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ABSTRACT

GROWTH OF GRASS SHRIMP, *PALAEMONETES PUGIO*, IN A CONTAMINATED AND AN UNCONTAMINATED SITE

by
Suruchi Bhan

Previous experiments have found that grass shrimp, *Palaemonetes pugio*, from a contaminated site, Piles Creek (PC), in Linden, New Jersey, are larger than those from a relatively pristine reference site, Sheepshead Creek, located in Tuckerton (T), New Jersey.

This study investigated the possibility that PC conditions provide more food for the shrimp, possibly by being a eutrophic environment, thus allowing for greater growth, or that salinity, toxicants, or other factors at PC stimulate growth. The current experiment indicated that PC conditions do not foster greater growth for the shrimp than T conditions and that PC shrimp are not inherently faster growers. In fact, T shrimp grew more when placed in T conditions. Additional experiments showed that PC shrimp do not grow more at a higher salinity. However, the opposite is found in the field. It can be concluded that inherent factors in PC are not responsible for the larger grass shrimp sizes at PC.

GROWTH OF GRASS SHRIMP, *PALAEMONETES PUGIO*, in A CONTAMINATED AND AN UNCONTAMINATED SITE

by
Suruchi Bhan

A Thesis
Submitted to the Faculty of
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APPROVAL PAGE

GROWTH OF GRASS SHRIMP, *PALAEMONETES PUGIO*, in
A CONTAMINATED AND AN UNCONTAMINATED SITE

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In memory of my mother.

Before you died, you told me that you were not afraid of dying,
but that you worried that I would suffer. That was true love.

- Lynn Johns

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CHAPTER 1

INTRODUCTION

Estuaries are tidally-influenced ecological systems where rivers meet the sea and fresh water mixes with salt water. The most notable characteristic of an estuary is the fluctuation of salinity due to the mixing of freshwater and saltwater and the need for organisms to be able to cope with these conditions. An estuary includes brackish seas, river mouths, lagoons, and tidal marshes. Estuaries provide: habitats, nurseries, productivity, water filtration, and flood control.

The fluctuating conditions of an estuarine system including temperature, light, oxygen, turbidity, desiccation, and salinity result in a large variety of species being able to thrive in this environment. Tens of thousands of birds, mammals, marine organisms and other wildlife depend upon the habitats and nurseries that are provided by estuaries at some point during their development.

Estuaries are highly productive, due in part to the input of nutrients from freshwater and the ability of the estuary to trap and release nutrients. A healthy, untended estuary produces from four to ten times the weight of organic matter produced by a cultivated cornfield of the same size. The porous salt marsh soils are responsible for the water filtration process and flood control.

Human activity threatens the vulnerable ecosystems found in the estuaries. Long considered to be waste lands, estuaries have had their channels dredged, marshes and tidal flats filled, water polluted and shorelines reconstructed to accommodate human needs.

Estuaries receive inputs of contaminants from a variety of sources. The most direct input are from point sources (pipe discharges). Nonpoint sources, also sources of contamination, are a result of urban and agriculture runoff. Agricultural pesticides are used intensively during the spring and summer, which coincides with the spawning and early life stages of many species. Additional contaminants arise from oil spills, the leaching of antifouling paint and wood preservatives, and discharges of cooling water from power plants.

Due to inputs of contaminants, estuarine levels of these chemicals has increased. The resultant increase has caused estuarine organisms to become stressed from coping with the hazards present. Consequently, there is considerable concern over toxicants and their long-term effects in the biota.

1.1 Effects of Contaminants on Growth

Pollution effects can be monitored by examining sublethal indices, such as growth, in organisms inhabiting polluted vs. clean estuaries. The scope for growth is an index of physiological fitness based on the energy budget of the organism (Bayne et al., 1985). It represents production, which depends on the amount of food available, the efficiency with which the organism can extract energy from food, and the demands of routine metabolism and excretion. The scope of growth provides an insight into the energy stability of the organism. It also provides clues of respiration, filtration activities, etc. This indicator correlates well with direct measurements on actual growth (Widdows, 1985). For example, Nelson (1987) found a high correlation between the scope of growth

in mussels exposed in the lab and the field to contaminated sediments, with a reduced scope of growth value being associated with reduced shell growth.

Weber (1996) reported that sublethal lead induced metabolic imbalance which could have caused decreased growth in juvenile fathead minnows (*Pimephalus promelas*). Fish that were exposed to lead required a greater effort to obtain food and defecate more. This implies that less of their food was used to build muscle and bone mass which directly decreased growth.

Sediments were selected from seventeen sites from the Hudson-Raritan estuary, NY, for measuring lethal and sublethal endpoints in polychaetes, sand dollars, and amphipods (Rice et al., 1995). With the exception of 2 sites, all of the sediments used in the study had elevated concentrations of anthropogenic chemicals. Fourteen of the 15 sites inside the mouth of the Raritan Bay showed a significant reduction in polychaete growth, sand dollar growth , and amphipod survival.

Zhou (1997) found that the growth of *Fundulus heteroclitus* ,mummichog, larvae from a reference site was reduced when placed in conditions from a polluted site for 14 days. It was also found that when larvae and embryos from the reference site were dosed with methylmercury (meHg) for a month, growth was significantly reduced. The larvae were feed with ample food and no effect on prey capture was present. Zhou proposed that the effect on growth was perhaps due to increased energy costs in swimming and feeding activity or alterations of normal physiology.

Several fish species have exhibited reduced food consumption when exposed to metals, pesticides and hydrocarbons. Reduced food intake can in turn alter growth rates.

Smith et al. (1976) reported that the intake of minnows by bluegills was modified by hydrogen sulfide. Average bluegill growth and mean weight of minnows consumed per day decreased with increasing hydrogen sulfide concentrations during 114 days of exposure. Similarly in another study, rainbow trout exposed to copper ate fewer trout pellets than control fish. This led to a 25% growth reduction in a 30 day period.

1.1.1 Hormesis

While contaminants generally reduce growth, stimulation of growth above control levels by low levels of toxicants has been observed as well and is termed "hormesis". Low doses of toxicants are hypothesized to cause an overcompensation by homeostatic regulatory control mechanisms which is responsible for the growth enhancement. Pickering and Gast (1972) observed an increase in egg production in fathead minnows (*Pimephales promelas*) when exposed to 13 ug/L cadmium. Increased growth in minnows exposed to polychlorinated biphenlys (PCBs) was noted by Bengtsson (1979). It was postulated that while it may be tempting to view the effect as beneficial, any deviation from normal growth should be regarded as detrimental and a sign of disturbance of normal function. Laughlin et al. (1981) observed enhancement of growth in crabs (*Rhithropanopeus harrisii*) exposed to water-soluble fractions of oil. Similarly, Sanders et al. (1983) found that low levels of copper stimulated growth of crab larvae.

Weis and Weis (1987) exposed mummichogs for 1 week to 0, 0.1 or 0.05 mg/L cadmium. Following the exposure, the lower third of the caudal fin was amputated, and the regowth was measured. The fish were then either placed in clean water or in water

with 0.1 mg/L cadmium. It was found that fish that were not pre-exposed to cadmium and were now placed in cadmium regenerated at the slowest rate. Fish that were pre-exposed regenerated as fast as, and in some cases faster, than control fish, which was evidence for hormesis.

Stebbing (1981) proposed that hormesis was associated with the production of metallothionein. Metallothioneins are metal-binding proteins found in the liver. Acclimation of heavy metal exposure can result from an increased metallothionein production which will form a nontoxic complex with the metal. Exposure to organic pollutants can also result in increased tolerance through activation of a hepatic microsomal mixed-function oxidase system (MFO), which converts organic agents into excretable metabolites.

1.2 Grass Shrimp Background

1.2.1 Nomenclature / Taxonomy / Range

Scientific name : *Palaemonetes pugio*
Common name : Grass shrimp
Subphylum : Crustacea
Class : Malacostraca
Order : Decapoda
Family : Palaemonidae

Range : Commonly found in submerged vegetation in estuaries along the Atlantic Coast and the Gulf of Mexico. USA.

1.2.2 Morphology / Identification Aids

Morphological features of *Palaemonetes* include the following: well-developed rostrum bearing both dorsal and ventral teeth, a smooth carapace and abdomen, rounded abdominal pleurae 1-4, well-developed eyes with globular pigmented corneas, well-developed spines on the telson (two pairs dorsally, two pairs posteriorly), and chelate walking legs 1-2 (the second legs are stronger than the first). Grass shrimp are transparent to yellowish brown. Few exceed 50 mm in total length.

Males can be distinguished from females by the presence of the appendix masculina attached to the appendix interna on the endopod of the second pair of pleopods. Also, the endopod of the first pleopod is larger in males than in females of the same age.

1.2.3 Life History

The spawning season of grass shrimp extends from March through October, but may slightly vary with species and geographic location. In prespawning females, the ripening ovaries can be observed as being greenish or brownish masses of tissue located dorsal and posterior to the stomach, and additional setae develop on the ventral surface of the abdomen and thorax. A female cannot mate until after molting. Males are not able to recognize the females' condition, if she is ready to mate, until physical contact is made with her exoskeleton. Copulation must occur within 7 hours after molting. Eggs normally hatch 12 to 60 days after fertilization, depending on the geographic location. In warmer climates, the incubation period is usually shorter. The female molts again within

a few days after spawning and may produce an additional brood, depending on the time of spawning. The fecundity of *P. pugio* varies depending on geographic region. The average number of eggs per female has been found to be between 247 - 486.

Larvae are planktonic and fed upon zooplankton, algae, and detritus. There are between 7 - 11 morphologically distinct stages during larval development depending upon environmental conditions. The transition from one stage to another occurs during molting. The morphology and behavior of larvae and postlarvae differ. The length at hatching of grass shrimp is 2.6 mm; The length of postlarvae are between 15 - 18 mm. Larvae also lack long appendages and swim with the head down and the dorsal surface oriented toward the direction of horizontal movement. The duration of larval development may range from 11 days to several months, depending on environmental conditions.

Juvenile grass shrimp mature when they are about 1.5 to 2 months old (15 -18 mm Total Length). Their life spawn is 6 to 13 months.

1.2.4 Growth

Growth rates vary slightly between species, sexes, habitats, and season. It can be difficult to characterize growth rates because populations of grass shrimp may produce more than two broods a year which results in a polymodal length-frequency distribution. According to Alon and Stancyk (1982), females in South Carolina can grow between 0.133 mm to 0.143 mm per day in the summer and between 0.089 mm to 0.090 mm per day in the winter. Males can grow between 0.069 mm to 0.087 mm per day in the summer to 0.068

mm to 0.090 mm per day in the winter. Growth rates also depend upon the salinity and temperature of the water. Grass shrimp are normally found at temperatures between 5 °C to 38 °C, but growth is most rapid in waters at temperatures above 30 °C and drops at water temperatures below 14 °C. *P. pugio* tolerate salinities from 1 to 55 ppt, but their optimum salinity is between 4-14 ppt. The larvae of *P. pugio* have slightly different salinity tolerances. The larvae can tolerate a salinity range of 3 to 31 ppt, the optimum salinity being 25 ppt.

1.2.5 Ecological Role and Importance

Although grass shrimp have only limited value as fish bait or food for cultured fish, their ecological importance is unquestioned. They are instrumental in transporting energy and nutrients between trophic levels. They are prey for numerous species of fish (sport and commercial fish and forage fishes) and other aquatic carnivores, which in turn are preyed upon by larger fish. As prey, grass shrimp transfer energy from the producer and decomposer level to higher consumer levels.

Depending on the availability of a particular food they may be classified as detritivores, herbivores, or opportunistic omnivores. As detritivores, grass shrimp aid in the mechanical breakdown of organic material, such as plants as well as the associated microflora, microfauna, and fungi. As herbivores, grass shrimp depend upon aquatic vegetation in many coastal waters. Alterations of estuaries that destroy vegetation could seriously reduce their abundance. Grass shrimp are predators of infaunal polychaetes, oligochaetes, nematodes, and even motile prey such as mysids. As opportunistic

omnivores, grass shrimp repackage their waste materials into protein-rich products that can be utilized by themselves or other organisms. As epibenthic predators and sediment disrupters, grass shrimp alter infaunal community structure (Kneib and Stiven, 1982). For example, in North Carolina a sharp decline in the abundance of grass shrimp due to predation by mummichogs brought about significant changes in the infaunal composition.

Grass shrimp are hosts for numerous species of parasites and ectocommensals. The most abundant are coccidia, microsporidians, trematodes, isopods and leeches. These parasites do not appear to be a major factor in limiting the abundance and growth of grass shrimp.

Grass shrimp are recommended for use as bioassay test organisms by the American Public Health Association. There is a great quantity of information that has been published about mortality and sublethal effects of various toxicants on grass shrimp (Anderson, 1985). They are commonly among the more sensitive estuarine organisms when tested against xenobiotics. Their sensitivity, availability, and adaptability to test conditions make them an appropriate test species for a variety of contaminants (Clark et al., 1985).

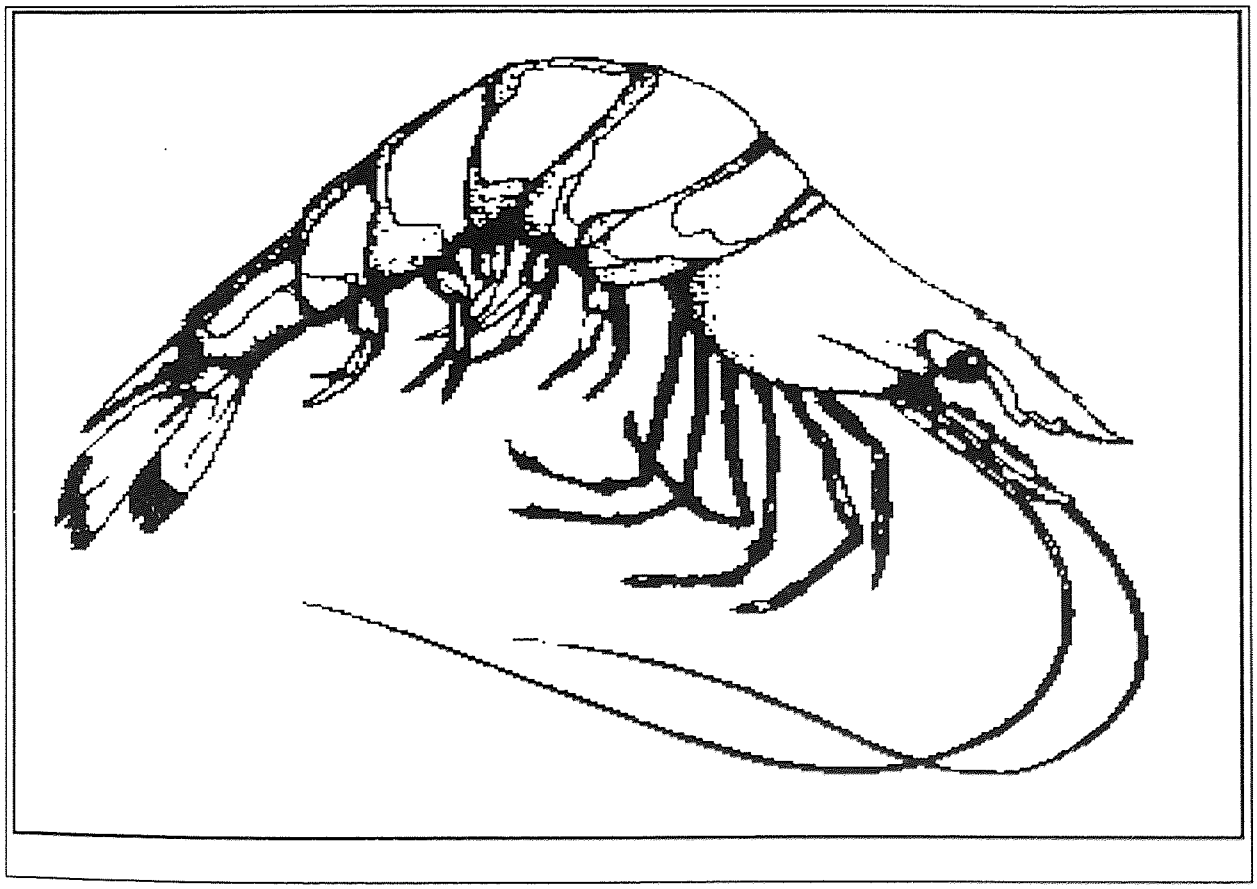


Figure 1.1 Representation of *Palaemonetes pugio*, grass shrimp.

