NOAA Technical Memorandum NOS ORCA 136

Baseline Clam Monitoring Study
Cannelton Industries Site
Sault Ste. Marie, Michigan
Summer 1997

Seattle, Washington
September 1998

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

National Ocean Service

Office of Ocean Resources Conservation and Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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NOTICE

Baseline Clam Monitoring Study
Cannelton Industries Site
Sault Ste. Marie, Michigan
Summer 1997: Final Report

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1.0 Introduction

The purpose of this document is to present the results of the baseline clam monitoring study conducted for the Cannelton Industries, Inc. site, situated adjacent to the St. Mary's River, Sault Ste. Marie, Michigan. This baseline is being conducted as an initial phase of long-term monitoring to verify the effectiveness of the selected remedy for this site. There is concern that indigenous and migrating species utilizing the site may be subject to adverse impacts from waste materials at the site (Cannelton Ind. 1995a). Metals contamination in Tannery Bay is largely present in tannery waste and organic soils, which have the capacity to immobilize metals and limit their bioavailability.

Previous analyses indicated that contaminated soils, wastes, and sediments have low potential for leaching (Cannelton Ind. 1995a). The results of these studies also suggest that there is minimal leaching and movement of contaminants from site soils into groundwater and surface water. Sediment toxicity and bioaccumulation studies performed during pre-design investigations indicated that contaminated soil and sediment which would remain unremediated do not pose an unacceptable risk to aquatic and terrestrial organisms. However, some results of these studies were inconclusive. The Pre-Design studies suggest that the high organic load in Tannery Bay sediments is reducing the availability of metals for accumulation by aquatic organisms (Cannelton Ind. 1995a). Analysis of aerial photos indicates that sedimentation is occurring in the western portion of Tannery Bay and may be providing a natural cap for contaminated sediments.

The Amended ROD (U.S. EPA 1996) requires that a monitoring program for Tannery Bay include evaluation of the bioavailability of site contaminants to ensure the protectiveness of the remedy for aquatic organisms and wildlife. In response to the U.S. EPA's request, NOAA designed a biological monitoring program using caged clams and conducted the baseline sampling. This report details the methods and results for the baseline study, and provides recommendations for future years' monitoring.

1.1 Background

The Cannelton Industries, Inc. site, the location of a former tannery, covers 23 hectares (ha) (75 acres) along St. Mary's River in Sault Ste. Marie, Michigan (Figure 1). Most of the shore areas are wetlands, with wetland vegetation, soils, and hydrology. Wetland forest species and emergent cattail marshes are the primary vegetation types present. From 1900 to 1958, tannery and animal-hide processing operations were conducted at the site. Waste products from these operations were routinely discharged to shoreline areas via three facility

drainage systems. Trace elements (chromium, mercury, lead, cadmium, and arsenic), cyanide, calcium carbonate, sulfide, brine, organic solvents, formic acid, carbolic acid, formaldehyde, ammonia, and alcohols were the primary contaminants associated with the waste products (WW Engineering 1991). In 1955 the site became the property of the Fiborn Limestone Company, a subsidiary of Algoma Steel Corporation. A fire damaged the buildings in 1958, which were subsequently torn down and removed. The facility has remained unused and vacant since then. In 1964 the property was transferred to Cannelton Industries, another Algoma subsidiary.

In 1978, the Michigan Department of Natural Resources determined that soils, groundwater, and river sediment from the site were contaminated with heavy metals, primarily chromium and mercury (U.S. EPA 1994). The site was listed as a National Priorities List (NPL) site in 1990 (U.S. EPA 1994). Supplemental investigations confirmed that surface sediments in Tannery Bay contained elevated concentrations of chromium and mercury (Kracko 1992). Maximum concentrations of chromium and mercury reported in that study were 40,000 and 2.29 mg/kg dry weight, respectively. Laboratory tests conducted with sediments collected from St. Mary's River and Tannery Bay suggested potential toxicity. However, the responses of test organisms were associated, not clearly correlated, with site contaminant concentrations. The small size of the data set limits definitive conclusions. Laboratory tests were conducted with the midge *(Chironomus riparius),* amphipods *(Hyalella azteca),* and green *algae (Selenastrum capricornutum).* The results of the *Chironomus* bioassays indicated that sediments were not acutely toxic; there were no statistically significant differences in mortality between sample locations and the reference location or the laboratory control. The weight of *C. riparius* was moderately correlated (r^2=0.63) with chromium concentration. The results of the *Hyalella* test were mixed. Mortality was observed in all sediment samples, including sediment from the upstream reference location, and ranged from 45% to 100%. There was no correlation between observed mortality and chromium concentrations, nor between any other metal concentration or physical parameter measured.

As mandated in the signed 1992 ROD for the Cannelton Industries site, a study was initiated in 1994 to determine the extent of contamination in river sediments and the bioaccumulation of chromium and mercury in aquatic biota. Sediments in Tannery Bay were found to be contaminated with chromium and mercury at maximum concentrations of 30,000 and 1.7 mg/kg wet weight, respectively (U.S. EPA/ERT 1995). Fish and crayfish were also collected from Tannery Bay during that study; tissues were analyzed for metals and percent moisture. Maximum concentrations of chromium in minnows and crayfish collected from Hairball Beach were 7.6 and 29 mg/kg wet weight, respectively. Maximum concentrations of mercury in the same species were 0.03 and 0.08 mg/kg wet weight, respectively. Based on the results of aquatic studies, the U.S. EPA has concluded that, although there are potential ecological risks due to mercury

exposure at the site, there is no incremental increase in mercury risk associated with the site (Jones 1996). This decision was based on the absence of any demonstrated difference in mercury body burden between the reference and any other sampling locations, or between sampling locations. The mercury risk conclusion was consistent with the system-wide problem of mercury in St. Mary's River.

1.2 Program Objectives

The purpose of the biomonitoring program is to document whether the selected remedy for the site is effective at reducing concentrations of bioavailable trace elements in Tannery Bay. The specific objectives of the biomonitoring program are to determine 1) whether chromium, total mercury, methylmercury, lead, cadmium, and arsenic in Tannery Bay sediments are available to biota residing in and/or using the Bay, and 2) whether exposure to bioavailable concentrations of metals may adversely affect local biota.

The objective of this study is to provide baseline data for the biomonitoring program. To assess availability, uptake of these trace elements was measured in tissues of caged clams, *Corbicula fluminea,* transplanted to Tannery Bay and reference areas. Changes in bioavailability over time will be determined by comparing tissue residue levels measured in future years with the values measured in the present baseline study. Survival and changes in clam whole-animal weights and end-of-test tissue weights were evaluated as indicators of potentially adverse effects. This study is not designed to assess all acute and chronic aquatic toxicity endpoints. Therefore, lack of effects demonstrated by this study does not preclude the potential for reproductive or other physiological effects. Measurements made during 1997 will provide a baseline for subsequent monitoring years. Impacts of contamination to the ecological food chain will be assessed in subsequent sampling events following remediation.

The long-term biomonitoring program will generate biological and chemical data to meet the program objectives. This biomonitoring program has three components: 1) evaluation of clams transplanted to the study area for uptake of trace elements and growth effects, 2) analysis of sediments for concentrations of metals and selected physicochemical parameters, and 3) analysis of surface water for chlorophyll-*a* and selected physicochemical parameters. Evaluation of these synoptic data can be used to evaluate changes in chemical bioavailability and potential effects on local biota.

2.0 Study Design and Methods

This section describes the methods used in the baseline biomonitoring study with caged clams. The bioavailability of chemicals was assessed by measuring accumulation in clam tissues after a fixed exposure period. Effects from exposure to site-specific conditions were assessed by comparing survival and changes in growth among stations. The methods used to collect and analyze the surface-water and sediment samples are being prepared by Cannelton as a separate report. The appendices contain all data obtained during the baseline monitoring study, as well as the statistical processes used to analyze this data, and procedures for elements of this study that are not readily available in the open literature.

2.1 Site Description, Sampling, and Reference Stations

The Cannelton Industries site is located on the south bank of St. Mary's River in Sault Ste. Marie, Chippewa County, Upper Peninsula, Michigan (Figure 1). The site is bounded to the north by St. Mary's River and Tannery Bay, to the south by 4th Avenue and the Soo Railway, to the west by 18th Street, and to the east by open land. Tannery Bay and St. Mary's River were general waste dumping areas and tannery waste discharge areas during facility operations (U.S. EPA/ERT 1995). Aerial photographs indicate that some of the tannery waste deposited on the St. Mary's River shoreline has eroded over time. Both this eroded material and material dumped into the river during the plant's operation were likely carried downstream by the river and deposited both along the shoreline of Tannery Point and in the low-energy water found downstream in Tannery Bay (WW Engineering 1991).

Tannery Bay was selected as the primary area of investigation for this biomonitoring program because sediments from this area historically have the highest concentrations of trace elements associated with tannery wastes. Eight stations in Tannery Bay were monitored during this baseline monitoring study (Figure 1). The distribution of stations in Tannery Bay was designed to allow a thorough evaluation of chemical bioavailability. Some of these stations represent areas previously identified as ìhot spotsî of chromium and/or mercury contamination.

Reference areas have a key role in evaluating field bioassays. Reference areas should be similar to the treatment sites, with no source of contamination, and reflect conditions that exist at the treatment sites. Because of the difficulty in identifying one representative reference site, more than one reference station is used. In this approach, the reference locations are not viewed as a single station or point, but as the average of all the individual reference samples. Because of widespread contamination in Tannery Bay and in St. Mary's River in the vicinity of the tannery site, it was deemed necessary to situate reference stations in other

embayments of the river. Potential reference sites along the open shore areas of St. Mary's River to the west of the Cannelton facility–including Seymour Creek, Izaak Walton Bay, and Waiska Bay–were surveyed and evaluated for their suitability as reference areas. One reference station (Reference Station 1) was established in Waiska Bay to represent highly vegetated, shallow habitats. A second reference station (Reference Station 2) was established in St. Mary's River near the mouth of Seymour Creek to represent sandy, shallow habitats with minimal vegetation. St. Mary's River is a highly dynamic system, with very few low-energy areas similar to Tannery Bay making it difficult to identify areas appropriate for use as reference.

In addition to the two reference areas, a holding site was identified and used for short-term holding of clams and as a source of clean water from St. Mary's River. The holding site was located nearshore in St. Mary's river upstream of the old Oriole Boulevard boat ramp (Figure 1).

2.2 Species Selection

A non-resident freshwater clam, *Corbicula fluminea,* was selected for this monitoring program because they are routinely used in environmental assessment programs and have been used extensively to assess metals and organic chemical contamination (Belanger et al. 1987; Colombo et al. 1995; Doherty 1990; Elder and Mattraw 1984; Farris et al. 1988; Foe and Knight 1987; Leland and Scudder 1990; Luoma et al. 1990; Mac et al. 1984; Tatem 1986). *Corbicula fluminea* exhibit a high tolerance for the effects resulting from exposure to toxic substances. They accumulate and concentrate trace elements and metals to concentrations that are orders of magnitude greater than concentrations found in surface waters without demonstrating high rates of mortality. If the transplanted species shows accumulation of chemicals, then exposure and effects in resident species, including predator species, may also be of concern.

Corbicula live in the sediments but are filter feeders – they feed primarily on suspended seston (i.e., phytoplankton, bacteria, and fine detritus) by filtering suspended material from water as it passes over the gills. *Corbicula* filter particles from 1.5 to 10 microns (μ) in size and can efficiently filter particles smaller than 1.0 μ. Although *Corbicula* inhabit, and remove detrital particles from the sediments, they do not ingest sediment directly (D. Cherry, pers. commun. 1998). Researchers conducting extensive studies on *Corbicula* over the past 20 years have examined numerous clams and found none to contain sediment in their gut. Denser, larger particles are bound in mucus and carried by a ciliated ventral groove to the tip of the palp for release onto the mantle as pseudofeces; pseudofeces are carried by mantle cilia and expelled through the inhalant siphon. Particle sorting appears to be a function of particle size and density (McMahon 1991). This feeding strategy makes *Corbicula* a good biomonitoring organism: they are actively exposed to the sediment/surface-water interface where chemical activity and chemical exchange between the water and sediments are high due to continuously changing physical/chemical conditions (D. Cherry, pers. commun. 1998).

2.3 Clam Collection, Sorting, Distribution, and Deployment

Clams *(Corbicula fluminea)* were collected by hand from runs and riffles in Saline River, Arkansas on July 8, 1997 by Dr. J. L. Farris, Arkansas State University. All clams were collected from areas presumed free of chemical contamination, disease, and pest species (e.g., Zebra mussels). At the collection site, clams were sorted by size (>1 cm, <3 cm shell length) and checked for condition (i.e., damaged shells). Clams outside the desired size range or in poor condition were rejected. Clams were held in a laboratory flow-through system without sediment for 4 days for acclimation to temperature, dissolved oxygen, and pH conditions characteristic of the deployment sites. The clams were not fed during the acclimation period to encourage elimination of all material from the gut. After acclimation, approximately 5000 clams were placed in ice chests containing cool, moist packing material (not wet) and sent via air freight to Sault Ste. Marie, Michigan. Total shipment time was approximately 15 hours. Within 6 hours of delivery in Sault Ste. Marie on July 15, 1997, the clams were removed from their packing and inspected for overall condition. The clams appeared to be in excellent health, with less than 1% mortality.

Whole-animal wet weight, measured to the nearest 0.01 g, was the criterion used to select clams for this baseline monitoring study. The clams were removed from their packing material and placed into tubs containing fresh water from the holding site. All clams were processed and treated according to the draft guidelines submitted to ASTM for review (Appendix A). A rough sort was conducted to separate clams into small, medium, large, and extra large size-classes. Based on the distribution of sizes, the number within each size category, and the amount of tissue required for chemical analyses, only clams >4.0 and <8.0 g whole-animal wet weight were selected for use in this study. Following the rough sort, the clams were distributed to the mesh tubes as described below. The pre-sorted clams were maintained in the holding tubs until needed for distribution. Their normal temperature range was maintained during all phases of the setup activities by placing bags of ice in the tubs of fresh river water. Detailed attention was given to the care and handling of clams throughout the setup process to minimize stress to the animals and to ensure that all test animals were of high quality.

Just before the final measurement and distribution processes, small batches of clams were removed from the holding tubs and placed into smaller bowls filled with cool, fresh water. The clams were kept in water before being measured to ensure the internal cavity between the shells was completely filled with water, eliminating potential errors in whole-animal wet weights associated with air bubbles. Only live animals that were completely submerged and fully closed, or those that closed immediately upon light physical stimulation, were used. Closed clams that appeared to be ìfloatingî or ìbuoyantî were not used because this is a sign of air bubbles between the shells.

The measurement process involved obtaining and recording the whole-animal wet weight for each clam, measured to the nearest 0.01†g with an electronic balance. After the weight measurements, each clam was placed into a pre-labeled mesh tube ~10.2 cm (4 inches) in diameter and 2.1 m (7 ft) long; 0.6-cm (0.25-inch) mesh size. Nylon cable ties were used to separate individual clams within the tube. Each tube contained 25 clams. After all clams were distributed to the mesh tubes, they were placed in an ice chest and transported to the holding area for overnight deployment. To minimize predation, the mesh tubes containing clams were placed inside an envelope made of heavy-duty plastic screen. The clams were held at this location for approximately 14 hours before deployment in Tannery Bay beginning on July 16, 1997.

Four cages, each containing 75 clams, were deployed at ten stations: eight Tannery Bay and two reference stations. Station 11 was used to represent the clams to be used for beginning-of-test weight measurements and chemical analysis of tissues. Prior to deployment in Tannery Bay and at the reference stations, the mesh tubes containing clams were affixed to cages ~0.5 m wide by 1 m high constructed of 2.5-cm diameter polyvinyl chloride (PVC) pipe material. Each cage contained 75 clams, and 4 cages were prepared for each station for a total of 300 clams per station. Large nylon cable ties were used to secure the mesh bags to the PVC cage. One continuously recording temperature-monitoring device was attached to one clam cage for each station and set to collect temperature data at 12-min intervals over the deployment period. The cages were then wrapped with the heavy-duty plastic screen (~2.5-cm mesh size) to discourage predators. The completed cages were then placed back into the water at the holding area until deployment.

Before deployment, a random-numbers table was used to assign cages to stations. The cages, numbered from 1 to 44, were assigned station numbers by using the first 2 digits of the 5-digit random numbers. If the 2-digit number was between 01 and 11, it was used as the station number for Cage 1. The next 2-digit number between 01 and 11 was identified and used as the station number for Cage 2. This process was continued until all cages were assigned a station number from 1 through 11, with four occurrences of each station number.

The data were normally distributed; an Analysis of Variance test (ANOVA) was used to confirm statistically similar size distribution of clams among cages and stations (P=0.05). At the beginning of the test, the mean clam weight was statistically similar among all 44 cages. The data were pooled by station and analyzed for similar size distribution; there was no statistical difference in mean clam size among any of the 11 stations at the beginning of the test. Results of the statistical analyses are summarized below; complete details are provided in Appendix D.

ANOVA Results
H_0 = No significant differences in whole-animal wet weight among cages.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between groups	32.243	42	0.7677	1.093392	0.314455	1.387843
Within groups	2234.168	3182	0.702127			
Total	2266.411	3224				

ANOVA Results
H_0 = No significant differences in whole-animal wet weight among stations.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between groups	5.851184	10	0.585118	0.831173	0.598455	1.833573
Within groups	2315.347	3289	0.703967			
Total	2321.199	3299				

SS–sums of squares; df–degrees of freedom; MS–mean square; F–F statistic = group MS/ error MS; P-value–probability value; F crit–critical value for determining significance of F statistic.

Cages were deployed at Stations 1, 3, 4, 5, 6, and 8 on July 16, 1997. The remaining cages for Stations 2, 7, 9 and 10 were held overnight at the holding area until deployment the following day. Four cages of clams were deployed at each station and placed about 2 m apart around the center of the station (Figure 2). A cement block was positioned in the center of the deployment station. The cages were secured to the block with nylon rope and situated ~2 m from the block. Smaller cement blocks were used as weights to hold each cage in position. Surface markers were used to identify the deployment locations. Cages for Station 8 and Reference Station 2, areas likely encountered by boaters, were labeled with a warning tag to discourage vandalism or removal by trespassers. Stations were positioned using a Trimble ProXL and ProBeacon differential GPS. Latitude and longitude coordinates for the stations are provided in Table 1. The survey locations are accurate to approximately ±2 m.

The water depth at each station was taken during deployment using a stick and metal tape measure. Depths ranged from 0.5 m (1.6 ft) to 1.4 m (4.5 ft) (Table 1). Because of the concern that some areas of Tannery Bay or Saint Mary's River would be exposed to air during a seiche, two pressure transducers (InSitu, Inc., PDX-260) were installed on July 18, 1997, one at the ìnorthernî end of the bay and one at the ìsouthernî end (Figure 1). The purpose of these transducers was to record water-level changes over the course of the biomonitoring study.

The transducers were removed on September 10, 1997. Figure 3 illustrates the water-level fluctuations during the study. The water levels ranged from –0.2 to 0.4 m (–0.47 to 0.97 ft) relative to the initial baseline measurement (Table 1). Comparing the initial water depths with the changes in depth shown in Figure 3 shows that the clams remained submerged throughout the entire study.

2.4 Beginning-of-Test Tissue Preparation

An additional 300 clams (i.e., 4 cages of 75 clams each) were used for initial tissue-weight determinations and chemical analyses to obtain background concentrations of contaminants. For tissue chemistry analysis, tissues from 75 individual clams in each cage are combined to form a replicate; therefore, each cage is considered an analytical replicate. All equipment (i.e., shucking knives and the aluminum foil covering the cutting boards) used during tissue extraction was thoroughly cleaned before processing a new batch (i.e., replicate) according to the following process: Wash with Liquinox, rinse with hot tapwater, rinse with deionized water. Prior to tissue removal, all staff thoroughly washed their hands with Liquinox. Gloves were not worn during the shucking process to reduce the potential for injury from slippery hands and handling wet clams. The shucking process began by notching the clam shell with a sturdy knife to allow penetration of a thin-bladed knife. A thin-bladed stainless steel knife was inserted into the notch and used to slice the clams in half. After the shells were spread apart, the thin-bladed knife was used to remove the soft tissues. The severed tissue was held in such a position that the excess liquid was allowed to drain. The soft tissues were kept on the shell during extraction and after complete separation. The shell was used as a ìholding dishî until tissue weights were made. A weigh pan was made from decontaminated aluminum foil. The soft tissues were placed on the weigh pan using the original shucking knife.

When all tissues of a ìreplicateî were weighed, the tissues were transferred from the weigh pan to certified clean sample jars provided by Brooks Rand, the analytical laboratory. Each sample jar was tightly capped, affixed with a prepared label, and placed in the freezer. The aluminum-foil weigh boat and cutting-board cover were discarded after all tissues of a given replicate were shucked and weighed. All shucking equipment was decontaminated before proceeding to the next sample.

The average whole-animal wet weights by cage for these 300 clams were statistically similar to each of the other cages prepared for deployment at the Tannery Bay stations. Actual whole-animal wet weights and tissue weight data for the 300 clams used to define initial weights for all clams are provided in Appendix E. The average tissue weight of 0.66 g was used as an initial estimate for all field-deployed clams.

2.5 End-of-Test Measurements and Tissue Preparation

All clam cages were successfully found and retrieved after the 55-day exposure period. Clams at Stations 1, 3, 4, 5, 6, and 8 were retrieved on September 9, 1997; clams at Stations 2, 7, 9 and 10 were retrieved the following day. After removal from the field stations, the caged clams were transported to Station 2 (the shallow-water reference site) for an overnight depuration period to purge their guts. To facilitate deployment logistics, the cages retrieved on September 9 were altered by combining all clam tubes for a given station onto one PVC frame. A fewer number of cages were retrieved on September 10th so that all station clams were not combined onto one cage for overnight depuration; clams remained attached to their original cages. For both days, the cages were deployed in a horizontal configuration on top of the cinder blocks used for tethering at each site. Several cinder blocks were used to ensure a stable configuration. This configuration prevented the clams from coming in direct contact with the sediments at the depuration site. Before retrieving the cages the following morning, they were visually inspected to ensure that they had not shifted via river current or vandalism during the night. Prior to making the end-of-test measurements, the clams were assessed for overall condition, and the number of dead and/or missing animals was recorded for each station. Clams that were gaping or did not close upon light physical stimulation were considered dead.

The end-of-test measurements involved whole-animal wet weights and soft-tissue weights for each live individual. The clams were processed one cage at a time. The clams were removed from the mesh tubes and placed, in sequence starting with the first clam in Bag-1, into compartmentalized holding trays. If a dead clam was encountered, the empty shells were placed into the compartmentalized holding tray as a marker. These holding trays were then placed into tubs containing river water to eliminate air bubbles between the clam shells. Starting with the first clam, the clam was taken from the holding tray, blotted dry, and the whole-animal wet-weight measurements were made using an electronic balance. The weighed clam was then put into a second compartmentalized tray to maintain proper sequence. The weight data were recorded manually onto laboratory data sheets and electronically to a computer file. The process was repeated until all individuals of a given cage were measured.

The clam tissues were processed after all whole-animal wet-weight measurements were made. The tissue extraction process was the same for the beginning-of-test clams (see Section 2.3). Tissues from all live clams (~75 individuals) found within each cage were pooled, creating a replicate sample for chemical analysis. When all tissues of a ìreplicateî were weighed, the tissues were transferred from the weigh pan into certified cleaned sample jars, as provided by Brooks Rand, Ltd. Immediately after compositing, the clam tissue samples were placed into a freezer. The frozen tissue samples were packed, cooled with blue ice to 0°C, and hand delivered to Brooks Rand, Ltd., of Seattle, Washington for homogenization, lipid analysis, percent water determination,

and chemical analysis of chromium, total and methylmercury, lead, cadmium, and arsenic.

2.6 Chemical Analyses

All tissue samples were received, stored, prepared, and analyzed according to Brooks Rand, Ltd., Standard Operating Procedures (Appendix C). Upon receipt, the tissue samples were assigned an internal tracking number. The tissue samples were preserved by freezing and stored in a Brooks Rand freezer until further processing.

For each chemical replicate, all tissues comprising that replicate were homogenized using stainless-steel homogenization equipment. All equipment was cleaned with Alconox and thoroughly rinsed with deionized water. One homogenization blank was collected for each homogenization batch. Blanks were collected between samples after equipment had undergone the normal cleaning procedure. All samples were homogenized prior to weighing aliquots for the various analytical parameters.

Methylmercury analyses were conducted in accordance with Brooks Rand Standard Operating Procedure (SOP) BR-0011. Before analysis, the tissue samples were digested in 25% KOH in methanol (w/v) in Teflon vials for 4 hr at 65°C. Samples were then analyzed by aqueous phase ethylation, Tenax trap collection, gas chromatograph (GC) separation, isothermal decomposition, and cold vapor atomic fluorescence spectrophotometry (CVAFS).

Total mercury analyses were conducted in accordance with SOP BR-0002. Before analysis, all tissue samples were digested with a 70:30 HNO_3:H_2SO_4 acid mixture and allowed to reflux for at least 3 hr. Samples were then brought to volume with deionized water and further oxidized with the addition of BrCl. Samples were analyzed by $SnCl_2$ reduction, gold amalgamation, and CVAFS detection.

Tissue samples to be analyzed for arsenic, cadmium, chromium, and lead were digested in accordance with EPA Method 200.3. No problems were encountered and no unusual observations were made during these analyses. Analyses for total lead, chromium, total cadmium, and total arsenic were performed in accordance with EPA Method 200.9. Samples were analyzed by stabilized temperature platform–graphite furnace atomic absorption (STP-GFAA) detection.

Dry-weight determinations (SOP BR-1501) were made by weighing out tissues on pre-weighed weigh boats and placing them in a drying oven (105°C). After 16 to 24 hr, the samples were removed and reweighed. One duplicate dry weight was measured for each batch of samples.

