5	11.9	49.3	33.1	330	11.6	19.0	10.9	60.6
Sr	231	76	222	230	243	123	207	63	234	193
Ta	–	–	–	0.19	–	–	–	–	0.03	0.48
Th	0.93	3.95	0.10	2.61	0.28	2.00	0.25	3.83	0.14	11.83
Ti	14.8	222	16.3	410	9.3	180	19.6	298	20.4	–
U	0.04	0.39	0.10	0.92	0.10	0.84	0.08	1.08	0.03	0.60
V	0.17	3.26	0.16	6.17	0.20	2.87	0.11	5.53	0.23	4.96
W	0.65	0.59	0.23	1.13	0.11	0.99	0.30	0.61	0.13	0.38
Yb	0.07	1.00	0.04	1.15	0.21	0.91	0.19	0.91	0.07	0.71
Zn	11.4	313	10.2	458	22.0	522	22.8	421	16.0	367

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617 North Main Street
Blacksburg, Virginia 24060
Phone (703) 961-5624