1.3 Mummichog Background

The mummichog, *Fundulus heteroclitus*, is an important fish which plays an intermediate role in the trophic structures of East Coast marshes. Roundtree and Able (1993) found that the population of mummichogs, grass shrimp, and silversides were over 75 % of the total fauna collected in Tuckerton, New Jersey. Hastings and Good (1977) found that in other New Jersey tidal creeks, mummichogs were over 85 % of all fish collected.

Adult mummichogs consume primarily crustaceans, annelids, and feed on the marsh surface at high tide (Kneib and Stiven, 1978). Adults are significant predators of the grass shrimp, *Palaemonetes pugio* (Kneib, 1988). Posey and Hines (1991) found that when mummichog predation in estuaries is present, the benthic infauana is increased due to the fishes' predation on the shrimp. Adult mummichogs are eaten by migratory fish, such as White Perch and Stripped Bass. The principal habitat for the mummichogs are tidal creeks, but these predators are rare in tidal creeks. The predominant predator in these habitats are the blue crab, *C. sapidus (*Kneib, 1986).

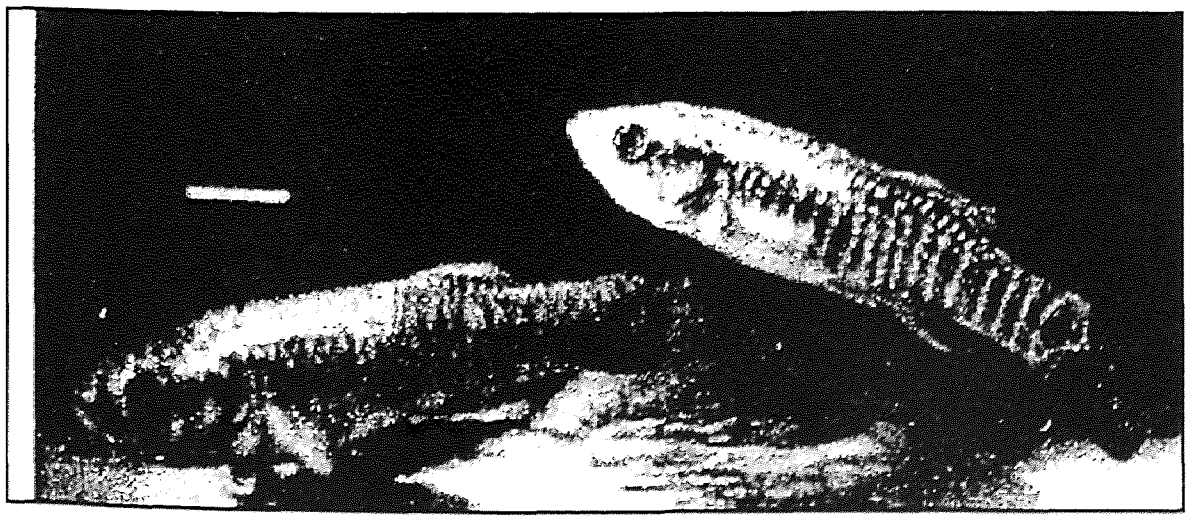
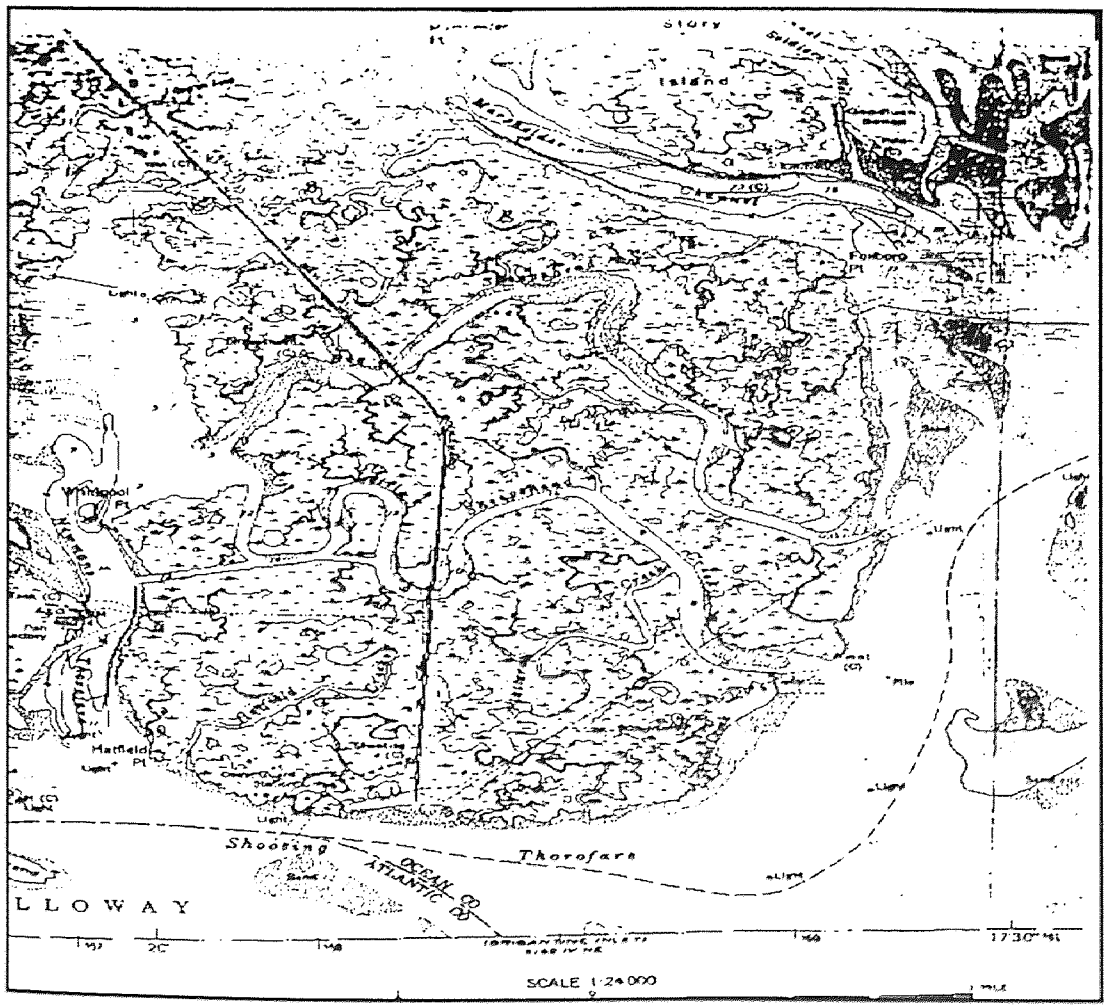


Figure 1.2 Representation of *Fundulus heteroclitus*, mummichogs.

1.4 Study Sites

1.4.1 Tuckerton, New Jersey

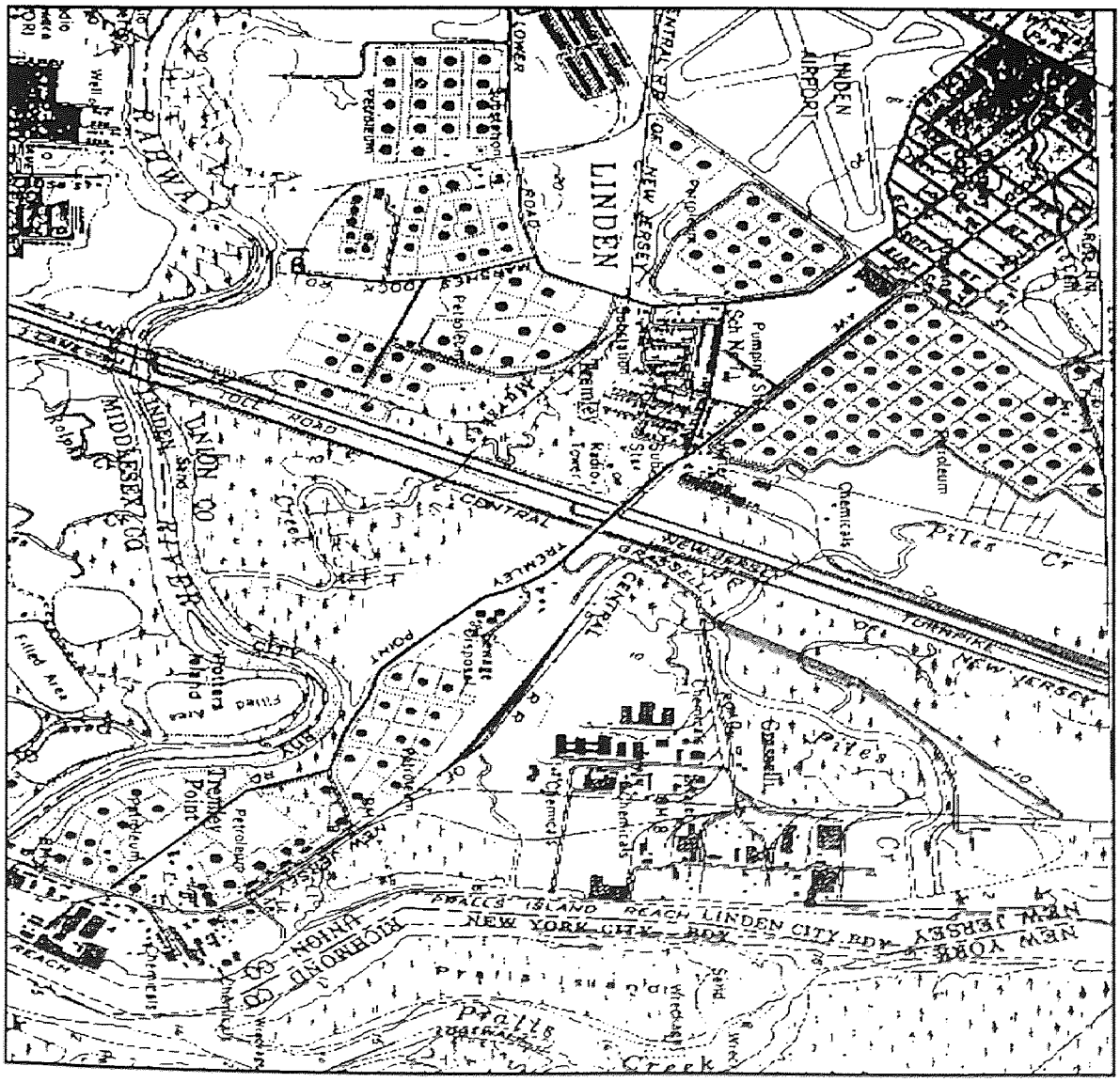
Bigsheephead Creek and Littlesheepshead Creek are relatively pristine tidal creeks of the Great Bay estuary located near Tuckerton, (T) New Jersey. This area is undeveloped and does not contain an industry which could contaminate the estuary. This location is used as the reference site.



Map 1.1 Tuckerton, New Jersey study site.

1.4.2 Piles Creek

Piles Creek (PC) is a polluted tributary of the Arthur Kill. It is located in a salt marsh in heavily industrialized Linden, New Jersey. The sediments and biota from this creek have elevated mercury level and other contaminants (Khan and Weis, 1987).



Map 1.2 Piles Creek, Linden, New Jersey study site.

1.5 Piles Creek Grass Shrimp and Mummichogs

Previous research has determined that mummichogs from Piles Creek neither live as long nor grow as well as conspecifics from uncontaminated reference sites (Toppin et al., 1987). Weis and Weis (1989) supported this observation when they reported that female Piles Creek fish were significantly smaller than those found in an unpolluted reference site. In addition, Weis et al. (1987) found that Piles Creek mummichogs regenerate fins more slowly and show greater mortality when exposed to 50 ug/l methylmercury than conspecifics from reference sites. Furthermore, Piles Creek mummichogs showed reduced ability to capture prey in the laboratory compared with uncontaminated conspecifics (Weis and Khan, 1991 and Smith and Weis, 1997).

Surprisingly, Smith (1997) noted that grass shrimp from the polluted site was larger than conspecifics from reference sites despite their elevated body burdens of contaminants. Khan et al. (1989) found that grass shrimp inhabiting polluted Piles Creek bioaccumulated higher levels of Hg, Cu, and Zn than conspecifics from unpolluted Tuckerton, New Jersey.

As Piles Creek is by far the more impacted of the two sites, it would be expected that chronic exposure to contaminants would negatively affect or be detrimental to the grass shrimp population as it does their predator, the mummichogs. Burton and Fisher (1990) report that cadmium, as well as copper and zinc, is more toxic to grass shrimp than mummichogs. Yet, Piles Creek grass shrimp appear to be relatively insensitive to the contaminants they are chronically exposed to. For example , Kraus and Kraus (1986)

reported that the predator avoidance abilities of grass shrimp are not significantly impaired in Piles Creek.