Percent lipid determinations were made by the Bligh and Dyer method. Weighed tissue-sample aliquots were placed in a glass tissue grinder with chloroform and methanol and ground for at least 2 min. More chloroform was added and the sample ground for 30 sec. Deionized water was added and the sample was ground again for approximately 30 sec. In the resulting biphase system, the chloroform layer contains the lipids and the methanol-water layer the non-lipids. A purified lipid extract is obtained when the chloroform layer is isolated. Samples were then allowed to dry at 55°C for at least 30 min. After drying, total lipids were determined by weight and converted to percent lipids based on the original aliquot weight, according to the following equation:

$$\text{Total lipid} = \frac{(\text{weight of lipid in aliquot}) * (\text{volume of chloroform layer})}{\text{Volume of aliquot}} .$$

For each chemical, the content (µg) in clam tissues was calculated on a per-replicate basis using the average whole-animal dry-weight value for that replicate and the chemical concentration data for that replicate. The content is reported in units of µg because this eliminates the need for many decimal places in the presentation. This process provided four content values per station for statistical comparison. Tissue content was calculated according to the following equation:

$$\text{Content (µg)} = [\text{concentration (mg/kg dry)}] * [\text{EOT tissue weight (g dry)}] * 1\ \text{kg}/1000\ \text{g} * 1000\ \text{µg}/1\ \text{mg} .$$

The content information was used to determine whether growing clams actually accumulated chemicals of concern, since the overall concentrations may actually decrease in fast-growing individuals due to growth dilution. Salazar & Salazar (1995) and Riisgård & Hansen (1990) have shown that faster-growing, smaller bivalves take up more contaminants, even though tissue concentrations decrease. Therefore, content provides data on net uptake or depuration and was used in this study to determine whether clams transplanted in St. Mary's River for 55 days contained more of a specific trace element than at the onset of the study.

2.7 Data Quality and Status Summary

2.7.1 Tissue Chemistry Data

All chemical data for this project were subjected to a quality assurance/quality control (QA/QC) review. Results of the laboratory QC measurements are provided in Appendix B. The data for the chemical analyses were also evaluated using the criteria described in the *ìFunctional Guidelines for Evaluating Inorganics Analysesî* in conjunction with laboratory-established quality control limits and the data-quality objectives specified in the *ìQuality Assurance Project Plan for Development and Implementation of Bivalve Monitoring Studyî* prepared for U.S. EPA Region V by NOAA/EVS Consultants (1997). In addition to checking the data against the project-specific data quality objectives (Table 2), the data were evaluated as listed below.

Holding Times ¾ The holding times for arsenic, cadmium, chromium, and lead are 6 months for unfrozen or 2 years for frozen samples. The holding times for mercury and methylmercury are 28 days for unfrozen and 1 year for frozen samples.

Initial calibrations and continuing calibration verifications ¾ The initial calibration must be established before each analysis period and have a regression factor of 0.995 or better. The continuing calibrations must be analyzed after every 10 samples and be within 25% of the absolute value.

Blanks ¾ A preparation blank must be digested and analyzed with each sample batch. In addition, a continuing calibration-verification blank must be analyzed after each continuing calibration verification. Analytes present in blanks must not be greater than 5 times the method reporting limit.

Laboratory control sample or certified reference material ¾ A laboratory control sample or certified reference material must be analyzed with each sample batch. The value must be within the project specific limit for accuracy.

Duplicate sample analyses ¾ A duplicate sample analysis must be analyzed with each sample batch. The relative percent difference determined from the two analyses must be within the project specific limit for precision.

Matrix spike analyses ¾ A matrix spike analysis must be performed with each sample batch. The percent recovery must be within the project specific limit for accuracy.

Sample result verification¾ At least 10% of the sample results should be verified for calculation and/or transcription errors. In addition, 100% of the quality-control sample results (relative percent differences and percent recovery) should be verified for calculation and/or transcription errors.

Overall assessment¾ Sample results should be assessed for overall use.

2.7.2 Clam Growth Data

The QA/QC procedures for the clam growth measurements stated that 5% of the clams would be remeasured for shell length and whole-animal wet weight. These procedures further stated that this QA/QC check would be conducted only if sufficient time was available, without jeopardizing the other components of the study. The formal QA/QC check was completed during both the initial and end-of-test field components of this study.

2.8 Data Analysis

The bioavailability and uptake of trace elements were assessed using the tissue concentration and content measurements. Whole-animal wet weights and tissue weights were used to calibrate, or normalize, the tissue chemistry data by determining whether growth dilution or ìshrinkage-enhancementî had occurred. Effects were assessed using survival, changes in whole-animal wet weights, and tissue weight measurements. Survival was used as a general indicator of conditions at the stations. Low survival would suggest physicochemical conditions at the station are degraded, but it would be impossible to determine which parameter is responsible for the observed mortality.

For bioaccumulation, each composited sample (e.g., tissues from all surviving clams from one cage) is considered a replicate. Four composites were prepared for each station; therefore, the level of replication for the bioaccumulation data is four. For whole-animal wet weight and end-of-test tissue weight, each individual clam is considered a replicate. Therefore, for these measurements, the maximum possible level of replication at each station is 300, if all clams survived. For this monitoring study, the maximum survival was 284 clams, which occurred at Station 8. Descriptive summary statistics (e.g., mean and standard deviation) were calculated for all bioaccumulation and clam growth data collected during this baseline monitoring study.

For the reference stations, all data for both reference stations were pooled and analyzed as a single unit for comparisons against the Tannery Bay stations. The pooled results are referred to as the average of the Reference Stations.

2.8.1 Survival, Tissue Chemistry, and Clam Growth Metrics

Statistical analyses were performed on bioaccumulation (i.e., concentration and content), survival, whole-animal weight, and tissue weight data from the *in situ* clam study. Two general hypotheses were tested:

1. Contaminants in Tannery Bay sediments and surface waters are bioavailable to aquatic receptors in Tannery Bay

2. Accumulation of bioavailable metals may adversely affect aquatic receptors in Tannery Bay as assessed by changes in whole-animal wet weights and tissue weights in clams

These general hypotheses were tested by statistical analyses of contaminant accumulation and growth in caged clams exposed to ambient Tannery Bay conditions. The following specific hypotheses were tested:

- There is no difference in mean response between Tannery Bay stations and reference stations.

- There is no difference in mean response among Tannery Bay stations.

- There is no difference in mean response between beginning and end of test.

The specific hypotheses were tested using a one-way Analysis of Variance (ANOVA). If the hypotheses were rejected, indicating that significant differences among all stations were detected, pairwise contrasts were performed to determine which stations differed from the reference stations. The Student Newman-Keuls test was used to test for differences among Tannery Bay stations. All tests were conducted at P=0.05.

Before proceeding with the ANOVA, the bioaccumulation, whole-animal weight, and tissue weight data were evaluated to ensure that they met the assumptions of the statistical tests (i.e., approximate normality and homogeneity of variances for the ANOVA, Bonferroni multiple contrasts, and Dunnett's multiple contrasts). This evaluation was performed using normal probability plots and a plot of the variance on a station-by-station basis (Appendix D). Data that violated the assumptions of the statistical tests were transformed before parametric analysis. The normal probability plots were used to guide the transformation process. Data that had a log distribution were log transformed; data that did not conform to a normal distribution were transformed using the rank-it process.

Survival¾ Survival rates for the *in situ* study were based on the number of live clams found at the end of the test relative to the total number of individuals (both dead and alive) found at the end of the test. Clams were considered ìmissingî if there was an empty space between 2 nylon cable ties, although only 3 clams were found to be missing out of the 3000 clams deployed in the study. Survival rates among stations were compared using a chi-squared contingency analysis (P=0.05). A chi-square test compares the observed and expected frequencies of animals alive or dead at the end of the test, with the null hypothesis stating that the probability of survival is the same at all stations. If rejected, the contingency table was partitioned to compare each station with a mean survival less than the mean of the reference stations with expected values to determine where differences occurred. ëExpected' frequencies were based on the mean of the percent survival for Reference Stations 1 and 2.

Pairwise multiple comparisons between survival values at all sites were performed using Simes method for binomial data (Piegorsch & Bailer 1997). The procedure is directly analogous to multiple comparisons between population means using normal statistics. The Simes procedure includes a necessary adjustment for using binomial data while maintaining some control over experiment-wise error. The null hypothesis (of no difference in survival) is rejected if the test statistic is greater than the Simes-corrected critical P-value, which takes into account the results from the other comparisons.

Tissue Chemistry —The bioaccumulation potential at Tannery Bay stations was considered to be the component of primary interest for this study. For this reason, the statistical design chosen for analysis of the bioaccumulation data was one which considered the Type I pair-wise and Type II experiment-wise error rates at each station. Using standard values for the pair-wise comparisons, the station-specific rates were set at 5% for false positives (Type I errors, a=0.05) and 20% for false negatives (Type II errors, a=0.2). An *a priori* power analysis using data on the variability among replicates for similar species and similar compounds indicated that three replicates were sufficient to detect as low as a 50% increase over reference tissue concentrations, for the one-tail t-test using the specified error rates. As a precaution against possible increased variability in the chemistry data, a forth replicate has been added to improve the confidence with which a 50% difference can be detected. These power results were used to approximate the power of the planned multiple contrasts.

For tissue chemistry data, the concentrations of chromium, lead, and mercury across all stations failed to fit a normal distribution. However, each of these trace elements came within reasonable bounds of a normal distribution when log-transformed. Cadmium, chromium, lead, and mercury were not normal after calculated as content. The first three were corrected through log-transformation, though mercury required rank-it transformation to correct for one data point which lay significantly outside of the bounds of the normal distribution.

Bonferroni's multiple contrasts test was used for the post hoc comparisons for the tissue chemistry data because of its ability to account for the number of means being tested against the two references. Because two reference stations were used in this study, the hypothesis comparing each Tannery Bay station to ìreferenceî is represented by the following equation:

$$\mu_{site1} = 1/2(\mu_{ref1} + \mu_{ref2}) .$$

The pair-wise error rate was set at 0.05 as an upper boundary.

Clam Growth Metrics ¾ Among the clam measurement data, tissue weights were normally distributed, end-of-test whole-animal wet weight required log-transformation, and growth rates based on weight needed to be transformed using rank-its to comply with statistical assumptions for the ANOVA.

Dunnett's multiple comparisons tests were used for the post hoc comparisons for the clam growth data. The Dunnett's test was used for these data rather than the Bonferroni test because of the high level of replication (i.e., n=284) available for each growth metric and the extreme robustness of the Dunnett's test.

2.8.2 Temperature

Water temperatures were taken at 8 study sites and 2 reference stations in 12-min intervals over a period of approximately 55 days (7/17/97–9/9/97). Temperature data were downloaded from the logging devices using the instruments' data recovery software. The start and end of the temperature series at some sites were dropped so that all series would be of equal length and covered the same time period. Minimum, maximum, and mean temperatures were calculated for each station. Temperature profiles were generated for each station and used to identify overall temperature trends. Temperature differences among reference and treatment stations were investigated using statistical approaches to test two primary hypotheses:

1. There is no difference in mean temperature across stations, and
2. There is no difference in the range of temperatures across stations.

Before testing for differences in mean temperatures across stations, it was necessary to test for autocorrelations, a measure of the dependence between

observations of the same series. The temperature series for all stations showed very strong trend and cyclical autocorrelations, requiring a non-standard analysis of mean differences. To reduce variability and autocorrelation, each series was reduced to daily mean temperatures, then a pair-wise station analysis was performed on the differences between the daily means at each site. This analysis requires the assumption that the trend in the daily averages is similar across stations. These series of mean differences were then regularly subsampled at a frequency determined by the autocorrelation function. For example, if the series of differences in daily means was autocorrelated to lag 6, an essentially independent set of observations was generated by choosing every 7th time point. The extent of the autocorrelation varies in the mean difference series; therefore, to achieve equal sample sizes across sites the maximum significant autocorrelation was used to subsample all sites. The observed pattern of differences in daily mean temperatures can be used to determine whether one station was consistently warmer than another; if the differences were not distinguishable from zero, then the two stations are said to have similar daily mean temperatures. The data were reduced to 16 sets of independent observations describing pair-wise differences in temperature between two reference sites and eight study sites. These 16 sets were tested for differences from zero using one-sample *t*-tests, with two-tailed alpha levels of 0.05.

To assess the effects of temperature conditions on clam growth, temperature ranges over 1-week periods were evaluated. First, the minimum weekly temperature was subtracted from the maximum weekly temperature at each station, resulting in eight observations of temperature range per station. These series were not significantly autocorrelated, and the variances were approximately equal across stations. Normality was assessed by plotting a histogram and quantile plot for residuals from an initial ANOVA fit. There was one large outlier (Reference Station 2, 7/17/97 6:48) which may have too large an influence on the results. With this outlier removed and the ranges recalculated, the data were approximately log-normal. A one-way ANOVA was performed to test for differences between the log-transformed ranges.

3.0 Results

The *in situ* bioaccumulation study with caged clams was completed as proposed. Clams were deployed on July 16 and 17, 1997 and retrieved 55 days (7.85 weeks) later from all field stations on September 9 and 10, 1997. All cages were in excellent condition upon retrieval. There were no signs of predation or vandalism. In general, the clams were in very good condition. A few individuals had broken or eroded shells.

Appendix B contains detailed data reports for tissue chemistry; Appendix C contains the laboratory operating procedures: Appendix D contains tissue chemistry and growth statistical analyses; Appendix E contains the data reports for clam whole-animal wet weight, growth rates, and tissue weights. Appendix F contains a series of photographs depicting the sampling events and activities.

3.1 Data Quality Review

All data collected as part of the baseline clam monitoring study were subjected to data quality review to ensure that the data met the project quality objectives and were suitable for analysis and interpretation. The data-quality parameters used to assess the acceptability of the data were precision, accuracy, representativeness, comparability, and completeness.

3.1.1 Tissue Chemistry Data

The chemistry data package received from Brooks Rand consisted of 40 tissue samples and three filter blank samples. All data were acceptable as reported and were considered usable. Data qualified *J* were considered usable as estimates. A summary of the data review is provided in this section. All data-quality objectives for this project (Table 2) were met with the exceptions discussed below. Chemicals reported as undetected were included in statistical calculations using a value of one-half of the reported detection limit.

Arsenic, Chromium, Cadmium, Lead ¾ A method blank was digested with each batch of samples submitted for metals. In addition, continuing calibration blanks were analyzed for every 10 samples. No target analytes were detected with the exception of chromium. Low levels of chromium were detected in two preparation blanks (0.62 µg Cr/L each) and two continuing calibration blanks (0.47 µg Cr/L each). The levels detected in the blanks were less than 5 times the target detection limit. Since the values detected in the associated samples were greater than 5 times the amount detected in the blanks, the results for chromium were not affected. A matrix spike and a certified reference material were analyzed with each batch, and all results were within the specified control limits. A sample duplicate was analyzed with each batch and the results met the established control limit.

Mercury, Methylmercury ¾ A method blank was digested with each batch of samples submitted for total mercury and methylmercury. In addition, continuing calibration blanks were analyzed for every 10 samples. No target analytes were detected in any of the blanks. A matrix spike and a certified reference material were analyzed with each batch, and all results were within the specified control limits. A sample duplicate was analyzed with each batch and the results met the established control limit.

3.1.2 Growth Data

All clam whole-animal wet-weight, tissue-weight, and growth-rate data are considered usable for the purpose of this report. The remeasurement process indicated that field staff were consistent in the measurement technique and that the error associated with those measurements was well within the 5% deviation as described in the Field Sampling Plan. No data were considered outliers; therefore, none were excluded from the data set.

Growth rates (mg/wk) were calculated as:

$$(\text{Measurement}_{\text{final}} - \text{Measurement}_{\text{initial}})/7.85.$$

Growth rates were calculated for individuals using the beginning- and end-of-test whole-animal wet-weight data. In some cases, negative values appear for growth rates. A loss in whole body weight can be attributed to adverse conditions or measurement error.

3.2 Survival

Survival was moderately high, ranging from 77% to 97% for all cages (Figure 4; Table 3). Average survival by station ranged from 87% to 95%. The survival data were analyzed for differences among stations using a contingency table. Station 5, with a significantly lower percentage of animals surviving, was the only treatment station that differed significantly from the average of the reference clams (Table 3). Survival of individual cages at Station 5 ranged from 77% to 96%, a difference of 19% among cages. Survival at other stations varied only 6% on average among the four cages. Results of the within-Tannery Bay comparisons using the Simes procedure indicated that Stations 5 and 8 were the only two bay stations which differed significantly from each other in percent survival.

3.3 Tissue ChemistryóConcentration and Content

The concentrations of all trace elements measured in clam tissues are expressed as dry weight. The results presented for each station represent the average of the four replicated samples for that station. For each trace element, the concentration results (Table 4) and the content results (Table 5) are presented**.** The end-of-test tissue chemistry results were statistically analyzed as follows: a) Tannery Bay stations (for each station, n=4) were compared with the 2 reference stations (n=8); b) Tannery Bay stations were compared against each other, and c) all stations (n=4 for each) were compared against the initial tissue chemistry measurements made on the 4 composited samples from the 300 T_0 clams. The results of statistical comparisons on tissue concentration are provided in Table 6; results for statistical comparisons on tissue content are provided in Table 7.

3.3.1 Arsenic

Clams at all stations, including the references, contained lower concentrations of arsenic at the end of the test than the average initial concentration of 6.25 mg/kg (Figure 5a; Tables 4, 6). Clams from Stations 4, 7, and 9 contained significantly less arsenic in their tissues than the T_0 clams. Average arsenic concentrations by station ranged from 5.04 to 5.92 mg/kg dry weight. The lowest mean concentration was detected in clams at Station 9 and the highest concentration was found in clams at Station 8. No significant differences (P=0.05) were detected between arsenic concentrations measured in any of the treatment station clams and the reference station clams. Similarly, no significant differences in arsenic concentration were detected among Tannery Bay stations when compared with one another (Table 6).

Arsenic content ranged from 0.62 µg in clams at Station 1 to 0.82 µg in clams at Station 8. The end-of-test arsenic content was significantly higher in clams at Stations 3, 6, and 8 than the initial arsenic content of 0.63 µg (Figure 5b; Table 5). Clams from these stations, as well as Station 7, also had significantly higher arsenic contents than the 0.65 µg average of clams at the reference stations (Table 7). Clams at Stations 4, 5, 9, and 10, while not statistically significant, had higher arsenic contents than the average of the reference clams. Results of the within-Tannery Bay comparison (Table 7) indicated the following statistical differences in end-of-test arsenic contents:

Station 8 □ Station 4, 5, 10.

3.3.2 Cadmium

Cadmium concentrations in end-of-test clams ranged from 2.23 to 3.40 mg/kg dry weight (Figure 6a, Table 4). None of these concentrations were significantly different from the average concentration of 3.06 mg/kg dry weight measured in T_0 clams (Table 6). At the end of the deployment, clams at Station 8 had a cadmium concentration of 3.40 mg/kg dry weight, which was significantly higher than the average concentration of the reference clams (Table 6). Although the cadmium concentration in clams at Stations 5, 6, and 10 were slightly higher than the average of the reference stations, the increase was not statistically significant. The results of the within-Tannery Bay comparison indicated cadmium concentrations in clams at Station 8 (3.40 mg/kg dry weight) were significantly higher than for clams at Station 4 (2.26 mg/kg dry weight). Among the Tannery Bay stations, only clams at Stations 4 and 8 differed from each other in cadmium concentration (Table 6).

Cadmium content ranged from 0.25 µg at Station 1 to 0.47 µg at Station 8 (Table 5). At the end of the study, clams at Station 8 contained significantly more cadmium than the initial content of T_0 clams (Figure 6b; Table 5) and significantly more cadmium per individual than the average of the reference

stations (Table 7). Results of the within-Tannery Bay comparison indicated cadmium content for clams at Station 8 was significantly different from clams at Stations 4, 5, 6, 9, and 10 (Table 7).

3.3.3 Total Chromium

All Tannery Bay clams accumulated chromium during the deployment period when compared with the initial concentration of 2.74 mg/kg dry weight (Figure 7a; Table 4). At the end of the study, clams at the reference stations had an average chromium concentration of 7.04 mg/kg dry weight. This average concentration was significantly lower than that measured in clams from Stations 4, 5, 6, 7, and 8 in Tannery Bay (Table 6). The highest chromium concentrations were measured in clams from Station 5 (70.23 mg/kg dry weight) and Station 8 (49.90 mg/kg dry weight); the lowest concentration measured in Tannery Bay clams was 9.47 mg/kg dry weight (Station 10). Results of the within-Tannery Bay comparison (Table 6) indicated that clams at Stations 5 and 8 had similar chromium concentrations, but these were significantly higher than concentrations measured in other Tannery Bay stations.

Historical concentrations of chromium in sediments indicate that the highest concentrations of chromium on the site are located between Stations 4 and 5 and range between 15,000 and 31,000 mg/kg dry weight (U.S. EPA/ ERT 1995). Clams from Station 4 had the third-highest and those from Station 5 had the highest chromium concentrations at the site. Clams from Station 8, where historical concentrations of chromium in the sediments are about 7,600†mg/kg dry weight, had the second highest concentration among all Tannery Bay stations.

Clams from all reference and Tannery Bay stations had significantly higher total chromium content per organism when compared with the initial content of 0.28 µg (Figure 7b; Table 5). The chromium content in Tannery Bay clams ranged from 1.19 µg at Station 10 to 8.36 µg at Station 5. Clams at the reference stations accumulated the least amount of chromium, with an average content of 0.81 µg. Clams at Tannery Bay stations 3 through 8 had significantly higher chromium contents than the average of the reference stations (Table 7). Results of the within-Tannery Bay comparison (Table 7) indicated the following statistical differences in chromium content:

Station 5 □ Stations 3, 4, 6, 7, 9, 10
Station 8 □ Stations 3, 4, 7, 9, 10
Station 10 □ Stations 3, 4, 5, 6, 7, 8.

3.3.4 Lead

Concentrations of lead in clams from the reference and Tannery Bay stations were significantly higher when compared with the average initial concentration of 0.244 mg/kg dry weight (Figure 8a; Table 4). The lead concentration in clams from Tannery Bay ranged from 0.64 to 1.68 mg/kg dry weight (Stations 3 and 5, respectively); the concentration in clams at the reference station averaged 0.89 mg/kg dry weight. Concentrations of lead in clams from Tannery Bay Stations 4, 5, 6, 8, and 10 were greater than the average of the reference stations, but these differences were not statistically significant (Table 6). Results of the within-Tannery Bay comparison indicated lead concentration in clams at Station 5 (1.68 mg/kg dry weight) was significantly higher than for clams at Station 3 (0.64 mg/kg dry weight). There were no differences in lead concentration among the other Tannery Bay stations (Table 6).

The lead content in all clams was significantly higher at the end of the study when compared with the initial content of 0.03 µg (Figure 8b; Table 5). Clams at Stations 4, 5, and 8 had the highest lead contents. Clams from all Tannery Bay stations, except Station 3, had higher lead contents than the average of the reference clams; however, the differences were not statistically significant (Table 7). Results of the within-Tannery Bay comparison indicated lead content in clams at Station 5 (0.20 µg) was significantly higher than for clams at Station 3 (0.09 µg). There were no differences in lead contents among the other Tannery Bay stations (Table 7).

3.3.5 Total Mercury

At the end of the study, all clams had a lower total mercury concentration when compared with the initial concentration of 1.26 mg/kg dry weight (Figure 9a; Table 4); the difference was statistically significant for clams from Stations 2, 6, and 7. For clams deployed in Tannery Bay, the highest mercury concentration, 1.100 mg/kg dry weight, was measured in clams at Station 9. Clams at Stations 4, 5, and 9 had mercury concentrations that were greater than the average of the reference stations (Table 4), but none of these were significantly higher than the average of the reference stations (Table 6). No significant differences in mercury concentration were detected among Tannery Bay stations when compared with one another (Table 6).

End-of-test total mercury content was not significantly different than initial content for clams at any station (Figure 9b; Table 5). Only clams at Stations 4 and 9 had final mercury contents higher than the initial content of 0.128 µg, but neither of these were significantly higher than the initial content. The lowest mercury content, 0.108 µg, was measured in clams at Station 10. Only clams at Station 4 had a mercury content that was significantly higher than the average of the clams at the reference stations (Table 7). The content value for

clams at Station 9 is not significantly greater than the average of the reference clams. This is because, although the mean content at Station 9 appears larger than Station 4 (Figure 9b), one replicate with a very large content caused the large mean and variance and skewed the distribution. When analyzing the rank-it transformed data, the other three replicates within Station 9, which lie directly around the mean of the references, were more influential in determining significance. No significant differences in mercury content were detected among Tannery Bay stations when compared with one another (Table 7).

3.3.6 Methylmercury

End-of-test concentrations of methylmercury in clams from all stations were significantly lower than the average initial concentration of 0.259 mg/kg dry weight (Figure 10a; Tables 4, 6). End-of-test methylmercury concentrations ranged from 0.102 to 0.183†mg/kg dry weight. Tissues of clams at Stations 3, 4, and 5 contained significantly higher concentrations of methyl-mercury when compared with the average of the reference clams. Clams at Stations 7, 9, and 10 had methylmercury concentrations that were slightly, but not significantly, higher than the average of the reference clams. Clams at Reference Station 2 had the lowest methylmercury concentration measured at all stations. Results of the within–Tannery Bay comparison (Table 6) indicated the following statistical differences in tissue methylmercury concentrations:

Station 8 □ Station 3, 4, 5
Station 4 □ Stations 6, 7, 8, 9, 10.

End-of-test methylmercury content in clam tissues was significantly lower than the initial content of 0.026 µg at all stations except 3 and 4 (Figure 10b; Table 5). The highest methylmercury contents, 0.023 to 0.025 µg, were found in clams from Stations 3 and 4, but these were not significantly different than the initial content. At the end of the study, clams at Stations 3, 4, 5, 6, 7, and 9 all had significantly higher methylmercury contents than the average of the reference clams (Table 7). Station 8 was the only Tannery Bay station with a methylmercury content that was below 0.015 µg, the average content of the reference clams. Results of the within–Tannery Bay comparison on methylmercury content (Table 7) indicated the following statistical differences:

Station 3 □ Station 8, 10
Station 4 □ Stations 5, 6, 7, 8, 9, 10.

3.3.7 Trace Element Bioavailability

The stations were ranked according to their relative degree of bioavailable trace elements. The increase in trace element content in clams was used as an indicator of bioavailability. For each trace element, the amount of trace element uptake was weighted by dividing the end-of-test content by the initial content. The quotients from each of the five trace elements were then summed for each station. The quotients calculated for each station are summarized in Table 8. By using this weighted ranking process, Station 5 appears to have the most bioavailable trace elements, followed by Station 8 and Station 4. The reference stations had the least amount of bioavailable trace elements, followed by Stations 10 and 9. The following ranked order, from stations with the most to the least bioavailable trace elements, resulted from this analysis:

Sta 5 > Sta 8 > Sta 4 > Sta 6 > Sta 7 > Sta 3 > Sta 9 > Sta 10 > Sta 2 > Sta 1.