1.5.1 Impaired Feeding Behavior of the Mummichogs

Smith (1997) suggested that it is possible that the Piles Creek shrimp are larger because Piles Creek mummichogs have impaired feeding behavior from exposure to contaminants. Impaired feeding behavior of fish in laboratory experiments has been noted in response to sublethal concentrations of various pollutants (Cairns and Loos 1967; Nyman 1981; Morgan and Kiceniuk 1990; Little et al., 1990). Pollutants may impair feeding behavior by affecting the motivation to feed and/or by reducing the ability to capture prey. Little et al. (1990) noted that the frequency of strikes was less sensitive to certain toxicants than the actual prey capture, indicating that coordination was impaired. However, Brown et al. (1987) found that PCP-treated fish performed fewer feeding acts, indicating decreased motivation to feed.

Analysis of mummichog stomach contents indicates that Tuckerton mummichogs have a more varied and nutritious diet than those in Piles Creek (Smith and Weis, 1997). About half of the Tuckerton diet consisted of live prey, while only about a quarter of the Piles Creek diet did, the remainder in both cases being detritus, from which mummichogs are unable to derive nutrition (Prinslow et al, 1974). The gut contents of Tuckerton fish contained roughly three times as much shrimp by weight as those of Piles Creek fish. This can be considered field validation of laboratory observations of predatory behavior

which showed that Piles Creek fish were less effective at capturing live prey than Tuckerton fish (Smith and Weis, 1997).

Predator/prey relationships have been shown to be affected by toxic contaminants which can impair prey capture by the predator. Thus, it is possible that impaired prey capture in Piles Creek mummichogs may be to some extent responsible for larger growth of grass shrimp in Piles Creek. However, it is premature to conclude that it is due only to impaired prey capture ability of Piles Creek mummichogs. It is necessary to learn whether there are factors in the Piles Creek environment that also may be responsible for the greater grass shrimp growth at Piles Creek.

1.6 Objectives

The direct effects of Piles Creek conditions on grass shrimp, were investigated in this study. It is possible that temperature, salinity, food supply , and / or toxicants at Piles Creek can provide stimulatory results or a hormesis effect for Piles Creek shrimp, thus allowing them to grow to greater lengths. It is also possible that Piles Creek shrimp have inherently faster growth rates than the Tuckerton shrimp.

This investigation had three objectives. The first objective of this investigation was to determine the concentrations of heavy metals in sediments at Piles Creek and at the reference site in Tuckerton. The results were compared to verify that Piles Creek does have higher contamination levels than the reference site.

The second objective was to compare the growth of Piles Creek shrimp and Tuckerton shrimp under various environmental conditions. It was composed of three

separate experiments. Experiment # 1 compared the growth of Piles Creek shrimp in Piles Creek conditions and Tuckerton conditions to Tuckerton shrimp in Piles Creek conditions and Tuckerton conditions. Experiment # 2 was a repeat of experiment # 1 but with a higher density of shrimp to determine if increased crowding could reduce growth. Experiment # 3 was set up the as experiment # 1 but with the shrimp were fed daily to determine if other factors from Piles Creek could be responsible for enhanced growth.

The third objective of this investigation was to determine if the salinity at either site could be responsible for the increased growth of the Piles Creek shrimp. A salinity experiment was set up within each of the three experiments. Piles Creek shrimp were exposed to higher salinity conditions than are normally found at Piles Creek. Tuckerton shrimp were exposed to lower salinity conditions than are normally found at Tuckerton.

If the shrimp grew better in Piles Creek conditions, it would be evidence for stimulatory factors. If there was no significant differences in growth in Piles Creek vs. Tuckerton conditions, it would suggest that other factors, such as reduced predation at Piles Creek, are responsible for the larger size-structure of its shrimp population.

CHAPTER 2

MATERIALS AND METHODS

2.1 Methods for Analysis of Metals

Concentrations of mercury, lead, copper, chromium, and zinc, in Piles Creek and Tuckerton sediments were determined. Sediment samples of the top 5 cm in shallow subtidal areas from each of the sites, plus replicates, were collected in acid-washed polycarbonate jars and stored at 4 degrees Celsius until analyzed.

2.1.1 Protocol for Analysis of Mercury

For mercury analysis, cold-vapor a.a. methods of Hatch and Ott (1968) were used. The procedure is as follows: The dry weight for wet weight for the Piles Creek and Tuckerton sediment samples and the replicates were calculated. Approximately 1 gram of sediment was weighed and placed into a test tube; Triple wet samples for each sample were made. Three standards using approximately 0.2 grams of internal sediment standard were made. One ml of H_2SO_4 / HNO_3 were placed into each tube.

Each tube covered with a marble and vortexed gently. Four more ml of the acid to each of the Piles Creek samples. All of the test tubes were incubated in a water bath @ 55 degrees for 2 hours. Two aliquots (0.5 ml and 0.1 ml) of Piles Creek acid per sample were made. Piles Creek aliquots and Tuckerton samples were placed into an ice bath. Three ml of K_2MnO_4 (drying agent) were added to each sample and samples had to

sit for 48 hours. Five ml of 1.5% N_2OH / HCl were added to each sample. The samples were then vortexed. One ml of 10% $SnCl_2$ was added to each test tube. The air bubbler was plunged into test tubes. The absorbance was then read on Perkin-Elmer Mercury Analyzer System Coleman 50. The concentrations were then calculated from the absorbance.

2.1.2 Protocol for Analysis of Copper, Chromium, Lead and Zinc

Approximately 1.5 to 2 grams of sediment were weighed and placed in 50 ml beakers. The samples were dried in an oven for 24 hours. Five ml of HNO_3 / $HClO_4$ was added to each sample. The samples simmered on F-level for 2 to 2 1/2 hours, then boiled off at 150 ° C. One % HNO_3 was added to each tube up to 10 ml in tube. The absorbance was read off the Perking Elder 602 Atomic Absorption Spectrophotometer. The concentrations of the metals were then calculated using the absorbance.

Wavelength for Chromium was set at 357.9 nm
Wavelength for Copper was set at 325 nm
Wavelength for Zinc was set at 213.9 nm
Wavelength for Lead was set at 283 nm

2.2 Methods for Microcosm Experiments

2.2.1 Experiment # 1

Ten forty liter microcosms were set up in the laboratory, 4 with Piles Creek sediment and sea water, four with Tuckerton sediment and sea water, 1 with Piles Creek sediment and Piles Creek sea water with the salinity adjusted to 29-30 ppt (Tuckerton salinity), and 1 with Tuckerton sediment and Tuckerton sea water with the salinity adjusted to 14-15 ppt (Piles Creek salinity). Sediments from the top 5 cm of creek were collected. Samples were taken at regular intervals along the creeks. Typically, the sediments were collected during low-tide in shallow subtidal areas to ensure that the samples obtained were actually the sediments the shrimp were exposed to. The sea water and sediment were chilled with ice-packs in the field and were kept at 4° C in the lab until they were used. The sediment and sea water was normally used within 2-3 days, allowing enough time to obtain necessary shrimp from the two sites. The tank bottoms were covered with sediments from either Piles Creek or Tuckerton, 5 cm in depth. Twenty-six liters of Piles Creek sea water was needed per tank for 5 tanks. In the Piles Creek high salinity experimental tanks, the salinity levels were adjusted by adding sea salt crystals until the salinity level reached 30 ppt. Twenty-six liters of Tuckerton sea water was needed per tank for 4 tanks. The Tuckerton low salinity experimental tanks required 13 liters of Tuckerton sea water and 13 liters of distilled water to dilute the salinity to 15 ppt. The salinity and temperature was recorded and maintained throughout the experiment. The sediment from each site was thoroughly mixed before dividing it into the tanks in order to have homogenous sediment.

Shrimp were collected from both sites by umbrella and 3-mm dip nets, which retains shrimp as small as 13 mm. Any gravid or fully grown shrimp were not used in the experiments because their growth rate would be slower than the growth rate of smaller shrimp. Shrimp were brought back to the lab, measured and sorted by length. The length of the shrimp was measured by a ruler, using millimeter units. Each tank was stocked with 20 Piles Creek or 20 Tuckerton shrimp with the same size distributions. See Table 2.2 for mean shrimp lengths per tank for the start of experiment #1. According to Smith, 1997, in May and June, Piles Creek shrimp are substantially larger than conspecifics at Tuckerton (mean length 27.7 mm TL and 35.0 mm TL, as compared to 26.2 mm TL and 27.8 mm TL respectively). Due to this size difference in the field, the initial mean sizes of the Piles Creek shrimp and Tuckerton shrimp in their appropriate tanks are different. Mean lengths of Piles Creek shrimp in Piles Creek sediment (tanks 1 and 2) are 25.8 ± 0.4 mm. Mean lengths of Piles Creek shrimp in Tuckerton sediment (tanks 7 and 8) are 26.0 ± 0.4 mm. Mean lengths of Tuckerton shrimp in Piles Creek sediment (tanks 3 and 4), and Tuckerton shrimp in Tuckerton sediment (tanks 5 and 6) are 22.5 ± 0.7 mm. Hence, it would be more relevant and accurate to measure the mean growth per tank, rather than total length per tank. See Table A.3 in Appendix A for size distribution per tank. Experiment 1 began on May 30; Intermediate measurements were taken on June 10 and final measurements were obtained on June 17. Statistical data are found in Tables A.3, A.4, and A.5 in Appendix A. The following table (2.1) indicates what type of sediment / water and what type of shrimp were placed in the tanks.

Table 2.1 Tank Combinations for Microcosm Experiments

Tank Number	Type of Sediment	Type of Water	Type of Shrimp
1	PC	PC	PC
2	PC	PC	PC
3	PC	PC	T
4	PC	PC	T
5	T	T	T
6	T	T	T
7	T	T	PC
8	T	T	PC
9	PC	PC - high salinity	PC
10	T	T - low salinity	T

Table 2.2 Mean Shrimp Lengths per Tank for Start of Experiment # 1

Tank	Mean Length (mm)
1	25.8
2	25.8
3	22.5
4	22.5
5	22.5
6	22.5
7	25.8
8	25.8
9	25.6
10	22.8

Tanks were monitored for aeration, salinity, and temperature throughout the length of the experiments. Table A.1 in Appendix A lists specific gravity, temperature, and salinity for each tank. On the 11th day of the experiment, an intermediate measurement of growth was made. On the 21st day, final measurements on growth were made and the experiment was concluded. The mean growth per tank in millimeters for each tank was compared by one way ANOVA analysis followed by the Bonferroni Multiple Comparison Test. The mean growth per tank for the salinity experiment was compared by using t-tests.

2.2.2 Experiment # 2

The experiment was repeated, with fresh sediment and water, and with a different density to see if increased crowding would reduce growth. Sixty shrimp were placed in each tank. The tanks were labeled in the same way as experiment 1 (Table 2.1). Table 2.3 illustrates the mean lengths of shrimp per tank for the start of experiment #2. See Table B.2, in Appendix B, for shrimp size distribution. Table B.1 in Appendix B lists specific gravity, temperature, and salinity for each tank.

It was difficult to capture all the shrimp for intermediate measurements without some type of device to prevent them from burying themselves in the sediment. Netting (2 mm holes) was placed in each tank on top of the sediment, and was covered with 1/4 inch of sediment. The spaces in the netting were large enough for the shrimp to have access to the sediment for food, but was small enough to prevent them from being lost in the

sediment. Experiment 2 began on June 27; Intermediate measurements were taken on July 8 and final measurements were obtained on July 18.

Table 2.3 Mean Shrimp Lengths per Tank for Start of Experiment #2

Tank	Mean Length (mm)
1	27.3
2	27.3
3	25.2
4	25.2
5	25.1
6	25.1
7	27.3
8	27.3
9	27.3
10	25.2

2.2.3 Experiment 3

An additional 10 tanks, with the same shrimp/sediment/water combinations (see Table 2.1), were set up in which 20 shrimp per tank were fed daily with Tetramin Fish Flake Food. (The amount of food was determined by adding a sample food to the tanks and seeing how much was readily eaten.) The amount added to the tank was 0.3 grams and was consistent throughout the experiment. Table C.1 in Appendix C lists specific gravity, temperature, and salinity for each tank. Experiment 3 began on August 2; Intermediate measurements were taken on August 13, and final measurements were obtained on August 23. See Table 2.4 for the mean shrimp lengths per tank for the start of experiment #3. The initial mean shrimp lengths for this experiment are much less than initial mean lengths for experiment #1 or experiment #2 because the young of the

year shrimp or the first generation of summer recruits were used. See Table C.2 in Appendix C for the Shrimp Length Distribution for experiment #3. Statistical data are found in Tables C.3, C.4, and C.5 in Appendix C.

Table 2.4 Mean Shrimp Lengths per Tank for Start of Experiment #3

Tank	Shrimp Lengths (mm)
1	17.7
2	17.7
3	17.2
4	17.2
5	17.2
6	17.2
7	17.7
8	17.7
9	17.7
10	17.2

CHAPTER 3

RESULTS

3.1 Analysis of Metals

Sediments in Piles Creek contained elevated levels of mercury, copper, chromium, zinc, and lead when compared with relatively "clean" sediments at the Tuckerton site. Table 3.1 compares the concentrations of the metals at the two sites.