3.4 Clam Growth Metrics

Two metrics were used to assess growth: whole-animal wet weight and end-of-test tissue weight. Only whole-animal wet weight was measured for each individual at both the beginning and end of the test. Therefore, the only growth rates based on changes (i.e., increase or decrease) in whole-animal wet weights could be calculated. Initial tissue weights were determined only for the T_0 clams sampled at the start of the test for chemical analysis. Because there was no statistical difference in the whole-animal weight of clams among individual cages (including the clams used for the initial tissue-weight determinations and chemical analyses) at the start of the test, it was assumed that the average tissue weight was also similar among all cages. Based on this assumption, the end-of-test tissue weights were evaluated for statistical differences; any differences observed were assumed to have occurred during the test period. Appendix E contains the actual weight measurements made during the field study.

Descriptive statistics were calculated for the various growth metrics and are summarized in Table 9. The end-of-test values are provided for each of these metrics; the absolute change after the 55-day exposure period is provided only for the whole-animal wet-weight data.

3.4.1 Whole-Animal Wet Weight

At the start of the test, whole-animal wet weights by individual ranged from 4.01 to 7.95†g; mean whole-animal wet weight by station was ~5.5 g. End-of-test whole-animal wet weights by individual ranged from 3.44 to 8.29 g. Mean end-of-test whole-animal weights by station ranged from 5.56 to 5.76 g. The lowest end-of-test whole-animal wet weights were found for clams at Reference Station 1; the highest for clams at Tannery Bay Stations 6 and 7 (Figure 11; Table 9).

The clams at Reference Stations 1 and 2 had the lowest increase in all growth metrics evaluated after the 55-day exposure. Clams at Station 1, the Waiska Bay site, had the poorest growth. The data for the two reference stations were compared statistically to determine the utility of the reference data in subsequent comparisons. The results of that comparison indicated that, based on growth rates and end-of-test tissue weights, the clams at Reference Station 1 were significantly smaller than those at Reference Station 2. However, data for both reference stations were retained as a point of comparison for clams exposed to relatively uncontaminated conditions even though clam growth was less than expected.

The end-of-test whole-animal wet-weight data were suitable for an ANOVA after log transformation. Results of the Dunnett's multiple range test indicated that clams at Stations 3, 4, 6 and 7 were, on average, significantly heavier than those at the reference stations (Figure 11; Table 10). There were no significant differences in end-of-test whole-animal wet weights among Tannery Bay stations (Table 10).

Growth rates based on whole-animal wet weight were calculated from the initial and end-of-test data. The lowest mean growth rate by station was 5.16 mg/week, measured for clams at Reference Station 1; the highest mean growth rate of 28.04 mg/week was measured for clams at Station 6 (Figure 12; Table 10). On an individual basis, the minimum growth rate was -80.15 mg/week and the maximum growth rate was 99.24 mg/week. The growth rate data required a rank-it transformation before testing with the ANOVA and Dunnett's test. Results of these analyses indicated that growth rates at Stations 3, 4, 6, 7, 8, 9, and 10 were significantly higher than those at the reference stations. Clams at Station 5 were the only animals that grew less than the average of the reference clams. Results of the within-Tannery Bay comparison (Table 10) indicated the following statistical differences in growth rates:

Station 3 ≠ Stations 4, 5, 6, 8, 9, 10
Station 4 ≠ Stations 3, 5, 6, 7, 9
Station 5 ≠ Stations 3, 4, 6, 7, 8, 9, 10
Station 6 ≠ Stations 3, 4, 5, 7, 8, 10
Station 7 ≠ Stations 4, 5, 6, 8, 9, 10
Station 8 ≠ Stations 3, 5, 6, 7, 9
Station 9 ≠ Stations 3, 4, 5, 7, 8, 10
Station 10 ≠ Stations 3, 5, 6, 7, 9.

Stations 4, 8, and 10 had similar growth rates, as did the following pairs: Stations 3 and 7, and 9 and 6. Clams at Station 5 had a significantly lower growth rate (9.57 mg/week) than clams at all other stations in Tannery Bay.

3.4.2 End-of-Test Tissue Weights

Mean tissue weight at the start of the test by station was estimated at 0.66 g wet weight. This estimate was based on the tissue weights measured for the 300 animals used for test initiation (T_0) tissue-chemistry analyses (Table 10). Mean end-of-test tissue weights by station ranged from 0.74 to 0.92 g wet weight, the overall range for individuals was 0.34 to 1.71†g wet weight (Figure 13; Table†10). The lowest mean tissue weights were measured in clams deployed at Reference Station 1 and Station 5. The end-of-test tissue-weight data were suitable for analysis with an ANOVA and Dunnett's multiple comparison without transformation. Results of these analyses indicated that the average end-of-test tissue weight for the reference stations was significantly lower than tissue weights for clams at all treatment stations, with the exception of Station 5. End-of-test tissue weights for clams at Station 5 were statistically similar to the average of the reference clams (Table 10). Results of the within-Tannery Bay comparison (Table 10) indicated the following statistical differences in tissue weights:

Station 3 ≠ Stations 4, 5, 7, 8, 9, 10
Station 4 ≠ Stations 3, 5, 10
Station 5 ≠ Stations 3, 4, 6, 7, 8, 9, 10
Station 6 ≠ Stations 5, 10
Station 7 ≠ Stations 3, 5, 10
Station 8 ≠ Stations 3, 5, 10
Station 9 ≠ Stations 3, 5, 10
Station 10 ≠ Stations 3, 4, 5, 6, 7, 8, 9.

Stations 4, 6, 7, 8, and 9 had similar tissue weights, as did stations 3 and 6.

3.4.3 Percent Lipids

Clams from all stations contained slightly higher percentages of lipids than the 1.30% found in T_0 clam tissues (Table 9). Station 9 clams had a significantly greater percentage of lipids than the average of the reference station clams (Figure 14). Clams from the other Tannery Bay stations had slightly more lipids per mass than the average of clams at the reference stations, but percentages were not statistically different. Results of the within-Tannery Bay comparison indicated no differences in percent lipids among clams at any of the stations (Table 10).

3.4.4 Percent Solids

Clams at Reference Station 2 and Tannery Bay Stations 5 and 10 had lower percentages of solids in their tissues at the end of deployment than T_0 clams (Figure 15). All the end-of-test values were significantly similar to the 15.2% solids measured in the T_0 clams (Table 9). Clams at Stations 6, 7, and 9 had significantly higher percentages of solids than the reference station clams. Only clams at Station 5 had a slightly lower percentage than the reference stations. Results of the within-Tannery Bay comparison indicated that Station 5 clams had a significantly lower percentage of solids in tissues than clams at Station 7 (Table 10).

3.5 Temperature

Water temperatures at each station were recorded at approximate 12-min intervals over the 55-day exposure period using one *in situ* computerized data logger per station (HoboTemp, Onset Instruments). Data were downloaded from the logging devices using the instruments' data-recovery software. Minimum, maximum, and mean temperatures for each station at the depth of the cages are summarized in Table 11. Reference Station 1 had a higher minimum, maximum, and mean temperature than all other stations over the deployment period, while Station 5 had the lowest minimum and mean temperature. The actual temperature profiles (Figure 16) show that the remaining eight stations follow similar patterns and seem to lie in approximately the same range.

The temperature data were statistically analyzed to determine whether the apparent differences were significant. The following two null hypotheses were tested:

1. There is no difference in daily average temperature across stations;
2. There is no difference in the range of temperatures across stations.

3.5.1 Testing for Differences in Mean Temperature

Temperatures at all stations displayed similar patterns with daily and seasonal cycles (Figure 16), although Reference Station 1 had a higher average temperature and treatment Station 5 had a lower average temperature than the other stations. The temperature series for all stations showed very strong autocorrelations (a measure of dependence between observations of the same series), requiring a non-standard analysis of mean differences. To reduce variability and autocorrelation, each series was reduced to daily mean temperatures (Figure 17), then an analysis of pairwise station differences was performed using one-sample *t*-tests (two tailed; P=0.05) to determine if there were statistical differences in daily average temperatures among stations. The

results of the *t*-tests on paired data (Table 12) show that the mean daily temperature for Reference Station 1 is significantly warmer than all study sites. The mean temperature for Reference Station 2 is significantly warmer than Station 5, and significantly colder than Stations 7, 8, and 10. Comparisons of mean daily temperature between Tannery Bay stations showed that several treatment stations also differed significantly from each other (Table 12).

3.5.2 Testing for Differences in Temperature Range

To assess the effects of temperature conditions on clam growth, temperature ranges over 1-week periods were evaluated. This time interval was selected because 7 days is a manageable time period, as opposed to comparisons based on an hourly or daily basis, and it is expected to have some biological relevance. Weekly intervals are also commonly used to measure changes in environmental conditions and growth in aquatic organisms.

The results of the one-way ANOVA performed to test for differences between temperature ranges indicate a significant difference between the average weekly temperature ranges at all stations (Table 13). The results of the Newman-Keuls Multiple Range test to determine which stations differed from which other stations indicated the weekly range in temperature at Reference Station 1 was significantly smaller than at all other stations (P=0.05). There is no evidence that the range of temperatures at Reference Station 2 is different from that at the study sites.

3.6 Sediment and Surface Water Chemistry vs. Tissue Chemistry

Results of chemical analyses performed on surface water collected by HydroQual at the beginning and end of test, and sediment samples collected at the end of the test are summarized in Tables 14 and 15. Sediments were also collected at the beginning of the test and analyzed for methyl- and total mercury.

The end-of-test (EOT) sediment chemistry values were compared with the lowest effect level (LEL) values developed by the Ontario Ministry of Environment (1993) as a means of ranking the stations for relative toxicity. For each trace element, the concentration measured in the sediment was divided by its corresponding LEL value. The quotients of the five measured trace elements (excluding methylmercury, since there was no LEL value) were summed by station and provide a relative estimate of the severity of sediment contamination (Table 16).

For example, LEL quotients <1 for a single contaminant indicate low risk from that contaminant; therefore, a sum of LEL quotients <5 would equate to low risk at the station based on the 5 trace elements measured; potential additive effects

of toxicity were not taken into account. Reference Stations 1 and 2 had the lowest Sums of Quotients, both < 5. The highest Sums (820 and 720, respectively, from Stations 3 and 4) were from sediments situated between the peninsula forming Tannery Point and the small island. Sediments in this area also have the highest amount of TOC at 11.7% and 12.4%, a potential source of binding ligands for the uncomplexed trace elements. The next highest Sums of Quotients were found for Stations 5, 6, 7, and 8, ranging between 161 and 423. The TOC concentration at each of these stations, except Station 5, was about half of that measured at Stations 3 and 4. TOC at Station 5 was similar to TOC at Stations 3 and 4. Although the Sums of Quotients from Tannery Bay were lowest at Stations 9 and 10 (40.52 and 51.96, respectively), chromium concentrations exceeded their LEL value at these stations. A TOC of <1% at Stations 9 and 10 may have reduced potential binding sites for trace elements resulting in lower concentrations at these stations. TOC at Reference Stations 1 and 2 was also <1%.

End-of-test sediment and surface-water data were compared with the tissue chemistry data, and correlation analyses (Table 17) were used to determine the strength of the relationship between these variables.

For non-detect values, one-half the detection limit was used. The strongest relationships were seen for chromium in surface water and clam tissues and methylmercury in sediment and tissue (Table 17). The concentration of chromium in clam tissues was better correlated with the chromium in surface water (r=0.62) than chromium in sediments (r=0.27). This is not surprising because the clams are filter feeders, and although placed directly on top of the sediments, they actively take in copious quantities of particulate material associated with the water column during the normal filtration process. These correlations suggest that the clams are obtaining chromium from particulates associated with the water column. The limited number of paired data points used in these analyses may alone drive a stronger correlation. The tissue and surface-water correlation used only 5 data points, and the tissue and sediment comparison used only 10.

The correlation coefficients for total mercury in water, sediment, and tissue were low (Table 17). The strongest correlation for methylmercury was for sediment and tissue (r=0.68). The correlation coefficients for arsenic, cadmium, and lead among the different media were very poor (Table 17). No correlation coefficients could be calculated for cadmium and lead for the water:sediment and water:tissue comparisons because for both cadmium and lead, the concentration in each surface-water sample collected at the four stations was reported as “less than” the detection limit, resulting in insufficient data to perform correlation analyses.

3.7 Tissue Chemistry vs. Survival and Clam Growth Metrics

The concentration of each trace element measured in clam tissue was compared with survival, whole-animal wet weight, growth rates, and end-of-test tissue weights (both wet and dry). All correlation coefficients were very low (Table 18), although there was a high degree of variability.

3.8 Temperature vs. Clam Growth

Temperature was compared with survival, whole-animal wet-weight, growth rates, and end-of-test tissue weights (both wet and dry). For each comparison, there was a high degree of variability and all correlation coefficients were very low (Table 19). Positive relationships were found for growth rates and survival; negative relationships were found for tissue weights (both wet and dry). These results suggest that none of the clam growth metrics are strongly correlated with temperature.

4.0 Discussion

The baseline biomonitoring study was successfully completed as proposed and the project-specific objectives were met. All cages were retrieved; high survival permitted assessments of chemical uptake and adverse effects. Clams at most of the Tannery Bay stations accumulated significant amounts of chromium when compared with reference clams. All clams increased in both soft-tissue weights and whole-animal wet weights after the 55-day exposure period; however, compared with reference clams, Tannery Bay clams did not demonstrate any significant growth effects due to exposure conditions. This discussion will focus on the interpretation of the tissue chemistry results when evaluated in light of the sediment and surface-water chemistry and the utility of growth metrics as indicators of effects.

4.1 Meeting the Purpose and Objectives of the Study

The purpose of the monitoring program is to document whether the selected remedy for the site is effective at reducing concentrations of bioavailable trace elements in Tannery Bay. This purpose is achieved by meeting the specific objectives of this study: 1) Determine whether chromium, total mercury, methylmercury, lead, cadmium, and arsenic in Tannery Bay sediments are available to biota residing in and/or using the Bay, and 2) determine whether exposure to bioavailable concentrations of metals may have adverse effects on local biota.

The concentrations of trace elements measured in the soft tissues of clams after the 55-day deployment provide a baseline of trace-element bioavailability for filter-feeding organisms that dwell within the surficial sediments or on top of these sediments.

4.2 Survival of Deployed Clams

Clam survival was very good at 92% which ensured sufficient tissues for the chemical analyses and sufficient individuals for assessment of effects. Although survival is usually not a very discriminating metric to evaluate adverse effects unless physical conditions (i.e., temperature, salinity, DO) are outside the normal range for the species, or toxic materials are present at extremely high concentrations, survival can provide a means of quickly identifying hot spots and prioritizing exposure conditions.

Based on mean survival by station, Station 5 appears to be the only station where exposure conditions may be deleterious. However, survival by cage within Station 5 is variable: two cages had low survival rates (77% and 81%; Table 3) and two had high survival (96% and 93%), comparable to other Tannery Bay stations. No other Tannery Bay station had such high variability in survival rates among cages at a single station. High variability in survival at Station 5 may be due to environmental heterogeneity. The American *Corbicula* has a preference for lotic conditions commonly found in shallow, well-oxygenated shore lake habitats (Aldridge & McMahon 1978, McMahon 1979). In native lotic habitats, *C. fluminea* is able to inhabit a wide variety of substrata, including bare rock, loose gravel, sand, and even silt and mud (Horne & McIntosh 1979). This species is nearly always eliminated from areas with decreasing sand, mud, or silt sediments of high organic and low oxygen content (Aldridge & McMahon 1978, Eng 1979, Fast 1971, Lenat & Weiss 1973, McMahon 1979). Station 5 was located at the furthest end of Tannery Bay in a highly vegetated area. It is possible that two of the cages were situated on top of decaying plant material, subjecting clams to high organics and low dissolved-oxygen conditions.

Percent survival in this study is comparable to survival reported for this species in other studies. For example, in a field study conducted to evaluate thermal plumes, survival of reference clams ranged from 93.5% to 99.6% (Foe & Knight 1987); survival of clams exposed to the thermal plumes ranged from 2% to 95.5%.

4.3 Tissue Chemistry

Changes in trace element concentration and content were used to assess bioavailability. The concentration data are useful for comparisons with previous or other studies. The change in trace-element content, or actual mass, in the clam is a direct measure of uptake, and provides an indication of exposure to organisms higher in the food chain. In this study, arsenic bioavailability was discovered only by analysis of the content data.

4.3.1 Tissue Concentration

The results of this study indicate that bioavailable chromium is present at all Tannery Bay stations. Although clams at Stations 9 and 10 accumulated the least amount of chromium, the end-of-test concentrations in clams at these stations were greater than initial concentrations. Clams at Stations 5 and 8 accumulated the most chromium, with an increasing gradient in tissue concentration from Stations 3 and 4 to 5.

The results for total and methylmercury are difficult to interpret due to the high concentration present in clams at the beginning of the test. *C. fluminea* collected from the Saline River in Arkansas for this study contained 1.263 µg/g dry weight (0.193 µg/g wet weight) total mercury compared with total mercury of 0.10-0.2 µg/g dry weight in *Corbicula* collected in other studies (Leland and Scudder 1990; Elder and Mattraw 1984). Unfortunately, the beginning-of-test tissue samples were frozen and not analyzed until the end-of-test. Therefore, there was no indication until the end of the study that the initial mercury concentration was high. Clams at all stations had lower end-of-test mercury concentrations when compared with initial concentrations. Although it is difficult to use the mercury tissue-chemistry data to establish true baseline conditions, they may be useful in establishing trends or ranking areas within Tannery Bay. Total mercury concentrations were highest at stations 4, 5, and 9. Methylmercury concentrations were highest at Stations 3, 4, and 5. Whether the differences noted in mercury concentrations within Tannery Bay are due to differential depuration among stations, differential uptake among stations, or some combination of these mechanisms cannot be determined from this study.

Clams at Stations 4, 5, and 8 had the highest lead concentrations. However, clams at all stations, including the reference stations, increased their lead concentration over the duration of the study. The lack of a statistically significant difference between reference and Tannery Bay stations suggests that lead contamination is not restricted to Tannery Bay.

By evaluating only the tissue-chemistry concentration data, arsenic and cadmium do not appear to be bioavailable in Tannery Bay. Except for cadmium at Station 8, end-of-test concentrations for both arsenic and cadmium were lower than those measured at the beginning of the test.

4.3.2 Tissue Content

The content data normalize the tissue chemistry with respect to clam growth, allowing comparisons of uptake unbiased by differences in tissue mass at the end of the test. The trends in the tissue content data are similar to those identified for the tissue concentration data, with one notable exception. The content data show that arsenic and cadmium were both bioavailable to clams.

Clams at Stations 3, 6, 7, and 8 accumulated significantly more arsenic than the average of the reference stations, with clams at Station 8 having the highest arsenic content. Cadmium content in clams at Stations 2 and 8 were significantly higher than the initial content. Station 8 cadmium content was significantly higher than the average of the reference stations.

Based on content, the clams at Station 3 also accumulated significant amounts of chromium compared with the average of the reference clams. For total mercury, clams at Station 4 had a statistically significant accumulation based on content. Clams at all Tannery Bay stations, except Stations 8 and 10, had significantly higher methylmercury contents compared with the average of the reference clams. However, content data for both total and methylmercury must be interpreted with the knowledge that initial values were higher than in the test area, as discussed in Section 4.3.1.

The bioavailability of arsenic and cadmium was not evident from analysis of the tissue concentration data alone. Although the clams accumulated arsenic and cadmium, they grew enough to maintain concentrations similar to, or slightly lower than, the initial concentrations, indicating that growth dilution did occur.

For predatory species, it is the content or dose (i.e., the quantifiable amount of a material introduced into an animal (Rand and Petrocelli 1985)) in food sources that is significant with respect to potential adverse effects. The toxicity of a metal is determined by the dose at the receptor site. The primary difference between concentration and content is that concentration allows for common reporting of a contaminant per unit weight of the animal, whereas content is an indication of the total amount of contaminant available within the animal. Thus, for arsenic and cadmium, there appeared to be no concern when only the tissue concentration data were examined; however, by evaluating the content data it is evident that these trace elements are available for uptake and could enter the food chain through organisms resident in Tannery Bay.

4.4 Sediment and Surface-Water Chemistry

Both sediment and surface-water samples were collected during clam deployment and retrieval. The sediment deployment samples were analyzed only for total- and methylmercury and conventional parameters (e.g., grain size, TOC, etc.). Sediment retrieval samples were analyzed for all study trace elements. These data indicate high variability in the sediment chemistry data, as well as in the composition of sediments. The area is heterogeneous, with wide fluctuations in the amount of fine-grained material and TOC present. Chromium and lead concentrations were highly correlated with TOC (r=0.94 and r=0.92, respectively). Chromium and lead concentrations also correlated with percent fines (r=0.80 and r=0.75, respectively). The association of metals with these fine organic-rich materials helps explain some of the spatial variability in sediment chemistry.

Surface waters for one reference and four Tannery Bay stations were analyzed from both the deployment and retrieval samples. Except for chromium and methylmercury, the correlation analyses indicated poor relationships between water and sediment chemistry. However, because of the small surface-water sample size, results from these correlation analyses must be used cautiously; small sample size alone may drive a stronger correlation. The correlation for chromium suggests that the unfiltered surface water over sediments has proportionate amounts of chromium, most likely associated with the particulate material within the water column.

4.5 Comparison of Bioavailability and Sediment Contamination

To assess the relative bioavailability of all five trace elements measured for clams at different stations, quotients calculated from the end-of-test tissue content divided by the initial tissue-content data were summed for five contaminants at each station (Table 8). Stations were ranked according to degree of uptake as follows:

Ranked order based on tissue quotients from greatest contaminant uptake to least uptake:

Sta 5 > Sta 8 > Sta 4 > Sta 6 > Sta 7 > Sta 3 > Sta 9 > Sta 10 > Sta 2 > Sta 1.

This ranked order is somewhat different than the station rankings calculated for sediments based on exceedance of the Ontario LEL values (Table 16).

Ranked order based on sediment LEL quotients from most contaminated to least contaminated:

Sta 3 > Sta 4 > Sta 5 > Sta 6 > Sta 7 > Sta 8 > Sta 10 > Sta 9 > Sta 1 > Sta 2.

The tissue and sediment rankings agree on the areas of lesser concern in Tannery Bay (i.e., Stations 9 and 10) and the areas of modest concern (i.e., Stations 6 and 7). There is some agreement on the most contaminated areasóthose around Stations 4 and 5. The primary differences in bioavailability and degree of sediment contamination are Stations 3 and 8. Based on tissue chemistry, Station 8 appears to be a greater concern than Station 3; sediment chemistry suggests that Station 3 is the area of greatest concern. The reason for this discrepancy is uncertain, but is probably a result of several environmental factors affecting contaminant availability discussed below. The reference stations had the lowest concentrations of contaminants and the smallest contaminant uptake.

Station 3 is characterized by sediments composed primarily of fines containing high concentrations of trace elements and TOC; bioavailability was found to be moderate. Station 8 is characterized by sediments composed primarily of sand and moderate-to-low concentrations of both trace elements and TOC; bioavailability was found to be very high. Bioavailability at Station 8 may be increased relative to sediment concentrations due to lower binding of contaminants. Another possible explanation is tied to the apparent semi-circular, northwest-to-northeast, surface-water flow in Tannery Bay. Under this scenario, Station 3 would receive more flow from the river, whereas Station 8 would receive water that had come in contact with contaminated bay sediments for a longer duration. Of all the areas monitored in Tannery Bay, Stations 3, 4, and 5 have the highest TOC levels and the highest percent fines. Although both organic carbon and fine, particulate material can serve as binding sites for labile trace elements, the high levels of trace elements measured in clam tissue at Stations 5 and 4 suggest that not all of the trace elements are bound and biologically unavailable to aquatic receptors.

Clams at Station 3 may not have accumulated trace elements in proportion to their supply in sediment due to both sediment binding and influence of water from St. Mary's River. A fair relationship was found between water and tissue chemistry (r=0.62), suggesting that biologically available trace elements are present in the water column. It is likely that the clams also accumulated chromium from the sediments, but the weakest relationship was found between these parameters (r=0.27). The tissue chemistry data and the correlation coefficients suggest that clams are integrating exposure from both the sediment and surface-water pathways, and that the contribution from each pathway is different, depending on conditions specific to the area of deployment. The moderate correlation coefficients obtained between sediment and tissues and between water and tissues are probably due to uptake from both sediment and water sources. Water circulation, and the distribution of particulate-bound trace elements, are likely a key factor in bioavailability to the filter-feeding clams. The beginning- and end-of-test surface-water chemistry (Table 15) clearly shows high variability in total trace elements. At the start of the test, the highest concentrations were found near Stations 4 and 5. Surface water was not collected at Station 8, but data for Station 9 indicate that trace elements in surface water were among the lowest at the start of the test. At the end of the test, the trace-element concentrations in surface water were similar for all locations sampled.

One unknown is the relationship between the horizon of sediment to which the clams were exposed and the horizon of sediment used in chemical analysis. Clams were probably exposed to trace element concentrations in the top 1-2 cm. It is uncertain if the sediment analyzed included deeper sediments and potentially different trace element concentrations. If surface sediments were homogenized with slightly deeper sediments, the correlation coefficients between tissue and sediment concentration could be lower as a consequence of sampling technique.

4.6 Comparison with Previous Studies

The 1997 baseline monitoring study data corroborate the presence of sediments in Tannery Bay contaminated with chromium and other trace elements. Sediment chromium concentrations measured during the 1997 baseline monitoring study are fairly consistent with data collected in 1993 (Cannelton Ind. 1995a), 1994 (US EPA/ERT 1995), and 1995 (Cannelton Ind. 1995b). The most comprehensive data set appears to be associated with the 1994 and 1995 sampling events. In all sampling events, the highest concentrations of chromium were found in sediments between the mainland and the small island in the western corner of the bay. In general, the highest concentrations are found to the west of the small island in Tannery Bay while the lowest are along the outer portion of Tannery Bay as it merges with the Saint Mary's River; mid-range concentrations are found in sediments in the eastern portion of Tannery bay. The surficial sediments from the area surrounding the 1997 baseline monitoring Station 4 historically have had the highest chromium concentrations: 18,430 mg/kg measured in 1993 (Cannelton Ind. 1995a), 30,000 mg/kg measured in 1994 (US EPA/ERT 1995), and 28,400 measured in 1995 in sediments collected from an area slightly to the southeast (Cannelton Ind. 1995b). In the 1997 baseline monitoring study, the highest chromium concentration in surficial sediments, 20,598 mg/kg, was measured in sediments collected from Station 3. In previous studies, chromium concentrations in sediments from the vicinity of Station 3 were reported as 1,871 mg/kg (Cannelton Ind. 1995a) and 8,200 mg/kg (US EPA/ERT, 1995); samples collected in 1995 from an area slightly to the east of Station 3 had a chromium concentration of 16,300 mg/kg (Cannelton Ind. 1995b). In the 1997 baseline monitoring study, the lowest chromium concentration was measured in sediments from Station 9. Historically, chromium concentrations in this area have been quite variable, reported as 3,014 mg/kg in 1993 (Cannelton Ind. 1995a), 5,800 mg/kg in 1994 (US EPA/ERT 1995), and 1,850 in 1995 (Cannelton Ind. 1995b). In the 1995 sampling event (Cannelton Ind. 1995b), subsurface sediments were collected and reported to contain chromium concentrations equal to, or higher than, those measured in the surficial sediments. It is possible that currents and ice movement in Tannery Bay and the Saint Mary's River continue to move surficial sediments, causing deeper, more contaminated sediments to become exposed. Both historical and recent data emphasize the need for continued monitoring.

The amount of chromium accumulated by crayfish in 1994 (U.S. EPA/ERT 1995) is similar to the amount accumulated by clams in this biomonitoring study. In 1994, tissues of crayfish from Tannery Bay were reported to contain between 1.4 and 9.6 mg Cr/kg tissue wet weight. One very high value of 29 mg/kg wet

weight was reported at one station from Hairball Beach (Station HB-3). The chromium concentrations in clams deployed in Tannery Bay ranged from 1.43 to 11.24 mg/kg wet weight. The concentrations of chromium in fish tissues measured in 1994 were within the ranges reported for both crayfish and clams. Tissue chemistry data were collected for the mayfly *Hexagenia* during the remedial pre-design studies (Cannelton Ind. 1995a). The concentration of chromium in mayflies collected from Tannery Bay ranged from 255 to 776 mg/kg dry weight compared with dry weights of 9.49 to 70.23 mg/kg in clams. Concentrations in mayflies are 1 to 2 orders of magnitude higher than measured in clam tissues during this baseline study (Table 4).

In contrast to the tissue:sediment correlations for the clams in this study, chromium concentrations in mayfly tissues were highly correlated with sediment concentrations measured in 1994 (r=0.987). It is unclear if the mayfly data, or even the crayfish or fish data, are directly comparable to the clam data. Concerns include their different feeding strategy as selective sediment feeders (mayflies actively feed on lighter, finer sediments containing higher amounts of organic material), their duration in the sediments (up to 2 years for mayflies), their migratory nature (none of these species remain within a specified area), and potential changes in exposure conditions between 1993 and 1997. Filter-feeding clams and sediment-feeding mayflies receive very different exposures to trace elements in the same sediments. Clams integrate exposure from two media, while the sediment- dwelling mayflies reflect a narrower source. Adding another species with a different feeding strategy (such as crayfish) to the monitoring program would improve the dataset on availability and sediment recovery. A sediment-feeding organism may have higher concentrations than the filter-feeding clams. The differences portrayed by the mayfly data support the need for a second species, particularly if information on the bioavailability of trace elements within the upper 10 cm of sediment is required.

4.7 Growth

One component of the study was to evaluate the potential for adverse effects associated with exposure to trace elements in Tannery Bay. The metrics used to evaluate growth, end-of-test whole-animal wet weight, growth rates based on whole weights, and end-of-test tissue weights did not indicate impact due to exposure in Tannery Bay when compared with the average of the reference stations. The data generated in this study should be used for baseline purposes. Limited comparison should be made to growth with respect to reference clams because of the poor growth observed in Reference Station 1 clams. Clams at Reference Station 1 had the lowest growth of all clams; the Reference Station 2 clams had slightly better whole-animal and tissue growth than those at Station 1. However, on average, the reference clams did not grow as well as the clams deployed in Tannery Bay.

The most interesting comparisons with the growth data are those among Tannery Bay stations only. The clams at Station 5 had the lowest performance for each of the growth metrics evaluated. Station 5 Replicates 3 and 4, with low survival, had very low growth (3.5 mg/week) compared with Replicates 1 and 2 (14.6 mg/week), with high survival. The replicates with high survival and growth still had lower growth rates than any of the other Tannery Bay stations. Growth rates, end-of-test tissue weights, and whole-animal wet weights all decreased along a gradient across Stations 3, 4, and 5. Although no strong relationships were found when the tissue-chemistry data were correlated with the growth data, a very strong relationship exists between these parameters for Stations 3, 4, and 5.

Although no significant differences were found in percent solids for the clams after deployment, there are some trends with solids that follow those seen with elevated tissue chemistry and reduced growth. Significant reductions in percent solids have been associated with stress and exposure to various chemicals (Belanger et al. 1986a,b; Doherty 1990). The clams at Station 5 had the lowest percent solid concentration at the end of the study when compared with the other clams. The lowest percent-solids data came from replicates 3 and 4 at Station 5. Although the percent-solid data do not distinguish between classes of contaminants or stressors, this metric responds in a negative fashion to any detrimental agent. Tissues of stressed clams will have higher percentages of water than unstressed individuals. This adds to the weight-of-evidence in evaluating the impact of exposure conditions.

These growth-effects data will be most useful in future years by providing a basis for comparison with other data. Significant differences in growth parameters compared with the baseline data may reflect changes in sediment and/or surface-water chemistry.

4.8 Temperature

Although the sites within Tannery Bay and St. Mary's River were selected to minimize temperature differences, statistically significant differences were found among stations. Separating statistical significance from ecological significance is important, but difficult. What effect, if any, do the measured temperature differences have on the observed growth results? None of the clam growth metrics were strongly correlated with temperature, as indicated by the poor correlation coefficients (i.e., $r<0.5$) obtained when each of the growth metrics were compared with temperature. Although there were some differences in temperature among stations, the overall exposure conditions are within the preferred limits (viz., 10–25°C) for this species, except at Reference Station 1 where the temperature reached 26.3°C for a very short period. Prolonged exposure to temperatures > 25°C have extensive effects on *Corbicula* biology, including depressed filtration rates (Mattice 1979), feeding rates, and

reproductive capacity. When exposed to these elevated temperatures, individuals spend most of the time with their siphons withdrawn and valves closed (McMahon 1979). It is doubtful that the brief exposure to the high temperature at Station 1 greatly affected the caged clams transplanted there, although this is one concern regarding the appropriateness of Station 1 as a reference area.

Station 5 is the only station that stands apart as having different temperatures within Tannery Bay. The mean temperature was 3.3°C lower than the means of the other Tannery Bay stations, and Station 5 had the lowest temperature, 10.5°C. Groundwater discharge occurring in the wetlands in the southwest corner of Tannery Bay possibly explains the lower water temperatures measured at this station. The temperatures measured at Station 5 are well within the clam's tolerance range, although it has been noted that low temperatures may reduce growth rates (Abbott 1979, Buttner & Heidinger 1980, Dreier & Tranquilli 1981) and inhibit veliger release (Heinsohn 1958, Aldridge 1976, Aldridge & McMahon 1978). The lower lethal temperature limit for *Corbicula* is near 2°C (Mattice & Dye 1976). Several reports of massive midwinter mortalities and/or total extinctions have been associated with ambient water temperatures near 0°C (Bickel 1966; Dreier & Tranquill 1981; Horning & Keup 1964).

4.9 Problems Encountered during the Study

The most significant problem encountered during this study was the presence of mercury in clam tissues at the beginning of the test. The problem of background contamination experienced in this and previous studies suggests that it may be very difficult to obtain freshwater bivalves that are free of mercury contamination. It may be necessary to obtain test specimens months in advance of the study to allow for depuration at a location known to be contaminant-free. The half-life of mercury depuration is approximately 90 days (N. Bloom, pers. commun., 1998); this length of time may be necessary to remove all traces of mercury from field-collected specimens. One of the most important elements of future monitoring studies should be the chemical characterization of source animals well before initiating the study.

A second problem in this study was the selection of the reference stations. The data strongly suggest that exposure conditions, excluding chemical contaminants, were dissimilar between the reference and Tannery Bay stations. The physical attributes of the reference stations must be as similar as possible to the test stations, including temperature ranges, food availability, vegetation, water depth, and currents.

5.0 Recommendations

1) NOAA recommends that studies conducted in future years retain all study parameters. Tissue chemistry, growth effects, sediment chemistry, and surface-water chemistry are required to determine the effectiveness of the remedial alternative. A minimum of three data sets must be collected to establish a trend and provide sufficient information to re-evaluate the program requirements. At that time it may be appropriate to adjust the study parameters.

2) The second round of monitoring should not occur until shore-side remedial activities are completed.

3) Further studies should be conducted at the same time of the year to allow direct comparison of tissue-chemistry and growth-effects data.

4) The initial mercury concentration in bivalves should be reduced. Either an alternative source of clams should be identified, or the clams should be collected long enough before the study commences to allow complete, or near complete, depuration of mercury.

5) Replicate data at Station 5 was quite variable. In future years, cages placed at this station should be located away from highly vegetated sediments to ensure similar conditions for all clams.

6) NOAA recommends conducting a site reconnaissance to determine if a more appropriate and representative reference station can be located to replace the Waiska Bay Reference Station 1 for use in future years' monitoring.

7) Although the clams integrate both sediment and water chemistry, it would be advantageous to add a second species (i.e., crayfish) to the study to obtain specific data on bioavailability of trace elements in the surficial sediments and to ensure sufficient characterization of chemical bioavailability to all species (i.e., filter-feeding and deposit/sediment-feeding) currently or potentially using Tannery Bay. This recommendation should be implemented to help assess food chain impacts in the event that future year sampling data reveals no decrease in contaminant bioavailability.

6.0 References

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7.0 TABLES

Table 1. Deployment position, time, water depth, and range of depth at each station.

Station	Cage numbers	Deployment time	GPS coordinates	Water depth (ft)	Range of depth (ft)
1 (Ref 1)	13, 22, 25, 43	7/16; 2:30pm	46°26'30.60"N 84°35'54.31"W	2' 6"	2'1" - 3'6"
2 (Ref 2)	5, 15, 24, 35	7/17;10:45am	46°29'21.51"N 84°24'03.37"W	2' 5"	2' - 3'5"
3	2, 11, 30, 37	7/16; 5:50pm	46°29'34.54"N 84°23'24.33"W	3' 6"	3'1" - 4'6"
4	3, 17, 23, 34	7/16; 7:00pm	46°29'32.94"N 84°23'23.72"W	2' 7"	2'2" - 3'7"
5	4, 18, 27, 42	7/16; 7:15pm	46°29'30.74"N 84°23'23.45"W	1' 9"	1'4" - 2'9"
6	14, 19, 26, 41	7/16; 7:30pm	46°29'32.34"N 84°23'19.23"W	1' 7"	1'2" - 2'7"
7	1, 9, 20, 38	7/17; 11:07am	46°29'31.89"N 84°23'15.05"W	2' 9"	2'4" - 3'9"
8	16, 28, 33, 44	7/16; 6:20pm	46°29'36.56"N 84°23'12.14"W	4' 6"	4'1" - 5'6"
9	8, 10, 21, 39	7/17: 10:08am	46°29'35.39"N 84°23'17.62"W	3' 8"	3'3" - 4'8"
10	6, 12, 31, 40	7/17; 10:20am	46°29'37.08"N 84°23'23.45"W	3' 2"	2'7" - 4'2"
11 (Initial tissue)	7, 29, 32, 36	NA	NA	NA	NA

NA - Not applicable

Table 2. Analyte list and targeted detection limits for clam tissues.

Analyte	Method	Target detection limit*
Chromium (total)	EPA 200.9 STP-GFAA	0.01 mg/kg
Cadmium	EPA 200.9 STP-GFAA	0.005 mg/kg
Lead	EPA 200.9 STP-GFAA	0.07 mg/kg
Arsenic	EPA 200.9 STP-GFAA	0.05 mg/kg
Total Mercury	BR-0002 CVAFS	0.0001 mg/kg
Methylmercury	BR-0011 CVAFS	0.001 mg/kg
Percent Solids	BR-1501	0.1%
Percent Lipids	EPA 8290	1.0%

* Detection limits are not guaranteed due to the possibility of matrix interferences
STP-GFAA – Stabilized temperature platform-graphite furnace atomic absorption
CVAFS – Cold vapor atomic fluorescence spectrometry
BR – Brooks Rand

Table 3. End-of-test percent survival for clams deployed in Tannery Bay and at reference stations.

	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Replicate 1	85	93	95	96	96	93	91	95	95	96
Replicate 2	96	95	88	87	93	97	92	95	95	91
Replicate 3	95	95	88	92	77	92	87	97	92	93
Replicate 4	93	91	93	85	81	96	97	92	92	89
Mean	92	94	91	90	87	94	92	95	94	92
SD	5.0	1.9	3.6	5.0	9.2	2.4	4.1	2.1	1.7	3.0
N	277	280	273	270	261	284	275	284	280	277

Results of statistical analyses on clam survival.

Tannery Bay stations compared with the average of reference stations

	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Survival	NS	NS	--	NS	NS	NS	NS	NS

-- Clams from Tannery Bay station significantly less than the average of reference stations.
NS – No significant difference between Tannery Bay station and the average of reference stations.

Table 4. Mean concentration (dry and wet weights) of trace elements in clam tissues.

Dry Weight Concentration (mg/kg)

	Initial	Sta 1 & 2[a]	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Arsenic												
Rep 1	6.07		6.09	4.68	5.75	4.63	4.67	4.82	5.44	5.14	5.04	5.45
Rep 2	6.25		4.78	6.01	4.53	5.41	5.48	5.00	4.73	5.76	4.45	5.33
Rep 3	6.56		5.82	5.56	5.99	5.00	6.47	5.98	5.30	6.52	5.43	5.37
Rep 4	6.12		5.79	5.41	4.89	5.17	6.52	5.90	4.95	6.26	5.22	5.15
Mean	**6.25**	**5.52**	**5.62**	**5.42**	**5.29**	**5.05**	**5.79**	**5.43**	**5.11**	**5.92**	**5.04**	**5.33**
±2SE	0.22	0.53	0.58	0.55	0.69	0.33	0.88	0.60	0.32	0.61	0.42	0.13
Cadmium												
Rep 1	3.19		2.61	2.81	3.10	1.91	2.44	1.99	2.54	2.92	2.47	2.83
Rep 2	3.15		1.78	3.35	2.01	2.60	2.63	2.09	2.47	3.22	2.17	2.82
Rep 3	2.74		2.44	3.64	3.01	2.25	2.91	2.81	2.52	3.97	2.53	3.19
Rep 4	3.15		2.08	2.93	2.36	2.29	3.15	3.97	2.56	3.48	2.55	2.72
Mean	**3.06**	**2.71**	**2.23**	**3.18**	**2.62**	**2.26**	**2.78**	**2.72**	**2.52**	**3.40**	**2.43**	**2.89**
±2SE	0.21	0.62	0.37	0.38	0.52	0.28	0.31	0.91	0.04	0.44	0.18	0.21
Chromium												
Rep 1	2.38		6.51	6.31	17.80	18.10	62.20	14.50	26.20	34.30	8.83	7.92
Rep 2	2.77		4.48	4.68	20.80	32.80	79.20	17.50	16.30	19.20	12.50	7.12
Rep 3	2.92		13.00	5.69	17.50	9.10	82.20	19.60	17.60	101.00	13.30	14.70
Rep 4	2.90		8.77	6.87	13.10	40.80	57.30	22.60	17.70	45.10	24.80	8.13
Mean	**2.74**	**7.04**	**8.19**	**5.89**	**17.30**	**25.20**	**70.23**	**18.55**	**19.45**	**49.90**	**14.86**	**9.47**
±2SE	0.25	2.76	3.65	0.94	3.17	14.27	12.32	3.42	4.54	35.68	6.91	3.52
Lead												
Rep 1	0.620		0.895	1.570	0.778	0.800	1.450	0.568	0.663	0.879	0.822	0.826
Rep 2	0.026		0.460	0.887	0.426	2.770	1.730	1.460	0.872	0.779	0.702	0.973
Rep 3	0.165		0.764	0.997	0.554	0.925	2.190	0.879	0.903	2.260	0.988	1.070
Rep 4	0.165		0.625	0.920	0.807	1.050	1.360	1.170	0.698	1.530	0.994	0.805
Mean	**0.244**	**0.890**	**0.686**	**1.094**	**0.641**	**1.386**	**1.683**	**1.019**	**0.784**	**1.362**	**0.877**	**0.919**
±2SE	0.259	0.326	0.187	0.321	0.183	0.928	0.373	0.383	0.121	0.685	0.141	0.126
Mercury												
Rep 1	0.993		1.210	0.793	0.830	0.885	0.932	0.827	0.644	0.697	0.879	0.781
Rep 2	1.660		0.858	0.771	0.876	0.995	1.030	0.844	0.814	1.090	0.783	0.873
Rep 3	1.060		1.130	0.877	0.862	0.981	1.260	0.678	0.987	0.792	1.930	0.853
Rep 4	1.340		1.100	0.893	0.894	1.040	1.020	0.675	0.810	1.030	0.807	0.926
Mean	**1.263**	**0.954**	**1.075**	**0.834**	**0.866**	**0.975**	**1.061**	**0.756**	**0.814**	**0.902**	**1.100**	**0.858**
±2SE	0.304	0.167	0.152	0.060	0.027	0.065	0.140	0.092	0.140	0.188	0.555	0.060
Methylmercury												
Rep 1	0.255		0.149	0.121	0.153	0.171	0.153	0.146	0.116	0.086	0.139	0.125
Rep 2	0.243		0.105	0.077	0.162	0.180	0.124	0.143	0.146	0.097	0.141	0.135
Rep 3	0.267		0.201	0.093	0.136	0.157	0.197	0.113	0.159	0.102	0.143	0.131
Rep 4	0.269		0.185	0.105	0.176	0.223	0.151	0.100	0.103	0.123	0.137	0.134
Mean	**0.259**	**0.130**	**0.160**	**0.099**	**0.157**	**0.183**	**0.156**	**0.126**	**0.131**	**0.102**	**0.140**	**0.131**
±2SE	0.012	0.045	0.043	0.019	0.017	0.028	0.030	0.023	0.026	0.016	0.003	0.005

Table 4 (continued)

Wet Weight Concentration (mg/kg)

	Initial	Sta 1 & 2[a]	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Arsenic												
Rep 1	0.91		0.93	0.68	0.89	0.76	0.73	0.78	0.92	0.85	0.79	0.84
Rep 2	0.97		0.73	0.88	0.77	0.82	0.88	0.80	0.74	0.88	0.72	0.80
Rep 3	0.98		0.89	0.84	0.87	0.81	1.04	0.98	0.82	1.02	0.87	0.81
Rep 4	0.94		0.89	0.81	0.79	0.76	1.05	0.95	0.85	0.94	0.84	0.77
Mean	**0.95**	**0.83**	**0.86**	**0.80**	**0.83**	**0.79**	**0.93**	**0.88**	**0.83**	**0.92**	**0.81**	**0.80**
±2SE	0.03	0.09	0.09	0.09	0.06	0.03	0.15	0.10	0.08	0.08	0.07	0.03
Cadmium												
Rep 1	0.48		0.40	0.41	0.48	0.32	0.38	0.32	0.43	0.48	0.39	0.44
Rep 2	0.49		0.27	0.49	0.34	0.40	0.42	0.33	0.39	0.49	0.35	0.42
Rep 3	0.41		0.37	0.55	0.44	0.36	0.47	0.46	0.39	0.62	0.41	0.48
Rep 4	0.48		0.32	0.44	0.38	0.34	0.51	0.64	0.44	0.52	0.41	0.41
Mean	**0.46**	**0.41**	**0.34**	**0.47**	**0.41**	**0.35**	**0.45**	**0.44**	**0.41**	**0.53**	**0.39**	**0.44**
±2SE	0.04	0.09	0.06	0.06	0.06	0.03	0.05	0.15	0.03	0.06	0.03	0.03
Chromium												
Rep 1	0.36		1.00	0.91	2.74	2.99	9.77	2.35	4.43	5.66	1.39	1.23
Rep 2	0.43		0.69	0.69	3.52	4.99	12.75	2.80	2.54	2.94	2.01	1.07
Rep 3	0.44		1.99	0.86	2.56	1.47	13.23	3.21	2.73	15.86	2.14	2.21
Rep 4	0.44		1.34	1.02	2.11	6.00	9.23	3.64	3.04	6.77	3.99	1.21
Mean	**0.42**	**1.06**	**1.25**	**0.87**	**2.73**	**3.86**	**11.24**	**3.00**	**3.19**	**7.80**	**2.38**	**1.43**
±2SE	0.04	0.43	0.56	0.14	0.59	2.02	2.04	0.55	0.85	5.60	1.12	0.52
Lead												
Rep 1	0.09		0.14	0.23	0.12	0.13	0.23	0.09	0.11	0.15	0.13	0.13
Rep 2	0.00		0.07	0.13	0.07	0.42	0.28	0.23	0.14	0.12	0.11	0.15
Rep 3	0.05		0.12	0.15	0.08	0.15	0.35	0.14	0.14	0.35	0.16	0.16
Rep 4	0.05		0.10	0.14	0.13	0.15	0.22	0.19	0.12	0.23	0.16	0.12
Mean	**0.05**	**0.13**	**0.10**	**0.16**	**0.10**	**0.21**	**0.27**	**0.16**	**0.13**	**0.21**	**0.14**	**0.14**
±2SE	0.04	0.05	0.03	0.04	0.03	0.14	0.06	0.06	0.01	0.11	0.02	0.02
Mercury												
Rep 1	0.149		0.185	0.115	0.128	0.146	0.146	0.134	0.109	0.115	0.138	0.121
Rep 2	0.257		0.131	0.113	0.148	0.151	0.166	0.135	0.127	0.167	0.126	0.131
Rep 3	0.159		0.173	0.132	0.126	0.159	0.203	0.111	0.153	0.124	0.311	0.128
Rep 4	0.205		0.168	0.133	0.144	0.153	0.164	0.109	0.139	0.155	0.130	0.138
Mean	**0.193**	**0.144**	**0.164**	**0.123**	**0.136**	**0.152**	**0.170**	**0.122**	**0.132**	**0.140**	**0.176**	**0.129**
±2SE	0.050	0.028	0.023	0.011	0.011	0.005	0.024	0.014	0.019	0.024	0.090	0.007
Methylmercury												
Rep 1	0.038		0.023	0.018	0.024	0.028	0.024	0.024	0.020	0.014	0.022	0.019
Rep 2	0.038		0.016	0.011	0.027	0.027	0.020	0.023	0.023	0.015	0.023	0.020
Rep 3	0.040		0.031	0.014	0.020	0.025	0.032	0.019	0.025	0.016	0.023	0.020
Rep 4	0.041		0.028	0.016	0.028	0.033	0.024	0.016	0.018	0.018	0.022	0.020
Mean	**0.039**	**0.020**	**0.024**	**0.015**	**0.025**	**0.028**	**0.025**	**0.020**	**0.021**	**0.016**	**0.022**	**0.020**
±2SE	0.002	0.007	0.007	0.003	0.004	0.003	0.005	0.004	0.003	0.002	0.001	0.000

[a]Value represents average of data (n=8) for Reference Stations 1 and 2

Table 5. Mean content (µg dry weight) of trace elements in clam tissues.

	Content (µg dry weight)											
	Initial	**Sta 1 & 2[a]**	**Sta 1**	**Sta 2**	**Sta 3**	**Sta 4**	**Sta 5**	**Sta 6**	**Sta 7**	**Sta 8**	**Sta 9**	**Sta 10**
Arsenic												
Rep 1	0.62		0.62	0.58	0.79	0.67	0.58	0.72	0.82	0.77	0.72	0.70
Rep 2	0.65		0.64	0.75	0.73	0.70	0.69	0.74	0.67	0.78	0.62	0.65
Rep 3	0.66		0.60	0.69	0.81	0.74	0.73	0.87	0.71	0.92	0.77	0.67
Rep 4	0.60		0.64	0.67	0.72	0.64	0.72	0.81	0.73	0.82	0.72	0.67
Mean	**0.63**	**0.65**	**0.62**	**0.67**	**0.76**	**0.69**	**0.68**	**0.79**	**0.73**	**0.82**	**0.71**	**0.67**
±2SE	0.02	0.05	0.02	0.07	0.05	0.04	0.07	0.07	0.06	0.07	0.07	0.02
Cadmium												
Rep 1	0.33		0.27	0.35	0.43	0.27	0.30	0.30	0.38	0.44	0.35	0.36
Rep 2	0.33		0.24	0.42	0.32	0.33	0.33	0.31	0.35	0.44	0.30	0.34
Rep 3	0.27		0.25	0.45	0.41	0.33	0.33	0.41	0.34	0.56	0.36	0.40
Rep 4	0.31		0.23	0.36	0.35	0.29	0.35	0.54	0.38	0.46	0.35	0.35
Mean	**0.31**	**0.32**	**0.25**	**0.40**	**0.38**	**0.31**	**0.33**	**0.39**	**0.36**	**0.47**	**0.34**	**0.36**
±2SE	0.02	0.09	0.02	0.05	0.05	0.03	0.02	0.11	0.02	0.06	0.03	0.02
Chromium												
Rep 1	0.24		0.66	0.78	2.45	2.61	7.73	2.18	3.97	5.16	1.26	1.02
Rep 2	0.29		0.60	0.58	3.36	4.22	10.04	2.61	2.32	2.60	1.74	0.86
Rep 3	0.29		1.35	0.71	2.37	1.34	9.31	2.85	2.35	14.18	1.90	1.83
Rep 4	0.29		0.97	0.85	1.93	5.09	6.36	3.09	2.62	5.90	3.40	1.05
Mean	**0.28**	**0.81**	**0.89**	**0.73**	**2.53**	**3.31**	**8.36**	**2.68**	**2.81**	**6.96**	**2.07**	**1.19**
±2SE	0.02	0.25	0.34	0.11	0.60	1.67	1.64	0.39	0.78	5.02	0.92	0.43
Lead												
Rep 1	0.063		0.091	0.195	0.107	0.115	0.180	0.085	0.100	0.132	0.117	0.106
Rep 2	0.003		0.061	0.111	0.069	0.356	0.219	0.217	0.124	0.106	0.098	0.118
Rep 3	0.016		0.079	0.124	0.075	0.136	0.248	0.128	0.120	0.317	0.141	0.133
Rep 4	0.016		0.069	0.114	0.119	0.131	0.151	0.160	0.103	0.200	0.136	0.104
Mean	**0.03**	**0.11**	**0.08**	**0.14**	**0.09**	**0.18**	**0.20**	**0.15**	**0.11**	**0.19**	**0.12**	**0.12**
±2SE	0.027	0.043	0.013	0.040	0.024	0.115	0.043	0.056	0.012	0.094	0.020	0.013
Mercury												
Rep 1	0.102		0.124	0.099	0.114	0.127	0.116	0.124	0.098	0.105	0.125	0.101
Rep 2	0.172		0.114	0.096	0.142	0.128	0.131	0.126	0.116	0.148	0.109	0.106
Rep 3	0.106		0.117	0.109	0.117	0.145	0.143	0.099	0.132	0.111	0.275	0.106
Rep 4	0.132		0.121	0.111	0.131	0.130	0.113	0.092	0.120	0.135	0.111	0.120
Mean	**0.128**	**0.111**	**0.119**	**0.104**	**0.126**	**0.132**	**0.126**	**0.110**	**0.116**	**0.125**	**0.155**	**0.108**
±2SE	0.032	0.010	0.004	0.007	0.013	0.008	0.014	0.017	0.014	0.020	0.080	0.008
Methylmercury												
Rep 1	0.026		0.015	0.015	0.021	0.025	0.019	0.022	0.018	0.013	0.020	0.016
Rep 2	0.025		0.014	0.010	0.026	0.023	0.016	0.021	0.021	0.013	0.020	0.016
Rep 3	0.027		0.021	0.012	0.018	0.023	0.022	0.016	0.021	0.014	0.020	0.016
Rep 4	0.026		0.020	0.013	0.026	0.028	0.017	0.014	0.015	0.016	0.019	0.017
Mean	**0.026**	**0.015**	**0.018**	**0.012**	**0.023**	**0.025**	**0.018**	**0.018**	**0.019**	**0.014**	**0.020**	**0.017**
±2SE	0.001	0.004	0.003	0.002	0.004	0.002	0.003	0.004	0.003	0.001	0.001	0.001

[a]Value represents average of data (n=8) for Reference Stations 1 and 2

Table 6. Results of statistical analyses on tissue concentration data.