Table 3.1 Metal Analysis for Piles Creek and Tuckerton

Mean Concentration of Metals (ug/g ± SE)		
Name of Metal	**Piles Creek**	**Tuckerton**
Mercury	7.0 ± 0.4	0.023 ± 0.002
Copper	1895.1 ± 177.6	7.2 ± 0.04
Chromium	88.8 ± 6.6	13.5 ± 0.04
Zinc	1407.6 ± 0.02	32.9 ± 0.1
Lead	55.4 ± 0.02	13.7 ± 0.1

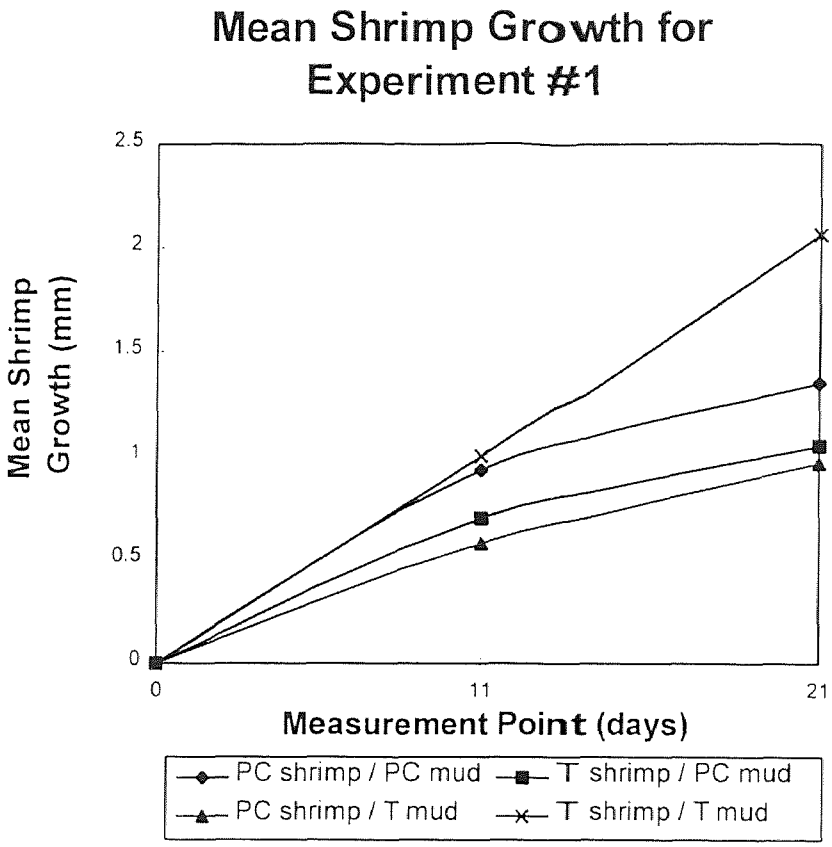
3.2 Experiment #1

In experiment #1, at the intermediate measurement point, it was found that there were no significant difference among the mean growth of the four different groups ($p = 0.12$). The four different groups are Piles Creek shrimp in Tuckerton sediment, Piles Creek shrimp in Piles Creek sediment, Tuckerton shrimp in Piles Creek sediment, and Tuckerton shrimp in Tuckerton sediment (Table 2.1). The mean growth for the different groups are 0.6 ± 0.1 SE mm, 0.9 ± 0.1 SE mm, 0.7 ± 0.1 SE mm, and 1.0 ± 0.2 SE

mm, respectively (Table 3.2 and Figure 3.1). It was noted that the number of shrimp that died was double for Tuckerton shrimp in Piles Creek sediment (10) than for Piles Creek shrimp in Piles Creek sediment (5). Refer to Table A.4 in Appendix A. However, by the end of the first experiment, Tuckerton shrimp in Tuckerton sediment (tanks 5 and 6) grew significantly more than the other three groups, $p = 0.01$ (Table 3.2 and Figure 3.1). The mean growth for Tuckerton shrimp in Tuckerton water sediment (tanks 5 and 6) at the final measurement point was 1.1 ± 0.1 mm, giving a total mean growth of 2.1 mm. The mean growth for the Piles Creek shrimp in Piles Creek sediment (tanks 1 and 2), Piles Creek shrimp in Tuckerton sediment (tanks 7 and 8), and Tuckerton shrimp in Piles Creek sediment (tanks 3 and 4) was significantly less at the final measurement point, 0.4 ± 0.1 mm, 0.4 ± 0.1 mm, and 0.4 ± 0.1 mm, respectively (Table 3.2 and Figure 3.1). The total mean growth for Piles Creek shrimp in Piles Creek sediment (tanks 1 and 2), Tuckerton shrimp in Piles Creek sediment (tanks 3 and 4), and Piles Creek shrimp in Tuckerton sediment (tanks 7 and 8) was 1.4 ± 0.2 mm, 1.1 ± 0.2 mm, and 1.0 ± 0.2 mm, respectively. For individual shrimp length measurements per tank for start, intermediate, and final results for experiment #1 refer to Tables A.3, A.4, and A.5 in Appendix A.

Table 3.2 Mean Amount of Shrimp Growth for Experiment #1

Variable	Intermediate Growth (mm ± SE)	Final Growth (mm ± SE)	Total Growth (mm ± SE)
T sediment T shrimp (tanks 5 and 6)	1.00 ± 0.2	1.1 ± 0.1	2.1 ± 0.2
PC sediment PC shrimp (tanks 1 and 2)	0.9 ± 0.1	0.4 ± 0.1	1.4 ± 0.2
PC sediment T shrimp (tanks 3 and 4)	0.7 ± 0.1	0.4 ± 0.1	1.1 ± 0.2
T sediment PC shrimp (tanks 7 and 8)	0.6 ± 0.1	0.4 ± 0.1	1.0 ± 0.2



igure 3.1 Mean shrimp growth at the initial, intermediate, and final measurement for Experiment #1.

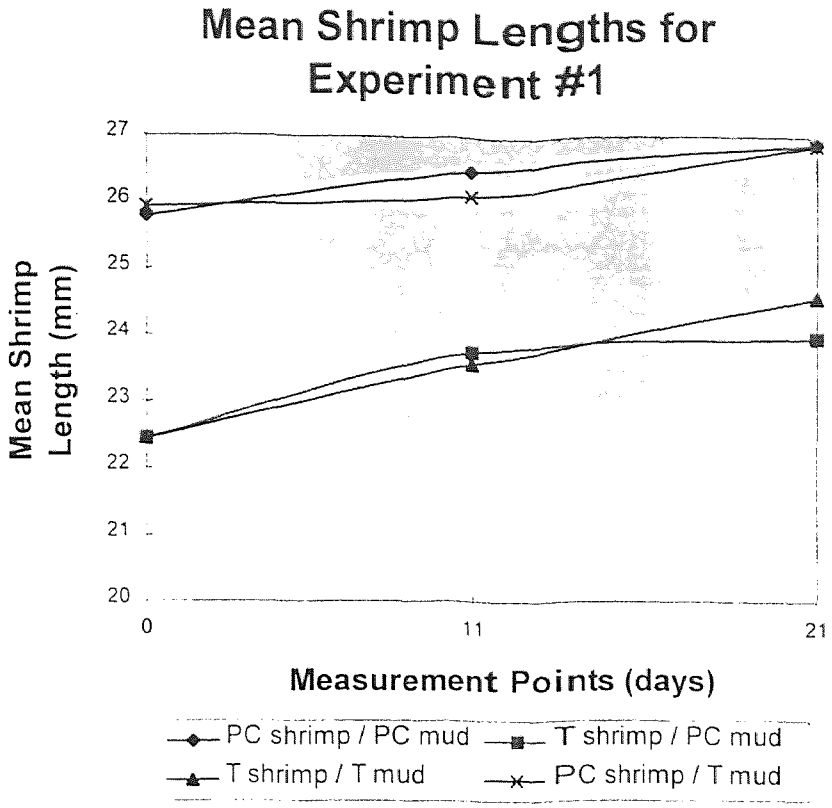


Figure 3.2 Mean shrimp lengths at the initial, intermediate, and final measurement points for Experiment #1.

3.3 Experiment #2

Experiment # 2 did not yield any substantial data because there was significant mortality in most of the tanks. Since mortality was high, it could have resulted in an increased growth rate of survivors, which would have yielded inaccurate data.

By the final measurements, Piles Creek shrimp in Piles Creek sediment (tanks 1 and 2) had 42 and 34, respectively, out of the 60 shrimp left (Table B.9). The other tanks (3 and 4, 5 and 6, 7 and 8) had even fewer shrimp left. Tanks 3, 4, 5, 6, 7, and 8 had 14, 11, 21, 19,18, and 11 shrimp left, respectively. This may indicate that Piles

Creek shrimp are more tolerant of dense conditions in polluted environments than are Tuckerton shrimp in polluted and unpolluted environments. See Tables B.2, B.3, and B.4 in Appendix B for the quantity and lengths of shrimp at the beginning, intermediate, and final measurements

3.4 Experiment #3

Similar results were obtained in experiment # 3 to those obtained in experiment # 1. At the intermediate measurement, Tuckerton shrimp placed in Tuckerton sediment (tanks 5 and 6) were growing the most, 1.1 ± 0.1 mm. Piles Creek shrimp in Tuckerton sediment (tanks 7 and 8) were growing at a comparatively similar rate, 1.1 ± 0.1 mm at this measurement point. Again, Tuckerton shrimp in Piles Creek sediment (tanks 3 and 4), and Piles Creek shrimp in Piles Creek sediment (tanks 1 and 2) were growing significantly less ($p = 0.01$), 0.8 ± 0.1 mm, 0.8 ± 0.1 mm, respectively (Table 3.3 and Figure 3.3). At the final measurement point, Tuckerton shrimp in Piles Creek sediment (tanks 3 and 4) grew significantly less ($p = 0.01$) than the other three groups. Tuckerton shrimp in Piles Creek sediment grew 0.5 ± 0.1 mm, while Tuckerton shrimp in Tuckerton sediment (tanks 5 and 6), Piles Creek shrimp in Tuckerton sediment (tanks 7 and 8), and Piles Creek shrimp in Piles Creek sediment (tanks 1 and 2) grew, 1.4 ± 0.1 mm, 1.4 ± 0.1 mm, and 1.3 ± 0.1 mm, respectively (Table 3.3 and Figure 3.3). Total mean growth measurements indicated that Tuckerton shrimp in Tuckerton sediment (tanks 5 and 6) had grown a total mean length of 2.5 ± 0.1 mm, Piles Creek shrimp in Tuckerton sediment (tanks 7 and 8) had a total mean growth of 2.5 ± 0.1 mm, Piles Creek shrimp in Piles

Creek sediment (tanks 1 and 2) grew to 2.1 ± 0.1 mm. However, Tuckerton shrimp in Piles Creek sediment (tanks 3 and 4) only grew 1.2 ± 0.1 mm ($p = 0.01$), indicating that not only does Piles Creek conditions not foster growth, but inhibits growth of the Tuckerton populations not tolerant of polluted environments. See Tables C.3, C.4, and C.5 in Appendix C for individual shrimp length measurements for initial, intermediate, and final results for experiment #3.

Table 3.3 Means Shrimp Growth for Experiment # 3

Variable	Intermediate Growth (mm ± SE)	Final Growth (mm ± SE)	Total Growth (mm ± SE)
T shrimp T sediment (tanks 5 and 6)	1.1 ± 0.1	1.4 ± 0.1	2.5 ± 0.1
PC shrimp T sediment (tanks 7 and 8)	1.1 ± 0.1	1.4 ± 0.1	2.5 ± 0.1
PC shrimp PC sediment (tanks 1 and 2)	0.8 ± 0.1	1.3 ± 0.1	2.1 ± 0.1
T shrimp PC sediment (tanks 3 and 4)	0.8 ± 0.1	0.5 ± 0.1	1.2 ± 0.1

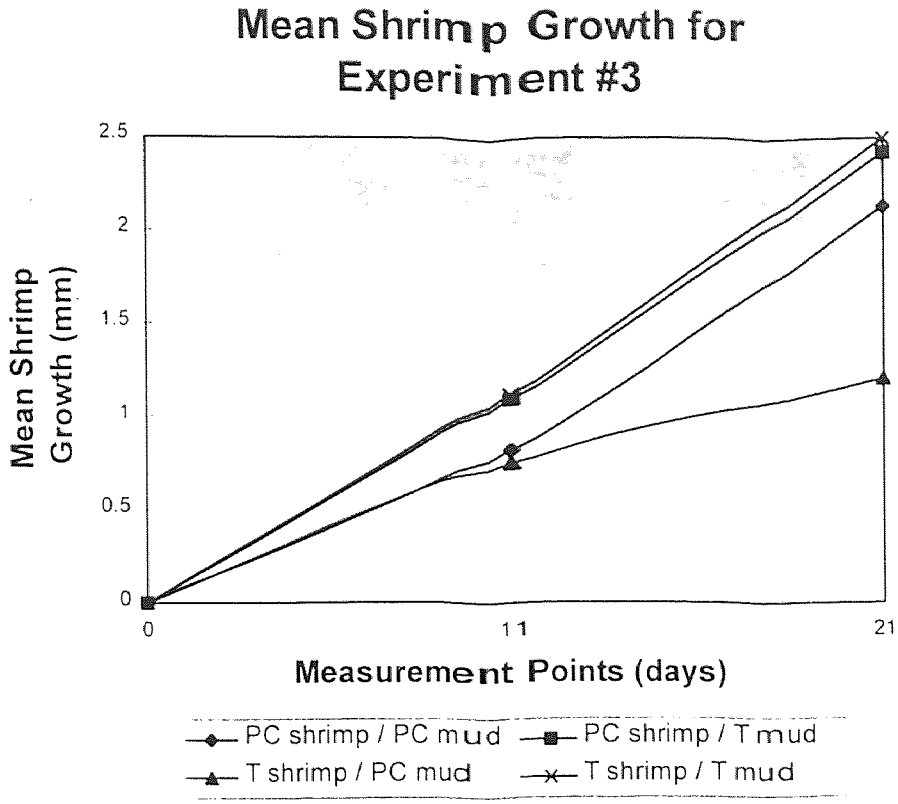


Figure 3.3 Mean shrimp growth at the initial, intermediate, and final measurement points for Experiment #3.

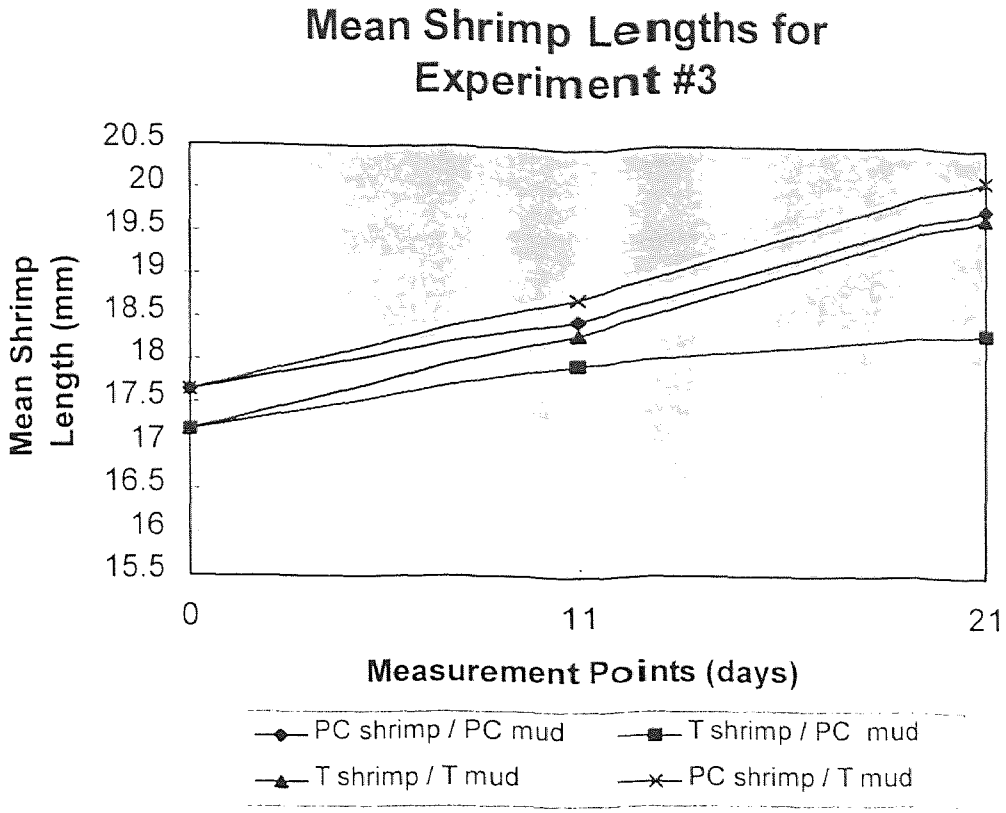


Figure 3.4 Mean shrimp lengths at the initial, intermediate, and final measurement points for Experiment #3.