Tannery Bay stations compared with the average of reference stations

	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Arsenic	NS	NS	NS	NS	NS	NS	NS	NS
Cadmium	NS	NS	NS	NS	NS	*	NS	NS
Chromium	NS	*	*	*	*	*	NS	NS
Lead	NS	NS	NS	NS	NS	NS	NS	NS
Mercury	NS	NS	NS	NS	NS	NS	NS	NS
Methylmercury	*	*	*	NS	NS	--	NS	NS

* Concentration in clams from Tannery Bay station significantly greater than the average of reference stations.
NS – No significant difference between Tannery Bay station and the average of reference stations.
-- Concentration in clams from Tannery Bay station significantly less than the average of reference stations.

All Stations compared with the Initial (T_0) concentration

	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Arsenic	NS	NS	NS	--	NS	NS	--	NS	--	NS
Cadmium	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Chromium	*	NS	*	*	*	*	*	*	*	*
Lead	*	*	*	*	*	*	*	*	*	*
Mercury	NS	--	NS	NS	NS	--	--	NS	NS	NS
Methylmercury	--	--	--	--	--	--	--	--	--	--

* Concentration in clams from station significantly greater than the initial (T_0) concentration.
NS - No significant difference between station and the initial (T_0) concentration.
-- Concentration in clams from station significantly less than the initial (T_0) concentration.

Results of Student Newman-Keuls analyses on Tannery Bay stations

Arsenic	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.814270	.584874	.935425	.637188	.495301	.911501	.928815
Sta 4		.430691	.869236	.893374	.311926	.964431	.894614
Sta 5			.361812	.420663	.730462	.476945	.471481
Sta 6				.841382	.420587	.910960	.798480
Sta 7					.317988	.982237	.838171
Sta 8						.340642	.432228
Sta 9							.942486

Cadmium	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.665661	.862052	.763521	.757503	.126046	.816730	.822549
Sta 4		.565403	.602881	.686484	**.02436***	.596451	.433798
Sta 5			.830683	.838204	.141291	.789479	.733573
Sta 6				.812403	.155535	.797992	.841996
Sta 7					.091184	.769555	.763650
Sta 8						.063363	.117045
Sta 9							.683025

Table 6 (continued).

Log-transformed Chromium	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.846750	**.00100***	.812555	.922308	**.04041***	.476774	.098294
Sta 4		**.00166***	.834543	.670226	**.03548***	.549013	.063644
Sta 5			**.00122***	**.00113***	.093466	**.00032***	**.00015***
Sta 6				.886829	**.04532***	.606781	.103420
Sta 7					**.03528***	.688880	.113172
Sta 8						**.01085***	**.00056***
Sta 9							.162674

Log-transformed Lead	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.098554	**.00935***	.391874	.361751	.102810	.363678	.401195
Sta 4		.416405	.348370	.377600	.922398	.523952	.480659
Sta 5			.140419	.060593	.246678	.119946	.134218
Sta 6				.815750	.550275	.906747	.831228
Sta 7					.407054	.652333	.786808
Sta 8						.585958	.589559
Sta 9							.837986

Rank-it transformed Mercury	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.728777	.494554	.438258	.585298	.994971	.932098	.752391
Sta 4		.560977	.181286	.352135	.564255	.502584	.658985
Sta 5			.069875	.162117	.385769	.424959	.399499
Sta 6				.602263	.552391	.435239	.460747
Sta 7					.748399	.660360	.504001
Sta 8						.728451	.943398
Sta 9							.904760

Methylmercury	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.089930	.973275	.308626	.423846	**.01550***	.500263	.329013
Sta 4		.190474	**.01073***	**.01939***	**.00039***	**.03636***	**.01444***
Sta 5			.256465	.337308	**.01273***	.280296	.225946
Sta 6				.711838	.120665	.758777	.919554
Sta 7					.138031	.815107	.986674
Sta 8						.103081	.215748
Sta 9							.557576

Values in **bold** face and marked with an asterisk indicate a significant difference between stations.

Table 7. Results of statistical analyses on tissue content data.

Tannery Bay Stations compared with the average of reference stations

	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Arsenic	*	NS	NS	*	*	*	NS	NS
Cadmium	NS	NS	NS	NS	NS	*	NS	NS
Chromium	*	*	*	*	*	*	NS	NS
Lead	NS	NS	NS	NS	NS	NS	NS	NS
Mercury	NS	*	NS	NS	NS	NS	NS	NS
Methylmercury	*	*	*	*	*	NS	*	NS

* Content in clams from Tannery Bay station significantly greater than the average of reference stations.
NS – No significant difference between Tannery Bay station and the average of reference stations.
-- Concentration in clams from Tannery Bay station significantly less than the average of reference stations.

All Stations compared with the Initial (T_0) content

	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Arsenic	NS	NS	*	NS	NS	*	NS	*	NS	NS
Cadmium	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
Chromium	*	*	*	*	*	*	*	*	*	*
Lead	*	*	*	*	*	*	*	*	*	*
Mercury	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Methylmercury	--	--	NS	NS	--	--	--	--	--	--

* - Content in clams from station significantly greater than the initial (T_0) content.
NS - No significant difference between station and the initial (T_0) content.
--Content in clams from station significantly less than the initial (T_0) content.

Results of Student Newman-Keuls analyses on Tannery Bay stations

Arsenic	**Sta 4**	**Sta 5**	**Sta 6**	**Sta 7**	**Sta 8**	**Sta 9**	**Sta 10**
Sta 3	.246178	.294896	.567017	.479323	.329379	.356169	.232615
Sta 4		.935554	.123708	.463488	**.02674***	.608212	.924048
Sta 5			.140279	.581636	**.02906***	.820743	.768725
Sta 6				.409248	.390203	.222626	.099445
Sta 7					.159087	.501585	.522781
Sta 8						.060453	**.01858***
Sta 9							.805475

Log-transformed Cadmium	**Sta 4**	**Sta 5**	**Sta 6**	**Sta 7**	**Sta 8**	**Sta 9**	**Sta 10**
Sta 3	.271655	.623085	.883704	.935928	.052864	.732871	.750743
Sta 4		.438111	.260652	.272000	**.00216***	.479573	.352153
Sta 5			.627829	.541491	**.01082***	.703402	.695554
Sta 6				.959430	**.02906***	.762610	.886242
Sta 7					.065513	.500424	.979693
Sta 8						**.02008***	**.04653***
Sta 9							.759936

Table 7 (continued)

Log-transformed Chromium	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.929033	**.00375***	.802568	.931000	**.04635***	.398803	**.03103***
Sta 4		**.00395***	.933628	.808083	**.02598***	.593180	**.02991***
Sta 5			**.00485***	**.00404***	.228600	**.00072***	**.00015***
Sta 6				.915009	.053327	.516024	**.03141***
Sta 7					**.03848***	.620461	**.03736***
Sta 8						**.00914***	**.00025***
Sta 9							.075181

Log-transformed Lead	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.124241	**.03979***	.330186	.354026	.104362	.555812	.540986
Sta 4		.724440	.479289	.451652	.835989	.397792	.410296
Sta 5			.459243	.213493	.580128	.256272	.214819
Sta 6				.760396	.628120	.552991	.671570
Sta 7					.419832	.923403	.901421
Sta 8						.435976	.404338
Sta 9							.800440

Rank-it transformed Mercury	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.592114	.961570	.647329	.905831	.999189	.997012	.630697
Sta 4		.825743	.384487	.720227	.959687	.925465	.382022
Sta 5			.599712	.844918	.996174	.979763	.565254
Sta 6				.711649	.438136	.520619	.921914
Sta 7					.469784	.710685	.495380
Sta 8						.953808	.343351
Sta 9							.461216

Methylmercury	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.338606	.102697	.133255	.080469	**.00140***	.092543	**.02270***
Sta 4		**.01893***	**.02323***	**.01710***	**.00027***	**.03042***	**.00305***
Sta 5			.956651	.888703	.112302	.791600	.558412
Sta 6				.979007	.074222	.892308	.333662
Sta 7					.123403	.612682	.642834
Sta 8						.058875	.199605
Sta 9							.454670

Values in **bold** face and marked with an asterisk indicate a significant difference between stations.

Table 8. Quotients derived by dividing end-of-test tissue content by initial tissue content.

	As	Cd	Cr	Pb	Hg	Sum
Sta 1	0.990	0.797	3.23	3.041	0.931	9.0
Sta 2	1.068	1.283	2.648	5.51	0.812	11.3
Sta 3	1.209	1.218	9.127	3.738	0.986	16.3
Sta 4	1.086	0.992	11.97	7.473	1.036	22.6
Sta 5	1.081	1.064	30.19	8.075	0.982	41.4
Sta 6	1.246	1.264	9.691	5.977	0.863	19.0
Sta 7	1.163	1.174	10.17	4.536	0.910	18.0
Sta 8	1.302	1.528	25.14	7.64	0.975	36.6
Sta 9	1.120	1.104	7.49	4.977	1.213	15.9
Sta 10	1.062	1.177	4.302	4.67	0.846	12.1

Table 9. Descriptive statistics on clam growth metrics.

		Initial (T_0)	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Initial	**Mean**	5.45	5.53	5.52	5.52	5.58	5.49	5.55	5.58	5.46	5.49	5.51
WAWW	**Min.**	4.01	4.02	4.04	4.01	4.02	4.10	4.07	4.04	4.02	4.01	4.02
(g)	**Max.**	7.79	7.90	7.93	7.92	7.95	7.79	7.89	7.91	7.75	7.75	7.85
	SD	0.83	0.84	0.84	0.88	0.88	0.79	0.83	0.88	0.80	0.85	0.82
	±2SE	0.10	0.10	0.10	0.10	0.10	0.09	0.10	0.10	0.09	0.10	0.09
End-of-test	**Mean**		5.56	5.62	5.71	5.72	5.58	5.76	5.76	5.58	5.70	5.63
WAWW	**Min.**		3.98	4.03	4.20	4.15	4.03	4.12	4.15	4.13	3.44	4.30
(g)	**Max.**		7.98	8.11	8.06	8.06	7.95	7.83	8.09	7.77	8.28	8.29
	SD		0.82	0.81	0.86	0.85	0.79	0.83	0.88	0.79	0.86	0.81
	±2SE		0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.09	0.10	0.10
□ WAWW	**Mean**		0.04	0.11	0.18	0.14	0.08	0.22	0.19	0.15	0.21	0.15
(g)	**Min.**		-0.39	-0.60	-0.25	-0.45	-0.55	-0.18	-0.21	-0.63	-0.58	-0.15
	Max.		0.31	0.36	0.57	0.78	0.39	0.56	0.55	0.70	0.58	0.46
	SD		0.09	0.11	0.12	0.12	0.11	0.12	0.12	0.13	0.11	0.09
	±2SE		0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.01	0.01
WAWW	**Mean**		5.16	14.49	22.49	17.92	9.57	28.04	24.26	19.25	27.24	18.56
Growth	**Min.**		-49.62	-76.34	-31.81	-57.25	-69.97	-22.90	-26.72	-80.15	-73.79	-19.08
(mg/wk)	**Max.**		39.44	45.80	72.52	99.24	49.62	71.25	69.97	89.06	73.79	58.52
	SD		11.80	14.17	15.31	15.49	14.63	15.56	14.77	16.40	14.51	11.18
	±2SE		1.42	1.69	1.85	1.88	1.81	1.85	1.78	1.95	1.73	1.34
End-of-test	**Mean**	0.66	0.74	0.84	0.92	0.87	0.81	0.90	0.88	0.89	0.88	0.83
Tissue	**Min.**	0.32	0.34	0.39	0.50	0.47	0.42	0.42	0.41	0.45	0.42	0.42
(g)	**Max.**	1.09	1.18	1.28	1.39	1.30	1.27	1.63	1.41	1.71	1.25	1.33
	SD	0.14	0.14	0.14	0.16	0.15	0.13	0.16	0.17	0.15	0.15	0.14
	±2SE	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Percent	**Mean**	15.2	15.2	14.8	15.8	15.7	14.7	16.2	16.3	15.6	16.0	15.1
Solids	**Min.**	15.0	14.4	14.5	14.6	14.7	14.0	16.0	15.5	15.0	15.7	14.9
	Max.	15.5	17.4	15.1	16.9	16.5	15.6	16.4	17.2	16.5	16.1	15.5
	±2SE	0.24	1.48	0.26	0.98	0.84	0.75	0.17	0.88	0.65	0.20	0.27
Percent	**Mean**	1.30	1.36	1.35	1.56	1.39	1.40	1.50	1.48	1.43	1.72	1.37
Lipids	**Min.**	1.08	1.11	1.06	1.41	1.00	1.24	1.34	1.33	1.21	1.54	1.15
	Max.	1.46	1.65	1.91	1.70	1.82	1.72	1.84	1.66	1.69	1.93	1.54
	±2SE	0.18	0.23	0.38	0.12	0.42	0.22	0.24	0.14	0.20	0.16	0.18
	N	300	277	280	273	270	261	284	275	284	280	277

WAWW – Whole-animal wet weight.

Table 10. Results of statistical analyses on clam growth metrics.

Tannery Bay stations compared with the average of reference stations

	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
WAWW	*	*	NS	*	*	NS	NS	NS
WAWW Growth rate	*	*	NS	*	*	*	*	*
EOT Tissue weight	*	*	NS	*	*	*	*	*
% Solids	NS	NS	NS	*	*	NS	*	NS
% Lipids	NS	NS	NS	NS	NS	NS	*	NS

WAWW – Whole-animal wet weight.
EOT – End-of-test.
* Clams from Tannery Bay station significantly greater than the average of reference stations.
NS – No significant difference between Tannery Bay station and the average of reference stations.

Results of Student Newman-Keuls analyses on Tannery Bay stations

Log-transformed end-of-test WAWW	**Sta 4**	**Sta 5**	**Sta 6**	**Sta 7**	**Sta 8**	**Sta 9**	**Sta 10**
Sta 3	.867246	.377873	.861547	.789735	.284385	.861222	.526827
Sta 4		.365780	.810651	.625932	.293884	.937562	.597062
Sta 5			.164255	.179095	.987677	.368545	.755777
Sta 6				.896708	.137959	.873297	.424607
Sta 7					.145318	.840497	.412874
Sta 8						.244659	.485442
Sta 9							.365668

Rank- it transformed Growth Rate	**Sta 4**	**Sta 5**	**Sta 6**	**Sta 7**	**Sta 8**	**Sta 9**	**Sta 10**
Sta 3	**.00072***	**.00002***	**.00004***	.139430	**.00892***	**.00012***	**.00266***
Sta 4		**.00001***	**.00003***	**.00002***	.437565	**.00002***	.597145
Sta 5			**.00003***	**.00002***	**.00001***	**.00003***	**.00002***
Sta 6				**.00683***	**.00002***	.708783	**.00002***
Sta 7					**.00014***	**.00782***	**.00002***
Sta 8						**.00001***	.485304
Sta 9							**.00002***

Tissue Weight	**Sta 4**	**Sta 5**	**Sta 6**	**Sta 7**	**Sta 8**	**Sta 9**	**Sta 10**
Sta 3	**.00072***	**.00003***	.075583	**.01181***	**.04229***	**.00485***	**.00003***
Sta 4		**.00002***	.151994	.581178	.352838	.554438	**.00523***
Sta 5			**.00003***	**.00002***	**.00002***	**.00001***	**.03653***
Sta 6				.403761	.527323	.330604	**.00002***
Sta 7					.513972	.687648	**.00090***
Sta 8						.542322	**.00010***
Sta 9							**.00207***

Table 10 (continued)

Percent Lipids	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.902962	.866733	.745944	.893682	.848253	.313136	.903733
Sta 4		.950793	.953924	.937862	.974102	.405374	.901736
Sta 5			.917972	.864730	.877328	.372000	.980931
Sta 6				.901736	.879546	.378010	.959420
Sta 7					.722749	.462647	.953924
Sta 8						.373886	.985781
Sta 9							.393714

Percent Solids	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Sta 3	.834347	.225505	.646079	.654861	.962322	.601823	.526351
Sta 4		.232043	.686619	.648643	.958376	.742218	.485736
Sta 5			.067887	**.04795***	.159345	.112709	.435463
Sta 6				.793791	.771365	.714562	.242913
Sta 7					.710338	.802691	.189968
Sta 8						.856783	.277800
Sta 9							.342190

WAWW – Whole-animal wet weight.
Values in **bold** face and marked with an asterisk indicate a significant difference between stations.

Table 11. Summary of water temperature conditions during the study, by station, summer 1997.

	Min. temp. (°C)	Max. temp. (°C)	Mean temp. (°C)
Sta 1	15.9	26.3	20.2
Sta 2	13.9	23.1	18.2
Sta 3	12.4	24.0	18.2
Sta 4	12.1	24.5	17.8
Sta 5	10.5	24.1	15.1
Sta 6	11.8	24.2	18.3
Sta 7	13.4	23.7	18.7
Sta 8	14.1	23.5	18.7
Sta 9	13.2	23.2	18.5
Sta 10	13.9	24.1	18.5

Table 12. Results of statistical analyses on mean daily temperature data.

Comparison stations	Mean difference	Standard deviation	*t*-statistic	df	*p*-value
Station 1 - Station 2	1.93	0.46	4.21	10	**0.0018***
Station 1 - Station 3	1.95	0.27	7.23	10	**0.0000***
Station 1 - Station 4	2.45	0.22	11.29	10	**0.0000***
Station 1 - Station 5	5.08	0.29	17.32	10	**0.0000***
Station 1 - Station 6	1.82	0.27	6.85	10	**0.0000***
Station 1 - Station 7	1.35	0.33	4.06	10	**0.0023***
Station 1 - Station 8	1.61	0.35	4.58	10	**0.0010***
Station 1 - Station 9	1.60	0.38	4.23	10	**0.0018***
Station 1 - Station 10	1.67	0.35	4.81	10	**0.0007***
Station 2 - Station 3	0.01	0.21	0.03	10	0.9765
Station 2 - Station 4	0.49	0.28	1.72	10	0.1164
Station 2 - Station 5	3.27	0.32	10.26	10	**0.0000***
Station 2 - Station 6	0.08	0.27	0.30	10	0.7705
Station 2 - Station 7	0.51	0.18	2.91	10	0.1555
Station 2 - Station 8	0.40	0.11	3.51	10	**0.0056***
Station 2 - Station 9	0.41	0.21	2.00	10	0.0732
Station 2 - Station 10	0.29	0.07	3.91	10	**0.0029***
Station 3 - Station 4	0.31	0.10	3.29	10	**0.0081***
Station 3 - Station 5	3.28	0.25	13.07	10	**0.0000***
Station 3 - Station 6	0.05	0.18	0.28	10	0.7865
Station 3 - Station 7	0.47	0.07	6.26	10	**0.0001***
Station 3 - Station 8	0.47	0.16	2.87	10	0.0166
Station 3 - Station 9	-0.37	0.09	-4.13	10	**0.0021***
Station 3 - Station 10	0.28	0.16	1.77	10	0.1076
Station 4 - Station 5	2.72	0.22	12.38	10	**0.0000***
Station 4 - Station 6	0.47	0.08	6.01	10	**0.0001***
Station 4 - Station 7	1.16	0.19	6.20	10	**0.0001***
Station 4 - Station 8	0.93	0.27	3.41	10	**0.0067***
Station 4 - Station 9	0.68	0.16	4.32	10	**0.0015***
Station 4 - Station 10	0.78	0.25	3.16	10	0.0102
Station 5 - Station 6	3.03	0.15	19.58	10	**0.0000***
Station 5 - Station 7	3.46	0.22	15.48	10	**0.0000***
Station 5 - Station 8	3.65	0.35	10.40	10	**0.0000***
Station 5 - Station 9	3.44	0.39	8.88	10	**0.0000***
Station 5 - Station 10	3.40	0.43	7.91	10	**0.0000***
Station 6 - Station 7	0.53	0.17	3.19	10	**0.0097***
Station 6 - Station 8	0.49	0.27	1.81	10	0.0999
Station 6 - Station 9	-0.24	0.18	-1.32	10	0.2161
Station 6 - Station 10	0.20	0.24	0.83	10	0.4281
Station 7 - Station 8	0.23	0.12	1.85	10	0.0948
Station 7 - Station 9	0.28	0.12	2.28	10	0.0460
Station 7 - Station 10	0.23	0.13	1.86	10	0.0924
Station 8 - Station 9	0.11	0.10	1.05	10	0.3172
Station 8 - Station 10	0.06	0.12	0.49	10	0.6319
Station 9 - Station 10	-0.02	0.09	-0.20	10	0.8481

NOTE: *p*-values in bold with asterisk represent significant difference between comparison stations.
df–degrees of freedom.

Table 13. Differences in weekly temperature ranges across stations.

	Sta 1	Sta 2	Sta 3	Sta 4	Sta 5	Sta 6	Sta 7	Sta 8	Sta 9	Sta 10
Means of ranges	4.87	7.00	7.97	8.43	8.47	8.84	6.79	5.90	6.62	7.32

Comparison	Test statistic	# of means	*p*-value
Station 1 - Station 2	5.676	5	**<0.005***
Station 1 - Station 3	7.763	7	**<0.001***
Station 1 - Station 4	8.551	9	**<0.001***
Station 1 - Station 5	8.296	8	**<0.001***
Station 1 - Station 6	9.182	10	**<0.001***
Station 1 - Station 7	5.376	4	**<0.005***
Station 1 - Station 8	3.329	2	**<0.025***
Station 1 - Station 9	4.888	3	**<0.005***
Station 1 - Station10	6.380	6	**<0.001***
Station 2 - Station 6	3.505	6	>0.10
Station 2 - Station 8	2.348	4	>0.20

NOTE: *p*-values in bold with asterisk represent significant difference between comparison stations.

Table 14. Results of chemical analyses on sediment samples collected at the end of the study.

	THg (μg/g)	MeHg (μg/g)	As (μg/g)	Cd (μg/g)	Cr (μg/g)	Pb (μg/g)	TOC (%)	Dry wt (%)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Porosity (%)	Dry bulk density (g/cm^3)
Sta 1	0.0896	0.000737	6.49	0.98U	27.1	16.8	0.86	23.2	0.07	91.79	6.23	1.91	48.15	1.37
Sta 2	0.0311	0.0000385	2.00U	0.98U	13.4U	13.6U	0.23	79.7	0.81	95.35	2.66	1.18	44.07	1.5
Sta 3	2.07	0.00226	12.3	5.33	20598	218	11.72	16.2	0	48.61	32.97	18.42	81.3	0.35
Sta 4	1.27	0.00648	24	13.1	17789	142	12.38	26	0	28.59	47.97	23.44	81.86	0.35
Sta 5	1.04	0.00461	14.4	14.1	10108	114	10.53	25.1	0	21.62	50.39	27.99	85.07	0.31
Sta 6	0.433	0.0032	23.8	2.75	7800	60.7	5.09	51.2	0	50.56	40.39	9.05	68.06	0.79
Sta 7	0.264	0.0016	8.36	3.67	4479	53	1.66	63.3	0	54.4	40.3	5.3	54.82	1.15
Sta 8	0.19	0.000998	10.5	2.15	3980	55.7	5.52	71	0.04	80.25	16.16	3.55	50.57	1.22
Sta 9	0.0969	0.000707	5.19	0.98U	984	15.7	0.7	69.8	0	89.06	8.22	2.71	50.87	1.28
Sta 10	0.126	0.000409	2.00U	0.98U	1291	21.5	0.67	72.7	0.54	93	4.79	1.67	49.04	1.37

Table 15. Results of chemical analyses on surface water samples collected at the beginning and end of the study.