3.5 Summary

Results indicate that Piles Creek sediment and Piles Creek water do not foster growth for Piles Creek shrimp or Tuckerton shrimp. There is not something present in the sediment or water that is the cause of the greater lengths of shrimp in Piles Creek field measurements. Both Piles Creek shrimp and Tuckerton shrimp grew less in Piles Creek conditions that in Tuckerton conditions. It even appears, in experiment # 3, that Piles Creek sediment and water inhibit growth of Tuckerton shrimp to some extent (Table 3.3). It can also be said that Piles Creek shrimp are not inherently faster growers than

Tuckerton shrimp. When placed in Tuckerton sediment, Piles Creek shrimp grew less than Tuckerton shrimp.

3.6 Salinity Experiment Results

3.6.1 Overview

The data from the salinity experiments were not pooled for the replicate tanks as they were in the previous experiments. The reason for this is because experimental tanks 9 and 10 do not have replicate tanks. Therefore, if the data from tanks 1 and 2 were combined to be compared with data from tanks 9, the growth of 40 shrimp would be compared with the growth of 20 shrimp. For this reason, data from tank 1 and tank 2 was compared separately with tank 9.

The overall salinity results indicate that in Experiments #1 and # 3, Piles Creek shrimp do not grow more in the higher salinity experimental tank (tank 9), than in lower salinity control tanks (tanks 1 and 2). The results from Experiments #1 and # 3 also suggest that Tuckerton shrimp grow do not grow more in the lower salinity tank (10) than in the high salinity tanks (5 and 6). Refer to Table 3.4. Thus, salinity did not play a significant role in the growth of grass shrimp for this investigation. A more detailed discussion of the results in given following Table 3.4.

Table 3.4 Summary of Mean Shrimp Lengths for Salinity Experiments #1 and #3

Variable	Experiment #1 Mean Shrimp Length (mm ± SE)		Experiment #3 Mean Shrimp Lengths (mm ± SE)	
	Intermediate	Final	Intermediate	Final
PC Control Tank 1	25.9 ± 0.5	26.3 ± 0.6	18.5 ± 0.3	20.0 ± 05
PC Control Tank 2	27.1 ± 0.3	27.5 ± 0.6	18.5 ± 0.3	19.6 ± 0.4
PC Experimental Tank 9	26.4 ± 0.4	26.5 ± 0.4	18.8 ± 0.4	20.3 ± 0.4
T Control Tank 5	23.8 ± 0.8	23.6 ± 0.6	17.6 ± 0.4	19.7 ± 0.1
T Control Tank 6	23.4 ± 0.7	24.3 ± 0.6	18.1 ± 0.3	19.8 ± 0.3
T Experimental Tank 10	23.2 ± 0.8	25.0 ± 0.4	18.4 ± 0.4	19.2 ± 0.3

3.6.2 Piles Creek Salinity Experiment #1

To determine whether a higher salinity has an effect on growth of the Piles Creek shrimp an experimental tank, 9, was set up with the salinity adjusted at a higher concentration. Tanks 1 and 2 were the control tanks with "normal" Piles Creek salinity levels at approximately 15 ppt. Tank 9 was the experimental salinity tank with the salinity adjusted to Tuckerton salinity levels of approximately 30 ppt. At the intermediate measurement point, experimental tank 9 did not grow significantly more ($p = 0.40$, $t = -.88$ and $p = 0.29$, $t = -.58$, respectively) than control tanks 1 and 2.

At the final measurement point, the mean length in control tanks 1 and 2 was not significantly different ($p = 0.80$, $t = -0.26$ and $p = .15$, $t = 1.49$, respectively) than the mean length in experimental tank 9. Refer to Table 3.4 and Figure 3.5 for the mean shrimp lengths at the intermediate and final measurement points. This data suggests that higher salinity does not enhance the growth of Piles Creek shrimp. However, this data does not take into account the growth of shrimp that had died throughout the experiment.

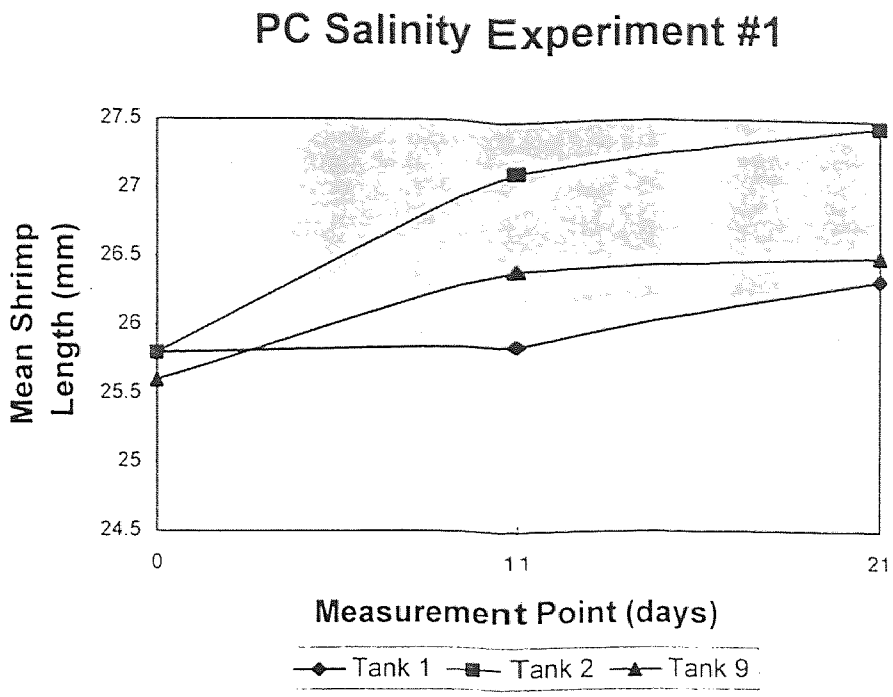


Figure 3.5 Mean shrimp lengths (mm) at the intermediate and final measurement points for PC Salinity Experiment #1. Tanks 1 and 2 are control tanks. Tank 9 is the experimental salinity tank.

3.6.3 Piles Creek Salinity Experiment #3

At the intermediate measurement point, the mean length in control tanks 1 and 2 was not significantly different ($p = 0.49$, $t = -0.69$ and $p = 0.49$, $t = -0.69$, respectively) than the mean length in experimental tank 9. Again, by the final measurement point, the mean shrimp length for control tanks 1 and 2 were not significantly less ($p = 0.57$, $t = -.57$, and $p = 0.23$, $t = -1.22$, respectively) than the mean length for experimental tank 9. This data suggests that Piles Creek shrimp do not grow longer at a higher salinity. Figure 3.6 illustrates the similar growth rates of the three tanks.

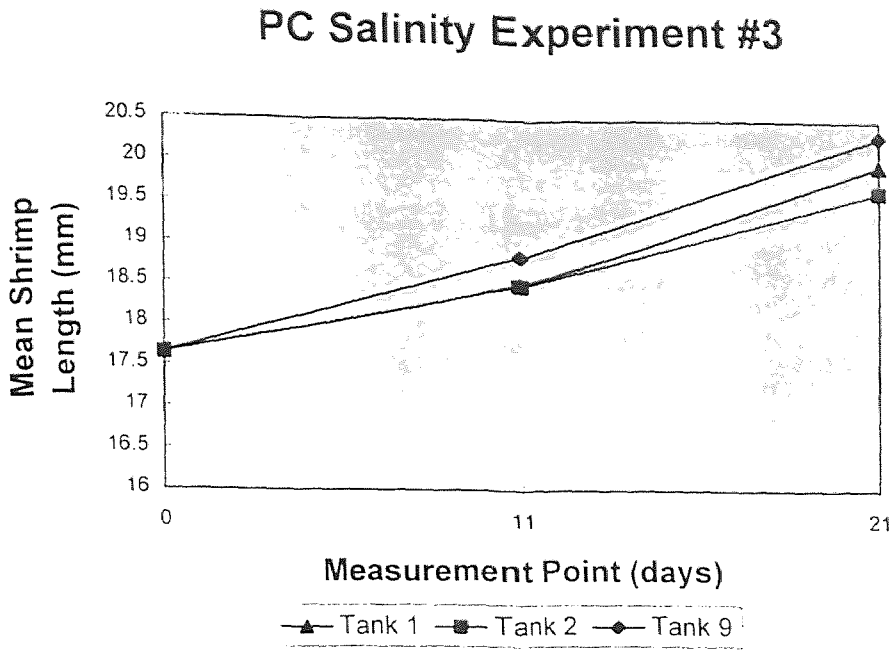


Figure 3.6 Mean shrimp lengths (mm) at the higher intermediate and final measurement points for PC Salinity Experiment #3. Tanks 1 and 2 are control tanks. Tank 9 is the experimental salinity tank.

3.6.4 Tuckerton Salinity Experiment #1

To determine whether a lower salinity has an effect on growth of the Tuckerton shrimp an experimental tank, 10, was set up with the salinity adjusted at a lower concentration. Tanks 5 and 6 were the control tanks with "normal" Tuckerton salinity levels at approximately 30 ppt. Tank 10 was the experimental salinity tank with the salinity adjusted to Piles Creek salinity levels of approximately 15 ppt. At the intermediate measurement point, control tanks 5 and 6 mean lengths were not significantly greater ($p = 0.57$, $t = .58$ and $p = .88$, $t = .15$, respectively) than experimental tank 10. Refer to

Table 3.4 and Figure 3.7 for the mean lengths at the intermediate and final measurement points.

By the final measurement point, results were similar to those obtained at the intermediate point. There was no significant difference in growth between tanks 5 and 6 ($p = 0.37$, $t = -0.93$ and $p = 0.32$, $t = -1.02$, respectively) and tank 10. However, this data does not take into account the growth of 16 shrimp that died throughout the course of the experiment. Due to such high mortality, conclusions can not be accurately drawn from this salinity experiment.

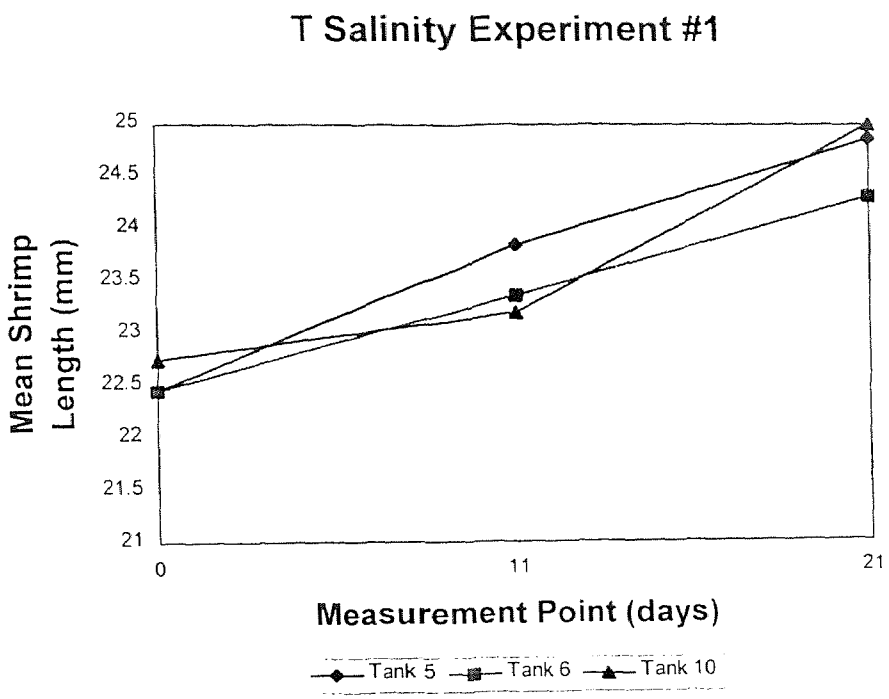


Figure 3.7 Mean shrimp lengths (mm) at the intermediate and final measurement points for PC Salinity Experiment #1. Tanks 5 and 6 are control tanks. Tank 10 is the experimental salinity tank.

3.6.5 Tuckerton Salinity Experiment #3

Control tanks 5 and 6 did not grow significantly different (p = 0.42, t = -0.80 and p = 0.57, t = 0.57, respectively) than experimental tank 10 at intermediate point and at the final measurement point (p = .30, t = 1.04 and p = .17, t = 1.41, respectively). Refer to Figure 3.8 for lengths at the intermediate and final measurement points. Figure 3.8 clearly indicates that the growth rates of the three tanks were similar. Because there was not significant mortality present in this experiment as there was in Tuckerton Salinity Experiments #1 and #2, it can be concluded that lower salinity did not play a role in the growth of Tuckerton grass shrimp.

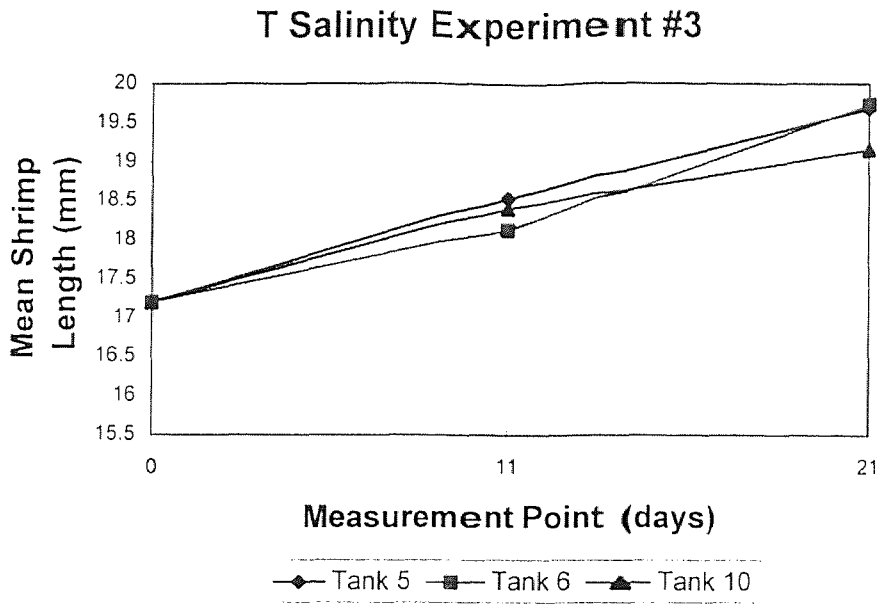


Figure 3.8 Mean shrimp lengths (mm) at the intermediate and final measurement points for PC Salinity Experiment #3. Tanks 5 and 6 are control tanks. Tank 10 is the experimental salinity tank.