	THg (UF) (ng/L)	THg (Dis) (ng/L)	MeHg (UF) (ng/L)	MeHg (Dis) (ng/L)	As (UF) (μg/L)	As (Dis) (μg/L)	Cd (UF) (μg/L)	Cd (Dis) (μg/L)	Cr (UF) (μg/L)	Cr (Dis) (μg/L)	Pb (UF) (μg/L)	Pb (Dis) (μg/L)	TSS (mg/L)	TOC (mg/L)	DOC (mg/L)	Hard-ness (mg/L)	NH_4 (mg N/L)	NO_2	Chl-*a* (μg/L)	Phaeo (μg/L)	pH
Deployment																					
Sta 1	2.07	1.87	0.224	0.201	0.26	0.18	0.1U	0.1U	1.70U	1.70U	0.61U	0.61U	2	10.2	11.42	46.8	0.018	NA	2.03	1.58	7.0
Sta 4	5.7	0.728	0.0939	0.0214(J)	0.18	0.11	0.1U	0.1U	45.4	3.06	0.61U	0.61U	2.63	2.13	2.12	79.7	0.015	NA	2.19	1.25	7.0
Sta 5	0.771	0.488	0.0843	0.0376	0.2	0.15	0.1U	0.1U	32.7	2.28	0.61U	0.61U	2.19	2.09	1.95	78.5	0.024	NA	1.86	0.78	7.0
Sta 9	1.35	0.315	0.0317	0.0294(J)	0.21	0.2	0.1U	0.1U	6.95	0.79J	0.61U	0.61U	2.49	1.39	1.88	51.3	0.011	NA	1.62	0.55	7.0
Sta 10	2.63	0.431	0.0173(J)	0.0279(J)	0.27	0.2	0.1U	0.1U	5.82	0.42J	0.61U	0.61U	4.38	1.86	1.73	48.7	0.008	NA	3.22	1.13	7.0
Retrieval																					
Sta 1	1.19	1.57	0.112	0.0788	< 0.05	< 0.05	< 0.05	< 0.05	< 0.20	< 0.20	< 0.41	< 0.41	0.641	3.94	3.2	40	0.005	0.0013	2.75	1.55	6.81
Sta 4	2.14	0.94	0.0478	0.0321	0.06	0.06	< 0.05	0.06	7.23	1.23	< 0.41	< 0.41	0.226	2.37	1.9	61.3	0.022	0.0034	1.99	0.76	5.99
Sta 5	1.9	0.755	0.0628	< 0.0306(U)	0.08	0.1	< 0.05	< 0.05	6.27	1.01	< 0.41	< 0.41	0.604	2.3	1.92	64.7	0.041	0.0042	1.83	0.97	6.07
Sta 9	1.93	1.12	0.0619	< 0.0310(U)	0.16	0.11	< 0.05	0.05	8.12	1.05	< 0.41	< 0.41	0.415	2.24	1.89	61.1	0.048	0.0037	1.95	0.93	6.29
Sta 10	1.32	1.08	0.0304	< 0.0307(U)	0.06	0.05	< 0.05	< 0.05	3.15	0.7	< 0.41	< 0.41	0.181	2.31	1.89	43	0.038	0.0038	2.8	1.34	6.52

J = uncertain value; U = below detection limit; UF = unfiltered; Dis = dissolved; NA = Not available
All metals in terms of total concentration

Table 16. Calculated quotients for EOT sediment concentration/LEL, and sum of quotients by station.

	THg	MeHg	As	Cd	Cr	Pb	Sum of Quotients	TOC	% fines
Sta 1	0.45	na	1.08	0.82	1.04	0.54	**3.93**	0.86	8.14
Sta 2	0.16	na	0.17	0.82	0.26	0.22	**1.62**	0.23	3.84
Sta 3	10.35	na	2.05	8.88	792.23	7.03	**820.55**	11.72	51.39
Sta 4	6.35	na	4.00	21.83	684.19	4.58	**720.96**	12.38	71.41
Sta 5	5.20	na	2.40	23.50	388.77	3.68	**423.55**	10.53	78.38
Sta 6	2.17	na	3.97	4.58	300.00	1.96	**312.67**	5.09	49.44
Sta 7	1.32	na	1.39	6.12	172.27	1.71	**182.81**	1.66	45.6
Sta 8	0.95	na	1.75	3.58	153.08	1.80	**161.16**	5.52	19.71
Sta 9	0.48	na	0.87	0.82	37.85	0.51	**40.52**	0.7	10.93
Sta 10	0.63	na	0.17	0.82	49.65	0.69	**51.96**	0.67	6.46
LEL values (µg/g)	0.2	na	6.0	0.6	26.0	31.0			

na – not available

Table 17. Correlation coefficients *(r)* for trace elements in surface water, sediment, and clam tissues.

	Cr	THg	MeHg	As	Cd	Pb
water : sediment	0.53	0.48	0.03	-0.83	na	na
water : tissue	0.62	-0.46	0.52	0.300	na	na
sediment : tissue	0.27	0.0001	0.68	-0.042	-0.3	0.12

na = not able to calculate coefficients because there was no linear spread in the data

Table 18. Correlation coefficients for tissue chemistry vs. clam growth metrics based on concentration and content.

Clam Tissue Concentration

	Cr	THg	MeHg	As	Cd	Pb
Survival	-0.251	-0.355	-0.484	-0.354	0.019	-0.253
EOT WAWW	-0.210	-0.055	0.097	-0.274	-0.284	-0.169
Growth Rate	-0.223	-0.340	-0.256	-0.477	-0.102	-0.283
Tissue Weight (wet)	0.267	-0.082	-0.238	0.115	0.089	0.109
Tissue Weight (dry)	0.342	-0.162	-0.324	0.247	0.260	0.175

Clam Tissue Content

	Cr	THg	MeHg	As	Cd	Pb
Survival	-0.172	-0.162	-0.309	0.064	0.223	-0.133
EOT WAWW	-0.175	0.190	0.351	0.238	-0.034	-0.075
Growth Rate	-0.133	0.068	0.162	0.380	0.307	-0.116
Tissue Weight (wet)	0.283	-0.031	-0.176	0.256	0.160	0.137
Tissue Weight (dry)	0.355	-0.114	-0.268	0.385	0.322	0.198

EOT WAWW – end-of-test whole-animal wet weight.

Table 19. Correlation coefficients for temperature vs. clam growth metrics.

Survival	0.363
Growth Rate	0.122
Tissue Weight (wet)	-0.196
Tissue Weight (dry)	-0.292

8.0 FIGURES

Figure 1. Location of Cannelton Industries, Inc., Sault Ste. Marie, Michigan, and clam deployment stations in Tannery Bay and at reference stations near Waiska Bay (REF-1) and Seymour Creek (REF-2).

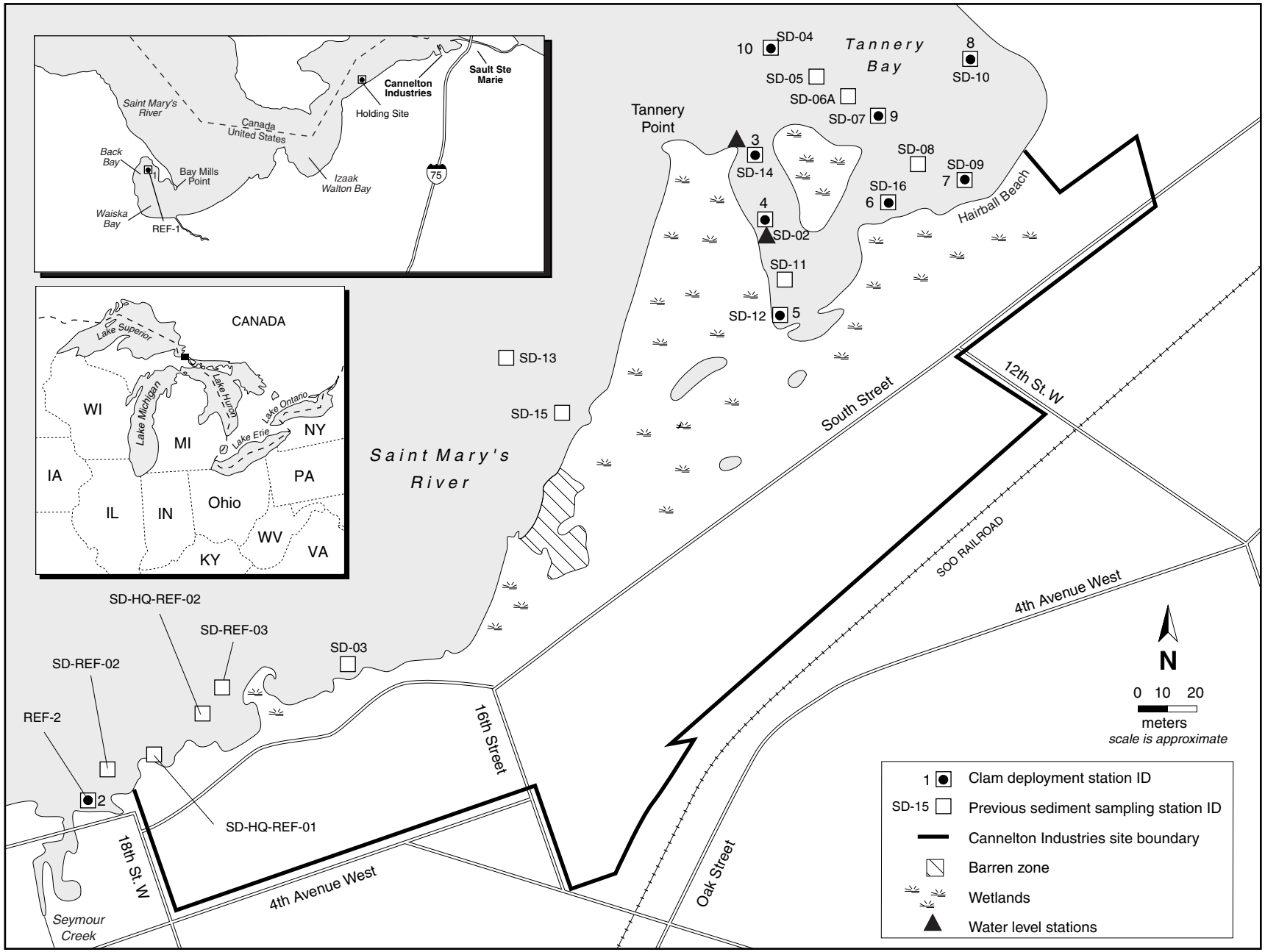
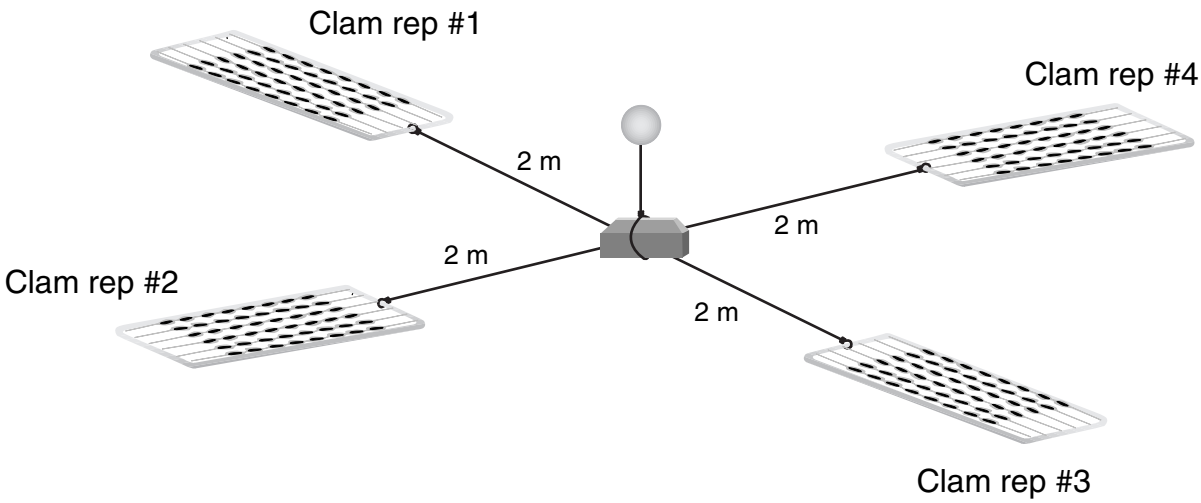


Figure 2. Deployment layout at each station.



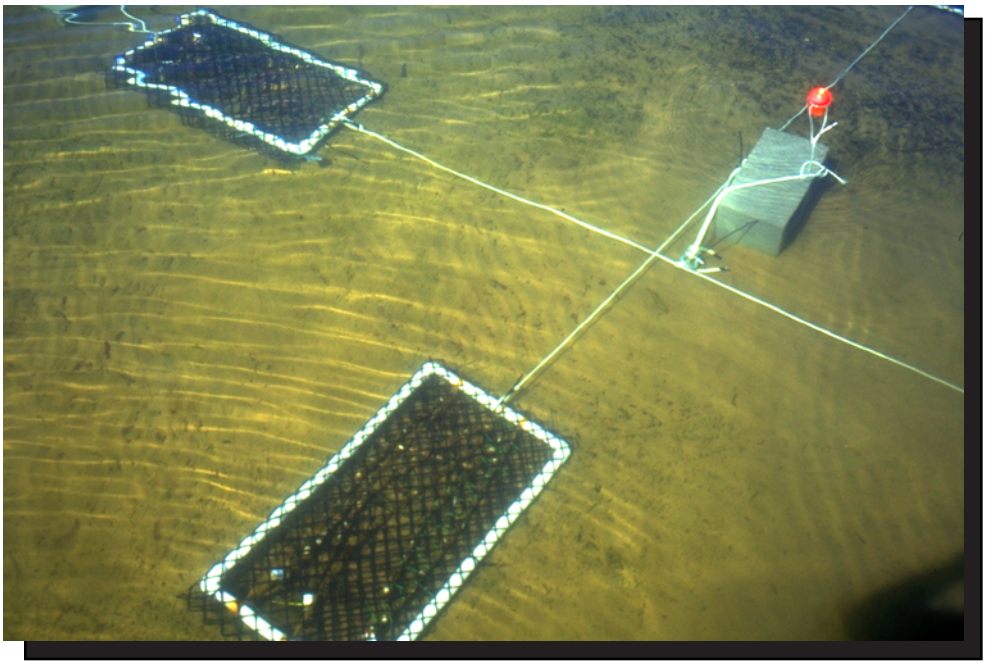
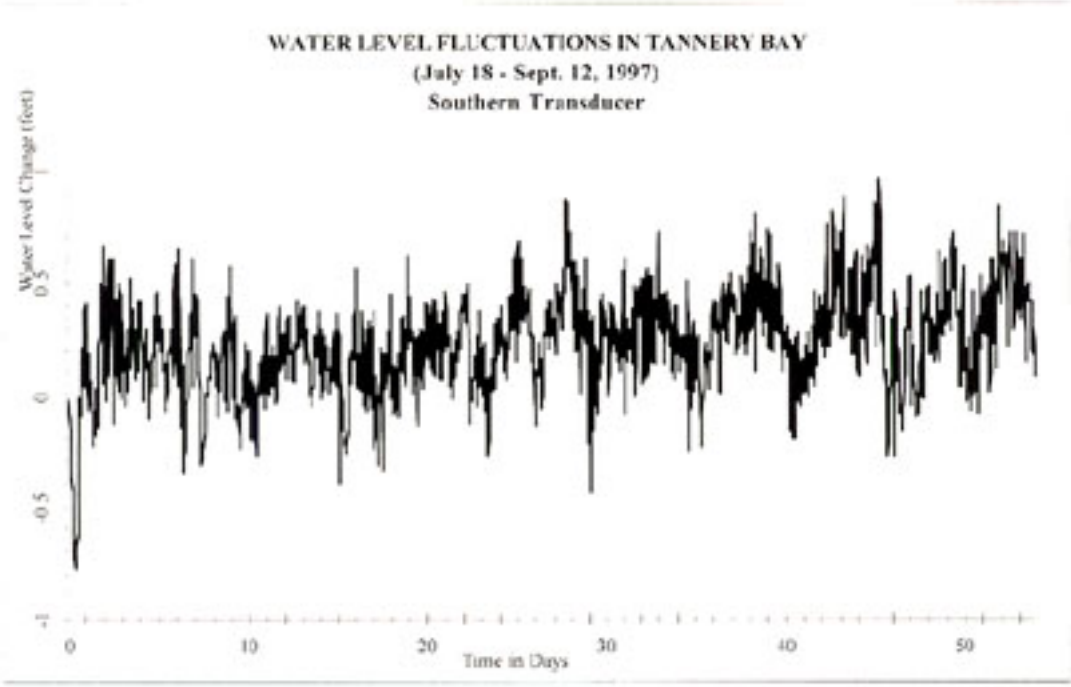


Figure 3. Water level fluctuations in Tannery Bay throughout the deployment period.



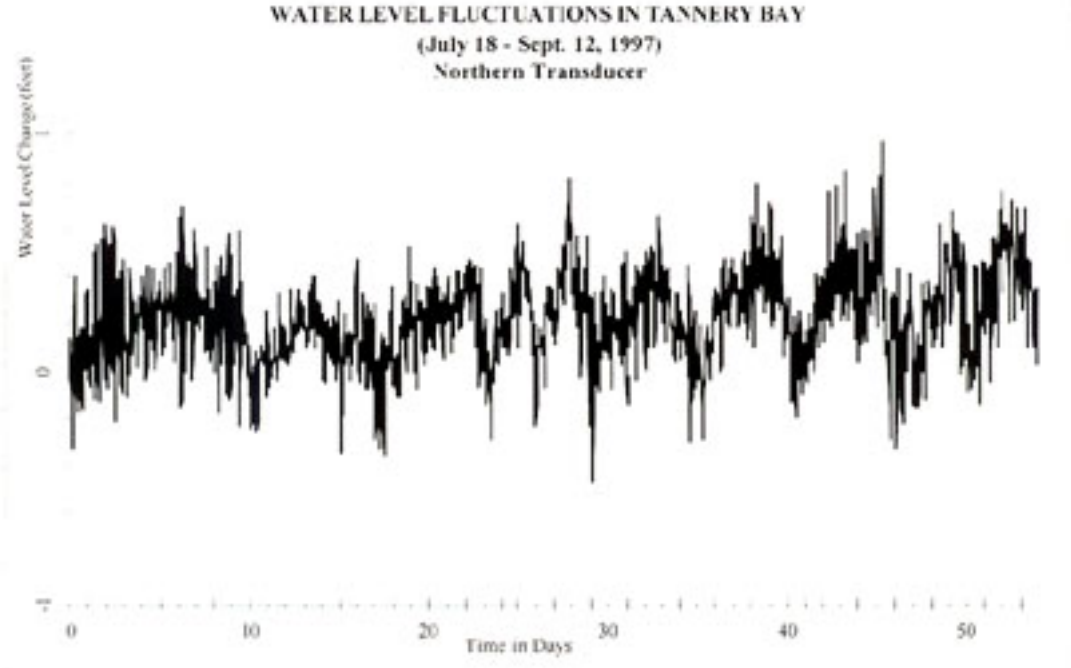
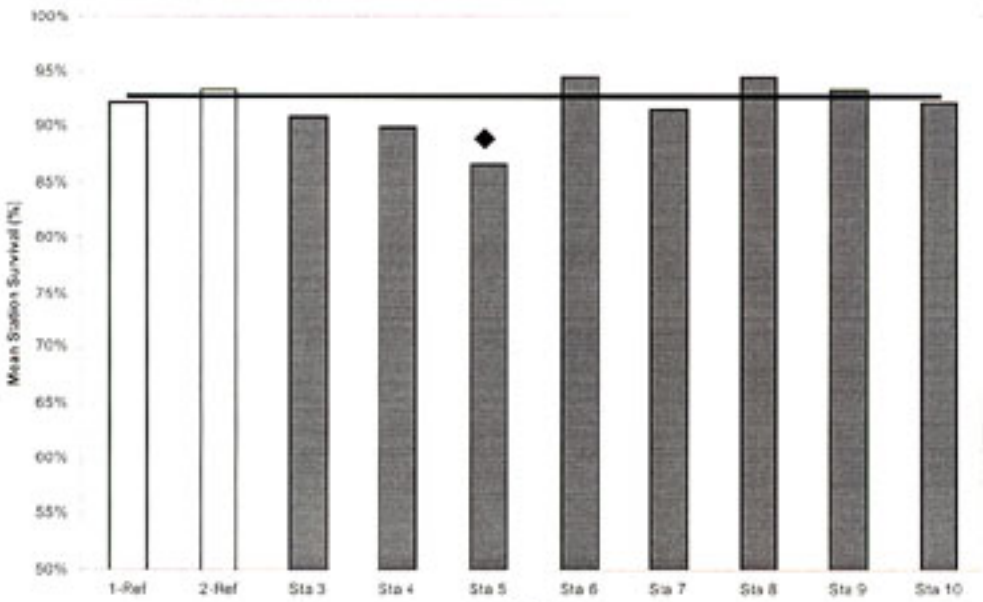


Figure 4. End-of-test percent survival for clams deployed in Tannery Bay and at reference stations.



Solid line = Average of reference stations

♦ Significantly less than average of reference stations

Figure 5a. Arsenic concentration in tissues of clams deployed in Tannery Bay and at reference stations.

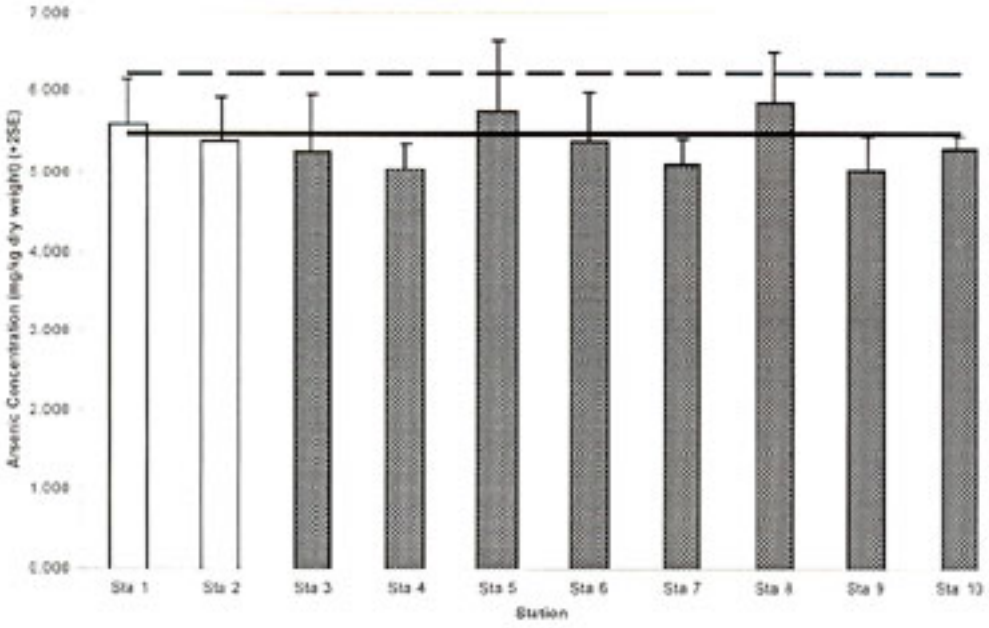
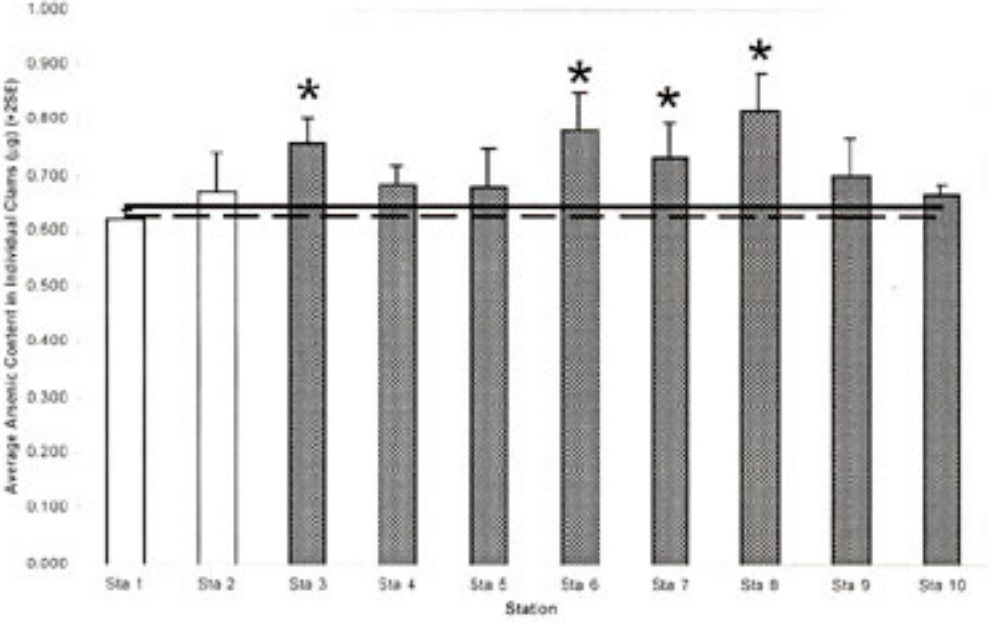


Figure 5b. Arsenic content in clams deployed in Tannery Bay and at reference stations.



Dashed line = T_0 (Initial)
Solid line = Average of reference stations
*Significantly greater than average of reference stations

Figure 6a. Cadmium concentration in tissues of clams deployed in Tannery Bay and at reference stations.