CHAPTER 4

DISCUSSION

4.1 Heavy Metal Contamination

This study reports concentrations of heavy metals (Hg, Cu, Cr, Pb, and Zn) in sediments to be higher in Piles Creek, New Jersey than in Tuckerton, New Jersey. These results would be expected as Piles Creek is located in a salt marsh in heavily industrialized Linden, New Jersey. This area contains several oil refineries, a power station, a sewage treatment plant, several chemical plants, and a section of the New Jersey Turnpike. Big Sheepshead Creek (BSC) is a relatively pristine tidal creek of the Great Bay estuary located near non-industrialized Tuckerton, New Jersey.

These concentrations are in ranges that are consistent with those that Khan et al. (1989) report. Khan reported that Piles Creek sediment contained higher concentrations of mercury, cadmium, copper, and zinc (11.2 ug/g Hg, 5.9 ug/g Cd, 623.5 ug/g Cu and 627.0 ug/g Zn) than BSC sediment (0.054 ug/g Hg, 0.13 ug/g Cd, 12.9 ug/g Cu and 7.7 ug/g Zn). Khan et al. (1993) also report that Piles Creek sediment contained higher concentrations of Hg, Cd, Cu and Zn (11.2 ppm, 5.78 ppm, 625 ppm, and 628 ppm, respectively) than another reference site in Long Island (<0.03 ppm, 0.460 ppm, 41.0 ppm, and 49.4 ppm, respectively).

4.2 Direct Effects of the Environment on Grass Shrimp

The potential direct effects of the environment on growth of grass shrimp were investigated in this study. In experiment #1, at the intermediate measurement point, although there was no difference in the amount of growth per tank, the number of grass shrimp that had died was double (10) for Tuckerton shrimp in Piles Creek sediment than for Piles Creek shrimp in Piles Creek sediment (5). It is likely that Piles Creek shrimp are more tolerant to stresses caused by exposure to heavy metal contamination than are Tuckerton shrimp. Kraus and Kraus (1986) found that Piles Creek shrimp, subjected to mercury in their natural environment, are more tolerant to sublethal effects of both $HgCl_2$ and meHg when compared with conspecific shrimp from Big Sheepshead Creek in Tuckerton.

At the final measurement point, Tuckerton shrimp in Tuckerton sediment had the greatest amount of growth and Tuckerton shrimp in Piles Creek sediment had significantly less growth, indicating that the Piles Creek sediment did not provide conditions to stimulate growth. Although Piles Creek shrimp in Tuckerton sediment had the least amount of growth (not significantly less), this group had the largest number of surviving individuals. This indicated that this group did gain some benefit by moving into a "clean" environment. Perhaps if this particular experiment was continued for an additional 3 weeks, the shrimp would have acclimated to their new environment. It would be interesting to observe if the growth of this group would be comparable to the growth of the Tuckerton shrimp in Tuckerton sediment or perhaps even out grow them.

At the end of experiment # 1, Piles Creek shrimp in Piles Creek sediment had the least number of surviving individuals indicating further that Piles Creek conditions do not provide stimulatory effects due to either the low organic enrichment of the sediment or due to the effects of contaminants in the sediment or a combination of both.

There was high mortality in experiment # 2 in comparison to experiment # 1 and experiment # 3. By final measurements, Piles Creek shrimp in Piles Creek sediment had 42 (tank 1) and 34 (tank 2) shrimp surviving out of the initial 60 shrimp that were placed in each tank at the beginning of the experiment. The other tanks had relatively fewer shrimp left; Tuckerton shrimp in Piles Creek sediment (tanks 3 and 4) had 14 and 11 shrimp left, respectively; Tuckerton shrimp in Tuckerton sediment (tanks 5 and 6) had 21 and 19 shrimp left, respectively; Piles Creek shrimp in Tuckerton sediment (tanks 7 and 8) had 18 and 11 shrimp left, respectively. This may indicate that Piles Creek shrimp are more tolerant of high density conditions in polluted environments than are Tuckerton shrimp in polluted and unpolluted environments. Santiago (1996) found similar results in the field. Santiago found that the density of shrimp in Piles Creek was three times higher than that in Tuckerton. Over a thirteen week period, Santiago collected 2628 shrimp in Piles Creek and 968 shrimp in Tuckerton using standard sampling protocols. Laboratory findings are consistent with field findings where Piles Creek shrimp are considered to be more tolerant of high density conditions.

Experiment # 3 appears to be the most reliable source of data for this study due to the least amount of mortality. By the end of this experiment, 198 shrimp out of 200 had survived, while only 150 out of 200 shrimp survived in experiment # 1, and 192 out of

600 shrimp survived in experiment #2. The survival rate was high in experiment # 3 because the shrimp were fed daily with fish flake food, whereas in the previous two experiments no external food source was supplied and the shrimp were solely dependent on the sediment over the testing period. It is possible that the sediment sources of food were depleted by the end of the 3 week period in experiments 1 and 2, leading to significant mortality. Mortality was observed throughout the experiment after the initial 7 days; However, it was noted to be greater after the intermediate measurement point. Mortality results in increased growth rate of survivors because the survivors have less competition and also obtain additional sources of nutrition from feeding off the dead shrimp. For example, in experiment #1, the mean shrimp length in tank 10 was the highest among the Tuckerton sediment tanks, while, it had the smallest number of surviving individuals.

At the intermediate point in experiment # 3, both Tuckerton shrimp and Piles Creek shrimp in Tuckerton sediment had the same growth. Tuckerton sediment did not enhance or inhibit growth of either group of grass shrimp. However, both groups of grass shrimp grew significantly less in Piles Creek sediment. As was found in experiment # 1, Piles Creek sediment did not enhance the growth of either Piles Creek or Tuckerton shrimp.

By the end of experiment # 3, Tuckerton shrimp and Piles Creek shrimp in Tuckerton sediment again grew at the same rate. Piles Creek shrimp in Piles Creek sediment did not grow as well as Piles Creek or Tuckerton shrimp in Tuckerton sediment. However, they did grow better than Tuckerton shrimp in Piles Creek sediment. This is

not unexpected as Piles Creek shrimp survive in and are tolerant of the conditions at Piles Creek, whereas the Tuckerton shrimp are not because they have not been exposed to such high concentrations of pollutants. Current literature suggests that organisms exposed to heavy metals in their natural environment may be better able to tolerate these toxicants than are conspecifics from minimally polluted environments. For example, in a study by Kraus and Weis (1988), differences in the effects of mercury on telson regeneration on grass shrimp from Tuckerton and Piles Creek were observed. It was found that Tuckerton shrimp tested with meHg had a significantly shorter intermolt period when compared with Tuckerton control shrimp, and Tuckerton meHg pre-treated shrimp had a significantly shorter intermolt period than did meHg-treated shrimp which had not been pre-treated. However, no significant difference between the control group and treated shrimp was noted in the Piles Creek population. This study has established that there are distinct population differences in mercury tolerance between Piles Creek and Tuckerton shrimp. The heightened tolerance to mercury exhibited by the Piles Creek shrimp is probably in response to elevated mercury levels in the Piles Creek estuary.

From the results in experiment # 3, it can be inferred that growth of Tuckerton shrimp was reduced by Piles Creek conditions. These conditions inhibited the growth of Tuckerton shrimp in experiment # 1 also, but not to the same extent. Possible explanation for this difference could be that in experiment # 3 juvenile shrimp were used. Earlier life stages are more sensitive to the effects of contaminants. Thus juveniles, experiencing faster growth, are more likely to be affected by contaminants than mature shrimp which may have reached their maximum length.

As previously stated, Piles Creek conditions did not provide a "hormesis" type of effect for the young Tuckerton shrimp in experiment # 3. This group grew at half the rate that both Piles Creek shrimp and Tuckerton shrimp grew in Tuckerton sediment. In fact, it can be said that Tuckerton conditions provide stimulatory effects for Piles Creek shrimp. Piles Creek shrimp in Tuckerton sediment grew 2.5 ± 0.1 mm, while Piles Creek shrimp in Piles Creek sediment grew 2.1 ± 0.1 mm throughout the experimental period. The difference in growth may not seem to be large. However, male grass shrimp from a low salinity environment grow only 0.069 ± 0.036 mm per day and male grass shrimp from a high saline environment grow 0.087 ± 0.060 mm per day during the summer season (Alon and Stancyk, 1982).

The results from this study are not surprising. If behavioral deficits, such as impaired conditioned avoidance responses of grass shrimp from exposure to mercuric chloride (Barthalmus, 1977), have been shown to arise from exposure to pollutants, physical disabilities such as reduced growth should be expected. Gundersen et al. (1996) studied the effects of crude oil (CO) and partially combusted crude oil (PCO) in the environment, as a consequence of the 1991 Gulf War , on *P. pugio*. Reductions in growth rates of shrimp were observed in shrimp exposed to ppb concentrations CO and PCO when compared to the controls. Exposures in the ppm range were found to cause mortality. There was a 0.56% - 0.82 % reduction in growth from exposure to PCO and a 0.39% - 0.63% reduction in growth from exposure to CO.

Doughtie et al. (1983) exposed adult grass shrimp to hexavalent chromium for 98 days. At the end of the exposure period, over 50% of the surviving shrimp possessed

cuticular lesions, and that there was proportionate increase in the loss of limbs, nearly 50%, in grass shrimp exposed to the highest test concentrations of chromium. It is proposed that chromium interferes with the normal functions of subcutucular epithelium and causes structural weaknesses to develop in newly molted shrimp.

Another study that determined the toxicity of waterborne and sediment-source chemicals to grass shrimp, by Clark et al. (1987), demonstrated that there was a 48 % mortality of shrimp when exposed to fenvalerate (100 ug/kg) in a 10 day exposure period. This study also found that during sediment-source tests with 1, 2, 4 - trichlorobenzene (TCB), tributylin oxide (TBTO), and di-*n*-butyl phthalate (DBP), grass shrimp clung to the sides of test containers above the sediment / water interface, demonstrating a type of behavioral avoidance observation of grass shrimp when exposed to contaminants. A similar observation was not observed in tanks where Tuckerton shrimp were placed in Piles Creek conditions. It would be interesting to see future study on detailed behavioral avoidance of polluted sediments by Tuckerton shrimp.

In experiments #1 and # 3, when comparing the growth of Piles Creek shrimp at the normal Piles Creek salinity of 15 ppt to the growth of Piles Creek shrimp at a higher Tuckerton salinity of 30 ppt, it was found that Piles Creek shrimp did not grow significantly more at the higher salinity level. It was also found that Tuckerton shrimp did not grow significantly more at a lower salinity. These results are consistent with the findings of Kneib (1987). Juvenile grass shrimp (≤ 15 mm total length) from the two sites in Georgia were measured for growth rates. Between July and August, the Upper Duplin site reached salinities of 15.5 ± 2.8 ppt, while the Kenan Field site reached

salinities of 22.8 ± 0.8 ppt. It was determined that there was no difference in growth rates from either population during this time period. Grass shrimp from Upper Duplin grew 0.253 ± mm per day, while grass shrimp from Kenan Field grew 0.280 ± 0.059 mm per day.

However, the results obtained from the salinity investigation are inconsistent with the findings of Alon and Stancyk (1982). A population of *Palaemonetes pugio*, inhabiting a fairly constant high salinity of 29.8 ± 4.8 ppt in North Inlet, S.C. exhibited more rapid growth, earlier first reproduction, a smaller cluster size and a shorter life span. A population in a less saline environment of 10.2 ± 6.9 ppt in Minim Creek, S.C. showed relatively slower growth, delayed first reproduction, higher clutch size, and longer life span.

Piles Creek shrimp inhabiting in Piles Creek exhibit similar life history patterns as grass shrimp from North Inlet, S.C., yet they reside in a much lower salinity system. Future studies need to take into consideration the interactions of salinity and heavy metals on the development of grass shrimp in Piles Creek. Fales (1978) studied the influence of temperature and salinity on the capacity of chromium to cause physiological damage to the grass shrimp. It was found that the capacity of chromium to cause physiological damage was increased by temperature and with decreasing salinity. The susceptibility of the shrimp was greatest at 25° C / 10 ppt and least at 10° C / 20 ppt. The implications are that grass shrimp are most likely to be adversely affected when the habitat is warm and dilute. However, this implication is the opposite of field findings where Piles Creek

shrimp inhabiting a dilute (less saline) and polluted estuary continue to grow to larger lengths than Tuckerton shrimp inhabiting a concentrated (high saline) estuary.

Results from this investigation clearly indicate that Piles Creek conditions do not provide stimulatory effects for the grass shrimp population. Piles Creek shrimp also did not have inherently faster growth rates that Tuckerton shrimp. Thus, other factors such as reduced predation capture by Piles Creek mummichogs may be in part responsible for larger growth of grass shrimp in Piles Creek. However, it is premature to conclude that it is due only to impaired prey capture ability of Piles Creek mummichogs. Grass shrimp at Piles Creek may also be larger due to less predation caused by the different population densities of the predator and prey at both sites.

The size of a predator relative to its prey species could have an important effect on predator efficiency which may be reflected in the abundance or distribution of potential prey species (Schoener, 1971). When predators consume a variety of prey species while undergoing continuous change in size with age, alterations in predator population structure may have consequences for the prey at both the population and community levels (Kneib and Stiven, 1982).

Santiago (1996) compared the size-structure of the *Palaemonetes* population at both sites, and related it to the relative abundance of predator and prey at both sites. If there are far fewer shrimp at Piles Creek than Tuckerton relative to fish, that could account for their greater growth due to less competition and less importance in the fish's diet. Santiago found that the relative density of Tuckerton shrimp to be fewer than Piles Creek Shrimp (1:3) and the relative density of Tuckerton mummichogs to Piles Creek

mummichogs was 3:1. This difference in mummichog density appears to be primarily due to removal of the mummichogs in Piles Creek for personal enjoyment and for re-sale to bait shops, as well as the effects of the pollutants at Piles Creek. Hence, overfishing may be causing an altered structure of the mummichog populations at Piles Creek and indirectly causing greater lengths of grass shrimp. However, further studies on the abundance of the predators of the mummichogs and the effects of pollutants on mummichogs must be performed before overfishing of the mummichogs can be concluded as the primary reason for the reduced number of mummichogs in Piles Creek.

Kneib and Stiven (1982) found that the responses of most infaunal invertebrates to mummichogs were dependent on fish size and to a lesser degree on fish density. Large mummichogs prey on large, medium, and small grass shrimp, medium mummichogs prey on medium and small shrimp and small mummichogs feed on small shrimp and shrimp appendages. Vince et al. (1976) found that *Fundulus* of size 4-6 cm fed mainly on the smallest size *Orchestia*, the 6-8 cm fish fed on small and medium amphipods and the largest fish, 8-10 cm, fed on all three size classes. Santiago found a low number of large mummichogs at Piles Creek. Since there are fewer large mummichogs at Piles Creek, small and medium grass shrimp can grow to larger sizes. This appears to be a probable cause for the larger grass shrimp sizes at Piles Creek.

CHAPTER 5

CONCLUSION

This study provides evidence that Piles Creek conditions do not provide stimulatory effects or a "hormesis" type of effect for growth in *Palaemonetes pugio* that reside in that estuary. Piles Creek sediment did not provide more food for the shrimp. Toxicants, salinity, or other factors at Piles Creek did not provide any type of benefit to the grass shrimp in terms of growth. Piles Creek shrimp did not have inherently faster growth rates than Tuckerton shrimp. It appears that Piles Creek conditions inhibit growth of Tuckerton shrimp to some extent. Piles Creek shrimp grew larger in Tuckerton conditions than they did in their natural conditions, which provides additional evidence to support the conclusion that was drawn from this study.

It appears that inherent environmental factors do not play a significant role in the greater shrimp growth in Piles Creek. The larger grass shrimp sizes at Piles Creek could then be explained by a combination of less predation by the mummichogs, simply because their population has been reduced due to bait fishing, and an impaired feeding behavior by the mummichog predator, as a result of chronic exposure to pollutants.

APPENDIX A

MEASUREMENTS FROM EXPERIMENT # 1

Table A.1 Temperature and Salinity for Experiment # 1

Tank #	Specific Gravity	Temperature (F°)	Salinity (ppt)
1	1.011	62	15
2	1.011	65	15
3	1.011	66	15
4	1.010	63	14
5	1.022	62	30
6	1.022	64	30
7	1.023	67	31
8	1.023	65	31
9	1.022	67	30
10	1.011	63	15

Table A.2 Shrimp Length Distribution for Experiment # 1

Tank Number	Quantity 17.5 mm	Quantity 21 mm	Quantity 24 mm	Quantity 26 mm	Quantity 27 mm
1	0	1	6	0	13
2	0	1	6	0	13
3	4	5	6	5	0
4	4	5	6	5	0
5	4	5	6	5	0
6	4	5	6	5	0
7	0	1	5	0	14
8	0	1	5	0	14
9	0	1	6	0	13
10	4	5	6	5	0

Table A.3 Individual Shrimp Lengths (mm) per Tank for Initial Point of Experiment #1

EXPERIMENT 1 - Start											
		Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9	Tank 10
Shrimp length (mm)											
	Start	21	21	17.5	17.5	17.5	17.5	21	21	22	18
		24	24	17.5	17.5	17.5	17.5	24	24	23	18
		24	24	17.5	17.5	17.5	17.5	24	24	24	19
		24	24	17.5	17.5	17.5	17.5	24	24	24	19
		24	24	21	21	21	21	24	24	24	20
		24	24	21	21	21	21	24	24	25	21
		24	24	21	21	21	21	27	27	25	22
		27	27	21	21	21	21	27	27	26	22
		27	27	21	21	21	21	27	27	26	22
		27	27	24	24	24	24	27	27	26	23
		27	27	24	24	24	24	27	27	26	24
		27	27	24	24	24	24	27	27	26	24
		27	27	24	24	24	24	27	27	26	24
		27	27	24	24	24	24	27	27	26	24
		27	27	24	24	24	24	27	27	27	25
		27	27	26	26	26	26	27	27	27	26
		27	27	26	26	26	26	27	27	27	26
		27	27	26	26	26	26	27	27	27	26
		27	27	26	26	26	26	27	27	27	26
		27	27	26	26	26	26	27	27	28	26
	Total	516	516	449	449	449	449	519	519	512	455
	Mean	25.8	25.8	22.5	22.5	22.5	22.5	26.0	26.0	26.0	22.8
	Aver Dev	1.5	1.5	2.7	2.7	2.7	2.7	1.5	1.5	1.2	2.4
	Stand Dev	1.8	1.8	3.1	3.1	3.1	3.1	1.7	1.7	1.5	2.7
	Stand Err	0.4	0.4	0.7	0.7	0.7	0.7	0.4	0.4	0.3	0.6
	Variance	3.1	3.1	9.3	9.3	9.3	9.3	3.0	3.0	2.4	7.9

Table A.4 Individual Shrimp Lengths (mm) for Intermediate Measurements in Experiment #1

EXPERIMENT # 1											
		Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9	Tank 10
Shrimp length (mm)											
	Intermed	21	25	19	18	18	20	22	23	23	19
		23	25	19	19	19	20	24	24	24	19
		24	26	20	21	20	20	25	25	24	19
		25	26	21	22	20	21	25	26	25	20
		25	27	22	24	21	21	25	26	26	20
		25	27	22	24	21	22	25.5	27	26	22
		25	27	23	25	22	24	27	27	26	23
		26	27	25	25	23	24	27	27	26	25
		26	28	25	26	24	25	27	27	27	25
		26	28	26	26	24	25	27	27	27	25
		27	28	26	26	25	25	27	27	27	25
		27	28	26	27	25	26	27	27	27	26
		27	28	26	28	26.5	27	27	27	28	26
		27	29	27		26.5	27	29	27	28	27
		27	29	27		27			28	28	27
		28				27			28	28	
		28				28			28	29	
		29				28					
						28					
	Total	466	408	354	311	453	327	311	451	449	348
	Mean	25.9	27.2	23.6	23.9	23.8	23.4	26.0	26.5	26.4	23.2
	Aver Dev	1.5	1.0	2.6	2.4	2.8	2.3	1.4	1.0	1.3	2.7
	Stand Dev	1.9	1.2	2.8	3.0	3.2	2.5	1.7	1.3	1.6	3.0
	Stand Err	0.5	0.3	0.8	0.9	0.7	0.7	0.5	0.3	0.4	0.8
	Variance	3.5	1.5	7.8	8.7	10.3	6.4	2.8	1.8	2.6	8.8

Table A.5 Individual Shrimp Lengths (mm) for Final Measurements in Experiment #1

EXPERIMENT # 1											
		Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9	Tank 10
Shrimp length (mm)											
	Final	21	23	19	19	20	21	22	23	23	24
		25	25	19	20	21	21	25	25	24	25
		25	26	21	20	22	21	26	26	25	25
		26	28	22	23	24	22	26	26	26	26
		26	28	22	24	24	22	26	26	26	
		26	28	24	24	24	22	26	27	26	
		27	28	24	25	24	24	26	27	26	
		27	29	25	25	25	25	26	27	26	
		28	29	26	26	26	25	26	27	27	
		28	29	26	26	26	25	27	27	27	
		28	29	27	26	27	26	27	28	27	
		29		27	26	27	26	27	28	27	
				27	26	27	27	27	28	27	
					26	28	27	27	28	27	
					27	28	27	27	28	28	
							28	28	29	28	
								29	29	28	
								29	29	29	
								29			
	Total	316	302	309	363	373	389	506	488	477	100
	Mean	26.3	27.5	23.8	24.2	24.9	24.3	26.6	27.1	26.5	25
	Aver Dev	1.5	1.5	2.4	2.0	2.0	2.2	1.1	1.1	1.1	0.5
	Stand Dev	2.0	1.9	2.8	2.6	2.4	2.4	1.6	1.5	1.4	0.7
	Stand Err	0.6	0.6	0.8	0.7	0.6	0.6	0.4	0.4	0.4	0.4
	Variance	4.1	3.5	7.9	6.2	5.7	5.7	2.4	2.2	2.0	0.5

APPENDIX B

MEASUREMENTS FROM EXPERIMENT # 2

Table B.1 Temperature and Salinity for Experiment # 2

Tank #	Specific Gravity	Temperature ° Celsius	Salinity (°/ ₀₀)
1	1010	19	15
2	1010	19	15
3	1010	18.5	15
4	1010	18	15
5	1021	19.5	30
6	1021	19	30
7	1020	19	29
8	1021	19.5	30
9	1021	19	30
10	1011	19	17

Table B.2 Shrimp Length Distribution for Start of Experiment # 2

Tank Number	Quantity 24 mm	Quantity 25 mm	Quantity 26 mm	Quantity 27 mm	Quantity 28 mm	Quantity 29 mm	Quantity 30 mm
1	3	6	9	13	15	9	5
2	3	6	9	13	15	9	5
7	3	6	9	13	15	9	5
8	3	6	9	13	15	9	5
9	3	6	9	13	15	9	5
	Quantity 22 mm	Quantity 23 mm	Quantity 24 mm	Quantity 25 mm	Quantity 26 mm	Quantity 27 mm	Quantity 28 mm
3	10	7	7	8	6	11	11
4	9	7	8	8	6	11	11
5	10	7	7	9	5	12	10
6	10	7	7	8	6	12	10
10	9	7	8	8	6	11	11

Table B.3 Shrimp Length Distribution for Intermediate Measurements for Experiment 2

Tank Number	Quantity 24 mm	Quantity 25 mm	Quantity 26 mm	Quantity 27 mm	Quantity 28 mm	Quantity 29 mm	Quantity 30 mm
1	2	6	6	17	14	7	3
2	1	7	7	13	11	11	1
7	3	6	4	15	14	6	1
8	3	6	9	13	8	11	2
9	3	5	5	11	9	7	2
	Quantity 22 mm	Quantity 23 mm	Quantity 24 mm	Quantity 25 mm	Quantity 26 mm	Quantity 27 mm	Quantity 28 mm
3	5	6	8	5	5	8	4
4	6	2	0	3	6	7	4
5	6	2	1	4	2	11	4
6	4	3	2	4	2	5	4
10	5	2	3	4	11	9	2

Table B.4 Shrimp Length Distribution for Final Measurements of Experiment #2

Tank Number	Quantity 24 mm	Quantity 25 mm	Quantity 26 mm	Quantity 27 mm	Quantity 28 mm	Quantity 29 mm	Quantity 30+ mm
1	0	3	3	6	2	9	23
2	1	0	1	4	4	6	18
7	0	0	2	4	6	5	1
8	0	2	3	2	2	1	1
9	0	3	3	2	2	6	0
	Quantity 23 mm	Quantity 24 mm	Quantity 25 mm	Quantity 26 mm	Quantity 27 mm	Quantity 28 mm	Quantity 29+ mm
3	0	2	1	3	1	3	4
4	0	0	1	1	2	3	4
5	3	1	51	5	6	0	1
6	2	2	3	2	6	4	0
10	0	0	0	1	0	1	0

APPENDIX C

MEASUREMENTS FROM EXPERIMENT # 3

Table C.1 Temperature and Salinity for Experiment # 3

Tank #	Specific Gravity	Temperature ° Celsius	Salinity (°/ ∞)
1	1010	20	15
2	1008	19.5	13
3	1010	19	15
4	1010	19	15
5	1020	20	29
6	1020	20	29
7	1020	19.5	29
8	1020	20	29
9	1022	20	31
10	1010	20	15

Table C.2 Shrimp Length Distribution for Experiment 3

Tank Number	Quantity 15 mm	Quantity 16 mm	Quantity 17 mm	Quantity 18 mm	Quantity 19 mm	Quantity 20 mm
1	0	4	6	5	3	2
2	0	4	6	5	3	2
3	3	5	4	3	3	2
4	3	5	4	3	3	2
5	3	5	4	3	3	2
6	3	5	4	3	3	2
7	0	4	6	5	3	2
8	0	4	6	5	3	2
9	0	4	6	5	3	2
10	3	5	4	3	3	2

Table C.3 Individual Shrimp Lengths (mm) for Initial Point of Experiment # 3

EXPERIMENT		# 3									
		Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9	Tank 10
Shrimp length (mm)											
	Start	16	16	15	15	15	15	16	16	16	15
		16	16	15	15	15	15	16	16	16	15
		16	16	15	15	15	15	16	16	16	15
		16	16	16	16	16	16	16	16	16	16
		17	17	16	16	16	16	17	17	17	16
		17	17	16	16	16	16	17	17	17	16
		17	17	16	16	16	16	17	17	17	16
		17	17	16	16	16	16	17	17	17	16
		17	17	17	17	17	17	17	17	17	17
		17	17	17	17	17	17	17	17	17	17
		18	18	17	17	17	17	18	18	18	17
		18	18	17	17	17	17	18	18	18	17
		18	18	18	18	18	18	18	18	18	18
		18	18	18	18	18	18	18	18	18	18
		18	18	18	18	18	18	18	18	18	18
		19	19	19	19	19	19	19	19	19	19
		19	19	19	19	19	19	19	19	19	19
		19	19	19	19	19	19	19	19	19	19
		20	20	20	20	20	20	20	20	20	20
		20	20	20	20	20	20	20	20	20	20
	Total	353	353	344	344	344	344	353	353	353	344
	Mean	17.7	17.7	17.2	17.2	17.2	17.2	17.7	17.7	17.7	17.2
	Aver Dev	1.1	1.1	1.3	1.3	1.3	1.3	1.1	1.1	1.1	1.3
	Stand Dev	1.2	1.2	1.6	1.6	1.6	1.6	1.2	1.2	1.2	1.6
	Stand Err	0.3	0.3	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.4
	Variance	1.5	1.5	2.5	2.5	2.5	2.5	1.5	1.5	1.5	2.5

Table C.4 Individual Shrimp Lengths (mm) for Intermediate Measurement Experiment # 3

EXPERIMENT		# 3									
		Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9	Tank 10
Shrimp length (mm)											
	Intermed	16	16	16	16	16	16	16	16	16	16
		17	16	16	16	16.5	16	17	16	16.5	17
		18	17	16	16	17	16	18	17	16.5	17
		18	17	16	16.5	17	17	18	17	17	17
		18	17	16.5	16.5	17	17	18	18	17	17
		18	18	17	17	17	17	18	18	18	17
		18	18	17	17	17	17.5	18	18	18	17
		18	18	17.5	17	18	17.5	18	18	18	17
		18	18	17.5	17.5	18	18	18	18.5	18	18
		18	18	17.5	18	18	18	19	18.5	18.5	18
		18	18.5	18	18	18	18	19	18.5	19	18
		18.5	18.5	18	18	19	18	19	19	20	19
		18.5	19	18	18	19	18	19	19	20	19
		18.5	19	19	18.5	20	19	20	19	20	19
		19	19	19	18.5	20	19	20	19.5	20	19
		19	20	19.5	19	20	19	20	20	20	20
		19	20.5	19.5	20	20	20	20	20	20	20
		20	20.5	20	20	21	20	21	20	21	21
		21	20.5	21	20.5	21	20.5	21	21	21	21
		21.5	21	21	20.5	21	21	21	21	22	21
	Total	370	369.5	360	358.5	370.5	362.5	378	372	376.5	368
	Mean	18.5	18.5	18.0	17.9	18.5	18.1	18.9	18.6	18.8	18.4
	Aver Dev	0.9	1.2	1.3	1.2	1.4	1.2	1.1	1.1	1.5	1.3
	Stand Dev	1.2	1.5	1.6	1.4	1.6	1.4	1.3	1.4	1.7	1.5
	Stand Err	0.3	0.3	0.4	0.3	0.4	0.3	0.3	0.3	0.4	0.4
	Variance	1.5	2.1	2.5	2.1	2.5	2.1	1.8	1.9	2.8	2.3