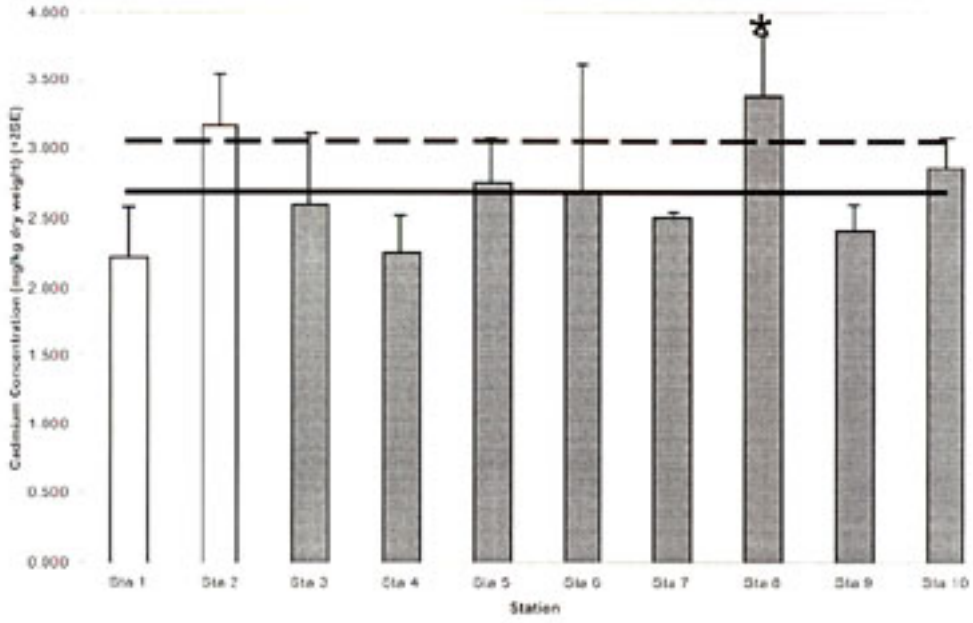
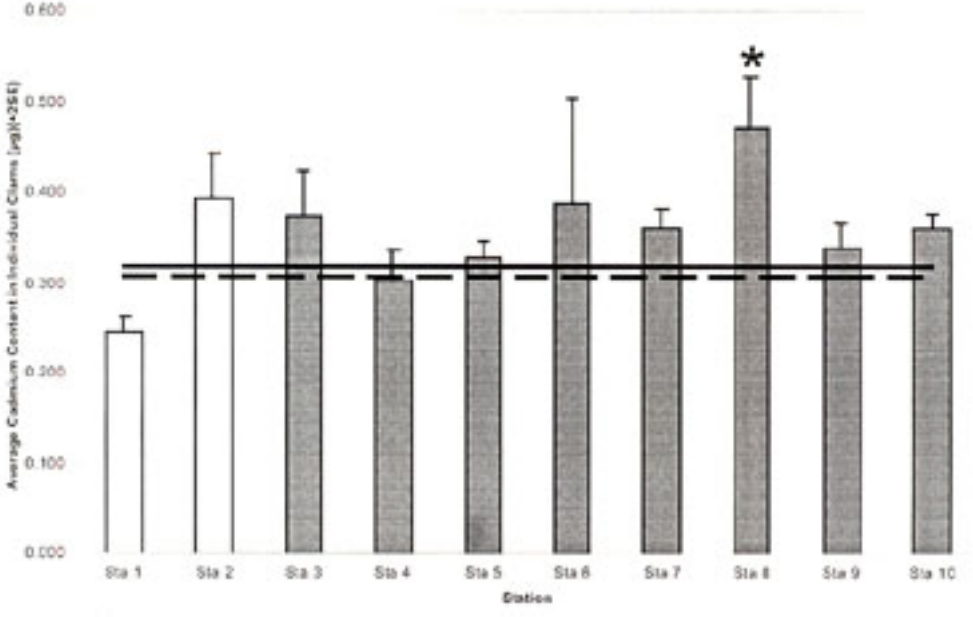


Figure 6b. Cadmium content in clams deployed in Tannery Bay and at reference stations.



Dashed line = T_0 (Initial)
Solid line = Average of reference stations
*Significantly greater than average of reference stations

Figure 7a. Total chromium concentration in tissues of clams deployed in Tannery Bay and at reference stations.

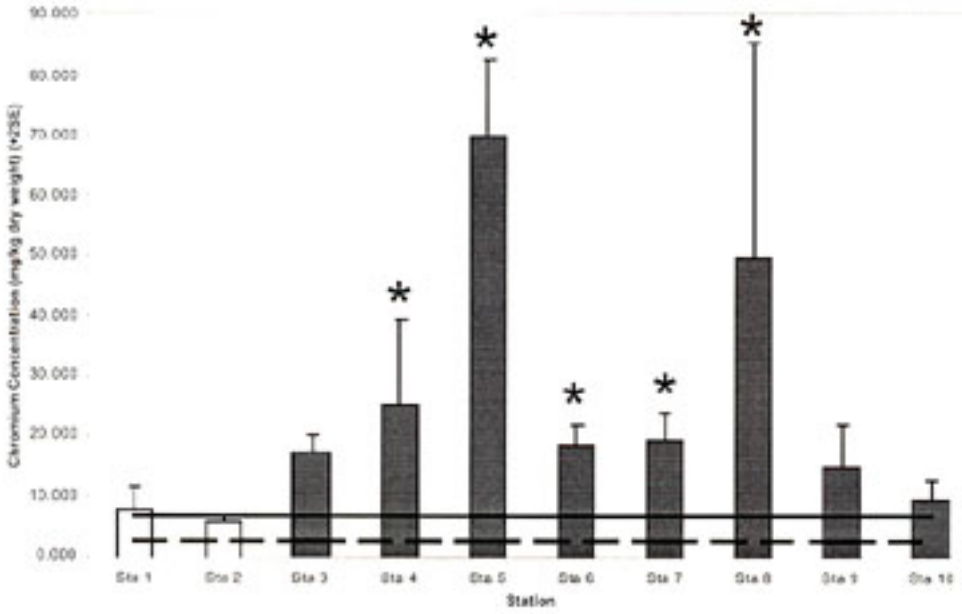
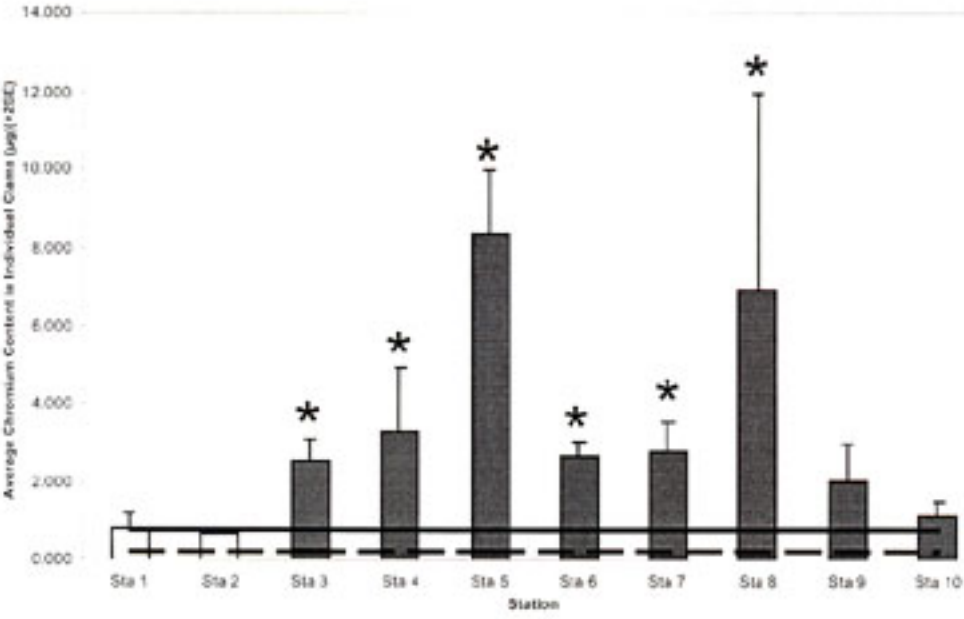


Figure 7b. Total chromium content in clams deployed in Tannery Bay and at reference stations.



Dashed line = T_0 (Initial)
Solid line = Average of reference stations
*Significantly greater than average of reference stations

Figure 8b. Lead concentration in clams deployed in Tannery Bay and at reference stations

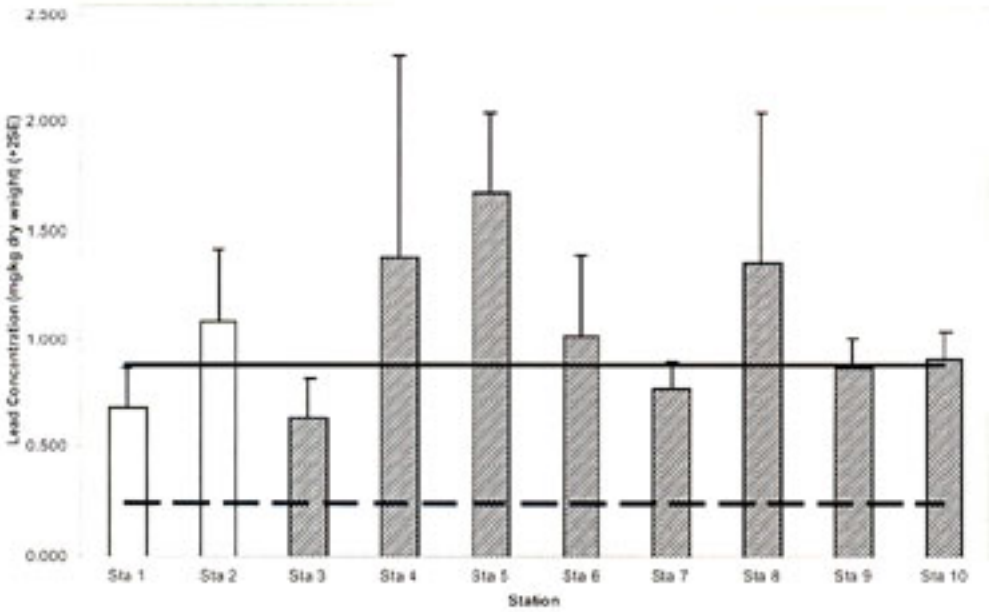
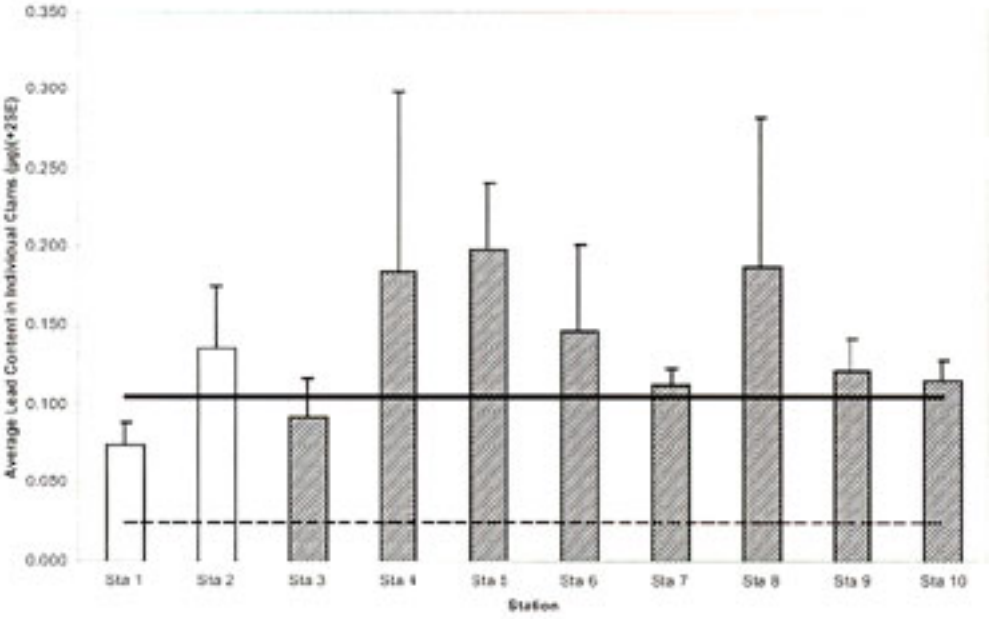


Figure 8b. Lead content in clams deployed in Tannery Bay and at reference stations



Dashed line = T_0 (Initial)
Solid line = Average of reference stations

Figure 9a. Total mercury concentration in tissues of clams deployed in Tannery Bay and at reference Stations.

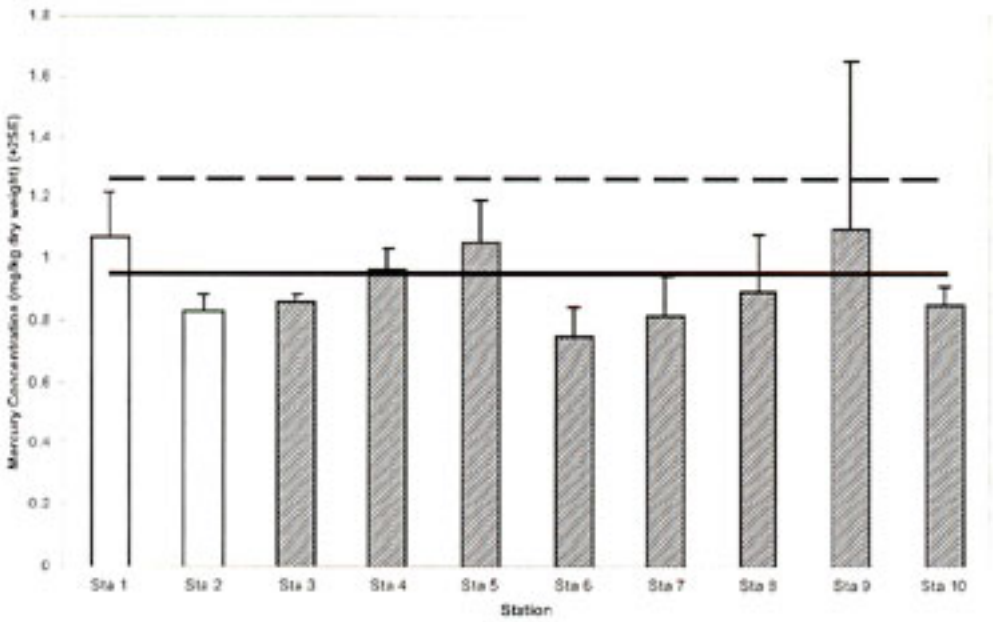
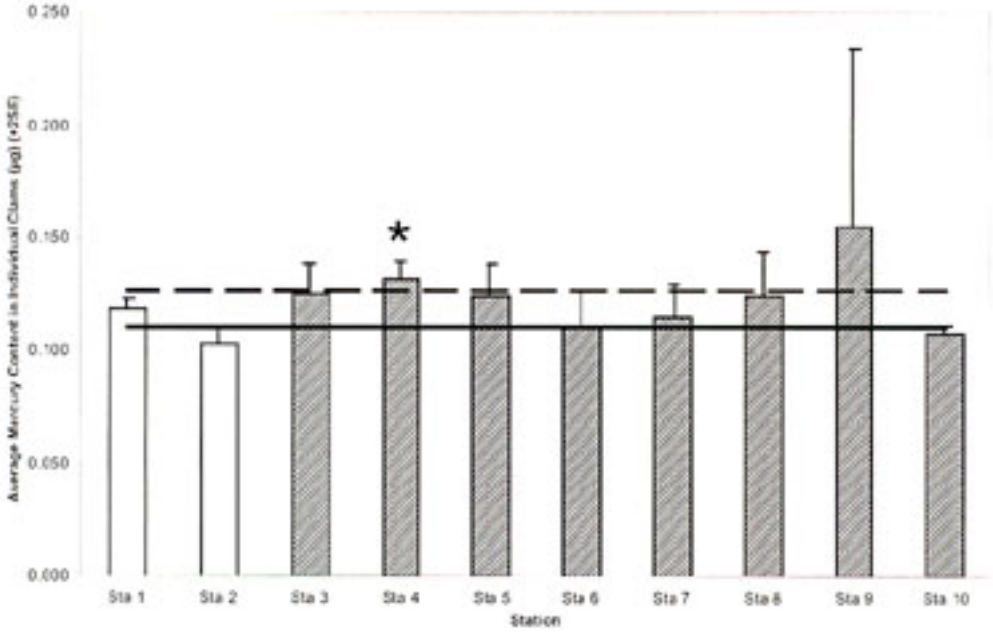


Figure 9b. Total mercury content in tissues of clams deployed in Tannery Bay and at reference Stations.



Dashed line = T_0 (Initial)
Solid line = Average of reference stations
*Significantly greater than average of reference stations

Figure 10a. Methylmercury concentration in tissues of clams deployed in Tannery Bay and at reference stations.

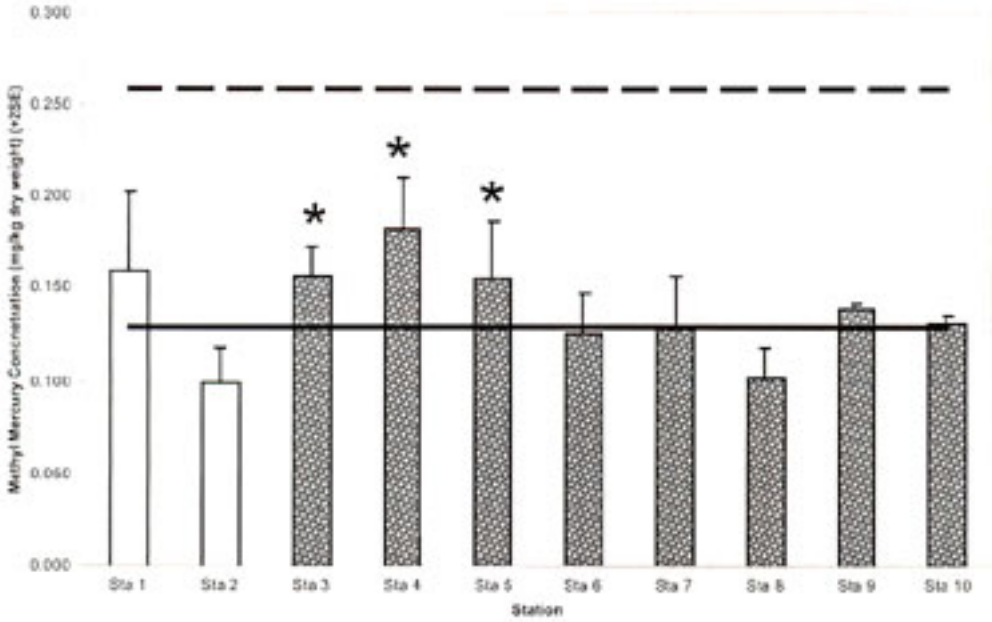
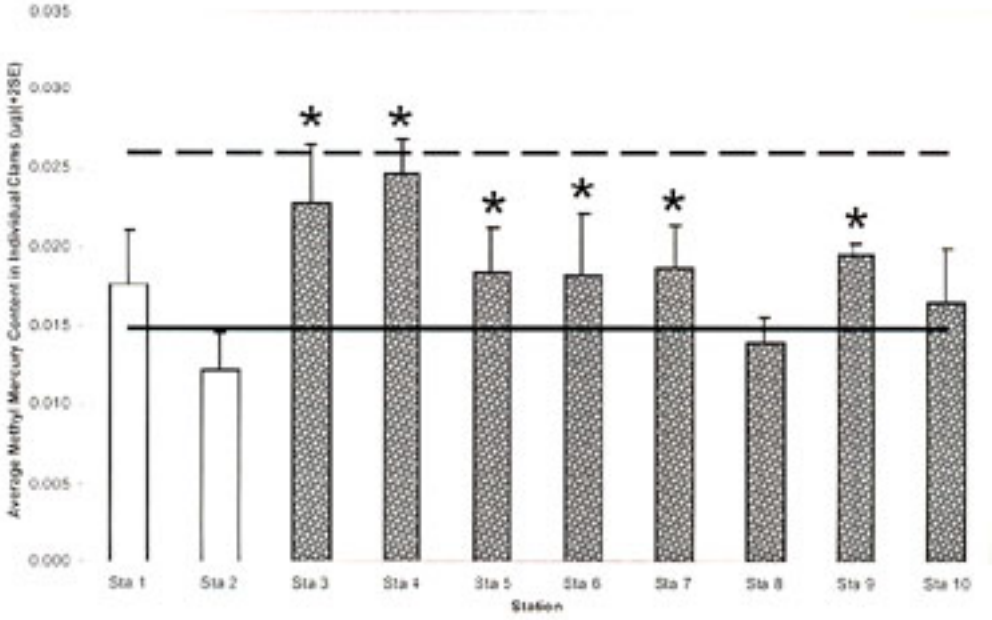


Figure 10b. Methylmercury content in tissues of clams deployed in Tannery Bay and at reference stations.



Dashed line = $\bar{T}_0$ (Initial)
Solid line = Average of reference stations
*Significantly greater than average of reference stations

Figure 11. End-of-test whole-animal wet weight for clams deployed in Tannery Bay and at reference stations.

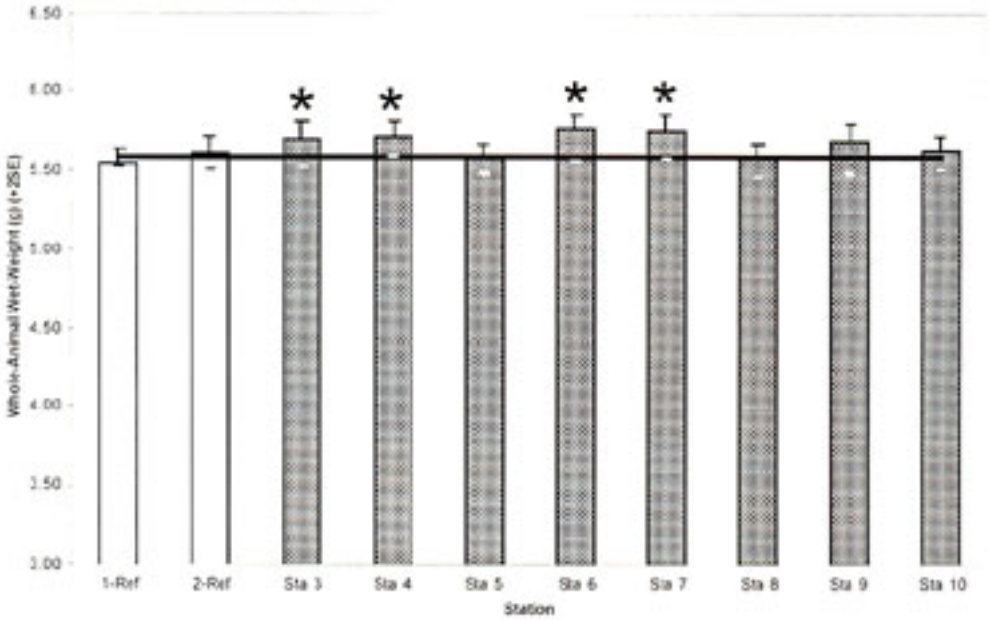
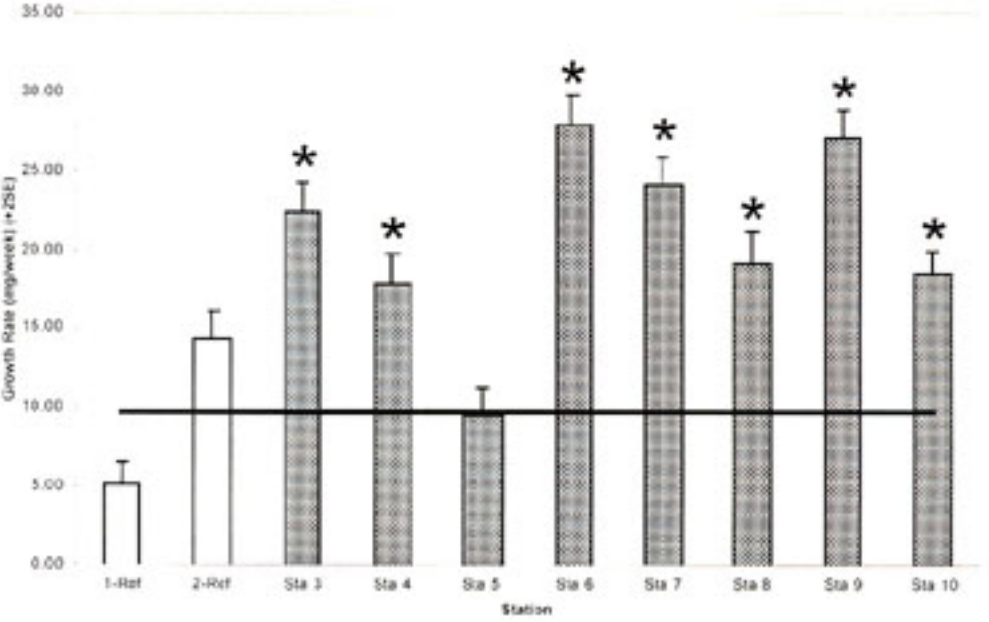


Figure 12. Whole-animal wet-weight growth rates for clams deployed in Tannery Bay and at reference stations.



Dashed line = T_0 (Initial)
Solid line = Average of reference stations
*Significantly greater than average of reference stations

Figure 13. End-of-test tissue weights for clams deployed in Tannery Bay and at reference stations.

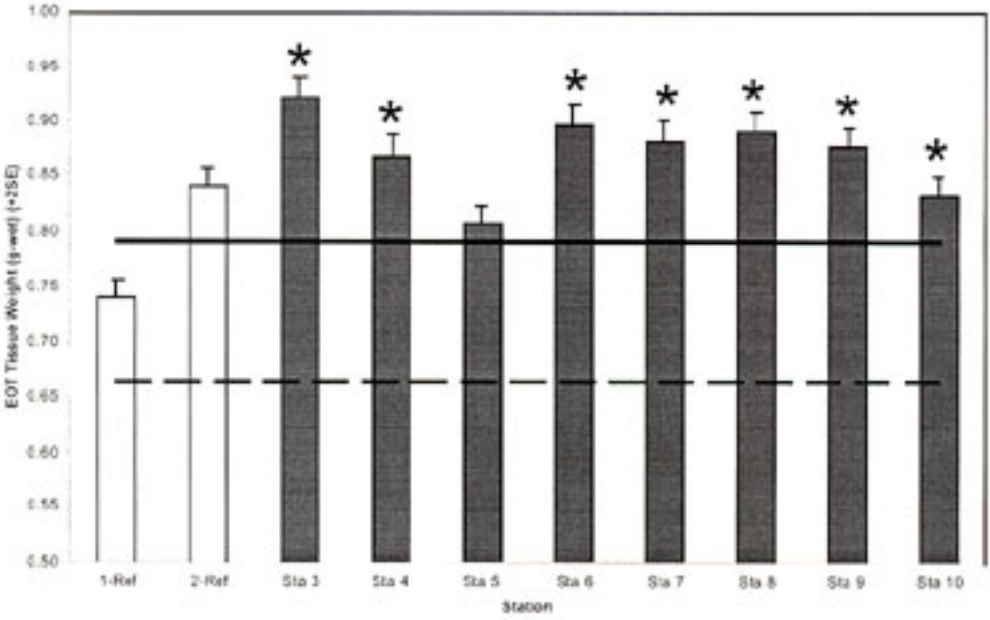
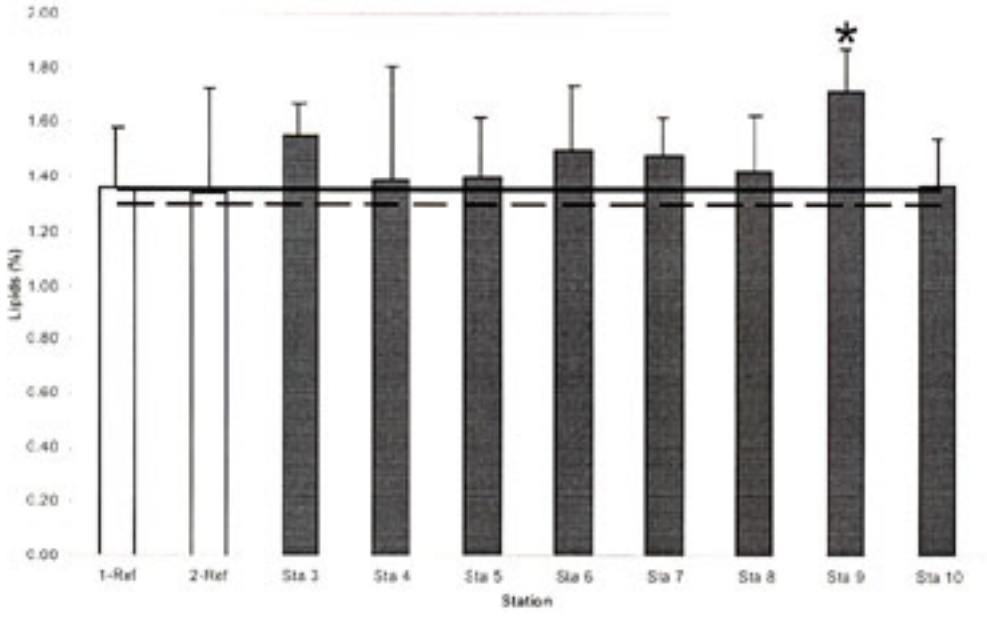


Figure 14. Percent lipids for clams deployed in Tannery Bay and at reference stations.



Dashed line = T_0 (Initial)
Solid line = Average of reference stations
*Significantly greater than average of reference stations

Figure 15. Percent solids for clams deployed in Tannery Bay and at reference stations.

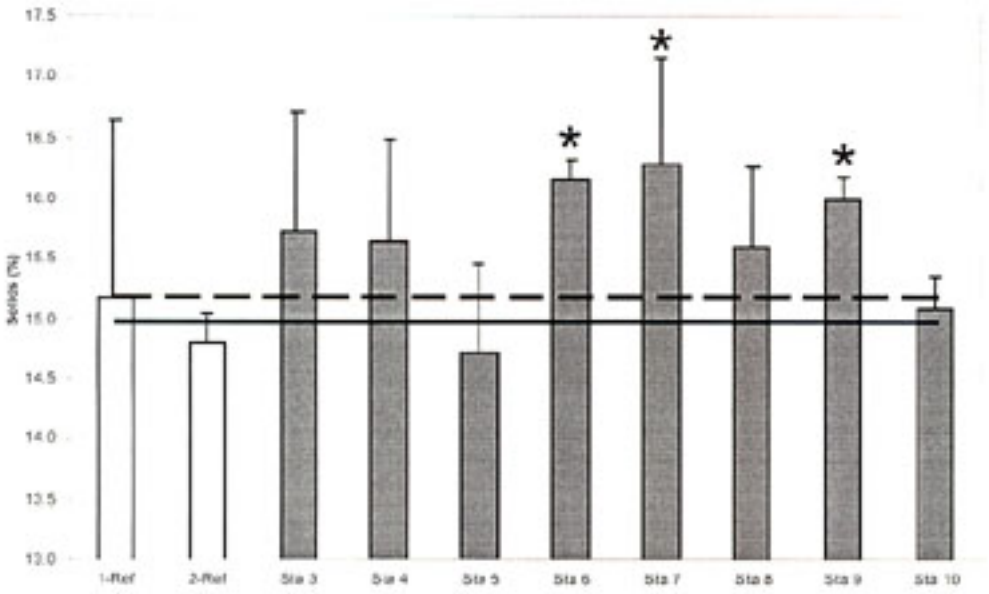
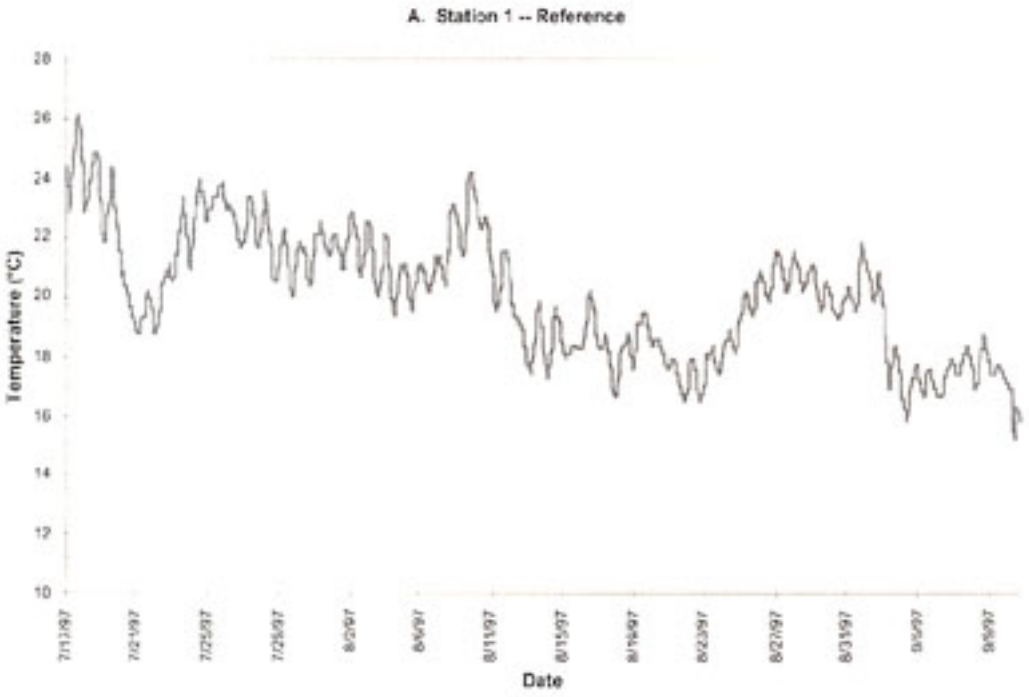


Figure 16. Water temperatures in Tannery Bay and at reference stations.



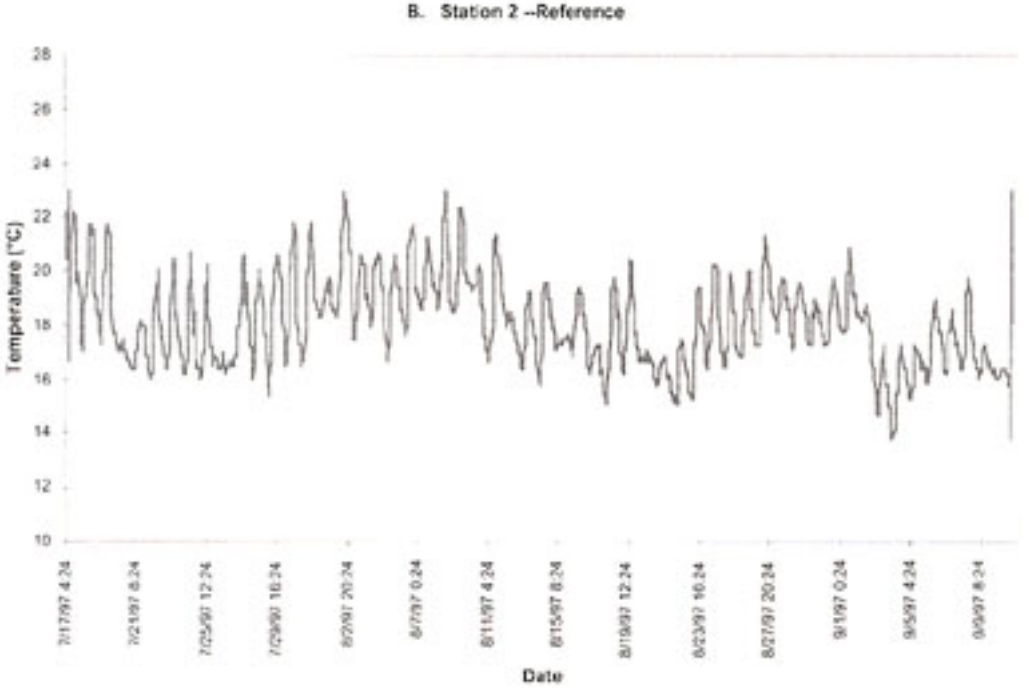
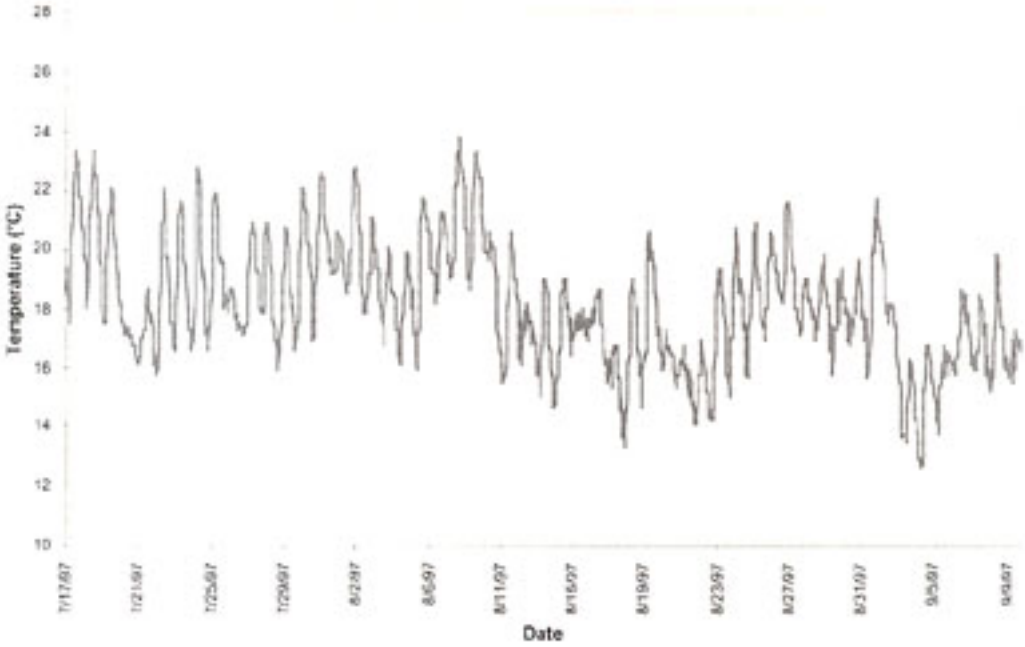


Figure 16 cont.

C. Station 3



D. Station 4

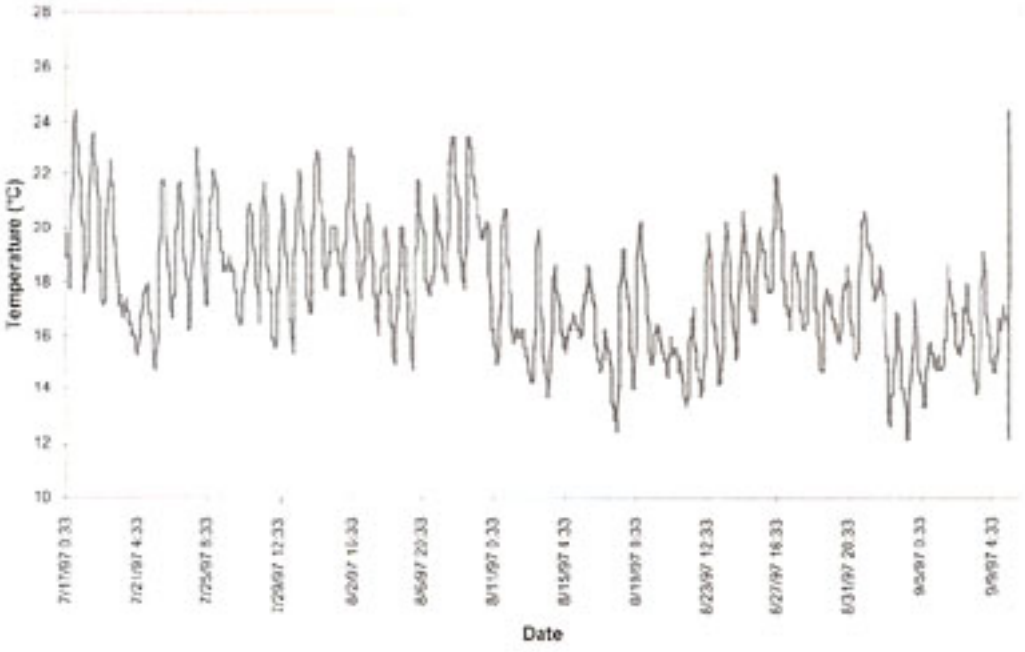
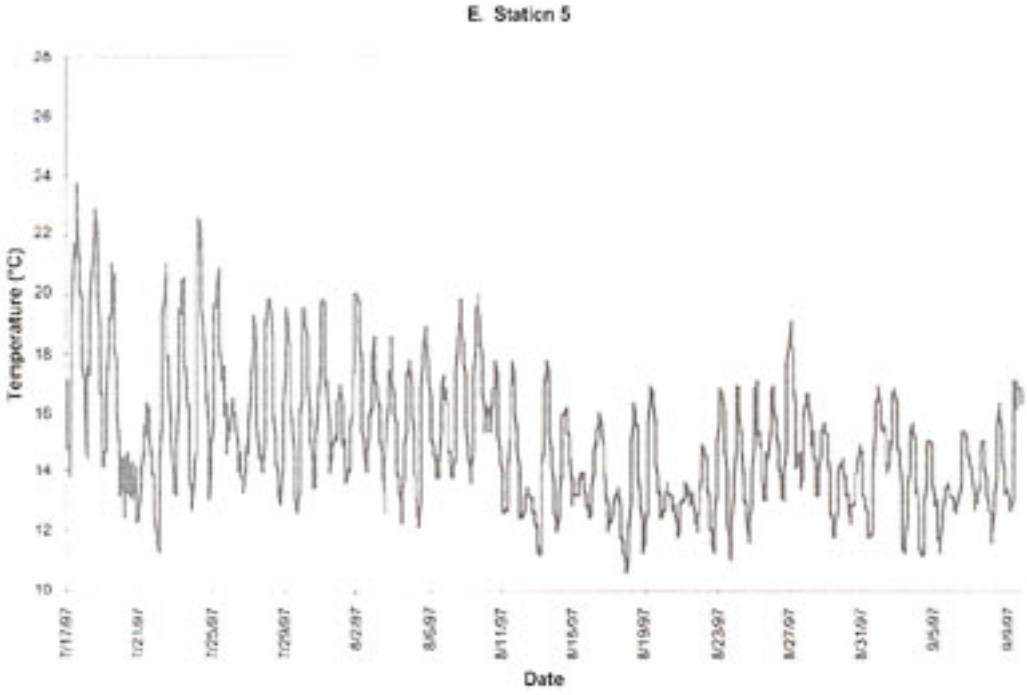


Figure 16 cont.



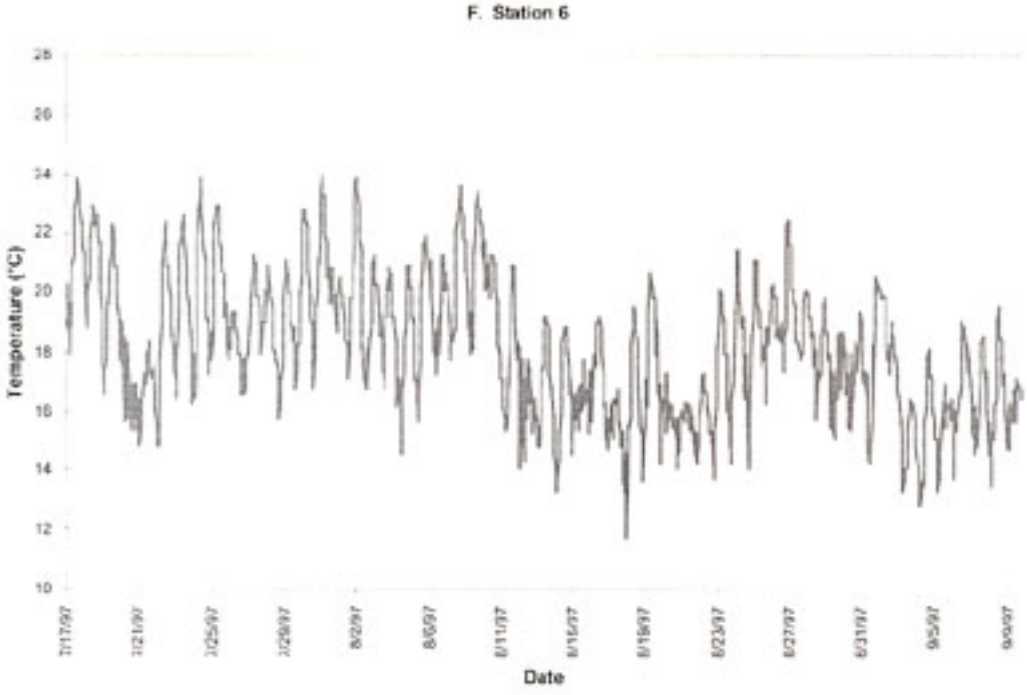
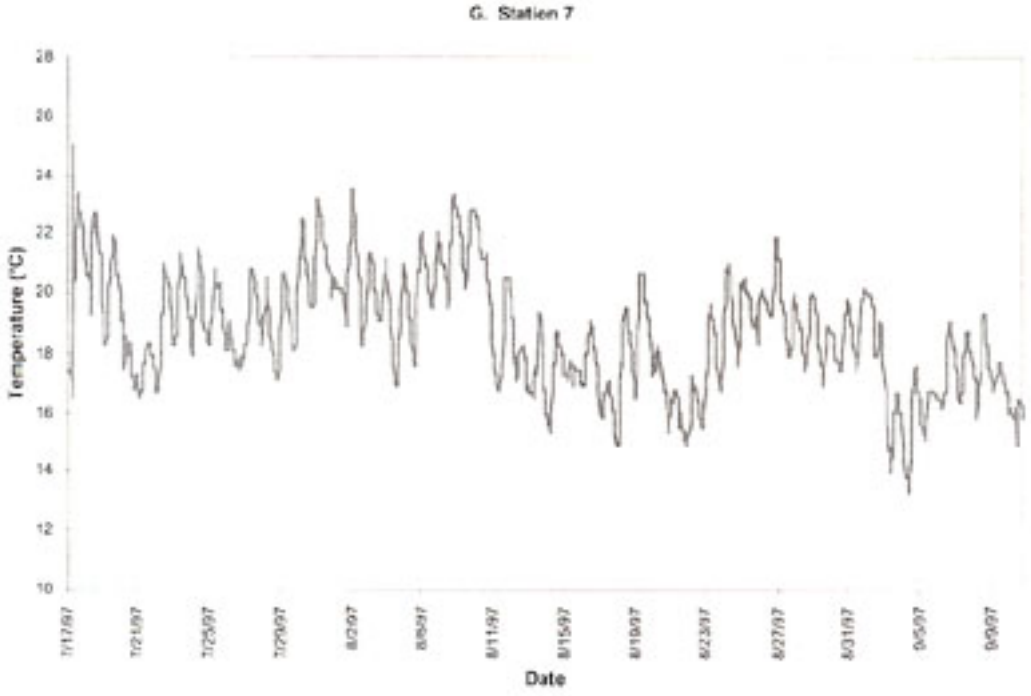


Figure 16 cont.



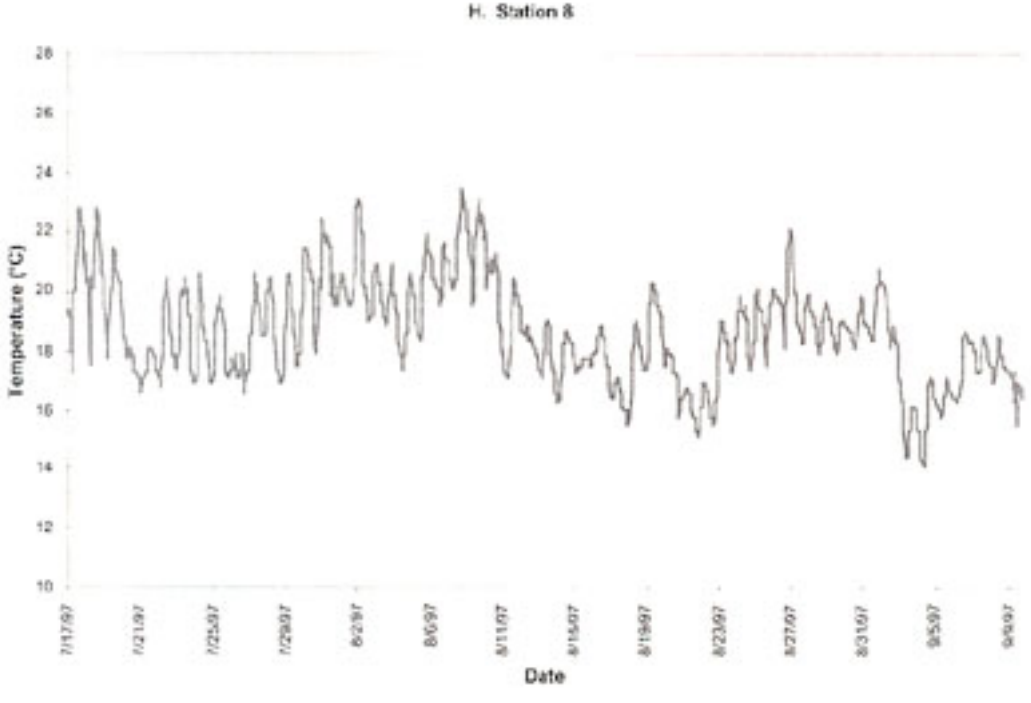
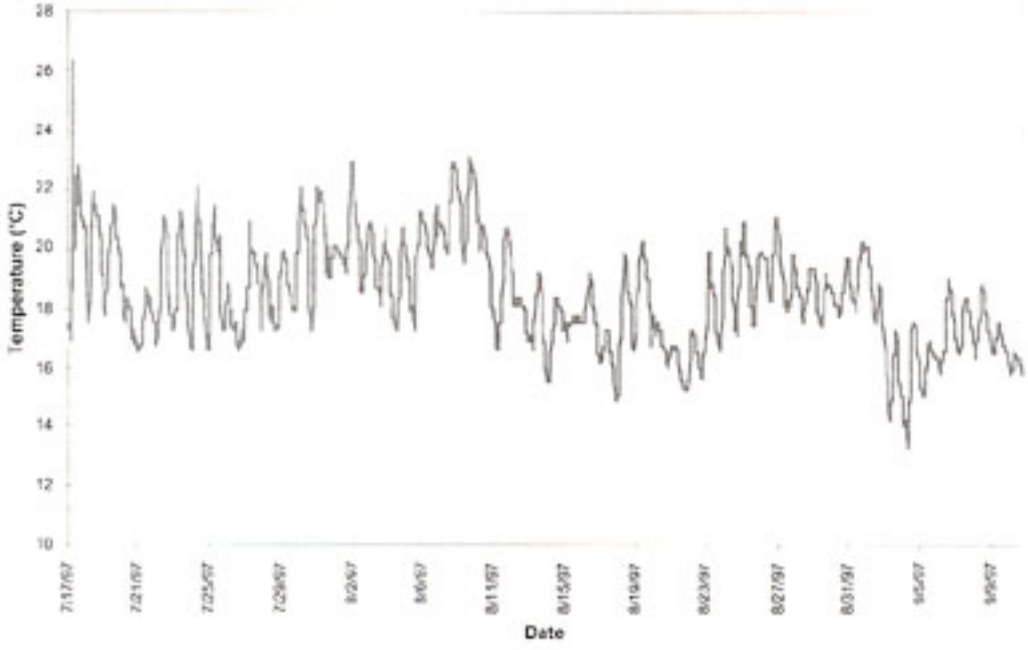


Figure 16 cont.

I. Station 9



J. Station 10

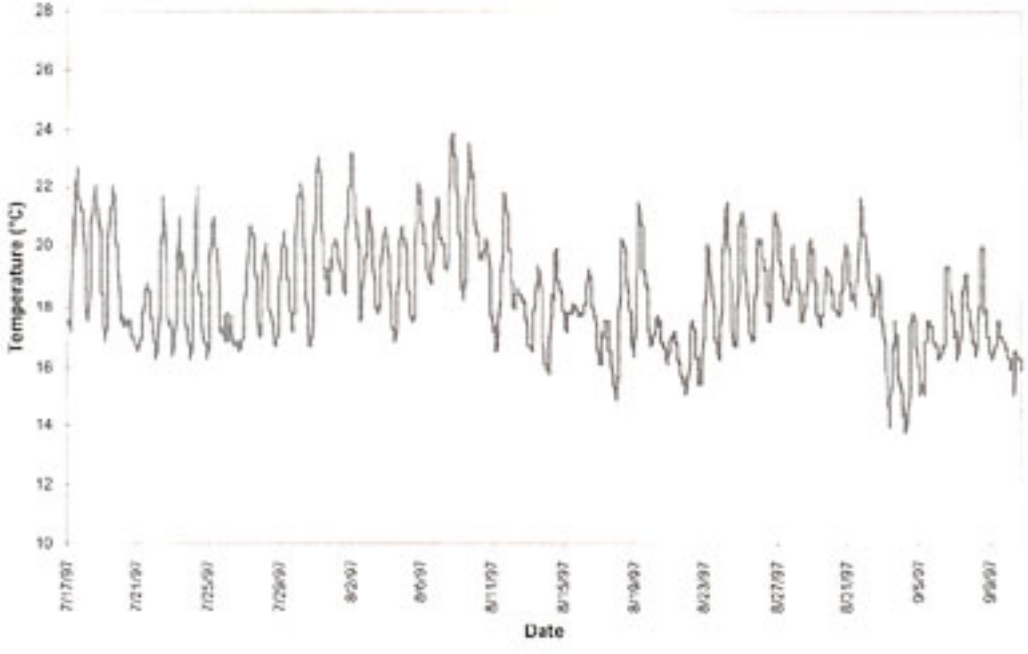


Figure 17. Average daily temperatures inTannery Bay and at reference stations.