Table C.5 Individual Shrimp Lengths (mm) for Final Measurements in Experiment # 3

EXPERIMENT	# 3									
		Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9	Tank 10
Shrimp length (mm)											
	Final	17	17	17	17	17	18	17	18	18	18
		18	17	17	17	17	18	19	19	18	18
		18	18	17	17	17	18	19	19	18	18
		18	18	17	17	17	18	19	19	18	18
		18.5	18	17	17	18.5	18	19	19	19	18
		19	19	17	17	18.5	18.5	19	19	19	18
		19	19	17	18	19	19	19	20	19	18
		19	19	18	18	19	19	20	20	20	19
		19	19	18	18	19	19	20	20	20	19
		19	19	18	18	19	20	20	20	20	19
		20	20	18	18	20	20	20	20	20	19
		20	20	18	18	20	20	20	20.5	20	19
		20	20	18	19	20.5	20	20	20.5	20	19
		20.5	20	18	19	21	21	20	21	21	20
		21	21	19	20	21	21	20	21	21	20
		21	21	19	20	22	21	21	21	22	20
		21	21	19	20	22	21	21	21	23	21
		22	22	20	21	22	21	22	22	23	21
		24	22	20	22	22	22	22	22	23	22
		25	22.5	22		22	22	23	23	24	
	Total	399	392.5	364	351	393.5	394.5	400	405	406	364
	Mean	20.0	19.6	18.2	18.5	19.7	19.7	20.0	20.3	20.3	19.2
	Aver Dev	1.5	1.3	1.0	1.2	1.6	1.2	0.9	1.0	1.5	1.0
	Stand Dev	2.0	2.0	1.3	1.5	1.8	1.4	1.3	1.2	1.8	1.2
	Stand Err	0.5	0.4	0.3	0.4	0.4	0.3	0.3	0.3	0.4	0.3
	Variance	3.8	2.5	1.7	2.1	3.2	1.8	1.7	1.5	3.3	1.4

REFERENCES

N.C. Alon and S.F. Stancyk, "Variation in Life-History Patterns of the Grass Shrimp, *Palaemonetes pugio* in two South Carolina Estuarine Systems," *Marine Biology*, vol. 68, pp. 265-276, 1982.

G. Anderson, *Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates*, Biological Report 82(11.35), Fish and Wildlife Services, 1985.

G.T. Barthalmus, "Behavioural Effects of Mercury on Grass Shrimp," *Marine Pollution Bulletin*, vol. 8, pp. 87-89, 1977.

B. Bayne, D. Brown, K. Burns, D. Dixon, A. Ivanovike, D. Livingston, D. Lowe, M. Moore, A. Stebbing, and J. Widdows, *Effects of Stress and Pollution on Marine Animals*, Praeger, New York, 1985.

B.E. Bengtsson, "Increased Growth in Minnows Exposed to PCBs," *Ambio*, vol. 8, pp. 169-170, 1979.

J.A. Brown, P.H. Johansen, P.W. Colgan and R.A. Mathers, "Impairment of Early Feeding Behavior of Largemouth Bass by Pentachlorophenol Exposure: a Preliminary Assessment," *Transactions of the American Fisheries Society*, vol. 116, pp. 71-78, 1987.

D.T. Burton and D.J. Fisher, "Acute Toxicity of Cadmuim, Copper, Zinc, Ammonia, 3,3-Dichlorobenzidine, 2,6-Dichloro 4-Nitroaniline, Methylene Chloride, and 2,4,6 Trichlorophenol to Juvenile Grass Shrimp and Killifish," *Bulletin of Environmental Contamination and Toxicology*, vol. 44, pp. 776-783, 1990.

J. Cairns and J. Loos, "Changed Feeding Rate of *Brachydanio revio* Resulting from Exposure to Sublethal Concentrations of Zinc, Potassium Dichromate, and Alyly Benzene Sulfonate Detergent," *Proc. PA Acad. Science*, vol. 40, pp. 47-52, 1967.

J.R. Clark, J.M. Patrick, Jr., D.P. Middaugh and J.C. Moore, "Relative Sensitivity of Six Estuarine Fishes to Carbophenothion, Chlorpyrifos, and Fenvalerate," *Ecotoxicol. Environmental Safety*, vol. 10, pp. 382-390, 1985.

J.R. Clark, J.M. Patrick, Jr., J.C. Moore, E.M. Lores, "Waterborne and Sediment-Source Toxicities of Six Organic Chemicals to Grass Shrimp (*Palaemonetes pugio*) and Amphioxus (*Branchiostoma caubaeum*)." *Arch. Environ. Contam. Toxicol.*, vol. 16, pp. 401-407, 1987.

D.C. Doughtie, P.J. Conklin, K.R. Rao, "Cuticular Lesions Induced in Grass Shrimp Exposed to Hexavalent Chromium," *Journal of Invertebrate Pathology*, vol. 42, pp. 49-258, 1983.

R.R. Fales, "The Influence of Temperature and Salinity on the Toxicity of Hexavalent Chromium to the Grass Shrimp, *Palaemonetes pugio*," *Bulletin of Environmental Contamination and Toxicology*, vol. 20, pp. 447-450, 1978.

D.T. Gundersen, S.W. Kristanto, L.R. Curtis, S.N. Al-Yakoob, M.M. Metwally, D. Al-Ajmi, "Subacute Toxicity of the Water-Soluble Fraction of Kuwait Crude Oil and Partially Combusted Crude Oil on *Menidia beryllina* and *Palaemonetes pugio*," *Arch. Environ. Contam. Toxicol.*, vol. 31, pp. 1-8, 1996.

R.W. Hastings and R.E. Good, "Population Analysis of the Fishes of a Freshwater Tidal Tributary of the Lower Delaware River," *Bull NJ Acad. Sci.*, vol. 22, pp. 13-20. 1977.

A. T. Khan and J.S. Weis, "Bioaccumulation of Heavy Metals in Two Populations of Mummichog (*Fundulus heteroclitus),*" *Bulletin of Environmental Contamination and Toxicology*, vol. 51, pp. 1-5, 1993.

A.T. Khan, J.S. Weis and L. D'Andrea, "Bioaccumulation of Four Heavy Metals in Two Populations of Grass Shrimp, *Palaemonetes pugio*," *Bulletin of Environmental Contamination and Toxicology*, vol. 42, pp. 339-343, 1989.

R.T. Kneib, "Testing for Indirect Effects of Predation in an Intertidal Soft Bottom Community," *Ecology*, vol. 69, pp. 1795-1805, 1988.

R.T. Kneib, "The Role of *Fundulus heteroclitus* in Salt Marsh Trophic Dynamics," *American Zoology*, vol. 26, pp. 2 59-269, 1986.

R.T. Kneib, "Predation Risk and Use of Intertidal Habitats by Young Fish and Shrimp," *Ecology*, vol. 68, pp. 379-386, 1987.

R.T. Kneib and A.E. Stiven, "Benthic Invertebrate Responses to Size and Density Manipulations of the common mummichog, *Fundulus heteroclitus*, in an intertidal salt marsh," Ecology, vol. 63, pp. 1518-1532, 1982.

R.T. Kneib and A.E. Stiven, "Growth, Reproduction and Feeding of *Fundulus heteroclitus* on a North Carolina Salt Marsh," *Journal of Experimental Marine Biology and Ecology*, vol. 31, pp. 121-140, 1978.

M.L. Kraus and D.B. Kraus, "Differences in the Effects of Mercury on Predator Avoidance in Two Populations of the Grass Shrimp, *Palaemonetes pugio*, *Marine Environmental Research*, vol. 18, pp. 27-289, 1986.

M.L. Kraus and J.S. Weis, "Differences in the Effects of Mercury on Telson Regeneration in Two Populations of Grass Shrimp, *Palaemonetes pugio*," *Arch. Environ. Contam. Toxicol.*, vol. 17, pp. 115-120, 1988.

R.B. Laughlin, J. Ng and H. Guard, "Hormesis: A Response to Low Environmental Concentrations of Petroleum Hydrocarbons," *Science*, vol. 211, pp. 705-707, 1981.

E.E. Little, R.D. Archeski, B. Flerov, and V. Kozlovskaya, "Behavioral Indicators of Sublethal Toxicity in Rainbow Trout," *Arch. Environ. Contam. Toxicol.*, vol. 19, pp. 380-385, 1990.

M.J. Morgan and J.W. Kiceniuk, "Effect of Fenitrothion on the Foraging Behavior of Juvenile Atlantic Salmon," *Environmental Toxicology and Chemistry*, vol. 9, pp. 489-495, 1990.

W. Nelson, "A Comparison of the Physiological Condition of the Blue Mussel, *Mytilus edulis*, after Laboratory and Field Exposure to a Dredged Material," *Pollution Physiology of Estuarine Organisms*, pp. 185-205, 1987.

H.G. Nyman, "Sublethal Effects of Lead (Pb) on Size Selective Predation by Fish-Applications on the Ecosystem Level," *Verh. Internat. Verein. Limnol.*, vol. 21, pp. 1126-1130, 1981.

Q.H. Pickering and M.H. Gast, "Acute and Chronic Toxicity of Cadmium to the Fathead Minnows (*Pimephales promelas*)," *Journal Fish. Res. Board Com.*, vol. 29, pp. 1099-1106, 1972.

M.H. Posey and A.H. Hines, "Complex Predator-Prey Interactions within an Estuarine Benthic Community," *Ecology*, vol. 72, pp. 2155-2169, 1991.

T.E. Prinslow, I. Valiela and J.M. Teal, "The Effect of Detritus and Ration Size on the Growth of Fundulus heteroclitus," *Journal of Experimental Marine Biology and Ecology*, vol. 16, pp. 1-10, 1974.

C. Rice, P. Plesha, E. Casillas, D. Misitano, and J. Meador, "Growth and Survival of Three Marine Invertebrate Species in Sediments from the Hudson-Raritan Estuary," *Environmental Toxicology and Chemistry*, vol. 14, pp. 1931-1941, Nov. 1995.

R.A. Roundtree and K.W. Able, "Diel Variation in Decapod Crustacean and Fish Assemblages in NJ Polyhaline Marsh Creeks," *Estuar. Coast. Shelfsci.*, vol. 37, pp. 181-201, 1993.

B. M. Sanders, K.D. Jenkins, W. Sanda and J.D. Costlow, "Free Cupric Ion Activity in Sea Water: Effects of Metallothionein and Growth in Crab Larvae," *Science*, vol. 222, pp. 53-53, 1983.

C. Santiago, "Size-Frequency Distribution of *Palaemonetes pugio* in Two New Jersey Estuaries and Predator-Prey Interactions with *Fundulus heteroclitus*," M.S. Thesis, Department of Chemical Engineering, Chemistry, and Environmental Science, New Jersey Institute of Technology, 1996.

T.W. Schoener, "Theory of Feeding Strategies", *Annual Review of Ecology and Systematics*, vol. 2, pp. 369-404. 1971.

G.S. Smith, "Predatory Behavior of Mummichogs *(Fundulus heteroclitus)* from a Polluted versus Unpolluted Environment," Ph.D. dissertation, Department of Biological Sciences, Rutgers University, Newark, NJ, 1997.

G.S. Smith and J.S. Weis, "Predator-Prey Relationships in mummichogs (Fundulus heteroclitus): Effects of Living in a Polluted Environment," *Journal of Experimental Marine Biology and Ecology*, vol. 209, pp. 75-87, 1997.

L.L. Smith, Jr., D.M. Oseid, G. Kimball, and S.M. El-Kandelgy, "Toxicity of Hydrogen Sulfide to Various Life History Stages of Bluegills *(Leponmis macrochinus)*," *Transactions of American Fisheries Society*, vol. 105, pp. 442-449, 1976.

A.R.D. Stebbing, "Hormesis - Stimulation of Colony Growth in *Campanularia flexuose* (Hydozoa) by Copper, Cadmium, and other Toxicants," *Aquatic Toxicology*, vol. 1, pp. 27-228, 1981.

S.V. Toppin, M. Herber, J.S. Weis, and P. Weis, "Changes in Reproductive Biology and Life History in *Fundulus heteroclitus* in a Polluted Environment," pp. 208-211, In *Pollution Physiology of Estuarine Organisms*, W. Vernberg, A. Calabrese, F. Thurberg, and F.J. Vernberg (eds.), University of South Carolina Press, Columbia, South Carolina, 1987.

S. Vince, I. Valiela, N. Backus, J.M. Teal, "Predation by the Salt Marsh Killifish, Fundulus heteroclitus, in Relation to Prey Size and Habitat Structure: Consequences for Prey Distribution and Abundance," *Journal of Experimental Marine Biology and Ecology*, vol. 23, pp. 255-266, 1976.

D. Weber, "Lead-Induced Metabolic Imbalances and Feeding Alterations in Juvenile Fathead Minnows (*Pimephales promelas*)," *Environmental Toxicology and Water Quality*, vol. 11, pp. 45-51, 1996.

J.S. Weis and A.A. Khan, "Reduction in Prey Capture Ability and Condition of Mummichogs from a Polluted Habitat," *Transactions of the American Fisheries Society*, vol. 12, pp. 127-129, 1991.

J.S. Weis, M. Renna, S. Vaidya, and P. Weis, "Mercury Tolerance in Killifish: a Stage-Specific Phenomenon," pp. 31-36, In *Oceanic Processes in Marine Pollution*, v.1, *Biological Processes and Wastes in the Ocean*, J. Capuzzo and D. Kester (eds.), Krieger Publishing Co., Malabar, FL, 1987.

J.S. Weis and P. Weis, "Pollutants as Developmental Toxicants in Aquatic Organisms," *Environmental Health Perspectives*, vol. 71, pp. 77-86, 1987.

J.S. Weis and P. Weis, "Tolerance and Stress in a Polluted Environment - The Case of the Mummichog," *BioScience*, vol. 39, pp. 89-95, 1989.

J. Widdows, "Physiological Responses to Pollution," *Marine Pollution Bulletin*, vol. 16, pp. 129-134, 1985.

T. Zhou, "Behavioral Development and Neurobehavioral Effects of Methlymercury on Larval Mummichogs, *Fundulus heteroclitus* from Polluted and Reference Environments," Ph.D. dissertation, Department of Biological Sciences, Rutgers University, Newark, NJ, 1997.